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Editorial office address: University of Petroşani, 20 University Street, 332006 Petroşani, Romania, Phone: (40) 254/54.29.94; 54.25.80; 54.25.81; 54.33.82; Fax: (40) 254/54.34.91; 54.62.38,

Contact person: **Marius Daniel MARCU**, e-mail: mariusmarcu@upet.ro

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CONSIDERATIONS FOR THE EXPLOSION RISK ASSESSMENT OF TECHNICAL INSTALLATIONS OPERATING IN ATMOSPHERES WITH COMBUSTIBLE DUST

CĂTĂLIN MIHAI POPA[1], FLORIN ADRIAN PĂUN[2], ADRIAN MARIUS JURCA[3], MIHAELA PĂRĂIAN[4], NICULINA VĂTAVU[5]

Abstract: The presence of combustible dust suspended in the air or deposited in layers on certain surfaces can lead to fires or even explosions with devastating effects. Particular attention should be paid to the identification and implementation of measures and means necessary for the protection and prevention of dust explosions, all the more so as the damage caused by a dust explosion is generally greater than that caused by explosions. flammable gases and vapors. A dust explosion may occur if, in addition to a potentially explosive dust / air atmosphere, a source of ignition is present. The physio-chemical properties of the present powders must also be taken into account, as well as the parameters of the necessary technical equipment and the operations that make up the applied technological processes.

This paper outlines the steps to be taken to carry out an explosion risk assessment in facilities where combustible dusts are processed, in order to establish prevention and protection measures, in order to ensure a tolerable level of risk.

Keywords: dust-air mixture, explosive atmospheres, explosion risk.

1. INTRODUCTION

In the presence of oxygen, combustible dust that is suspended or deposited on various surfaces can cause fires or even explosions. In most cases, explosions of combustible dust can lead to considerable material damage and sometimes even loss of life.

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[1] *Sc. Res., PhD. Student Eng., INCD INSEMEX Petrosani, mihai.popa@insemex.ro*
[2] *Sc. Res. Ist, PhD. Eng., INCD INSEMEX Petrosani, florin.paun@insemex.ro*
[3] *Sc. Res. Ist, PhD. Eng., INCD INSEMEX Petrosani, adrian.jurca@insemex.ro*
[4] *Sc. Res. Ist, PhD. Eng., INCD INSEMEX Petrosani, mihaela.paraian@insemex.ro*
[5] *Sc. Res. IInd, PhD. Eng., INCD INSEMEX Petrosani, niculina.vatavu@insemex.ro*

The danger of explosion in combustible dust processing plants must be treated as a major hazard, as the explosions can affect both the bodily integrity of the personnel involved in the production process and the environment as a whole.

Therefore, it is necessary to adopt and implement precautionary measures to prevent and ensure explosion protection. These measures must be developed following an explosion risk assessment existing in the analysed installation.

The assessment of the risk of explosion in an installation in which combustible dusts are processed will take into account the nature of the hazardous materials and substances present in the form of dust used in technological processes, protective systems and technical equipment that make up the analyzed plant.

An explosive atmosphere of combustible dust is defined as a mixture of combustible dust air, dust or flakes, a mixture in which, after ignition, combustion is transmitted to the entire unburned mixture. [1]

An explosion occurs when combustible dust is present in suspension when mixed with air in the explosive range of those dusts, ie between their lower explosive limit (LFL) and upper explosive limit (UFL), at the same time as a source of ignition. whose initiation energy is high enough to ignite the air / dust mixture formed. The explosion of combustible dust occurs if there is a simultaneous interaction of the combustible substance with the oxidant and the ignition source, also taking into account the aspects related to the closure of the mixture. In this situation the pentagon of the explosion, shown in Figure 1 can be defined. [2], [3], [4].

Fig.1. Pentagon of explosion

The factors on which the violence and dynamics of an explosion depend are presented below:

✓ The chemical composition of the combustible dust - a combustible dust is characterized by the specific constant of the respective dust, constant which also bears the name of explosion index. This explosion index is a measure of the explosive value of combustible dust. Depending on the explosion index, the fuel dust can be divided into four explosion classes, as can be seen in table no. 1.

Table 1. ***Classification of combustible dusts according to k_{st}.***

Dust Explosion Class	Kst [bar×m/s]	Characteristic
St 0	0	No explosion
St 1	>0 ÷200	Weak explosion

St 2	>200 ÷ 300	Strong explosion
St 3	>300	Very strong explosion

✓ The concentration of combustible dust mixed with air - is the factor depending on which may or may not form a potentially explosive atmosphere. If the concentration value is too low or too high, no explosion occurs. In this case, only a slow combustion reaction may occur. Thus, an explosion can only occur if the concentration of combustible dust is within the explosive range of that combustible dust. In general, the literature states that the lower explosive limit is between 20 and 60 g/m^3, while the upper explosive limit can be between 2 and 6 kg/m^3.

✓ The particle size of the dust particles has a decisive role in determining the severity of an explosion. In this sense, the finer the dust particles look, the lighter they are and the lower they tend to be suspended in the air for a longer period of time.

✓ Homogeneity of dust clouds formed and the way dust particles are present;

✓ Aspects related to how cleanliness is ensured in areas affected by the presence of combustible dust. If there is no cleaning plan according to which a systematic cleaning is ensured, there is a possibility that the suspended dust particles will be deposited on different surfaces, which leads in time to the formation of layers or dust deposits of different thicknesses. In the event of an explosion, these layers or deposits of dust may be swirled, thus providing the fuel needed for other secondary explosions.

2. ANALYSIS OF POSSIBILITIES TO ELIMINATE OR MINIMIZE THE RISK OF EXPLOSION

2.1 Principles of explosion prevention and explosion protection [5]

The basic principles of explosion prevention and protection start from the need for an explosive atmosphere to coincide with the existence of an effective source of initiation, in conjunction with the analysis of the expected effects of an explosion. These can be addressed in the following order:

a) the concept of explosion prevention - can be materialized by:
- avoiding the presence of explosive atmospheres of combustible dust. This objective can be achieved by changing the fuel dust concentration to a value outside the explosive range, or by changing the oxygen concentration to a value below the oxygen limit (LOC).
- avoiding efficient sources of ignition.

b) explosion protection - can be achieved by:
- adoption and implementation of protection measures in order to reduce the effects of the explosion. Among these protection measures we can mention: the design and construction of equipment in explosion-proof construction, the release of explosion pressure, the suppression of the explosion, the prevention

of the spread and explosion of the flame. In this case, an explosion is acceptable.

In some cases, the risk of explosion may be reduced or eliminated by implementing only one of the above principles. There are also situations where a combination of these principles needs to be applied to minimize or eliminate the risk of explosion. It should also be noted that the first option is to avoid a potentially explosive atmosphere generated by the air-dust mixture.

In conclusion, the requirement to prevent explosions can be expressed in the following form: the probability that a source of ignition will occur simultaneously with an explosive atmosphere is minimal. Based on this requirement, it is necessary to establish specific requirements that apply to technical equipment and protective systems designed to operate in combustible dust atmospheres.

In order to be able to develop a concept of explosion safety, in each case, it is necessary to select appropriate precautions by following the steps below:

A. Ex-classification of hazardous areas with combustible dusts

Ex classification of hazardous areas is a way of analysing and classifying jobs in industrial facilities where combustible dusts are circulated, in relation to the likelihood of explosive dust / air mixture formation and deposition of combustible dust in the layer. This analysis is especially necessary for the correct choice of technical equipment that is intended for safe use in combustible dust environments, taking into account its characteristics.

It is necessary to specify exactly the nature of the dust and the technical facilities in which it is processed, in order to be able to classify the hazardous areas where explosive air / dust mixtures are present. The following steps will also be taken:

• Identification of the physio-chemical characteristics of combustible dust: size and humidity of dust particles, minimum ignition temperature in the cloud and layer, electrical resistivity, and the corresponding dust subgroup (IIIA, IIIB or IIIC);

• Highlight those spaces and workplaces where combustible dust may be present. The possibilities of forming dust layers must also be known;

• Carrying out an analysis of the probability of explosive dust / air mixtures occurring in different parts of the technical installation in which the combustible dust is processed.

According to SR EN 60079-10-2:2015 [6], Ex classified areas for explosive dust atmospheres are divided into zones, which are identified and classified according to the frequency and duration of the explosive dust atmosphere, as follows:

- **Zone 20**: A place where an explosive atmosphere of dust in the form of a cloud of dust in the air is present continuously or for long periods of time or frequently.

- **Zone 21:** A place where an explosive atmosphere of dust in the form of a cloud of dust in the air is likely to occasionally occur during normal operation.

- **Zone 22:** A place where an explosive atmosphere of dust in the form of a cloud of dust in the air is not likely to occur during normal operation, but which, if it occurs, will persist only for a short period of time.

B. Establish the zoning plan and the appropriate location of the warning signs

In accordance with the requirements and provisions of European Directive 1999/92/EC [7], it is necessary for the employer to classify into zones all workplaces where dust and / or combustible dusts are present and where, by default, atmospheres may occur. potentially explosive. At the same time, the warning sign "Ex", which must comply with the requirements set out in European Directive 1999/92 / EC on shape, color and size, shall be displayed in workplaces where potentially explosive atmospheres may form.

C. Prevention of ignition sources

The sources of ignition of combustible dusts may be of an electrical and / or mechanical nature. Among these sources of ignition we mention the following:

- hot surfaces;
- electric springs that may be present in switches, contacts, brushes, etc.
- electrostatic discharges;
- thermal sparks;
- mechanical or frictional sparks;

In order to avoid the occurrence of efficient ignition sources, in areas with combustible dust, where potentially explosive atmospheres may form, one of the explosion protection measures that can be adopted is the selection of electrical and non-electrical equipment with Ex type of protection appropriate to those areas.

Tables 2 and 3 show the types of Ex protection that technical equipment intended for use in hazardous areas with combustible dust may present, as well as their choice according to the Ex classified areas in which they may be located.

Table 2. ***Types of explosion protection for electrical equipment in dusty areas***

Types of protection / reference standard	**Category 1 EPL a** Very high level of protection	**Category 2 EPL b** High level of protection	**Category 3 EPL c** Normal level of protection
	USE Zone 20 Zone 21 Zone 22	USE Zone 21 Zone 22	USE Zone 22
Optical radiation interlocked with optical breakage SR EN IEC 60079-28	-	Ex op sh	-
Intrinsic safety Ex i SR EN IEC 60079-11 SR EN IEC 60079-25	Ex ia	Ex ib	Ex ic

systems			
Inherently safe optical radiation SR EN IEC 60079-28	Ex op is	-	-
Encapsulation Ex m SR EN IEC 60079-18	Ex ma	Ex mb	Ex mc Ex n*
Pressurised enclosure Ex p SR EN IEC 60079-2	-	Ex pxb, Ex pyb	Ex pzc
Protection using enclosure Ex t SR EN IEC 60079-31	Ex ta	Ex tb	Ex tc
Protected optical radiation SR EN IEC 60079-28	-	Ex op pr	-

Table 3. ***Types of explosion protection for nonelectrical equipment in dusty areas***

Types of protection / reference standard	**Category 1** **EPL a** Very high level of protection	**Category 2** **EPL b** High level of protection	**Category 3** **EPL c** Normal level of protection
	USE Zone 20 Zone 21 Zone 22	USE Zone 21 Zone 22	USE Zone 22
Constructional safety SR EN IEC 80079-37	Ex h	Ex h	Ex h
Control of ignition source SR EN IEC 80079-37	Ex h	Ex h	Ex h
Liquid immersion SR EN IEC 80079-37	Ex h	Ex h	Ex h
Pressurised enclosure Ex p SR EN IEC 60079-2	-	Ex pxb, Ex pyb	Ex pzc
Protection by enclosures Ex t SR EN IEC 60079-31	Ex ta	Ex tb	Ex tc

D. Choice of technical equipment

After the classification of hazardous areas Ex, identified the combustible dusts that can generate potentially explosive atmosphere, their ignition temperatures and the environmental characteristics around the technological installation, the technical equipment to be used in these hazardous areas can be selected.

The selection of technical equipment must take into account the category of equipment. It must correspond to the type of classified area, depending on the level of protection required in accordance with the criteria set out in Table 4.

Table 4. ***Selection of technical equipment intended for areas with combustible dust***

ZONE	Presence of the explosive atmosphere (explosion hazard)	Avoidance of effective ignition sources (ignition hazard)	Required level of protection	Group II CATEGORY	EPL
22	Infrequently and for a short period only	During normal operation	NORMAL	3D	Dc
21	Likely to occur	Also during foreseeable malfunctions (single fault)	HIGH	2D	Db
20	Continuously, for long periods or frequently	Also during rare malfunctions (two independent faults)	VERY HIGH	1D	Da
USERS		**MANUFACTURERS**			
Directive 1999/92/EC (HG 1058/2006)		**Directive 2014/34/EU (HG 245/2016)**			

3. IGNITION RISK ASSESSMENT ISSUES FOR BUCKET ELEVATORS

The likelihood of a fire or explosion depends on the likelihood of a potentially explosive atmosphere, the existence of sources of ignition and the actual ignition. In the case of a bucket elevator, the consequences of a fire or explosion are determined by the location of the bucket elevator and the proper presence of the protection systems.

Thus, if the ignition of combustible dust inside a bucket elevator occurs, we can have as a result of this ignition the appearance of a smoldering fire, a fire that manifests itself with flame, an explosion or even a propagation explosion. If there is an explosion of dust, a fire may spread inside or outside the bucket elevator.

Another particularly important aspect to consider when evaluating the risk of explosion in bucket lifts is the nature and appearance of the bulk product. In this case, a decisive role is played by the fine fraction of the bulk material, with particle sizes smaller than 500 μm and how easily a cloud of dust forms.

Even if the concentration of combustible dust mixed with air is low, over time, the existing dust may adhere to the surface of the elevator housing, resulting in the formation of dust layers up to a few millimeters thick. Although these dust layers are not in themselves explosive mixtures, however, in the event of damage to the bucket elevator, the housing may shake, leading to turbulence of the adherent dust and the formation of clouds of explosive dust.

In most cases, in the case of a bucket elevator, it is difficult to assess the risk of explosion. Normally, the person using the bucket elevator will choose it according to his category and then perform a risk analysis and assessment according to local circumstances.

In principle, the analysis of the danger of fire and explosion in the case of a bucket elevator can be done by going through the logic diagram shown in Figure 2.

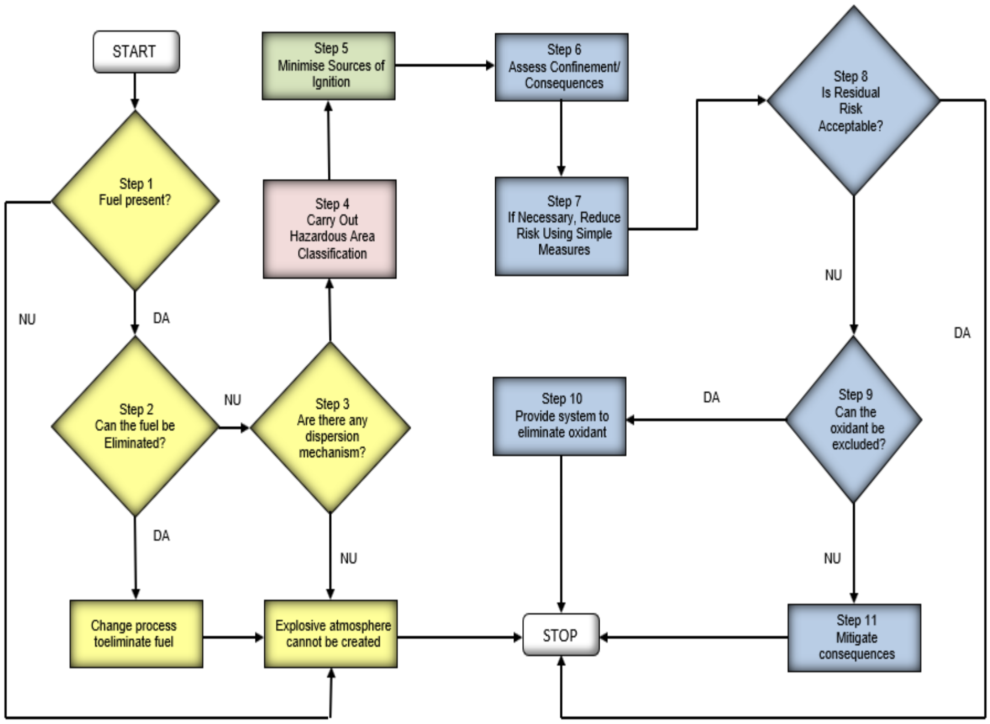

Fig. 2. The explosion risk logic diagram

If we analyse the above logic diagram, if there is fuel dust, it is observed that, after the classification of hazardous areas, it is necessary in the first phase to identify the sources of ignition. It is also necessary to check whether the protection measures adopted and implemented can prevent the occurrence of effective ignition sources in the following cases.:

- during normal operation, if the potential ignition source is in zone 22;
- and during foreseeable failures (for a single failure), if the ignition source is in Zone 21;
- and during rare failures (two independent failures) if the ignition source is in Zone 20.

From the point of view of the existence of potential sources of ignition, in the case of bucket elevators, the following sources of initiation can be found:

Equipment ignition sources - are shown in Table 5.

Table 5. ***Equipment ignition sources***

Potential ignition sources	Possible causes
Hot surfaces	• Bucket lifting belt friction with elevator housing wall due to misalignment • Friction between the lift belt and the drive wheel (drum) due to slipping • Friction of loose parts in the elevator with buckets (loose bucket, lost pulley parts, etc.) with moving parts • Damage to bearings and gears
Mechanical sparks	• Mechanical sparks due to cups colliding with the housing wall (due to insufficient belt tension, defective belt, loose cups) or with the discharge chute • Non-alignment of the drive wheel
Electrical equipment	• Electrical equipment and motors • Improper grounding and / or equipotential bonding
Electrostatics	• Electrostatic charging due to the separation processes between the belts and the drive pulleys • Electrostatic charging of cups due to electrostatic induction •Electrostatic charging of any other installed conductive components that is not grounded

Ignition sources introduced or acting from the outside.

A summary of the potential sources of ignition introduced or acting from the outside is given in Table 6.

Table 6. ***Ignition sources introduced or acting from the outside***

Potential ignition sources	Possible causes
Hot surfaces	• Foreign material introduction • Incandescent particles introduction • Welding, grinding, cutting operations • Damage to the housing due to external mechanical action
Hot flames and gases, including hot particles	• Incandescent particles introduction • Fire or explosion propagation from connected or external installations
Mechanical sparks	• Foreign material introduction • Damage to the housing due to external mechanical action
Lightning	• Inadequate lightning protection

Ignition sources from the product itself.

There are also possible sources of ignition arising from the product itself. Depending on the characteristics of the bulk dust, it must be checked whether self-ignition or exothermic decomposition can occur.

In the case of bucket elevators, large accumulations of dust are expected to form in the feed base and in the horizontal feed and outlet sections. It should be noted that with increasing volume and thickness of the dust layer, the temperature of self-ignition or degradation will decrease.

4. CONCLUSIONS

The assessment of the danger of ignition and explosion, given the use of technical equipment and protection systems in hazardous areas with combustible dusts, is of particular importance for ensuring the health and safety of workers involved in the production process. In accordance with the provisions and requirements of the legislation in force, both equipment manufacturers and their users are responsible for assessing the risk of explosion and for adopting and implementing the necessary protection measures to ensure an acceptable level of safety.

To this end, a risk analysis must be carried out on all technical equipment that makes up an installation operating in hazardous areas with combustible dust, which identifies all potential sources of ignition and all protective measures to be taken and implemented in order to prevent potential sources of ignition from becoming effective.

The technical equipment used will be selected on the basis of the classification of hazardous areas in the three zones 20, 21 and 22, the identification of existing combustible dusts, ignition temperatures, the environmental characteristics of the site and taking into account the category of equipment to be appropriate. with the type of classified area.

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LABORATORY TESTING OF CUTTING STRENGTH PERFORMANCE OF PROTECTIVE GLOVES AGAINST MECHANICAL RISKS

FLORIN ADRIAN PĂUN[1], DAN GABOR[2], MIRELA RADU[3], CĂTĂLIN MIHAI POPA[4], ANCA ALEXANDRA TĂZLĂUANU[5]

Abstract: In general, during work tasks, workers are exposed to risk factors, which requires the use of appropriate personal protective equipment in terms of ensuring protection. Protecting workers from risk factors requires that personal protective equipment meets certain constructive and safety requirements, which are very important for the level of protection to be provided.

This paper aims to identify both general and security requirements applicable to gloves that provide protection against mechanical hazards, as well as the applicable test methods, whose results allow their subsequent characterization from protection against risks that are present during the performance of work tasks perspective. The methodology for assessing gloves that provide protection against mechanical risks is described, in relation to the essential safety and health requirements applicable under Regulation 2016/425, as well as the innovative solutions for building the stand for determining the shear strength by cutting protective gloves.

Keywords: personal protective equipment, protective gloves, mechanical hazards, laboratory tests, explosive atmosphere.

1. INTRODUCTION

Protective gloves against mechanical hazards are part of the category of personal protective equipment, their role being to offer protection [1].

Protective gloves against mechanical hazards are part of the category of personal protective equipment, their role being to protect the worker against at least one of the mechanical hazards such as: abrasion, cutting and perforation.

[1] *Ph.D. Eng., INCD-INSEMEX Petroșani, florin.paun@insemex.ro*
[2] *Ph.D. Eng., INCD-INSEMEX Petroșani, dan.gabor@insemex.ro*
[3] *D. Eng., INCD-INSEMEX Petroșani, mirela.radu@insemex.ro*
[4] *PhD. Student Eng.INCD INSEMEX Petroșani, mihai.popa@insemex.ro*
[5] *Ec., INCD-INSEMEX Petroșani, anca.tazlauanu@insemex.ro*

Given the role of personal protective equipment in ensuring the protection of workers against the risks present during the performance of work tasks, at national level, the aspects related to ensuring the best conditions in the work process, defense of life, bodily integrity and the health of employees and other persons participating in the work process, are regulated by the Law on safety and health at work no. 319/2006 and the Methodological Norms for the application of the provisions of this law [5].

According to the law on safety and health at work no. 319/2006 respectively of the Decision on the minimum safety and health requirements for the use by workers of personal protective equipment at work, personal protective equipment means any equipment intended to be worn or held by the worker to protect it against or several risks that could endanger his safety and health at work, as well as any additional elements or accessories designed for this purpose. The obligation to use personal protective equipment by workers, established by the Law on Safety and Health at Work no. 319/2006, makes the gloves for protection against mechanical risks to be used in all applications involving the presence of risk factors with mechanical action (abrasion, cutting and perforation) [4], [5].

In the context of above mentioned aspects, it should be noted that the mandatory use of personal protective equipment or gloves against mechanical hazards in all applications involves their use, including by workers in hazardous areas. In general, in industrial spaces where combustible / flammable substances are processed, handled and stored, they can occur under normal working conditions due to accidental processes or leaks, explosive mixtures of gases, vapors, mists or dusts and air [2].

In order to reduce the risk of explosion in these potentially explosive atmospheres, special protective equipment must be used in special construction for potentially explosive atmospheres, that do not produce or constitute sources of energy which could initiate an explosion.

This means that personal protective equipment and mechanical safety gloves, used in potentially explosive atmospheres, comply with the essential safety requirements regarding the danger of explosions by preventing (avoiding) intrinsic sources of ignition of explosive atmospheres, such as, for example, those of an electrostatic nature [3].

The essential health and safety requirements for personal protective equipment, both at national and European level, are governed by Regulation (EU) 2016/425 of the European Parliament and of the Council of 9 March 2016 on personal protective equipment and repealing Directive 89 / 686 / EEC [5].

2. METHODOLOGY FOR ASSESSING PROTECTIVE GLOVES AGAINST MECHANICAL RISKS IN RELATION TO THE ESSENTIAL SAFETY AND APPLICABLE HEALTH REQUIREMENTS

2.1. Procedures for assessing the conformity of personal protective equipment with the requirements of Regulation (EU) 2016/425 for making available on the European market

The main objectives of Regulation (EU) 2016/425 refers to:

-providing the essential safety and health requirements that personal protective equipment must meet, in order to maintain health and ensure the safety of potential users;

- ensuring the free movement of personal protective equipment throughout the European Union.

At the same time, Regulation (EU) 2016/425 also regulates the assessment procedures in relation to the essential safety and health requirements, applicable to the certification of personal protective equipment [6].

In order to certify personal protective equipment by third parties, the manufacturer is required to provide information in the technical documentation on the measures he has taken to ensure compliance of personal protective equipment with the applicable essential health and safety requirements.

If the manufacturer chooses to use harmonized European standards to ensure that personal protective equipment complies with Regulation (EU) 2016/425, he must be sure that these standards cover all the essential safety and health requirements applicable to his product under the foreseeable conditions for the intended use.

If harmonized European standards do not cover all the applicable essential health and safety requirements, it must, in addition to the application of these standards, ensure compliance with the essential health and safety requirements not covered by the use of other relevant technical specifications and other test methods.

In this context, it is important to note that personal protective equipment should be made available on the market and intended for use only if it complies with all applicable essential health and safety requirements.

According to Regulation (EU) 2016/425, the manufacturer is required to submit the model of personal protective equipment to one of the following certification procedures:

a) internal production control together with the EU declaration of conformity for category I PPE, in which case the manufacturer shall take all measures necessary to ensure that the manufacturing process and its monitoring ensure conformity of the PPE produced with the technical documentation and the applicable requirements of this Regulation.;

b) the EU-type examination, which is accompanied by the conformity to type based on internal production control and the EU declaration of conformity, for category II PPE, in which case the manufacturer shall take all measures necessary to ensure that the manufacturing process and its monitoring PPE products of the type described in the EU-type examination certificate and with the applicable requirements of Regulation (EU) 2016/425.

c) EU-type examination, which is accompanied by the manufacturer's choice of one of the procedures : conformity to type based on internal production control plus supervised product inspections at random intervals ; conformity to type based on quality assurance of the production process as well as by EU declaration of conformity for category III PPE, in which case the manufacturer shall take all measures necessary to ensure that the manufacturing process and its monitoring ensure conformity of production and conformity of PPE produced with the type described in the EU-type examination certificate and with the applicable requirements of Regulation (EU) 2016/425. approved for the production, inspection of finished products and testing of the PPE concerned and subject to supervision.

After PPE certification, the manufacturer or his authorized representative might apply the CE conformity marking, attesting their conformity with all the provisions of Regulation (EU) 2016/425, including the certification procedures provided for in Art. 19. The European CE conformity marking consists of the initials "CE" and is subject to the general principles set out in Article 30 of Regulation (EC) No 1234/2007. 765/2008.

Where the notified body is involved in the production control phase, the European conformity marking shall be followed by the identification number of that body.

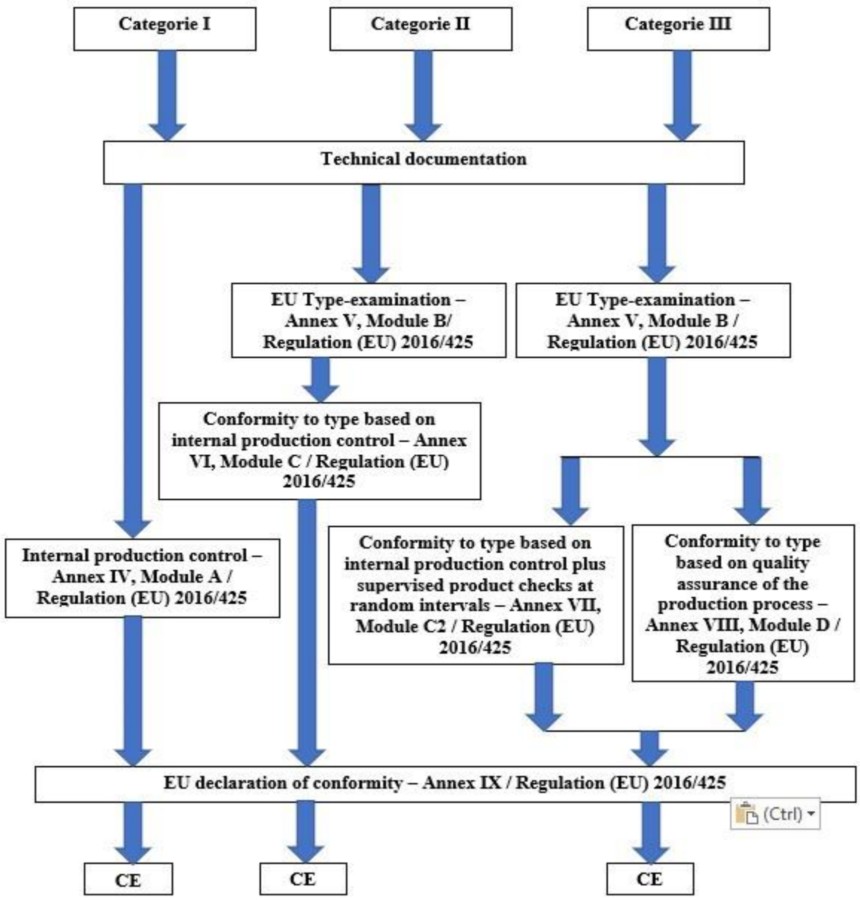

Fig.1. Conformity assessment procedures for personal protective equipment according to Regulation (EU) 2016/425

2.2. General and specific requirements for protective gloves

In accordance with the standard EN ISO 21420: 2020 "Protective gloves. General requirements and test methods ", protective gloves must meet a number of general requirements in order to ensure protection against risk factors related to the ergonomics and construction of gloves, the resistance of constituent materials to water penetration, their safety, comfort and effectiveness, plus the marking and information provided by the manufacturer applicable to all protective gloves [7].

From the point of view of design and construction, protective gloves must be designed and constructed in such a way as to ensure the highest possible level of protection under the foreseeable conditions of use for which they are intended, the user being able to perform normally when exposed to hazards.

If required, protective gloves should be designed to minimize wear and / or tear. If the protective gloves contain seams, their material and strength must be such that the overall performance does not decrease significantly.

The constituent materials of the gloves must have a certain resistance to water penetration expressed by one of the performance levels given in the table 1:

Table 1. ***The performance levels given***

Performance level	**Penetration time minutes**
1	30
2	60
3	120
4	180

Protective gloves must also be designed to provide protection without harming the user when used in accordance with the manufacturer's instructions.

The constituent materials of the protective gloves, the degradation products, the built-in substances, the seams, the edges and in particular the parts which come into direct contact with the user, must not harm his health and hygiene.

Regarding the size and dimensions of the hand, two main measures are considered, namely the circumference of the hand and the length of the hand (distance from the joint of the hand to the tip of the middle finger). The size of the protective gloves is determined by the size of the gloves they are wearing. However, the actual dimensions of the gloves must be determined by the manufacturer, taking into account the behavior of the glove material and the intended use.

The dexterity of protective gloves is very important. It is recommended that a protective glove be as dexterous as possible for the intended use. The dexterity of a protective glove depends on many factors, such as the thickness of the glove material, its flexibility and deformability.

Also, if necessary, protective gloves should have a water vapor permeability of at least 5 mg / (cm2h) . When the protective characteristics of the glove reduce or exclude water vapor permeability, the glove should be designed to minimize the effects of perspiration.

In addition to these general requirements, gloves for protection against mechanical hazards must meet a number of safety requirements relating to abrasion resistance, shear strength, tear strength and puncture resistance.

3. TEST METHOD FOR DETERMINING CUTTING STRENGTH BY CUTTING MECHANICAL RISK PROTECTIVE GLOVES

The test method for blade cut resistance determination for protective gloves is provided in SR EN 388+A1:2019 „Protective gloves against mechanical risks".

The test method consists in cutting test samples with a device having a circular blade, moving with an alternate motion under a specified load. Thus, the test sample is submitted to a number of cutting cycles, subsequently recorded and the blade cut resistance index is then calculated.

This blade cut resistance index represents one of the safety parameters of the protective gloves, showing their resistance to cutting by blade. The protective gloves fulfilling this requirement are considered to be adequate from a blade cut resistance standpoint.

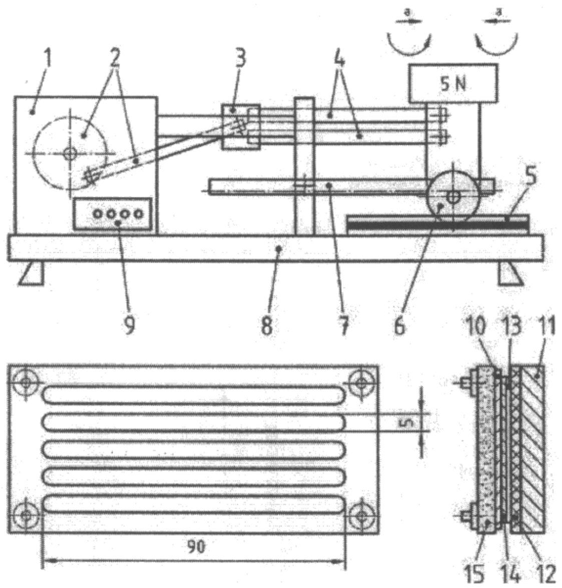

Fig.2. Schematic diagram of the test stand

Legend:

1 – motor casing and electronic detection
2 – driving wheel and rod
3 – sliding system
9 – counter
10 – test sample
11 – insulating support

4 – connecting rod
5 – sample support
6 – circular blade
7 – cogged rail
8 – support plate
12 – conductive rubber
13 – Aluminum foil
14 – filter paper
15 – upper part
a – blade alternate motion

The apparatus required for carrying out the test consists in the following:

- a testing machine, moving horizontally, alternative, a rotating circular blade. The stroke is 50mm and the blade fully rotates in a sense opposed to the motion sense. The maximum circumferential velocity is 10 cm/s;
- a weight pressing the blade with a force of (5 ± 0,05) N;
- the circular blade having the diameter of (45 ± 0,5) mm, thickness of (3 ± 0,5) mm and a cutting angle between 30º and 35º, made of wolfram steel having a Vickers hardness between 740 and 800;
- a conductive rubber support (hardness 80 ± 3 DIDC);
- a frame to hold the test sample;
- an automatic cut detection system;
- a cycle number counter, adjusted for tenths of cycles.

The test method for determining the shear strength of cut-resistant protective gloves shall be performed using the test stand shown in figure 3.

Fig.3. Test stand for determination of blade cut resistance of protective gloves

4. LABORATORY TESTS FOR DETERMINING BLADE CUTTING STRENGTH BY CUTTING MECHANICAL RISK PROTECTIVE GLOVES

In order to determine the shear strength, which is one of the essential protective performance of gloves against mechanical hazards, a series of laboratory tests have been carried out by applying the test method and using the stand test, previously presented. The laboratory tests were performed according to the requirements of the standard SR EN 388 + A1: 2019, on samples taken from several varieties of gloves for protection against mechanical risks, within the INSEMEX-GLI laboratory, laboratory accredited according to the requirements of the standard SR EN ISO / IEC 17025 : 2018.

The laboratory tests were mainly aimed at determining the shear strength of the samples taken from the gloves against mechanical hazards, the accuracy of the results obtained, the repeatability and reproductibility of the tests and last but not least the identification of factors influencing the quality of the test results. The results obtained on the test samples, as a result of the determination of the shear strength of the gloves for protection against mechanical hazards, are presented in the table below:

Table 2. ***The determination of the shear strength of the gloves for protection against mechanical hazards***

Test sample	Sampling area	Temperature and relative humidity	Test number	Index value, i	Average index value, i	Performance level
A(split cowhide)	palm	20 ºC and 63 %	1	2,61	2,62	Level 2
			2	2,50		
			3	2,66		
			4	2,65		
			5	2,71		
B (split cowhide)			1	1,21	1,29	Level 1
			2	1,34		
			3	1,27		
			4	1,45		
			5	1,20		

From the results obtained, shown in the table above, it can be seen that although the test samples were conditioned and tested under the same conditions of temperature and relative humidity, the level of performance is different.

If the tests on the two test samples (A and B) were performed in the same way, according to the requirements of the standard SR EN 388 + A1: 2019, it can be seen that the level of performance is different, so that the difference is due test sample material [8].

Although the material of both test specimens under test was bovine skin splinters, the samples being taken from different assemblies of gloves for protection against mechanical risks, led to a different level of performance.

Therefore, the performance level of gloves against mechanical hazards is mainly influenced by the material of which these gloves are made, while the conditioning and test conditions do not affect the results obtained, provided that the tests are performed and meet the requirements of SR. EN 388 + A1: 2019 [8].

At the same time, based on the results obtained and presented in the paper as well as other results obtained from the determination of shear strength on different types of gloves for protection against mechanical risks, it can be stated that in compliance with the test requirements of SR EN 388+ A1: 2019, both the test method and the test stand used, allow to obtain comparable results which leads us to ensure the repeatability and reproducibility of the tests performed.

5. CONCLUSIONS

Gloves that provide protection against mechanical hazards must comply with the applicable essential health and safety requirements in order to ensure a high level of protection of the user during the performance of work tasks.

Laboratory testing of their properties with a role in ensuring protection against risk factors is particularly important and at the same time necessary to establish the compliance of mechanical risk protection gloves with the applicable essential health and safety requirements.

Testing gloves against mechanical hazards for certification is particularly important given the risk of mechanical aggression and the risk of explosion that exists and must be minimized, in order to ensure the safety of life and health of workers.

Test methods ensure the repeatability and reproducibility of tests in various test laboratories, which is of particular importance as it provides a real basis for comparing the results of tests performed in European accredited laboratories in order to properly assess compliance with essential safety requirements. .

In order to have a basis for comparison, tests must be performed with well-defined test methods that take into account the influencing factors and that can ensure adequate repeatability and reproducibility.

In order to obtain results as accurate and as close as possible to the real ones, it is necessary to apply standardized test methods, respectively to perform the tests in an accredited laboratory according to the requirements of the SR EN ISO / IEC 17025: 2018 standard.

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DETERMINATIONS OF GAS CONCENTRATION IN TESTS CARRIED OUT ON PRESSURIZED CARCASES

GABRIELA PUPĂZAN[1], SORIN BURIAN[2], MARIUS DARIE[3], TIBERIU CSASZAR[4], COSMIN COLDA[5], DĂNUȚ GRECEA[6], ADRIANA ANDRIŞ[7], ALEXANDRU BELDIMAN[8]

Abstract: The paper estimates the resolution value of the test gas concentration found by indirect measurement, using a high-precision oxygen analyser (two decimal places). The first part of the paper briefly presents the pressurized housing protection "p" type of equipment protection to explosion and their specific test requirements. The last part of the paper presents a model for calculating the resolution of the test gas concentration.

Keywords: value resolution, test gas concentration, pressurized housings, purging.

1. INTRODUCTION

The operation of installations and equipment using combustible gases involves the build-up of flammable clouds (mixtures) in the form of fine gas dispersion [11], [12].

Explosive atmospheres are mixtures of air with flammable substances, in the form of fine gas dispersion, under normal atmospheric conditions, for which, after ignition, the combustion violently (explosively) propagates from the initiating source to the entire volume of mixture [1].

Explosive clouds generate explosions, following direct contact with efficient ignition sources. These explosions occur with the release of a large amount of heat and,

[1] *Asist. Res., PhD. Stud, INCD INSEMEX Petrosani, Gabriela.Pupazan@insemex.ro*
[2] *Sc. Res. Ist, PhD. Eng., INCD INSEMEX Petrosani, Sorin.Burian@insemex.ro*
[3] *Sc. Res. Ist, PhD. Eng., INCD INSEMEX Petrosani, Marius.Darie@insemex.ro*
[4] *Sc. Res. Ist, PhD. Eng., INCD INSEMEX Petrosani, Tiberiu.Csaszar@insemex.ro*
[5] *Sc. Res. IInd, PhD. Eng., INCD INSEMEX Petrosani, Cosmin.Colda@insemex.ro*
[6] *Sc. Res. IIIrd, PhD. Eng., INCD INSEMEX Petrosani, Danut.Grecea@insemex.ro*
[7] *Sc. Res., Eng., INCD INSEMEX Petrosani, Adriana.Andris@insemex.ro*
[8] *Tehn., INCD INSEMEX Petrosani, Alexandru.Beldiman@insemex.ro*

at the same time, flames arise, generating fires, high temperatures, vertiginous increases in pressure, etc.

The emission of flammable substances, followed by their ignition, can produce a wide variety of thermal and dynamic effects [2].

Any explosion (whether or not followed by a fire) is the consequence of random cumulative effects of a technical cause (s), on one hand, and of circumstances created by negligence, lack of foresight or caution and different levels of non-compliance with technical operating requirements, on the other hand [10], [13].

2. FEATURES FOR TESTING EQUIPMENT PROTECTED TO EXPLOSION BY PRESSURIZED HOUSING "p" PROTECTION TYPE

The purge test for pressurized casings without any internal release source and the fill test for static pressurization shielded equipment involves filling with test gas, at a concentration of at least 70%, in any measured point [14]. After the pressurized housing is filled, test gas supply is switched off and air supply is switched on, at the minimum purge flow rate specified by the manufacturer. Purging time must be measured and recorded. If a second test is required, the pressurized housing must be filled with a second test gas, the density of which is opposite to the first gas (relative to air density), at a concentration of at least 70% in any measured point and purging time for the second test must be also measured [5].

Equipment explosion-proofed [15] by air or inert gas pressurized housings, having a density equal to the density of air ± 10%, must be initially filled with air at normal atmospheric pressure. Their housing must then be purged with the inert gas specified by the manufacturer.

Equipment explosion-proofed by housing pressurized by static pressure must be initially filled with air at normal atmospheric pressure [3]. Equipment must then be filled with inert gas according to manufacturer's specifications. After filling, there must be no points inside the housing in which oxygen concentration exceeds 1% (v/v), compared to atmospheric conditions [6].

The shielding gas supply must then be switched on at the minimum purge rate specified by the manufacturer.

The dilution test shall be performed after the purge test and the shielding gas source shall be set to the minimum flow rate specified by the manufacturer.

The purge test for equipment with a pressurized housing, where the flammable substance is not a liquid, the pressurization is carried out by continuous circulation and the shielding gas is air, must be carried out using the test procedure specific to pressurized equipment [7].

In addition, during the test, the test gas must be injected into the pressurized housing through the receiving system at a maximum release rate so as to represent the most unfavorable release conditions, taking into account the position, number and nature of releases and their proximity related to the flammable equipment outside the dilution area.

If a second test is required, the test must be repeated using a second test gas and purging time must be recorded as the measured purge time.

Interior atmosphere of the pressurized housing must be tested in various points where it is assumed that the test gas is most likely to persist and in the vicinity of the flammable equipment outside the normal dilution area.

Gas concentration in test points must be analyzed or measured over the entire test period (s). For example, the pressurized housing may be provided with a number of small diameter tubes, the open ends of which must be placed inside the pressurized housing at the sampling points.

If the test consists of sampling, quantities taken should not have a significant effect on the test.

If necessary, the openings in the pressurized housing may be closed to allow the pressurized housing to be filled with the specified test gas, provided that they are reopened for the purge and dilution tests [8].

For specific applications, tests may be performed for specific flammable gases and vapors. In this case, flammable gases must be specified and the test gas (es) must be chosen to have densities within ± 10% of the heaviest gas and the lightest gas specified. In the case of a single specified gas, a single test shall be performed with a test gas having a density within ± 10% of the specified gas.

If it is necessary to cover all flammable gases, two tests must be carried out. A test must be performed to cover gases lighter than air, using helium as test gas. The second test must be performed to cover gases heavier than air, using argon or carbon dioxide as test gas.

Test gas concentration in sampling points, after purging and where the dilution is applied, when air is the shielding gas, must not exceed the following values:

- a value equivalent to 25% of the most unfavorable value of LEL, when tests for specific flammable gases are applied.
- a value equivalent of 25% of LEL, when a single specific flammable gas is covered.
- 1% for the helium test and 0.25% for the argon or carbon dioxide test when all flammable gases are covered.

These values correspond to approximately 25% of LEL for light and, respectively, heavy flammable gases.

If the shielding gas is an inert gas, the oxygen concentration after purging and dilution must not exceed 2% (V/V).

3. TEST GAS CONCENTRATION RESOLUTION CALCULATION MODEL

Internationally, for purge testing of explosion-proof equipment by pressurized casings, the assessment of test gas concentration values is performed indirectly by measuring oxygen concentration using high-precision oxygen analyzers that have a value resolution of hundredth of percent [9].

The theoretical model resulting from the balance of concentrations of gaseous substances present inside the equipment casing during the purge test shall be used to determine the test gas concentration [4].

Indicated equation of the analyzer:

$$\mathrm{C}_{\mathrm{indicat}} = \mathrm{C}_{\mathrm{O}_2} + \mathrm{k}_{\mathrm{Ar}} \cdot C_{Ar} + \mathrm{k}_{\mathrm{g1}} \cdot C_{g1} \cdot C_x + \mathrm{k}_{\mathrm{g2}} \cdot C_{g2} \cdot C_x \tag{1}$$

$$\mathrm{C}_{\mathrm{O}_2} + C_x + C_{N_2} + C_{Ar} = 1 \tag{2}$$

$$\frac{\mathrm{C}_{\mathrm{O}_{2\mathrm{ini}}}}{\mathrm{C}_{\mathrm{N}_2} + C_{Ar}} = \frac{C_{O_{2ini}}}{1 - C_{O_{2ini}}} = ct. \tag{3}$$

$$\frac{\mathrm{C}_{\mathrm{O}_2}}{C_{Ar}} = \frac{20,95\%}{0,98\%} = c \tag{3.1}$$

By dividing the relation (2) to $\mathrm{C}_{\mathrm{O}_2}$ results:

$$1 + \frac{\mathrm{C}_{\mathrm{x}}}{\mathrm{C}_{\mathrm{O}_2}} + \frac{C_{N_2}}{C_{O_2}} + \frac{C_{Ar}}{C_{O_2}} = \frac{1}{C_{O_2}} \tag{4}$$

Replacing the report $\frac{\mathrm{C}_{\mathrm{N}_2} + C_{Ar}}{\mathrm{C}_{\mathrm{O}_2}}$ from expression (4) with the one from expression (3) the resulted value of $\mathrm{C}_{\mathrm{O}_2}$ becomes:

$$C_{O_2} = C_{O_{2ini}}(1 - C_x) \tag{5}$$

Replacing the value of $\mathrm{C}_{\mathrm{O}_2}$ in expression (1), it becomes:

$$C_{indicat} = (1 - C_x) \cdot C_{O_{2ini}} \cdot \left(1 + \frac{\mathrm{k}_{\mathrm{Ar}}}{c}\right) + C_x \underbrace{(C_{g1} \cdot k_{g1} + C_{g2} \cdot k_{g2})}_{K} \tag{6}$$

$$C_x = \frac{C_{indicat} - C_{O_{2ini}}}{k - C_{O_{2ini}}} = \frac{C_{O_{2ini}} \cdot \left(1 + \frac{\mathrm{k}_{\mathrm{Ar}}}{c}\right) - C_{indicat}}{C_{O_{2ini}} \cdot \left(1 + \frac{\mathrm{k}_{\mathrm{Ar}}}{c}\right) - k} \tag{7}$$

To identify the relationship between value resolutions of the gas concentration to be measured, the following relation is used:

$$\Delta C_x = \frac{-\Delta C_{indicat}}{C_{O_{2ini}} \cdot \left(1 + \frac{\mathrm{k}_{\mathrm{Ar}}}{c}\right) - k} \tag{8}$$

where:

$C_{O_{2ini}}$ - oxygen content of atmospheric air;

$\mathrm{C}_{\mathrm{indicat}}$ - oxygen concentration indicated by the analyser;

C_{g1} - gas 1 concentration in the mixture;

C_{g2} - gas 2 concentration in the mixture;

k_{g1} - gas 1 correction coefficient in the mixture;

k_{g2} - gas 2, correction coefficient in the mixture;

C_{O_2} - oxygen concentration in the mixture;

C_{Ar} - argon concentration in air.

The parameter that influences the indication of the oxygen analyser is the offset value. Values of this parameter for test gases used are given in Table 1.

Table 1. ***Values of this parameter for test gases used***

No.	Substance	Offset (at 20°C) echiv. [%] oxygen	Value resolution [%]
1	Helium	0,29	-0,0484
2	Carbon Dioxide	-0,26	-0,0472
3	Argon	-0,22	-0,0472

4. CONCLUSIONS

The use of oxygen analysers for the purpose of indirectly measuring the concentration of test gases to perform tests for pressurized equipment has the advantage of generating a general solution applicable to all test gases.

On the other hand, the value of about 21% v/v of oxygen in the atmospheric air makes the value resolution of test gases measurement by using the method of indirect measurement with the help of oxygen analysers to be five times lower than the value resolution of the oxygen analyser.

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ASPECTS REGARDING THE MAINTENANCE OF ELECTRICAL EQUIPMENT USED IN POTENTIALLY EXPLOSIVE ATMOSPHERE

FOTĂU DRAGOȘ[1], MAGYARI MIHAI[2], MOLDOVAN LUCIAN[3], RAD MARCEL[4], COSMIN COLDA[5]

Abstract: The use of electrical equipment in potentially explosive atmospheres requires special attention, namely from the point of view of their construction and maintenance. Together with the technological developments, these objectives can easily be met, objectives which are defined by European standards concerning the construction, use and maintenance of explosive proof equipment. The purpose of this paper is to present the importance of the correct maintenance and repair of electrical equipment with type of protection flameproof enclosure „d" and type of protection increased safety „e" designed to be used in explosive atmosphere. Electrical equipment that operates in potentially explosive atmosphere, have characteristics specially designed for operation in this area. For security reasons, it is essential that the integrity of these special features be preserved in these areas throughout the life of the installation. To prevent an explosion it is very important that the maintenance and repair of electrical equipment is done correctly and is performed by trained personnel who know the principles of type of protection.

Keywords: electric equipment, increased safety, flameproof enclosure, repair, explosive atmosphere.

1. INTRODUCTION

Using electric equipment in potentially explosive atmospheres brings forward several particularities therefore the problems that appear during the design, construction and operation of electrical devices and installations brings forward numerous difficulties, their approach requiring special attention considering all the

[1] *Sc. Res. IIIrd, PhD.Eng., INCD INSEMEX Petrosani, dragos.fotau@nsemex.ro*
[2] *Sc. Res. Ist, PhD.Eng., INCD INSEMEX Petrosani, mihai.magyari@insemex.ro*
[3] *Sc. Res. Ist, PhD.Eng., INCD INSEMEX Petrosani, lucian.moldovan@insemex.ro*
[4] *Sc. Res. IIIrd, PhD.Eng., INCD INSEMEX Petrosani, marcel.rad@insemex.ro*
[5] *Sc. Res. IInd, PhD.Eng., INCD INSEMEX Petrosani, cosmin.colda@insemex.ro*

technical, economical and labor safety aspects. Due to this fact, it is very important that the equipment is properly inspected, maintained and repaired during the entire life of the equipment. The purpose of this paper is to identify improvements that can be made during the repair process of the equipment.[3]

2. MAINTENANCE OF ELECTRICAL EQUIPMENT USED IN POTENTIALLY EXPLOSIVE ATMOSPHERE

The electrical installations found in hazardous areas have especially designed characteristics in order to operate in such atmospheres. For safety reasons, it is essential that in these area, during the entire lifespan of the installation, the integrity of these special characteristics to be maintained. [17], [18], [2]

When a electric equipment is installed in areas in the atmosphere of which there may be inflammable gases, vapors or mists in hazardous concentrations and quantities, protection measures for the reduction of the probability of an explosion due to spark ignitions, electric arks or incandescent surfaces during normal or specified malfunctioned operation, need to be applied. [1][19]

The general state of the whole equipment needs to be periodically checked, by applying the specified periodic inspections, and if necessary, measures to remedy them need to be undertaken. The current actions undertaken in order to maintain the state of full operation of the installed equipment is called maintenance. The maintenance of the integrity of the type of protection foreseen for the equipment has to be especially considered. Spare parts need to be according to the documentation for the safety protection and assurance.[7] [20]

The electric equipment found in a hazardous area may be negatively influenced by the environmental conditions where it is used. Some of the essential elements which need to be considered are: corrosion, environmental temperature, ultraviolet radiations, water penetration, dust or sand accumulation, mechanical effects and chemical aggression. [4][20]

If the case or one of the components if severely corroded, the part affected needs to be treated by covering it accordingly against corrosion, the frequency and the nature of such a treatment being determined by the nature of the environmental conditions. [21], [5]

If the flameproof enclosures are reassembled, all the joints need to be thoroughly cleaned and lubricated easily with a sort of Vaseline for the prevention of corrosion and to increase their weatherproofing. In order to clean the flanges a non metallic grater and noncorrosive cleaning products need to be used. The bolds and tenons and similar parts on which the type of protection depends, need to be replaced only with similar parts according to the design and recommendations of the producer. The deteriorated sealing gaskets need to be replaced. The condensation proof devices shall be verified to see if they work accordingly. [21], [6]

3. INSPECTION OF ELECTRICAL EQUIPMENT USED IN POTENTIALLY EXPLOSIVE ATMOSPHERE

Inspection - an action involving a thorough examination of an object carried out either without disassembly or with partial disassembly, as the case may be, supplemented by means such as measurements, in order to reach a definite conclusion on the condition of the object in question. [17], [20]

In order to carry out inspections and maintenance of electrical installations in optimal conditions, the following updated documents must be available.

a) classification of hazardous areas;

b) equipment group and the temperature class;

c) sufficient records to allow explosion-protected equipment to be maintained in accordance with their types of protection.

The inspection and maintenance of electrical installations must be carried out only by experienced personnel whose training has included training on the different types of protection and practical methods of installation, all relevant rules and regulations, as well as the general principles of classification of hazardous areas. [10]

The main factors that cause damage to the equipment are: susceptibility to corrosion; exposure to chemicals and solvents; the possibility of accumulation of dust and dirt; the possibility of water penetration; exposure to excessive ambient temperatures; danger of mechanical damage; exposure to abnormal vibrations; staff training and experience; the possibility of unauthorized modifications and adjustments; the possibility of incorrect maintenance, for example not in accordance with the manufacturer's recommendations. [8], [9]

Inspections are classified into degrees and types of inspection.

Types of inspection: initial, periodic, survey.

Degrees of inspection: visual, rigorous, detailed.

Visual inspection - the inspection that identifies without the use of auxiliary equipment and tools, those defects that can be identified visually. [8]

Rigorous inspection - Inspection that includes the aspects covered by the visual inspection and, in addition, identifies those defects, for example loose screws, which can only be highlighted by using access equipment eg calibrated sills (if necessary) and tools. [11], [12]

Detailed inspection - the inspection that includes the aspects included in the RIGOROUS INSPECTION and in addition identifies those defects that can be highlighted only by opening the housing and / or when necessary using tools and test equipment. INITIAL INSPECTION - the inspection provided for all electrical appliances, systems and installations, before commissioning, in order to verify whether the type of protection chosen and its installation conditions are appropriate. [13]

The initial inspection must be carried out with a detailed degree of inspection. [8]

4. REPAIR OF ELECTRICAL EQUIPMENT USED IN POTENTIALLY EXPLOSIVE ATMOSPHERE

The general requirements for the repair and overhaul of an equipment are established by SR - EN 60079-19 which presents recommendations not only on the practical means of maintaining electrical safety and performance requirements for the repaired equipment, but also defines the procedures for maintaining after repairs, compliance of the equipment with the requirements of the certificate of conformity or with the provisions of the corresponding explosion protection standard. [15]

Users must use the most appropriate repair options for each piece of equipment that is provided by the manufacturer or a suitable, competent and equipped repairer.

While some manufacturers recommend that certain equipment be returned for repair and others nominate repairers, there are also independent and competent repair organizations that have the means to carry out this type of work. [2][9]

Repair is the action by which a faulty appliance is restored to full operation and in accordance with the relevant standard (the standard according to which the appliance was originally designed). [9]

The overhaul is the action of restoring the state of operation of a device that has been in use or in storage for a certain period of time, but which is not defective. [6]

The repair organization must have adequate repair and overhaul capabilities, as well as the appropriate equipment required to perform the required checks and tests, taking into account the specific type of protection. [14]

The repairer must focus on the need to be informed and to comply with the relevant explosion protection standards and certification requirements applicable to the equipment to be repaired or overhauled. [9]

The repairer must ensure that the persons directly involved in the repair and / or overhaul of the certified equipment are trained and supervised for this type of work.

Data available for repair and / or overhaul must include details of:

- Technical specifications;
- performance and conditions of use;
- assembly and disassembly instructions;
- certification limitations, if specified;
- marking;
- indicated methods of repair / overhaul.

The data specified above must be obtained from the manufacturer or the beneficiary of the repair. These may include information related to previous repairs, overhauls or modifications. [9]

The repairer must provide the user with the following:

- details on the detected faults;
- complete details of repair and overhaul works;
- list of replaced or corrected parts;
- the results of all checks and tests.

It is preferable to obtain spare parts from the manufacturer, and the repairer to ensure that only the appropriate spare parts are used for the repair or overhaul of the certified equipment.

The repairer must keep records with full details of the repair work performed In order to identify the repair and overhaul, as well as the identity of the repairer, the repaired equipment must be marked. The marking may be provided on a separate label. It may be necessary to remove or complete the label in certain cases, as follows:

a) If after repair, overhaul or modification the equipment is changed so that it no longer conforms to the standard and certificate, the certification label must be removed unless an additional certificate has been obtained.

b) If the appliance is replaced during repair or overhaul so that it conforms to the standard, but compliance with the certificate is not required, the marking label shall not be removed and the equipment should be marked with the symbol seen in figure 1.

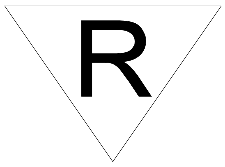

Fig.1. The equipment is in full compliance with the standard but compliance with the certificate is not required

c) If the appliance is replaced during repair or overhaul so that it conforms to the standard and the certificate, the marking label must not be removed and the equipment should be marked with the symbol seen in figure 2.

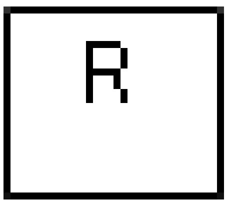

Fig.2. The equipment is in full compliance with the standard and certificate

Current maintenance and repair work which consists of simple replacement of worn parts with original spare parts, reconditioning of explosion-proof joints, reconditioning of simple spare parts such as axles, bushings, screws, etc. they can be executed in a regular workshop.

5. CONCLUSIONS

Flameproof enclosure electrical equipment has features specifically designed for operating in hazardous areas. For these reasons it is essential that equipment with type of protection flameproof enclosure throughout their lifetime, need to be properly maintained so that the type of protection is not canceled.

For the proper functioning of electrical equipment used in potentially explosive atmosphere, the inspection, maintenance and proper repair of these is of great importance. These things must be done by personnel who know the principles of the types of protection, and also to have the necessary infrastructure for a proper repair.

The inspection and maintenance of the equipment is done according to the requirements of the standard EN 60079-17, and the revision and repair of the equipment is done according to the requirements specified in the standard EN 60079-19.

Over the years, research conducted at INSEMEX has shown that the maximum period of three years between two detailed inspections is often too long. Because of this, the equipment may suffer damage that may invalidate the type of protection, or high repair costs.

The most suitable is that users of electrical equipment used in potentially explosive atmospheres to reduce as much as possible the time between two detailed inspections, in order to be able to identify possible equipment failures in advance.

The electrical installations found in hazardous areas have especially designed characteristics in order to operate in such atmospheres. For safety reasons, it is essential that in these area, during the entire lifespan of the installation, the integrity of these special characteristics to be maintained.

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EVALUATION FOR TYPE OF PROTECTION OPTICAL RADIATION "op"

DĂNUȚ GRECEA[1], SORIN BURIAN[2], MARIUS DARIE[3], TIBERIU CSASZAR[4], COSMIN COLDA[5], ADRIANA ANDRIȘ[6], GABRIELA PUPĂZAN[7], ALEXANDRU BELDIMAN[8]

Abstract: This paper proposes the analysis, evaluation and highlighting of the essential requirements for equipment and transmission systems that use optical radiation in areas with a potentially explosive atmosphere. The first part of paper deals with the risk of explosion and presents fundamental characteristics regarding the protection against explosions applied to technical equipment. The systematized presentation of applicable requirements to the equipment and transmission systems that use optical radiation is presented in second part of the paper. Among the conclusions, it is mentioned that, although the testing in explosive atmospheres is relevant, ensured by the specific standards, it is important to comply with the required conditions, still in the design faze and also, later in the production, installation and maintenance faze.

Keywords: explosive atmosphere, explosion protection; electrical equipment, type of protection, optical radiation, explosion risk.

1. INTRODUCTION

In the industrial field such as production, transport, extraction, processing, storage of petroleum products, interaction with various substances, mostly fuels and explosives, is predominant. The use of technical equipment in activities related to the

[1] *Sc. Res. IIIrd, PhD.Eng., INCD INSEMEX Petrosani, Danut.Grecea@insemex.ro*
[2] *Sc. Res. Ist, PhD.Eng., INCD INSEMEX Petrosani, Sorin.Burian@insemex.ro*
[3] *Sc. Res. Ist, PhD.Eng., INCD INSEMEX Petrosani, Marius.Darie@insemex.ro*
[4] *Sc. Res. Ist, PhD.Eng., INCD INSEMEX Petrosani, Tiberiu.Csaszar@insemex.ro*
[5] *Sc. Res. IInd, PhD.Eng., INCD INSEMEX Petrosani, Cosmin.Colda@insemex.ro*
[6] *Sc. Res., Eng., INCD INSEMEX Petrosani, Adriana.Andris@insemex.ro*
[7] *Asist.Res., Ph.D..Stud, INCD INSEMEX Petrosani, Gabriela.Pupazan@insemex.ro*
[8] *Tehn., INCD INSEMEX Petrosani, Alexandru.Beldiman@insemex.ro*

storage, transfer and / or processing of this type of substance involves the formation of a specific area with a significant risk of explosion. [27], [3], [31]

Explosion prevention and protection are of major importance for health and safety at work. For an atmosphere to become explosive, the flammable substance must be present in certain concentrations. Therefore, the explosion can only occur if there is a source of ignition and only if the concentration falls within the flammability (explosive) limits of the substance, i.e., between the lower flammability limit and the upper flammability limit. The limits of flammability (explosiveness) of the substance depend on the pressure and concentration of oxygen in the air. Thus, the mechanism of an explosion generated by a mixture of flammable gases, vapours or vapours with air can be expressed by the well-known explosion triangle shown in Figure 1 (a) and the explosion pentagon for or dust, lint and fibres, Figure 1 (b). [5], [4], [15]

Fig.1. a) explosion triangle (for gases, vapours, mists); b) explosion pentagon (for dusts, lint and fibres)

The dust explosion has different characteristics from the gas explosion and can be in many cases more devastating. If, for example, a stream of air swirls a layer of dust, in a small space, dust along the oxygen generates a flammable mixture of air-dust. If this mixture is ignited by a source of ignition, it will explode. The force of explosion swirls more dust in the air, being ignited in turn, like a chair reaction. [6]

Consideration must also be given to the fact that in order to be considered a combustible dust, the dust must be explosive - it must be suspended in the air, in order to have a distribution of particles capable of propagating combustion and a concentration, between explosion limits. Therefore, the explosion pentagon shown in figure 1 (b) can be defined by adding to explosion triangle aspects related to mixture or dispersion of combustible substances and oxidant, as well as those related to mixture suspensions. [8], [2], [10]

New concepts for explosion prevention and protection develop new strategies to prevent the propagation of explosions or to limit their effects, by taking into account specific related to the explosive mixture (limitation, containment, etc.). This representation provides a clear picture of the explosion conditions and allows identification of safety measures for design, manufacture, installation and repair of installations in order to prevent an explosive atmosphere, to eliminate sources of ignition or to reduce the effects of explosions by using protective systems. [11], [29]

2. THE EXPLOSION PROTECTION

All equipment used in installations operating in potentially explosive atmospheres must meet the following requirements:

• be adequately protected to explosion;

• maintain degree of protection to environmental conditions for which they were built;

• be able to withstand all the stresses to which they are subjected during storage, transport, installation and operation of installation. [12], [16]

All constructive solutions applied to electrical or non-electrical equipment that are used in potentially explosive atmospheres, in order to avoid the ignition of the surrounding explosive atmosphere, are included in specific types of protection. Constructively, electrical equipment may be designed using two or more types of protection, specified by manufacturer on the label, in accordance with the requirements of applicable standards. Each type of protection is based on a specific technical solution in order to implement explosion protection, Table 1. [2]

Table 1. ***Technical solutions and types of protection***

Types of protection to explosion		**Technical solution used**
Symbol	**Name**	
Ex m	Encapsulation „m”	Separates electrical equipment or parts that are likely to cause explosive atmospheric ignition
Ex p	Pressurized enclosure „p”	
Ex q	Powder filling „q”	
Ex e	Increased safety „e”	Eliminates the ignition source
Ex n	Type of protection „n”	
Ex d	Flameproof enclosures „d”	Prevents the ignition from spreading throughout the mixture in hazardous area
Ex i	Intrinsic safety „i”	It limits electric energy in circuits that can be a source of ignition
Ex op	Optical radiation	Energy limitation (is), blocking of optical radiation in equipment with other types of protection (pr), interlocking (sh)

The correlation of the types of protection with EPL (Equipment Protection Level) and the area in which they can be used is presented in figure 2.

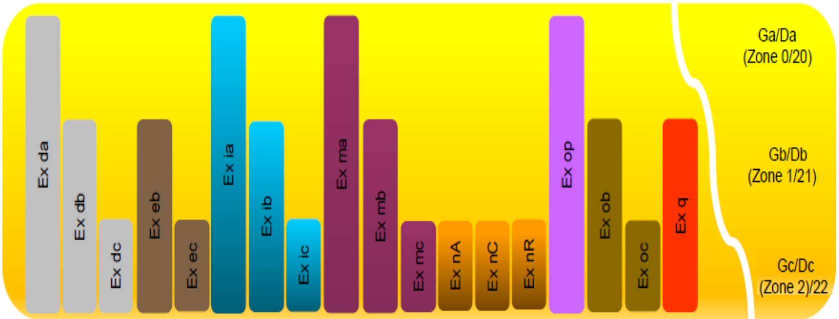

Fig.2. Correlation between the types of protection and the equipment EPL/ corresponding area

The use of technical equipment in areas where explosive atmospheres may form is clearly regulated, so preventive methods and solutions have been proposed to meet these requirements in order to minimize the risk of undesirable events. [13], [24]

3. TYPE OF PROTECTION OPTICAL RADIATION "*op*"

Optical equipment in the form of lamps, lasers, LEDs, optical fibers is increasingly used for communications, surveying, monitoring and measurement. In material processing, optical radiation of high irradiance is used. Where the installation is inside or close to explosive atmospheres, the radiation from such equipment may intersect with these atmospheres. [9], [28]

Depending on the characteristics of the radiation it might then be able to ignite a surrounding explosive atmosphere, and the presence or absence of an additional absorber, such as particles, significantly influences the ignition. [14], [26]

There are two possible ignition mechanisms:

a) Optical radiation is absorbed by surfaces or particles, causing them to heat up;

b) Direct laser induced breakdown of the gas or vapour at the focus of a strong beam, producing plasma and a shock wave both eventually acting as ignition source. These processes can be supported by a solid material close to the breakdown point.

Three types of protection can be applied to prevent ignitions by optical radiation in explosive atmospheres. These types of protection encompass the entire optical system.

These types of protection are:

a) inherently safe optical radiation, type of protection "*op is*",

b) protected optical radiation, type of protection "*op pr*", and

c) optical system with interlock, type of protection "*op sh*".

Where the ignition hazard assessment, shows that ignition due to optical radiation may be possible, the principles of using the types of protection shown in Table 4 shall be applied.

Table 4. ***Relationship between EPL and the probability of an ignition source***

EPL	Protection required
Ga	Ignition not likely with one fault and two independent faults or in the case of rare malfunctions
Gb	Ignition not likely with one fault or in the case of expected malfunctions
Gc	Ignition not likely in normal operation

3.1 Type of protection inherently safe optical radiation, "*op is*"

Inherently safe optical radiation means that the visible or infrared radiation is incapable of supplying sufficient energy under normal or specified fault conditions to ignite a specific explosive atmosphere. The concept is a beam strength limitation approach to safety. Ignition by an optically irradiated target absorber requires the least amount of energy, power, or irradiance of the identified ignition mechanisms in the visible and infrared spectrum. The inherently safe concept applies to unconfined radiation and does not require maintaining an absorber-free environment. [18], [22]

3.2 Type of protection protected optical radiation "*op pr*"

This concept requires radiation to be confined inside optical fibre or other transmission medium based on the assumption that there is no escape of radiation from the confinement. In this case the performance of the confinement defines the safety level of the system, "*op pr*". Safety levels that are applicable include EPL Gb or Gc and Db or Dc and Mb. All optical components shall be suitable for the ratings and temperature range for which they are used [19], [25].

3.3 Type of protection optical system with interlock "*op sh*"

This type of protection is also applicable when the radiation is not inherently safe. The concept requires radiation to be confined inside an optical fibre or other transmission medium based on the assumption that there is no escape of radiation from the confinement under normal operating conditions.

4. EVALUATION OF EQUIPMENT AND TRANSMISSION SYSTEMS USING OPTICAL RADIATION

Electrical equipment and electrical Ex components (e.g., fibre optic terminal devices) shall comply with one or more of the specific electrical equipment protection technique standards listed in SR IEC EN 60079-0, [17], suitable for the application if intended to be installed inside the hazardous area. [1], [7], [23] Optical equipment shall be subjected to a formally documented ignition hazard assessment using the principles stated in figure 3. This assessment shall be made to determine which possible optical ignition source can arise in the equipment under consideration, and which measures may need to be taken to mitigate the risk of ignition.

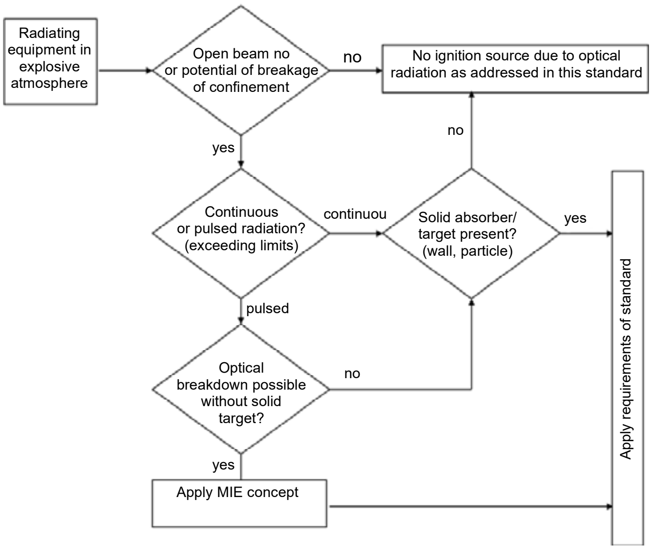

Fig.3. Ignition hazard assessment

In all cases, where optical radiation is to be considered, the ignition hazard assessment shall be the first step. If the assessment shows that no ignition is to be expected, the further application of this standard is not necessary.

An explosive atmosphere can be ignited by optical radiation provided that the beam strength exceeds an inherently safe level and an absorbing solid exists in the beam that can cause a hot spot and an ignition source accordingly, or in case of pulses the conditions for a break down apply (threshold irradiance exceeded).

4.1 Requirements for inherently safe optical radiation "*op is*"

Either optical power or optical irradiance shall not exceed the values listed in Table 5, Table 6 and Table 7, categorized by equipment group and temperature class.

As an alternative to compliance with Table 5 the following options are available:

- For irradiated surface areas above $400\ mm^2$, the maximum temperature measured on the irradiated surface shall be used to establish the temperature class, with no limit on irradiance. The temperature measurement shall consider the possibility of nonhomogeneous beam strength.

- For limited irradiated areas not greater than *130 mm²*, maximum radiated power values other than those as permitted by Table 2 for temperature classes *T1*, *T2*, *T3* and T4 and Groups *IIA*, *IIB* or *IIC* are detailed in Table 7.
- Passing the ignition tests.

Table 5. ***Safe optical power and irradiance for Group l and 11 equipment, categorized by Equipment Group and temperature class, [28]***

Optical radiation sources with		**Can be used for the following atmospheres (temperature classes in combination with equipment groups)**	**Remarks**
Radiated power (no irradiance limit applies) mW	**Irradiance (no radiated power limit applies)** mW/mm2		
≤ 150		IIA with T1, T2 or T3, and I	No limit to the involved irradiated area
≤ 35		IIA, IIB independent to T-class, IIC with T1, T2, T3 or T4, and I	No limit to the involved irradiated area
≤ 15		All atmospheres	No limit to the involved irradiated area
	≤ 20	IIA with T1, T2 or T3, and I	Irradiated areas limited to ≤ 30 mm2
	≤ 5	All atmospheres	No limit to the involved irradiated area

Table 6. ***Safe optical power and irradiance for Group III equipment [28]***

Equipment Group	**IIIA, IIIB and IIIC**		
EPL	**Da**	**Db**	**Dc**
Radiated power (no irradiance limit applies) mW	≤ 35	≤ 35	≤ 35
Irradiance (no radiated power limit applies) mW/mm2	≤ 5	≤ 5	≤ 10

Table 7. ***Safe limit values for intermediate area, Group I or 11, constant power, T1 - T4 atmospheres, equipment Groups IIA, IIB or IIC, [28]***

Limited irradiated area mm2	Maximum radiated power value mW
< 4 * 10–3	35
≥ 4 * 10–3	40
≥ 1,8 * 10–2	52
≥ 4 * 10–2	60
≥ 0,2	80
≥ 0,8	100
≥ 2,9	115
≥ 8	200
≥ 70	400
For irradiated areas equal to or above 130 mm2 the irradiance limit of 55 mW/mm2 applies	

For optical pulse duration of less than *1 ms*, as determined in accordance with the applicable equipment protection level, the optical pulse energy shall not exceed the minimum spark ignition energy (MIE) of the respective explosive gas atmosphere.

For optical pulse duration from *1 ms* to *1 s* inclusive, as determined in accordance with the applicable equipment protection level, an optical pulse energy equal to 10 times the MIE of the explosive gas atmosphere shall not be exceeded.

For a single pulse, optical pulse energy is equal to the product of the average power and the optical pulse duration of that single pulse.

The MIE values for the application of this standard, [30], are:

- Group IIA: *240 μJ;*
- Group IIB: 82 *μJ;*
- Group IIC: 17 *μJ.*

4.2 Requirements for protected optical radiation "*op pr*"

This concept requires radiation to be confined inside optical fibre or other transmission medium based on the assumption that there is no escape of radiation from the confinement. [20]

In this case the performance of the confinement defines the safety level of the system, "*op pr*". Safety levels that are applicable include EPL Gb or Gc and Db or Dc and Mb.

All optical components shall be suitable for the ratings and temperature range for which they are used. [21]

The optical fibre, figure 4, or cable protects the release of optical radiation into the atmosphere during normal operating conditions. For EPL Gb, Db or Mb protected optical fibre cables shall be used provided by additional armouring, conduit, cable tray, or raceway.

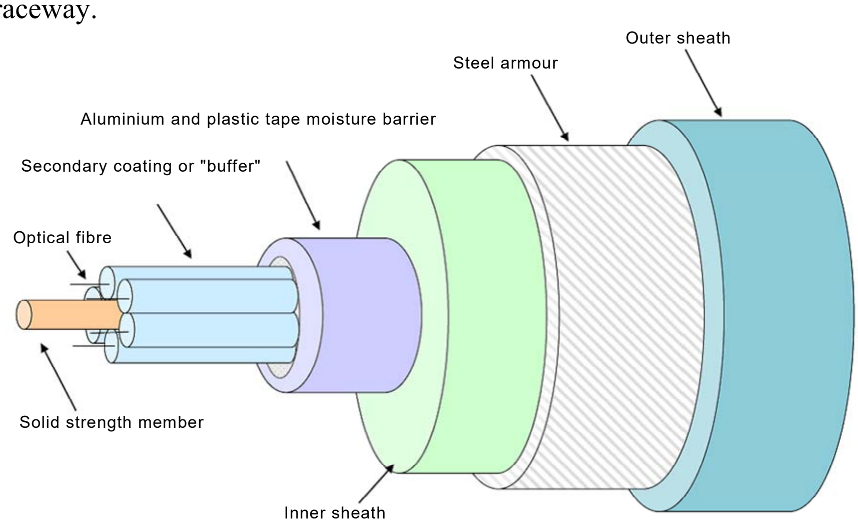

Fig.4. Example multi-fibre optical cable design for heavy duty applications, [28]

Internal or external cables can be terminated/ spliced from one fibre (from a cable) to another fibre (in a new cable) by using dedicated coupler or joining kits giving a fixed termination. For external termination/splicing, the cable connection shall provide equivalent mechanical strength to that of the cable.

For EPL Gc or Dc optical fibre or cables and internal pluggable factory connections that comply with the applicable industrial standard are suitable.

Ignition capable radiation inside enclosures is acceptable if the enclosure complies with recognised types of protection for electrical equipment designed to contain an internal ignition (flameproof "d" enclosure), or where it is not to be expected that there are absorbing targets inside the enclosure according to the ignition hazard assessment (such as an IP ox enclosure, pressurized "p" enclosure, restricted breathing "nR" enclosure, dust ignition protection by enclosure "t" etc.).

4.3 Optical system with interlock "*op sh*"

This type of protection is also applicable when the radiation is not inherently safe. The concept requires radiation to be confined inside an optical fibre or other transmission medium based on the assumption that there is no escape of radiation from the confinement under normal operating conditions.

Depending on the EPL, "*op sh*" requires the application of "*op pr*" principles, along with an additional interlock cut-off, as follows:

- For *Ga*, *Da* or *Ma* "*op sh*" applications, protected fibre optic cable "*op pr*" for *Gb/Db/Mb*, along with a shutdown functional safety system based on ignition delay time of the explosive gas atmosphere, is required.

- For *Gb*, *Db* or *Mb* "*op sh*" applications, protected fibre optic cable "*op pr*" for *Gc/Dc*, along with a shutdown functional safety system based on eye protection delay times, is required.

- For *Gc* or *Dc* "*op sh*" applications, unprotected fibre optic cable (not "*op pr*"), along with a shutdown functional safety system based on eye protection delay times, is required.

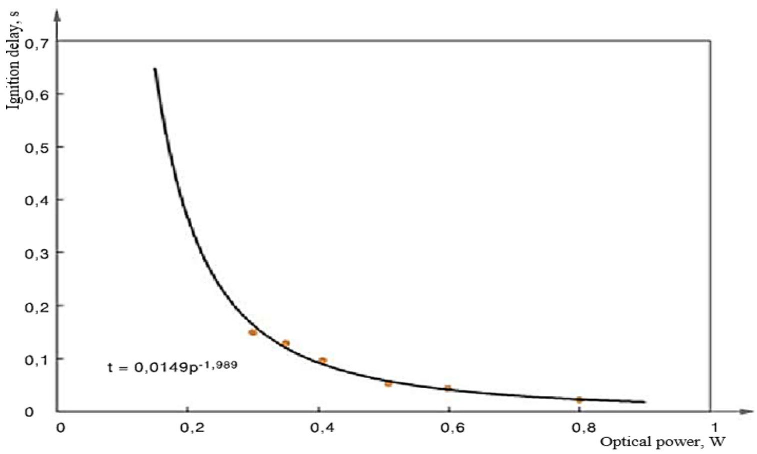

Fig.5. Optical ignition delay times and safe boundary curve with safety factor of 2, [28]

The interlock cut-off shall operate if the protection by the confinement fails and the radiation becomes unconfined on time scales shorter than the ignition delay time or the delay time for eye protection.

The interlock cut-off delay time of equipment for use for Group *I*, Group *IIA* temperature class *T1* and Group *IIA* temperature class *T2* shall be less than the boundary curve of figure 5 represented by the curve fit to minimum ignition delays with a safety factor of *2* included.

The interlock cut-off shall be required to perform according to the requirements defined by the risk analysis.

5. CONCLUSIONS

The risk of ignition of an explosive atmosphere may be reduced by the use of equipment, components and protective systems designed in accordance with the provisions of the technical standards for protection against explosions in force. The explosion risk assessment shall also take into account the determinations and interpretations of the parameters of the flammable substance. The importance of determining, identifying the factors influencing and the measures to be taken to determine as accurately as possible the parameters of influence are necessary for explosion prevention and explosion protection, of major importance for health and safety at work and to minimize losses (both human and materials).

The paper presents relevant aspects for the evaluation of technical equipment and transmission systems that use optical radiation in potentially explosive environments, useful aspects in the choice of materials, components of the equipment manufacturing process, all in order to minimize the risk of initiation atmospheres in which it is used. This equipment must comply with the requirements briefly presented in this paper and correspond in terms of protection against the initiation of the Ex atmosphere in which it is used, as a result of the tests to be performed depending on the type of protection.

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OPERATIONAL SYSTEMIC MODEL OF OCCUPATIONAL SAFETY AND HEALTH MANAGEMENT INTENDED TO MINIMIZE ELECTRICAL RISKS

CRINA MARIA BARB[1], ROLAND IOSIF MORARU[2], CĂTĂLIN VALENTIN DREGAN[3]

Abstract: The existing systems, applied and validated on occupational safety and health management in electrical organizations, seem to focus on management functions, national and international guidelines, quality standards and principles, to define, describe and ensure conditions for the implementation of occupational safety and health management systems. In this paper, the systemic approach has been adopted to develop a systemic model of occupational safety and health management. The purpose of the model is to maintain the electrical risk in an acceptable range in the operations of an organization whose object of activity is the supply and distribution of electricity, regardless of the internal, external and risk management context in which it is located.

Keywords: Occupational Health and Safety (OHS), Systemic Model, Safety Management System (SMS), electrical risk.

1. INTRODUCTION

Most of the available approaches, applied and validated on occupational safety and health management in economic organizations in the field of electricity, seem to focus on management functions, national and international guidelines, quality standards and principles, to define, describe and ensure the conditions for the implementation of the occupational safety and health management systems of the industrial organizations [1, 7, 9, 20, 21]. These approaches may be a necessary and useful step in the effort to effectively manage workers' safety and health, but may or may not be comprehensive enough to properly address all the complex issues associated with occupational risk management in the complex context of current

[1] *Ph.D.Stud. Eng. University of Petrosani, crinabarb92@gmail.com*
[2] *Professor, Ph.D., University of Petrosani, roland_moraru@yahoo.com*
[3] *Ph.D.Stud. Eng. University of Petrosani, dre_cata@yahoo.com*

challenges of the major changes in the dynamic reality of emerging work environments [22, 24, 27, 33]. It seems that the need to identify, develop and implement a new pragmatic approach, realistic and adapted to the conditions, but - at the same time - ***systemic*** of occupational safety and health management, is becoming more and more stringent [6, 12].

In this paper, the systemic approach has been adopted to develop a systemic model of occupational safety and health management. In this context, we will define the term "***systemic***" as an attempt to interpret events as a whole in their causal course and to see events, including technical failures and human errors, as "*products of the functioning*" of a system and, in this regard, to analyze the consequences of scenarios (accidents / incidents / occupational diseases / damages / major accidents / property damage, etc.), as a result of the systems operation. ***The ultimate goal of the model is to maintain the electrical risk in an acceptable domain, in the operations of an organization whose object of activity is the supply and distribution of electricity, regardless of the internal, external and risk management context in which this is situated***. We consider that when the features of the model (i.e. embedded systems, their associated functions and communication channels) are operational and functioning efficiently, then the probability of failure / malfunction should be significantly lower than otherwise.

2. LITERATURE REVIEW

Traditionally, both scientific research and practitioners have tended to approach the analysis of electrical hazards by focusing on the technical aspects and looking for the immediate causes of accidents or incidents after they have taken place [2, 3, 19, 28]. Major accidents occurred have highlighted the need for a proactive approach to safety [8]. In addition to the perpetuation of events with severe consequences and as a direct consequence of these, the emergence of new regulations and international standards has required organizations to improve their safety performance. [16]. As a result, companies have been forced to move from a prescriptive, regulatory approach to a ***flexible, tailored*** and ***more dynamic*** approach to analyzing, assessing and - most importantly - managing operational risk affecting their important components of the activity, including risks to safety and health of workers [18].

In the prescriptive approach, regulations explain how to "achieve safety", while in the flexible approach, regulations make explicit what organizations need to do, but leave it to decision makers (CEOs, Boards, top managers etc.) how achieving / materializing the predetermined safety objectives [17].

For a long time, safety approaches have focused on the dysfunctions that immediately precede an unwanted event [20], understood as "***active causes***" or "***human errors***" that have a direct and immediate impact on the integrity of the system. More recently, especially in the last two decades, however, an understanding of the substrate of organizational error has been the focus of the process of minimizing the risks of accidents at work, incidents and major accidents [21]. OSH approaches seem to focus on management functions, guidelines, industry safety standards, quality principles, to establish the OSH management system in organizations [4, 5, 13, 14].

Such well-established approaches have the potential to be a step forward in safety management, but not infrequently they may not be sufficient for effective risk management in the practice of industry organizations, especially due to the emphasis on formalization of documents to the detriment of actual implementation. Moreover, it is openly stated (and up to a point, in line with reality) that such approaches are "***systematic" in the sense of "methodical" and / or "orderly"*** [25, 32].

This means that the above-mentioned approaches tend to focus on organizational functions that deal with policy, organization, planning, auditing, performance measurement, etc [26]. All these functions are of course necessary, but they may not be enough to ensure the effectiveness of an OHS management system [23]. However, an SMS must be more than that, and we mean - first of all - that it must be "systemic", meaning that an SMS should try to consider the organization as a whole; that is, from top management to frontline workers, from the base of the hierarchical line, communication channels, people (with their values, beliefs and attitudes), etc. In addition, it should take into account the "external environment" (or what the ISO 31000: 2018 standard calls the external context of the organization); that is, all those circumstances that are outside the system represented by the organization, but to which the system's response will be necessary; for example, political, economic, legislative, stakeholder factors, etc. [15]. In short, a ***systemic and contextual approach is needed.***

We define systemicity as an attempt to see things as a whole and to consider undesirable events, including *failure / human error* as a result of the operation of the industrial system and, in particular, to interpret *death / injury / temporary incapacity for work / disability / property damage, etc*., as a result (obviously, undesirable) of the very functioning of the systems [34].

3. MATERIAL AND METHOD

In further research, we have taken a systemic approach to develop a systemic model of occupational safety and health management, which addresses explicit the “environmental” factors in detail and includes the development of the recursion concept [29]. We also developed a case study on the application of the model in an industrial company in the field of electricity supply and distribution, in order to illustrate its own characteristics and particularities of the model.

The ultimate goal of the proposed model is to maintain risk within an acceptable range of an organization's operations, from the primary perspective of workers' safety and health, and is proposed as a *sufficient* structure for an effective safety management system. Its foundation is based on an increased preventive potential, in the sense that if all the subsystems and connections involved in the model are present in the reality of the organization and work correctly / efficiently, the probability of occurrence of dysfunctions should be lower than in the opposite case.

The approach adopted starts from the *Viable System Model* (VSM) developed and proposed by Golineli [11] and the *Failure Paradigm Method* (FPM), proposed by Fortune and Peters [10]. A "***viable system***" is defined as a system that is able to maintain a separate existence. It is argued that in any *viable system* there are five necessary and sufficient subsystems involved interactively and interdependently in any organization / organism that is able to preserve its own identity independently of other such organizations / organisms coexisting in a common environment, in a given context [30, 31].

On the other hand, the *Failure Paradigm Method* facilitated the identification and analysis of examples of good practice, not only useful but - we can say - decisive in understanding aspects related to the human component, so important in discerning the "*human error*" component in the approach analysis of potential accident scenarios. Table 1 summarizes the main methodological elements characteristic to the developed Model of Systemic Management of Occupational Safety and Health (MSMSSM). Starting from these systematized characteristics in the first phase, we elaborated the block diagram of the structural organization of the proposed MSMSSM, represented in figure 1.

Table 1. ***Fundamental features of the proposed MSMSSM model***

Crt. no.	Characteristics of the developed model
1.	MSMSSM and “its environment” (external context)
2.	Stratified (recursive) structure combined with relative autonomy
3.	A structural organization consisting of a "basic unit" in which it is necessary to perform five functions associated with systems 1-5. • System 1: Implementation of OSH policy • System 2: OSH coordination • System 3: OHS operationalization • 3 * system: Audit • System 4: Development • 4 * system: Confidential reporting system • System 5: OSH Policies • "Communication channel".
4.	Commitment to OSH
5.	*RMA* (Maximum Acceptable Risk), *Viability* and *Acceptable Risk Range* concepts.
6.	"Paradigms" are intended to act as "templates" providing essential features for effective communication, control and "human factors".

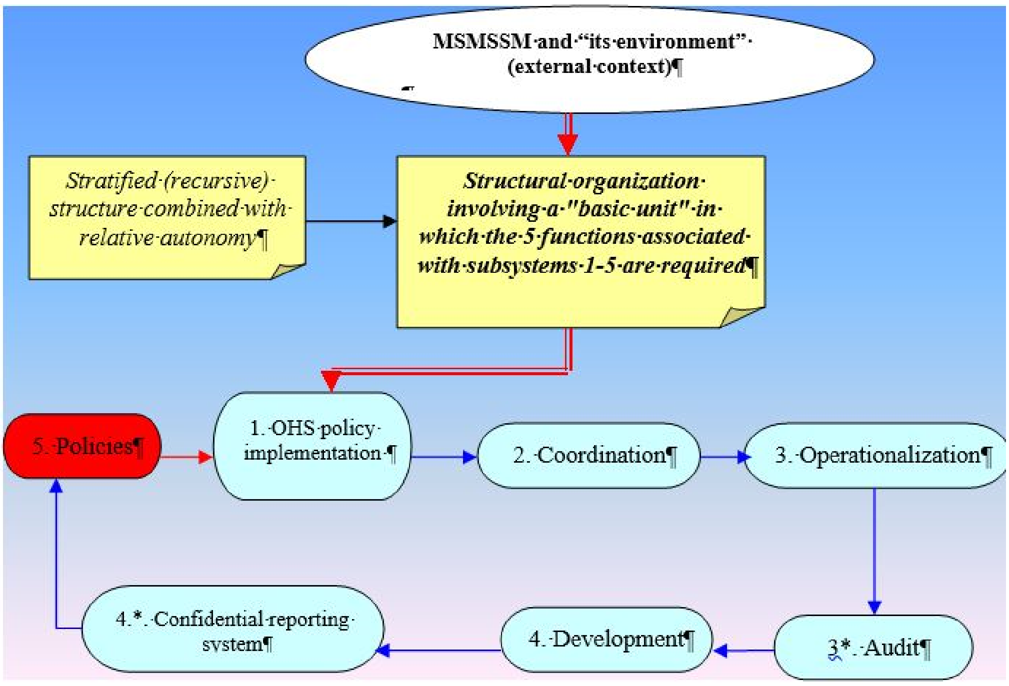

Fig.1. Block diagram of the proposed structural organization of the MSMSSM

In the following, we have provided a detailed description of the three basic features of the model, namely: (1) MSMSSM and its "environment"; (2) "Recursive structure"; and (3) Structural organization (systems 1-5).

According to the Explanatory Dictionary of the Romanian Language, recursion is "the intrinsic property of a process, program, phenomenon, etc. to be able to be described, decomposed, processed and analyzed**". Recursion** is a process that is done by appealing to a simpler form of it. In mathematics and computer science, "recursion is a way of defining certain functions. The function is recursive, if its definition uses a reference to itself, creating at first sight a vicious circle, which is only apparent, not real. Recursion is closely related to iteration, but if the iteration is the repeated execution of a part of the program, until a condition is met (e.g. while, repeat, for), recursion involves the repeated execution of a module, but during its execution (and not at the end, as in the case of iteration), a condition is verified whose dissatisfaction implies the resumption of the execution of the module from its beginning".

A recursion can be seen as a "level" that has other levels below or above it, and can be assimilated to stratification. The concept of recursion is intended, in the context of the present research, to identify the level of the organization modeled or considered for analysis. Very often, in the literature it is not very clear whether an SMS refers to an entire organization, to several parts of it or only a part of the industrial organization.

4. MODEL DEVELOPMENT AND CASE STUDY AT THE ORGANIZATION INVESTIGATED IN THE FIELD OF ELECTRICITY DISTRIBUTION

The organizational structure of MSMSSM was developed as interacting in a defined way with its "environment", through the operations of system 1 and system 4, as illustrated in Fig. 2. "Environment" is understood as the set of circumstances to which the MSMSSM must be able to provide certain answers. In a broad sense, we have equated the environment with what ISO standard ISO 31000: 2018 calls the "*external context*". The "environment" is outside the system, but it interacts with it; it is the source of the circumstances in which the system's response is needed; therefore it is important to consider it. System 4 treats both the "*total environment*" represented by an ellipse delimited by a dashed line and the "*future safety environment*" incorporated in the "*total environment*", as we represented in figure 2. The "*future safety environment*" takes into account threats and opportunities for the future development of OSH. If the MSMSSM is to be effective, it must have the means to scan, interpret and respond to the implications of all those external factors. We consider that the external context may include, but is not limited to, the following:

- cultural, political, legal, regulatory, financial, technological, economic, natural and competitive environment, international, national, regional or local;
- factors and trends having a decisive impact on the organization's objectives;
- perceptions and values of external stakeholders.

Whenever a line appears in figure 2 representing the SSMS model, this is a communication channel, except for the lines connecting the balancing loop between systems 4 and 3. Table 2 summarizes the external "environmental" factors that will have to be taken into account by MSMSSM.

Table2. ***Considered structure of external "environmental" factors***

Crt. no.	Social and political factors	Economic factors	Physical factors
1.	a. Legal requirements	l. Insurers	n. Geographic location
2.	b. Safety, Health, Quality and Environmental standards		
3.	c. Legislation enforcement practices		
4.	d. Major accidents or catastrophes		
5.	e. Non-governmental organizations and Occupational Associations		
6.	f. Public opinion	m. Economic conditions and commercial interests	o. Climate conditions
7.	g. Technological level		
8.	h. Suppliers of goods and services		

9.	i. Workers representatives (trade unions)		
10.	j. Production markets and the labor market		
11.	k. National, regional and local culture		

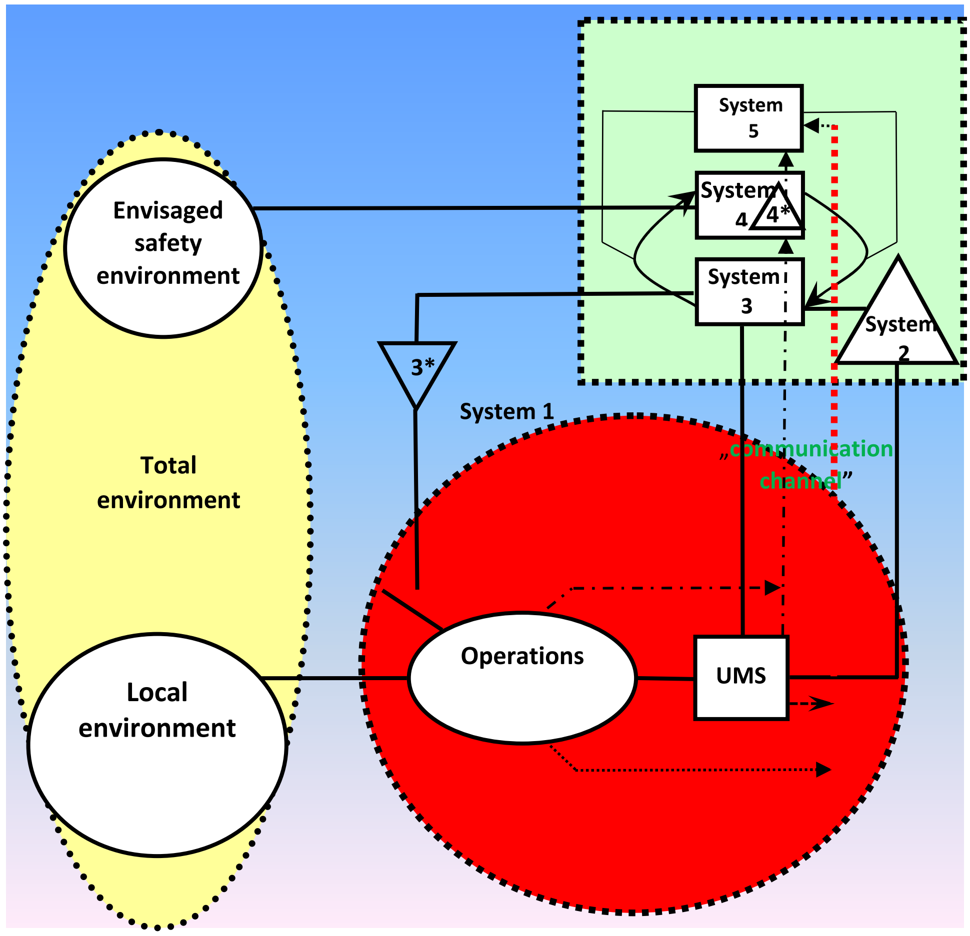

Fig.2. Systemic model of occupational safety and health management system (adapted from Santos-Reyes et al, 2001)

The main activity of the investigated organization is the supply and distribution of electricity to its customers. The activities carried out within the Organization are focused on the following aspects: operation of electrical installations, customer service and troubleshooting, distribution of electricity to consumers, development and modernization of energy installations, management of system informatics. Also, within the Organization, related activities are carried out, such as: dispatching, telecommunications, PRAM services. The distribution of electricity is carried out through networks and high voltage substations as well as through medium and low voltage networks and substations.

There are three Electricity Distribution Companies in this Organization, namely:

- ***Level I Electricity Distribution Company***, being the electricity distribution operator, serving the southern and central area of Transylvania. This company operates in the counties of Sibiu, Alba, Brasov, Covasna, Harghita and Mures, and covers an area of 34,100 square kilometers. The company has more than 2,120 employees and provides services to approximately 1.13 million consumers through a distribution network with a length of over 57,300 kilometers.
- ***Level II Electricity Distribution Company***, being the electricity distribution operator, serving the North-West area of Transylvania. This company operates in the counties of Cluj, Satu Mare, Maramureș, Bistrița-Năsăud, Bihor and Sălaj, being spread over an area of 34,160 square kilometers. With a tradition of 120 years, the Company has more than 2,240 employees and provides services to approximately 1.26 million consumers, through a distribution network with a length of over 68,700 kilometers.
- ***Level III Electricity Distribution Company***, being the electricity distribution operator, serving the northern part of Muntenia. This company operates in the counties of Prahova, Galați, Buzău, Brăila, Vrancea and Dâmbovița, being spread over an area of 29,000 square kilometers. With a tradition of 120 years, the Company has a number of over 2,260 employees, through a distribution network with a length of over 70,700 kilometers.

Figure 3 includes the strategic objectives of the organization.

Fig.3. The strategic objectives of the Organization under investigation

In 2019, the Organization made the transition from the Integrated Quality Management System - Environment - OSH from OHSAS 18001: 2007 to SR ISO 45001: 2018 and its recertification, according to the requirements of the international reference standards SR EN ISO 9001: 2015, SR EN ISO 14001: 2015 and SR ISO 45001: 2018, by the certification body SRAC Cert affiliated to IQNet, in October of the same year. Figure 3 illustrates an example of a recursive OSH management system applied to the case of the organization that was the object of the analysis, in the field of electricity supply and distribution. The vertical interdependence of safety management systems is highlighted.

It should be emphasized that each of the above subsystems can be broken down into additional subsystems depending on the practical level of interest. In principle, each subsystem that is part of system 1 at level 3 may be further decomposed, depending on the level of interest of the SMSSM modeler or the analysts involved in the process. MSMSSM contains a structure that promotes "relative autonomy" and local capacity to solve electrical risks.

"***Relative autonomy***" means that each operation of system 1 of the MSMSSM is responsible for its own activity, with minimal intervention of systems 2-5. The organizational structure will facilitate decision-making at the local level; thus, decision making is distributed rationally and efficiently throughout the organization. Decision-makers in system 1 should be relatively autonomous in making their own decisions and will be able to act independently, based on their own understanding of the risk, the level of safety and the specific tasks. In view of the above, it is important that subsystems have "relative autonomy" in carrying out their tasks, while complying with the safety requirements of the management system as a whole. The decision on the extent of relative autonomy is a sensitive / difficult issue and it certainly should not be possible for subsystems to become isolated. However, it is important to ensure the highest possible degree of relative autonomy, but its exercise is compatible with the efficient operation of the SMS assembly.

The MSMSSM model has a “*basic unit*” in which it is necessary to perform five functions associated with systems 1–5. Systems 2-5 also facilitate the function of system 1, as well as ensuring the continuous adaptation of the organization as a whole.

System 1 is considered to be the core of MSMSSM. Essentially, it is the "*place*" where an organization's business process takes place, and therefore the risks are there (there may be other risks, due to the interaction with the "*external environment*"). System 1 implements safety policies in System 1 operations, consisting of all operations within an organization that are directly involved in the "core" activities of the organization.

How system 1 can be further "broken down" or "*fragmented*" is a key question; for example, system 1 could be broken down by *geographical* or *functional* criteria.

The role of ***System 2*** is to coordinate the activities of System 1 operations in relation to the overall environment of the SMSSM. System 2, together with the management units of system 1, implements the safety plans received from system 3. It informs System 3 about routine information regarding the performance of System 1 operations. In order to carry out plans of System 3 and needs of System 1, System 2 collects and manages safety information for System 1 operations. There is potential for certain organizations in the ”Total Environment” to create some conflict situations in the operation of the system 1. An example of a coordination activity could be the resolution of any conflicts that may arise between the operational departments (Network Operations Division) and the auxiliary departments (Common Services Division or Risk Management Office) which act as the electricity supply and distribution branch.

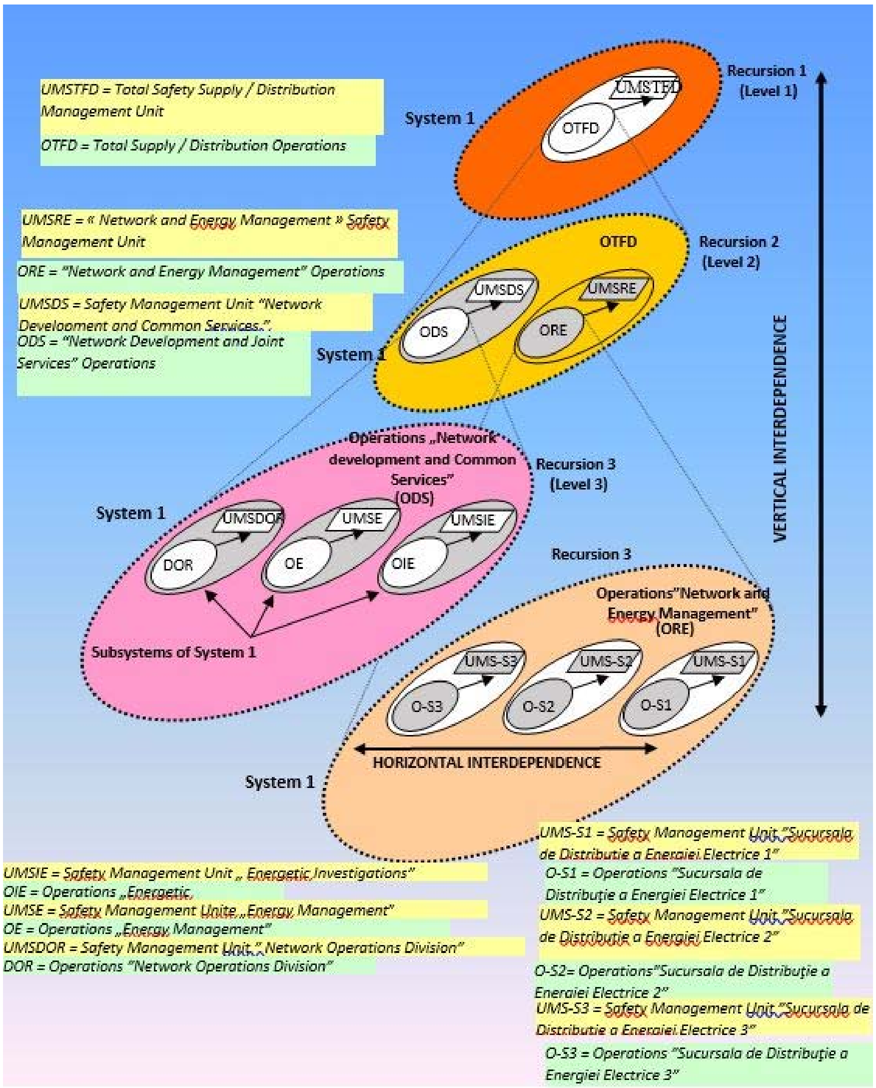

Fig.4. Recursive structure of MSMSSM. Applying the systemic model to the investigated organization in the field of electricity supply and distribution

System 3 will be directly responsible for maintaining the risk within an acceptable range in system 1 and will ensure that system 1 implements the organization's safety policy. It will perform its day-to-day functions in accordance with its own safety plans and the strategic and regulatory security plans received from system 4. The purpose of these plans will be to anticipate and act proactively to maintain the risk arising from the operations of subsystems forming part of system 1, substantially below the *maximum acceptable risk*. System 3 will require from systems 1, 2 and 3 * either information directly related or indirectly related to the safety performance of system 1 in order to be able to formulate its programmatic safety plans. These plans are then communicated to systems 1, 2 and 3 *. System 3 will also be responsible for allocating the resources needed for System 1 to implement the organization's safety plans.

System 3 * will be part of system 3 and its function will be to perform sporadic audits in system's 1 operations. System 3 * intervenes in the operations of system 1 according to the safety plans received from system 3. System 3 will need to ensure that accountability reports received from System 1 not only reflect the current state of System 1 operations, but are also aligned with the overall objectives of the organization.

System 4 will aim at safety research and development objectives, for the continuous adaptation of the system as a whole. Taking into account strengths, weaknesses, threats and opportunities, System 4 will be able to suggest significant changes to the organization's safety policies. System 4 will also address the current needs of system 1 and its potential future requirements are reflected in the "local environments" of system 1. On the other hand, system 3 communicates to system 4 all relevant requirements of the existing safety performance system related to the operations of system 1. In addition, system 3 will need to clarify the difficulties that the current (existing) level of performance of system 1 will face in trying to assimilate and implement new safety developments that are not in line with pre-existing safety technologies, and - in particular - with the level of safety culture existing in the analyzed industrial company / organization.

System 4* will be part of System 4 and will cover confidential reports or concerns from any employee about any aspect of OSH, some of which may require direct and immediate intervention by System 5. This means that system 4 * analyzes all the information that comes through this channel and develops and plans actions to act on what has been reported, so that these or similar incidents or causes do not become a cause for concern in the future. Workers, groups / teams or departments within the 4 * system should have both authority and responsibility, due to their ability to understand the need for confidentiality.

System 5 is responsible for deliberating safety policies and making regulatory decisions. According to the alternative safety plans received from system 4, system 5 considers and chooses realistic, pragmatic, feasible alternatives that aim to keep the risk within an acceptable range throughout the life cycle of the total system.

5. CONCLUSIONS AND FUTURE RESEARCH

The developed systemic model of occupational health and safety management is a dynamic system, which aims to maintain the risk of an electrical nature (generator of severe consequences with high frequency in the studied organization) in the acceptable field in a consistent manner, for all operations of an organization in the electrical field. The model consists of a set of five necessary, sufficient and interrelated subsystems, generically called systems 1-5, described in detail in the paper. On the other hand, the model possesses an organizational structure that interacts in a defined way with its local "environment" and with the external environment (the external context of the organization), both influencing the system and being influenced by it. The structural organization of the model ensures the integrated premises for the continuous adaptation to threats and opportunities, with the identification and treatment of weaknesses, as well as the capitalization / amplification of the strengths. Moreover, the structural organization of the model is intended to manage security in a consistent manner by simultaneously addressing the interdependencies of an organization both vertically and horizontally. Finally, the model is intended to help ensure a structural organization that can facilitate the implementation and development of the ***safety culture***.

If the characteristics of the model, i.e. the systems, their associated functions and the communication channels are properly implemented and work efficiently, then the probability of failure will be lower, considerably increasing the ***preventive potential***. The model can be applied proactively in the case of a new system or an existing one, as well as reactive. In the latter case, any undesirable event that has already occurred can be examined using the model to minimize its repeatability. The proposed model can also be used as a "template" for examining an existing safety management system.

As future research, it is intended:

(a) the application of the model in a proactive manner, by extending the case study carried out in the case of an industrial organization in the field of electricity supply and distribution;

(b) applying the model in a 'reactive' context, in order to highlight the strengths offered in the process of increasing confidence in measures to prevent risks that have already materialized, in order to illustrate its potential as an investigative tool;

(c) quantitative assessment of the effectiveness of an existing occupational health and safety management system using the concept of viability, considered as the ability to maintain the risk within an acceptable range for a predetermined period of time.

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ELECTRICAL OCCUPATIONAL RISK ANALYSIS AND SAFETY ASSESSMENT: METHODOLOGY PROPOSAL AND CASE STUDY

CĂTĂLIN VALENTIN DREGAN[1], ROLAND IOSIF MORARU[2], CRINA MARIA BARB[3]

Abstract: The main objective of the article is to evaluate the technical, organizational and other options that can be used in the future in Romanian industrial companies, in order to understand how theory and practice can be integrated to improve the prevention of electrical risks and related economic results. To this end, a complex methodology for electrical risk analysis and occupational safety assessment has been developed, based on a systematic and integrative approach to the issues associated with the components of work systems and those derived from compliance audit tools. The main novelty is related to the definition and consideration of the corrected probability and the corrected gravity, which facilitates a finer and more specialized analysis of the particularities of the investigated system by applying the proposed methodology. The article includes a case study on the application of the methodology in an industrial organization whose object of activity is the distribution of electricity. The results obtained confirmed the validity and usefulness of the tools developed to substantiate occupational safety and health policies aimed at minimizing electrical risks.

Keywords: Electrical Occupational Risk, safety level evaluation, risk analysis, corrected probability, corrected gravity.

1. INTRODUCTION

Traditionally, both scientific research in academia [1, 2] and practitioners have tended to address and analyze electrical hazards by focusing on the technical aspects and looking for the immediate causes of accidents or incidents after they have occurred (a posteriori analysis) [4, 13, 27, 28]. However, major accidents have highlighted the need for a proactive approach to safety. In addition to the perpetuation of events with severe consequences and as a direct consequence of them, the emergence of new

[1] *Ph.D.Stud. Eng. University of Petrosani, dre_cata@yahoo.com*
[2] *Professor, Ph.D., University of Petrosani, roland_moraru@yahoo.com*
[3] *Ph.D.Stud. Eng. University of Petrosani, crinabarb92@gmail.com*

regulations and international standards has required organizations to improve their safety performance [5, 6, 11, 12, 23, 24, 25]. As a result, companies have been forced to move from a prescriptive, regulatory, flexible, tailored, to a more dynamic approach to analyzing, evaluating, and, most importantly, managing operational risks that can affect important components of the activity, including electrical risks to the safety and health of workers [15, 19].

Electrical risk differs from other technological risks in that sensory perception is not sufficient to detect electrical hazards. Regarding the typology of the forms of manifestation of electrical risks, the potential risk factors can materialize in the activities of isolation and access of electrical networks and installations, when working in the vicinity of electric arc sources, when modifying or repairing high, medium and low voltage electrical installations, when testing and finding faults in high, medium and low voltage equipment and installations, when working with high fault currents - operation, testing or fault identification, as well as in many other areas and types of industrial and, in general, economic activity [18, 20]. The evolution of the statistical indicators regarding the collective work accidents produced in Romania in the last two decades according to the records of the National Institute of Statistics, in section 35 - Production and supply of electricity at national level, indicates that there is a decrease in the number of accidents [18]. However, the number of accidents caused by electrical risks continues to remain unacceptably high, with all the associated human, economic and social consequences, which attests to the importance of the topic addressed.

Existing, applied and validated approaches to occupational risk minimization may be a necessary and useful step in the concerted effort to effectively manage the safety and health of workers, but may not be comprehensive to properly address all complex issues related to occupational risk management, in the complex context of the current challenges posed by the major changes in the dynamic reality of emerging work environments [7, 8, 21]. With increasing relevance, it is necessary to identify, develop and implement a new pragmatic approach, realistic and adapted to the conditions, but - at the same time - systemic, with applicability in the area of manifestation of electrical risks [9, 10, 16].

The need for such an approach to electrical hazards may facilitate the development of a systemic model of occupational safety and health management, in the context of attempting to interpret events as a whole and to "see" events, including technical failures and human error, as "*products*" of a system operation and, in this regard, to analyze the consequences of scenarios as a result of the operation of the systems [17, 22]. The ultimate goal of such research is to maintain risk in an acceptable field in the operations of any industrial organization, regardless of the internal, external and risk management context in which it is located [26].

A methodology for the analysis of electrical risks in medium and high voltage installations has been proposed and applied. A logical sequencing of the stages regarding the proposed methodology was carried out, the priority areas for assessing compliance with safety requirements were defined, structured on the components of the investigated work system - ENS module, a set of tools for assessing risks used for quantification; an assessment of the level of safety and quantification of the risk was also carried out in a real organization, generically referred to as "*Electrical Risk*".

The methodology adapted and applied for the analysis of electrical risks within the organization allowed the investigation of work systems taking into account the dynamics of development and the existing inter-conditioning between the components of the system.

2. MATERIAL AND METHODS: RESEARCH METHODOLOGY

The role of the audit or assessment of compliance is to assess the degree of compliance with the provisions of the legislation and to assess qualitatively the efficiency of the elements of the OHS management system. The safety level is one of the performance indicators on the basis of which the OHS management analysis is performed [3].

In order to take into account the influences generated by the interdependencies of the human operator or the workload with the other elements of the system, the applied method introduced a series of correction coefficients determined based on the level of safety associated with the two human components (performer and work task). To assess the risk level associated with the material components of the work system (in this case, equipment and the work environment), the instrument uses a combination of the corrected severity of the probable consequences, the corrected probability of an undesirable event and the exposure to the risk factor of the target - staff [14].

The risk analysis completed with the conformity assessment carried out is an important first step in terms of the possibilities to make a coherent radiography, to develop a "landscape" as realistic as possible, systematic and coherent of the nature and magnitude of the risks in an organization that has as main object of activity work systems and processes that frequently involve the existence of electrical risks [1].

The methodological investigation tool adapted and applied in this paper for the analysis of electrical risks in the investigated organization, generically called "Electrical Risk", is based on the logic and essential structure of the general method [14], which is characterized by flexibility and best suited to the purpose of the study. By combining the tools / stages of the safety level assessment technique with those corresponding to the risk assessment method per microsystem / workplace / functional unit, there are performed, according to the methodology described in figure 1, the following analysis steps:

i. **Structural and functional description of the investigated system**;
ii. **Identification of electrical hazards / risks in medium and high voltage installations, with the important feature of the prior assessment of the system's safety level**; the evaluation criteria (essential safety conditions) are not pre-established, the checklists that constitute the analysis tools, being built according to the particularities of the investigated system, so as to best define its safety level.

Thus, the methodology becomes very flexible and easy to customize for each work system / organization. For the assessment of compliance, the checklist used in the safety level assessment (ENS) method was used for each checklist criterion by using a six-level scale (0-5). The identification of the risk factors within each component of the work system is done by comparing an ideal situation, provided by legislative acts (laws, norms, norms, standards, instructions) with the real situation found in the investigated system.

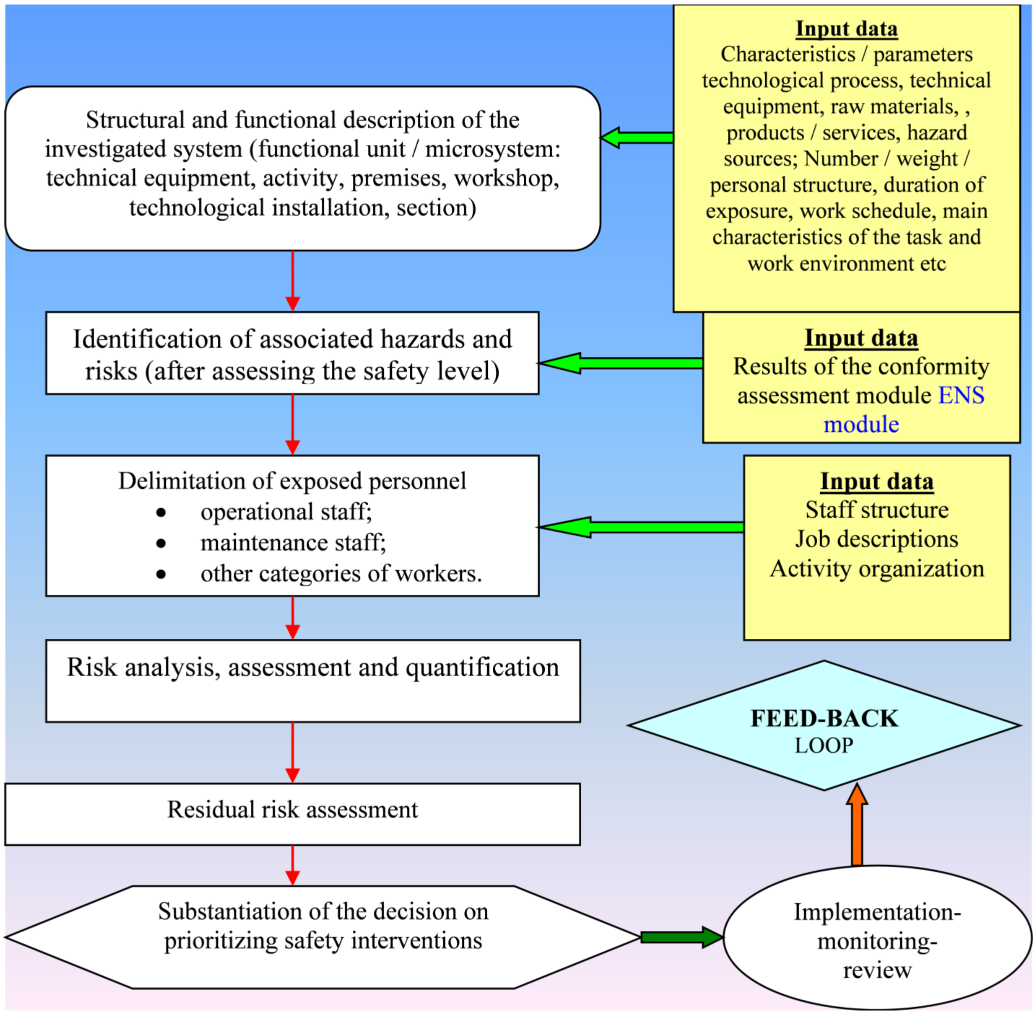


Fig.1. Proposed methodology for the analysis of electrical risks in medium and high voltage installations: logical sequencing of stages

In order to better identify the occupational risks present in the analyzed system and to be able to establish a more exhaustive list of the applicable essential safety requirements, the components of the work system are divided into several priority areas, according to figure 2. In order to establish the criteria (indicators) on the basis of which the risk factors are identified, a development is proposed in which, for each area of the components of the work system that may present non-conformities (work equipment and work environment), in parallel with establishing the criteria to determine the risk factors, the minimum safety requirements imposed on the respective domain are also identified, which are thus constituted in criteria for evaluating the safety level of the analyzed domain. Based on them, the questions that make up the checklists for assessing the level of safety for each area were established.

E01	Degree of training and professional competence
E02	Professional skills and abilities
E03	Attitude towards workload
E04	Ability to identify risks
E05	Attitude towards occupational risks

a. Defining priority areas for the "HUMA N FACTOR" component

SM01	First aid organization
SM02	Fulfilling the forms of work or arranging works
SM03	Admission to work
SM04	Organizing and securing work area
SM05	Supervision of the work team's activity

b. Defining priority areas for the "WORK LOAD" component to reduce the severity of the consequences (protection)

SM06	Execution of works without de-energizing power in installations
SM07	Execution of de-energized works
SM08	Execution of intervention works in case of damages, disturbances and incidents
SM9	Operational maintenance (supervision) of electrical installations
SM10	Execution of works at height specific to electrical installations
SM11	Physical overload - generated by microclimate and work environment
SM12	Mental overload coupled with factors external to load and work environment

c. Defining priority areas for the "WORK LOAD" component to reduce likelihood (prevention)

ET 01	Electrical insulating means
ET 02	Means of protection for earthing and short circuit
ET 03	Means of protection for the material delimitation of the work area
ET 04	Risks related to old SEN energy installations and equipment
ET 05	Personal work and protection devices and equipment including for working at heights
ET 06	Tools, devices and equipment for work under voltage
ET 07	Special vehicle, special devices and equipment (cranes, trolleys stepper, OHL, hoists, chainsaw)
ET 08	Mechanical risk
ET 08	Thermal risk
ET 10	Chemical risk

d. Defining priority areas for the "WORK EQUIPMENT" component

MM01	Working microclimate;
MM02	Noise;
MM03	Natural ultraviolet or infrared radiation.

e. Defining priority areas for the "WORK ENVIRONMENT" component

Fig.2. Defining the priority areas for assessing compliance with safety requirements, structured on the components of the investigated work system-ENS module

At the same time, depending on the importance given to each criterion for assessing the level of safety, a weighting is achieved by coefficients that can vary from 0.5 to 2, in order to establish a relative balance regarding the importance of that criterion in the risk management process. The specific coefficients required in the calculation of the parameters "***corrected severity***" and "***corrected probability***" related to the areas that assess the level of risk generated by technical non-conformities characteristic of "*means of production / work equipment*" and "*work environment*", respectively, are established, in this way their influence on the level of risk of the analyzed system, as follows:

- e_1 **-** probability correction coefficient, directly proportional to the safety level;
- SM_1 – severity correction coefficient, determined by the level of safety presented by the organizational measures to reduce the severity ;
- SM_2 – probability correction coefficient directly proportional to the level of safety, determined by the level of safety presented by the technical and organizational measures to reduce the probability.

iii. **Delimitation of the categories of exposed personnel;**

iv. **Analysis, evaluation and quantification of the risk level:** it is performed exclusively for the material components of the investigated system (figure 3);

v. The assessment and quantification of the risk level is based on the combination of the exposure, the maximum severity of the most likely consequences and the probability of materialization of the risk. The semantic value of the notion of risk level, within the concept of the proposed methodology, defines the level of residual risk as representing the level of residual risk **depending on the safety level of the system existing at the time of evaluation**. A summary table is used in which are listed: staff structure, number of workers per category of participants in the work process, weight in relation to the total number of workers in the system, exposure, severity of consequences and probability of occurrence (figure 4);

vi. **Residual risk assessment**; in order to assess the residual risks in terms of acceptability / unacceptability, the methodology uses a criticality of risks; In this sense, the occupational risk assessment form, for each analyzed field, is completed with a grid of risk classes, in which the corrected probability classes were written on the ordinate and the corrected severity classes were written on the abscissa. The inscription on this diagram of the values of the severity-probability couple determined for a risk factor allows the appreciation of the character of acceptability / unacceptability. The grid used is divided into three areas of risk classes: a) the field of acceptable risks; b) the field of acceptable risks with the taking of additional organizational measures; c) the field of unacceptable risks. The transposition on this grid of the pair of values of corrected gravity / corrected probability characteristic of each category of participants in the work process allows a global assessment of the area of occupational risks to which they are subjected (figure 4);

Probability		Frequency of manifestation
Class	**Simbols**	
class 6	FF (very frequent)	$P>1^{-1}$/lună.
class 5	F (frequent)	$1^{-1}/an<P<1^{-1}$/lună.
class 4	PF (low frquency)	$2^{-1}<P<1^{-1}$/an.
class 3	R (rare)	5-1<P<2-1/an.
class 2	FR (very rare)	$10^{-1}<P<5^{-1}$/an.
class 1	ER (extremely rare)	$P<10^{-1}$/an.

a. Probability rating: depending on the safety level of the material components of the work system (means of production, work environment), reliability of technical equipment, length of service of technical equipment, share in the staff structure of representatives of sensitive groups

b. Corrected probability

Consider the influences of “a posteriori” statistical analysis of accidents and elements of characterization of the staff structure / seniority of the ET in the form of correction coefficients and the influence of the level of safety determined by the human factor and the workload in the form of the coefficients e_1 and sm_2, thus:

$$P_c = P \times E \times k_2 \times k_3 \times k_4 \times e_1 \times sm_2 \quad \text{where:}$$

E – probability correction coefficient depending on the level of exposure;

k_2 - probability correction coefficient depending given by the ratio between the frequency index of the analyzed system and the frequency index of the industrial branch to which the analyzed system belongs;

k_3 - correction coefficient given by the seniority of the technical equipment in service;

k_4 - correction coefficient given by the share in the personnel structure of workers with less than 4 years of employment and of workers with more than 20 years of employment.

c. Hazard exposure classes

- analyzing the photo-schedule for each category of workers, standard operating procedures:
- by direct observation of the work process;
- through direct discussions with workers / line management.

Exposure	Interpretation value
ER (extremely rare)	exposure of up to one hour per month;
R (rare)	exposure of up to one hour per week;
A (incidental)	exposure of up to one hour per day;
T (temporary)	exposure between one and four hours a day;

Class	Symbol	Meaning
class 1	N (negligible)	minor reversible consequences of foreseeable inability to work up to 3 calendar days - healing without treatment;
class 2	Mc (low)	reversible consequences with a foreseeable incapacity for work of 3-45 days, requiring medical treatment;
class 3	Md (average)	reversible consequences with a predictable incapacity for work between 45 and 180 days requiring medical treatment and hospitalization;
class 4	M (high)	irreversible consequences with a decrease in work capacity of maximum 50% - degree III disability;
class 5	G (serious)	irreversible consequences with the loss between 50 - 100% of the work capacity but with possibility of self-service - degree II disability
class 6	FG (very serious)	irreversible consequences with total loss of work capacity and self-service capacity degree I disability;
class 7	Ma (maximal)	death.

d. Severity (gravity) of consequences: rating grid

e. Corrected severity (gravity): $GCc = GC \times k_1 \times sm_1$; where:

k_1 - severity correction coefficient given by the ratio between the severity index of the analyzed system and the severity index of the industrial branch to which the analyzed system belongs ;

sm_1 - severity correction coefficient, determined by the level of safety presented by the organizational measures to reduce the severity

Fig.3. Research methodology: risk assessment tools used for quantification

Score	Explanation
0	there is no evidence that the requirement of the indicator is met - (answer no or yes without interpretation)
1	totally insufficient evidence of the requirement of the indicator
2	existing evidence regarding the partial satisfaction of the requirement provided by the indicator - (missing or incomplete documentation, incomplete solutions regarding the elimination of non-compliance)
3	existing evidence regarding the almost complete satisfaction of the requirement of the indicator - (existing documentation, almost complete solutions regarding the elimination of non-compliance)
4	existing evidence of good satisfaction of requirement set out in the indicator (complete documentation, good solutions to eliminate non-compliance)
5	very good evidence of excellent satisfaction of the requirement of the indicator - (complete documentation, very good solutions to eliminate non-compliance; answer no or no without interpretation)

a. Indicator rating grid from checklists

b. Safety/ conformity level calculation

$$\text{Conformity index} = \frac{\text{Obtained score}}{\text{Maximum possible score}} \times 100 \quad [\%]$$

where: The ***score obtained*** is the sum of the products between the score given for each criterion (valid) and the weighting coefficient of the indicator, ie = Σ (individual score given x weighting coefficient); ***Maximum possible score*** = the sum of the products between the maximum score (5) for each indicator (valid) and the weighting coefficient of the indicator, ie = Σ (5 x weighting coefficient)

c. Estimating the safety level (ENS-IC)

91%-100%	→ excelent;
81% - 90%	→ very good;
71%-80%	→ good;
61% - 70%	→ average;
51% - 60%	→ low;
sub 50%	→ unsatisfactory.

d. Risk level cuantification

The results of the assessments of the **corrected severity** and of the **corrected probability** are identified in the grid of risk levels, which is a summary of all combinations of the severity and the probability of their occurrence ordered by **risk levels**.

Risk level	Severity - probability coupling
1. Minimal	(1,1) (1,2) (1,3) (1,4) (1,5) (1,6) (2,1)
2. Very low	(2,2) (2,3) (2,4) (3,1) (3,2) (4,1)
3. Low	(2,5) (2,6) (3,3) (3,4) (4,2) (5,1) (6,1) (7,1)
4. Average	(3,5) (3,6) (4,3) (4,4) (5,2) (5,3) (6,2) (7,2)
5. High	(4,5) (4,6) (5,4) (5,5) (6,3) (7,3)
6. Very high	(5,6) (6,4) (6,5) (7,4)
7. Maximal	(6,6) (7,5) (7,6)

$$N_r = \frac{\sum_{i=1}^{n} r_i \times R_i}{\sum_{i=1}^{n} r_i}$$

e. Global rik cuantification

where: N_r - the level of global risk at work; r_i -the rank of the risk factor "i"; R_i - represents the partial level of risk for the risk factor "i"; n - the number of risk factors identified at work place.

Fig.4. Research methodology: Safety level assessment and risk quantification

Hazard level	The priority of implementing the prevention measure
NP > 3,5	Immediate correction. The activity is interrupted until the risk is eliminated.
3,5 > NP > 2,5	Urgent situation. Action is required as soon as possible.
2,5 < NP	The risk must be eliminated without delay, but situation is not an emergency.

a. Prioritization of preventive intervention according to the calculated hazard level

Priority no.	Explanatory criteria
1	• the risk factors analyzed can seriously affect the physical and mental integrity of the workers; • the values of the measurements of chemical, physical or biological noxious substances exceed • the maximum allowed limits; • medium consequences (ITM 45 and 185 days), large (grade III disability), severe (grade II disability), very severe (grade 1 disability) or severe (death); • probability of infrequent manifestation (1-2 times every 2 years), frequent (1 / year - 1 / month); • small investments; • corrective actions of an organizational nature.
2	• the risk factors analyzed may affect the physical and mental integrity of workers; • the values of the measurements of chemical, physical or biological noxious substances are close to the maximum limits; • small consequences (temporary incapacity for work between 3 and 45 days); • probability of rare manifestation (2-3 times every 10 years); • large investments.
3	• the risk factors analyzed affect to a small extent the physical and mental integrity of the workers; • there are exceedances of the maximum permissible limits only extremely rarely; • negligible or minor consequences (temporary incapacity for work between 3 and 45 days); • probability of very rare manifestation (1-2 times every 10 years); • large investments.
4	• the risk factors analyzed do not affect the physical and mental integrity of the workers; • there are no exceedances of the maximum admissible limits provided by the regulations in force; • negligible consequences (incapacity for work less than 3 days); • extremely rare probability of manifestation (less than once every 10 years); • very large investments, financially onerous, technology change.

b. The degree of priority and the hierarchical order of OSH interventions, explainedbased on criteria of severity, probability and associated macro-estimated costs

For measures deriving from the conformity assessment sheets		For measures deriving from risk assessment sheets		
NC	Priority	NRR	NC	Priority
95 ÷ 100%	4	1	Indifferent IC	4
91 ÷ 95%	4	2	NS>80%	4
85 ÷ 90%	3		NS<80%	3
81 ÷ 85%	3	3	NS>85%	3
75 ÷ 80%	2		NS<85%	2
71 ÷ 75%	2	4	NS>90%	2
65 ÷ 70%	1		NS<90%	1
61 ÷ 65%	1	5	Indifferent NC	1
55 ÷ 60%	1	6	Indifferent NC	1
50 ÷ 55%	1	7	Indifferent NC	1

c. Grid for assessing the priority degree allocated to safety interventions

Fig.5. The tools for substantiating the decision on the allocation of resources for prevention and protection

vii. Substantiation of the decision regarding the prioritization of safety interventions (prevention - protection)

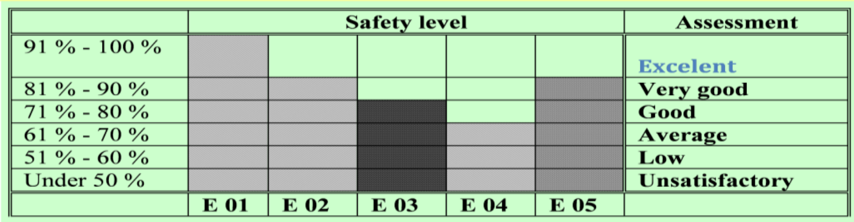
The classification of acceptable / unacceptable risks in the area resulting from the grid, correlated with the analysis of the answers to the minimum occupational safety and health requirements found in the checklists and the calculated hazard level allow the substantiation of the decision-making priorities, feasible, pragmatic and that will have the potential to ensure an optimal cost-benefit ratio. The content elements that ensure the substantiation of the decisions regarding the treatment of risks, in case of application of the proposed methodology are systematized and presented in figure 5. In order to establish the prevention / protection measures necessary to improve the level of compliance of the analyzed work system, it is also necessary to take into account the hierarchy of assessed risks, according to the scale of risk / safety levels.

3. RESULTS AND DISCUSSION

3.1. Analysis/interpretation of safety level induced by the human factor

The results of the synthesis regarding the level of safety induced by "Human Factor", on the 5 pre-established priority areas, are presented in figure 6, highlighting values of the safety level (compliance index) ranging from 60.95% (average) to 94.66% (excellent). The calculated average value of the global safety level induced by the human factor is NSG = 80.74% (very good level).

Work system component: HUMAN FACTOR	Priority area analyzed	Safety Level
E 01	Degree of training and professional competence	94,66%
E 02	Professional skills and abilities	88,95 %
E 03	Attitude towards workload	74,12 %
E 04	Ability to identify risks	60,95 %
E 05	Attitude towards occupational risks	85,00 %



NSG = 80,738% e_1 = 1,00

Fig.6. Results of the analysis regarding safety level induced by the "Human factor", on 5 priority areas

3.2. Analysis/ interpretation of the safety level induced by the work task

3.2.1. The component of reducing the consequences severity

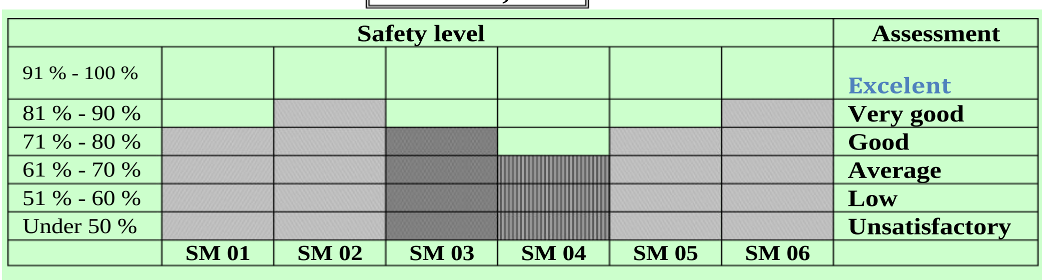
The results of the synthesis regarding the level of safety induced by the component of diminishing the gravity of the consequences of the “Work task”, on the 6 pre-established priority areas, are presented in figure 7, highlighting values of the safety level (compliance index) ranging from 61.54% (average) to 85% (very good). The calculated average value of the overall safety level induced by this component of the work task is NSG = 75.53% (good level).

3.2.2. Probability reduction component

The results of the synthesis regarding the level of safety induced by the probability reduction component of the “Work task”, on the 6 pre-established priority areas, are presented in figure 8, highlighting values of the safety level (compliance index) ranging from 66.00% (average) to 84.55% (very good). The calculated average value of the global safety level induced by this component of the work task is NSG = 74.17% (good level).

Work system component: WORK TASK	Priority area analyzed	Safety Level
SM 01	First aid organization	80,00 %
SM 02	Fulfilling the forms of work or arranging works	85,00 %
SM 03	Admission to work	70,71 %
SM 04	Organizing and securing work area	61,54 %
SM 05	Supervision of the work team's activity	72,63 %
SM 06	Execution of works without de-energizing power in installations	83,31 %

NSG = 75,532%



SM_1 = 0,695

Fig.7. Results of the analysis on the safety level induced by the "Work task", the component of diminishing the consequences severity

Work system component: WORK TASK	Priority area analyzed	Safety Level
SM 06	Execution of works without de-energizing power in installations	70,86 %
SM 07	Execution of de-energized works	84,55 %
SM 08	Execution of intervention works in case of damages, disturbances and incidents	70,77 %
SM 09	Operational maintenance (supervision) of electrical installations	80,00 %
SM 10	Execution of works at height specific to electrical installations	74,55 %
SM 11	Physical overload - generated by microclimate and work environment	72,50 %
SM 12	Mental overload coupled with factors external to load and work environment	66,00 %

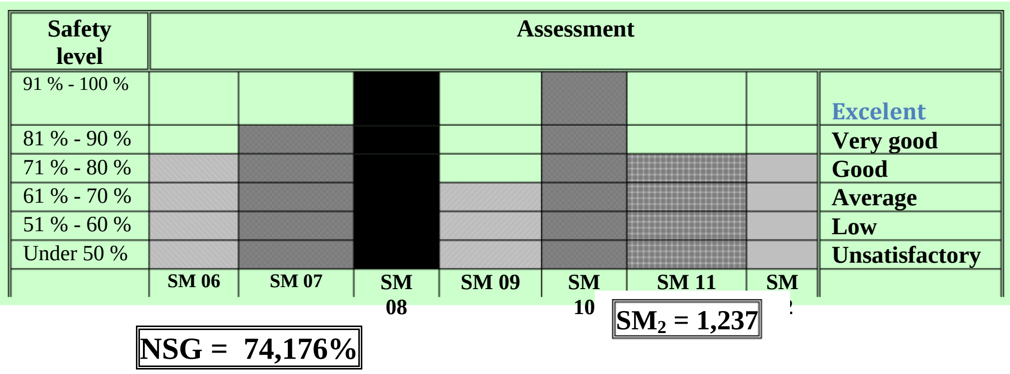


Fig.8. Results of the safety level analysis induced by the "Work task", the component of probability reduction

3.3. Residual risk resulting from assessment sheets and overall safety level

In order to assess the residual risks in terms of acceptability / unacceptability, based on the calculated values of the corrected probability and the corrected severity, the risk criticality grid was used, according to the described methodology. In this sense, the occupational risk assessment sheet, for each area analyzed, was completed with a grid of risk classes.

The transposition on this grid of the pair of values of corrected gravity / corrected probability characteristic of each category of participants in the work process allowed an estimate of the area of occupational risks to which they are subjected (figure 9.a).

Crt. no.	Assessment card code	NRR
1	ET 01.	5
2	ET 02.	4
3	ET 03.	2
4	ET 04.	3
5	ET 05.	4
6	ET 06.	5
7	ET 07.	3
8	ET 08.	1
9	ET 09.	2
10	ET 10.	2
11	MM 01	3
12	MM02.	1
13	MM03.	2

a)

For measures deriving from the conformity assessment sheets		*For measures deriving from risk assessment sheets*		
NSG	Priority	NRR	NSG	Priority
95 ÷ 100%	4	1	Indifferent NSG	4
91 ÷ 95%	4	2	NSG>85%	4
85 ÷ 90%	3		NSG<80%	3
81 ÷ 85%	3	3	NSG>85%	3
75 ÷ 80%	**2**		NSG<85%	**2**
71 ÷ 75%	2	4	NSG>90%	2
65 ÷ 70%	1		NS<90%	1
61 ÷ 65%	1	5	Indifferent NSG	1
55 ÷ 60%	1	6	Indifferent NSG	1
50 ÷ 55%	1	7	Indifferent NSG	1

b)

Fig. 9. Results of the residual risk analysis and the level of global safety.
a) Residual risk values; b) Framing the global safety level

The calculation of the global residual risk level (relation in figure 4.e) leads to the following result, using the residual risk values related to the 10 areas associated with "**Work Equipment**" and the three predefined and investigated areas of the "**Work Environment**" component:

$$N_{rg} = \frac{\sum_{i=1}^{13} r_i \cdot R_i}{\sum_{i=1}^{13} r_i} = \frac{2(5x5)+2(4x4)+3(3x3)+4(2x2)+2(1x1)}{(2x5)+(2x4)+(3x3)+(4x2)+(2x1)} = \frac{102}{31} = 3{,}29 \qquad (1)$$

The calculation of the global safety level is performed using a mathematical relationship that makes the percentage ratio between the sum of the actual safety levels, for each applicable criterion (human factor, work task) and the sum of the maximum possible level (theoretical):

$$NS = \frac{80{,}738 + 75{,}532 + 74{,}176}{300} = 76{,}82 \qquad (2)$$

according to the table is a good level

Priority grade 2 corresponding to the case study performed, according to the table in fig. 9.b, indicates the following: i) the analyzed risk factors may affect the physical and mental integrity of the workers; ii) a prevalence of low level consequences (temporary incapacity for work between 3 and 45 days); iii) the most frequent probability class of manifestation is the so-called generic rare (2-3 times every

10 years); iv) the values of the measurements of chemical, physical or biological noxious substances are close to the maximum allowed limits provided by the regulations in force; v) prevention / protection measures associated with priority class 2 generally involve significant investments.

4. CONCLUSIONS

The methodology adapted and applied for the analysis of electrical risks in the organization allows the investigation of the work system taking into account the dynamics of development and the existing inter-conditions between the components of the system.

In order to take into account the influences generated by the interdependencies of the human operator and / or the workload with the other elements of the system, the applied method introduced a series of correction coefficients determined based on the level of safety associated with the two human components (worker and work task).

The correction coefficients for the severity of the consequences and the probability of occurrence, respectively, were determined by:

- the exposure level;
- the ratio between the frequency index of the analyzed system and the frequency index of the industry to which the analyzed system belongs;
- the ratio between the severity index of the analyzed system and the severity index of the industry to which the analyzed system belongs;
- average length of service of technical equipment;
- the positioning in the personnel structure of the workers belonging to the groups sensitive to specific risks;
- the level of global safety presented by the areas of work task aimed at increasing the safety level;
- the level of global safety presented by the areas of work task aimed at reducing the severity of the consequences.

To assess the level of risk associated with the material components of the work system (in this case, equipment and the work environment), the instrument uses a combination of the corrected severity of the probable consequences, the corrected probability of an undesirable event and the exposure to the risk factor of the target staff members.

The residual risk fell within the acceptable risk range, and the overall safety level in the “GOOD” category (70% <NSG <80%).

The risk analysis, completed with the conformity assessment that has been performed, is an important first step in terms of the possibilities to achieve a coherent radiography, to develop a "landscape" as realistic, systematic and coherent as possible of the nature and magnitude of risks in an organization whose main object of activity is work systems and processes that frequently involve the existence of electrical risks.

Given the capacity / potential for improvement detected, the next stage of the research will logically be directed to the human and managerial components involved in these activities. It is considered imperative to develop a statistical study on the perceptions of workers / managers on how to achieve and - implicitly - the effectiveness of the operation of the occupational safety and health system.

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ON THE INSPECTION OF ELECTRIC EQUIPMENT WITH TYPE OF PROTECTION FLAMEPROOF ENCLOSURE “d” AND INCREASED SAFETY “e” OPERATING IN POTENTIALLY EXPLOSIVE ATMOSPHERES

MOLDOVAN LUCIAN[1], BURIAN SORIN[2], MAGYARI MIHAI[3], FOTĂU DRAGOŞ[4], RAD MARCEL[5], MOLDOVAN CLEMENTINA[6]

Abstract: Electrical equipment designed for use in potentially explosive atmospheres has some specific properties and characteristics providing explosion protection. These must be preserved on the entire period of their use. Verification of these special properties and characteristics is made by performing specific inspections. This paper underlines specific aspects related to inspections and the importance of performing them.

Keywords: electric equipment, type of protection, inspection

1. GENERALITIES

Installations, operating in hazardous areas endangered by potentially explosive atmospheres, and equipment used in such installations possess specific properties and characteristics in order to provide explosion protection and to avoid the ignition of the surrounding explosive atmosphere. These specific properties and characteristics providing explosion protection have to be preserved on entire period of use for such installations [3, 4], [11]. In the European Union countries, the equipment operating in explosive atmospheres shall be according the ATEX Directive [2].

The correct operation of an equipment does not mean that the integrity of the special features related to explosion protection is preserved [3], [5].

1 Sc. Res. Ist, PhD.Eng., INCD INSEMEX Petrosani, Lucian.Moldovan@insemex.ro
2 Sc. Res. Ist, PhD.Eng., INCD INSEMEX Petrosani, Sorin.Burian@insemex.ro
3 Sc. Res. Ist, PhD.Eng., INCD INSEMEX Petrosani, Mihai.Magyari@insemex.ro
4 Sc. Res. IIIrd, PhD.Eng., INCD INSEMEX Petrosani, Dragos.Fotau@insemex.ro
5 Sc. Res. IIIrd, PhD. Eng., INCD INSEMEX Petrosani, Marcel.Rad@insemex.ro
6 Assoc. prof., PhD.Chem., University of Petrosani, clemymoldovan@gmail.com

For older installations, the recommendation is to perform inspections according to the standards that were applicable at the date of the installation erection [8].

The types of protection "d" and "e" were chosen because a lot of equipment in installations operating in explosive atmospheres are designed with these two types of protection.

The type of protection flameproof enclosure "d" consists in placing the parts that could ignite an explosive atmosphere inside of an enclosure that can withstand the pressure developed during an internal explosion of an explosive mixture and which prevents the explosion transmission to the explosive atmosphere surrounding the enclosure [6]. In general, it can be applied to electrical equipment which in normal operation produces electrical arcs and sparks.

Increased safety "e" represents a type of protection applied to electrical equipment or Ex components in which additional measures are applied so as to give increased security against the possibility of excessive temperatures and against the occurrence of arcs and sparks [7].

An inspection represents the action comprising careful examination of an item carried out either without dismantling, or with the addition of partial dismantling, supplemented by means such as measurement, in order to arrive at a reliable conclusion regarding the condition of an item [8].

The classification of inspections is made according to the grade and type of inspection [8].

The classification of inspections according their grade is as follows [8]:

- Visual inspection;
- Close inspection;
- Detailed inspection.

The classification of inspections according their type is as follows [8]:

- Initial inspections;
- Periodic inspections;
- Sample inspections.

Another concept for inspection of installations is represented by continuous supervision, using visual or close inspections. In case the installation is not within the continuous supervision capability, it must be subjected to periodic inspection [1].

The results of inspections must be recorded and retained. The results of inspections may indicate some further actions to be taken (maintenance or repair).

2. SPECIFIC CONCEPTS REGARDING INSPECTIONS

Electrical equipment designed for use in explosive atmospheres shall be installed considering the technical documentation supplied by the manufacturer [1, 3, 4, 5, 6, 8, 9]. The initial inspection must be performed after installing of equipment or installation, before the first put into operation and the results shall be recorded and retained [8, 9]. Initial inspection shall be performed with a detailed grade (to verify that all the specific features providing explosion protection are valid). Inspection requirements and other specific requirements, according the types of protection are specified in SR EN 60079-14 standard [9]. The type of protection is also important regarding the aspects to be verified during inspections. The aspects to be checked in relation to the type of inspection and type of protection ("d", "e") are detailed in the Table 1 below.

Table 1. ***Specific inspection features for equipment with type of protection „d" and „e" [8]***

	Check that:	**Ex "d"**			**Ex "e"**		
		D	**C**	**V**	**D**	**C**	**V**
A	**GENERAL (ALL EQUIPMENT)**						
1	Equipment is appropriate to the EPL/zone requirements of the location	X	X	X	X	X	X
2	Equipment group is correct	X	X		X	X	
3	Equipment temperature class is correct (only for gas)	X	X		X	X	
4	Equipment maximum surface temperature is correct						
5	Degree of protection (IP grade) of equipment is appropriate for the EPL/group/conductivity	X	X	X	X	X	X
6	Equipment circuit identification is correct	X			X		
7	Equipment circuit identification is available	X	X	X	X	X	X
8	Enclosure, glass parts and glass-to-metal sealing gaskets and/or compounds are satisfactory	X	X	X	X	X	X
9	There is no damage or unauthorized modifications	X			X		
10	There is no evidence of unauthorized modification		X	X		X	X
11	Bolts, cable entry devices (direct and indirect) and blanking elements are of the correct type and are complete and tight						
	– physical check	X			X		
	– visual check		X	X		X	X
12	Threaded covers on enclosures are of the correct type, are tight and secured						
	– physical check	X			X		
	– visual check		X	X		X	X
13	Joint surfaces are clean and undamaged and gaskets, if any, are satisfactory and positioned correctly	X					
14	Condition of enclosure gaskets is satisfactory	X			X		
15	There is no evidence of ingress of water or dust in the enclosure in accordance with the IP rating	X			X		
16	Dimensions of flanged joint gaps are: - within the limits in accordance with the manufacturer's documentation or - within maximum values permitted by the relevant construction standard at time of installation or - within maximum values permitted by site documentation	X					
17	Electrical connections are tight				X		
18	Unused terminals are tightened				X		

	Check that:	Ex “d”			Ex “e”		
		D	C	V	D	C	V
19	Enclosed-break and hermetically sealed devices are undamaged						
20	Encapsulated components are undamaged				X		
21	Flameproof components are undamaged				X		
23	Breathing operation is satisfactory (type “nR” only)	X			X		
24	Breathing and draining devices are satisfactory	X	X		X	X	
	EQUIPMENT SPECIFIC (LIGHTING)						
25	Fluorescent lamps are not indicating EOL effects				X	X	X
26	HID lamps are not indicating EOL effects	X	X	X	X	X	X
27	Lamp type, rating, pin configuration and position are correct	X			X		
	EQUIPMENT SPECIFIC (MOTORS)						
28	Motor fans have sufficient clearance to the enclosure and/or covers, cooling systems are undamaged, motor foundations have no indentations or cracks	X	X	X	X	X	X
29	The ventilation airflow is not impeded	X	X	X	X	X	X
30	Insulation resistance (IR) of the motor windings is satisfactory	X			X		
B	**INSTALLATION − GENERAL**						
1	Type of cable is appropriate	X			X		
2	There is no obvious damage to cables	X	X	X	X	X	X
3	Sealing of trunking, ducts, pipes and/or conduits is satisfactory	X	X	X	X	X	X
4	Stopping boxes and cable boxes are correctly filled	X					
5	Integrity of conduit system and interface with mixed system maintained	X			X		
6	Earthing connections, including any supplementary earthing bonding connections are satisfactory (for example connections are tight and conductors are of sufficient cross-section)						
	– physical check	X			X		
	– visual check		X	X		X	X
7	Fault loop impedance (TN systems) or earthing resistance (IT systems) is satisfactory	X			X		
8	Automatic electrical protective devices are set correctly (auto-reset not possible)	X			X		
9	Automatic electrical protective devices operate within permitted limits	X			X		
10	Specific conditions of use (if applicable) are complied	X			X		
11	Cables not in use are correctly terminated	X			X		
12	Obstructions adjacent to flameproof flanged joints are in accordance with SR EN 60079-14	X	X	X			
13	Variable voltage/frequency installation complies with documentation	X	X		X	X	

	Check that:	**Ex “d”**			**Ex “e”**		
		D	**C**	**V**	**D**	**C**	**V**
	INSTALLATION – HEATING SYSTEMS						
14	Temperature sensors function according to manufacturer’s documents	X			X		
15	Safety cut off devices function according to manufacturer’s documents	X			X		
16	The setting of the safety cut off is sealed	X	X		X	X	
17	Reset of a heating system safety cut off possible with tool only	X	X		X	X	
18	Auto-reset is not possible	X	X		X	X	
19	Reset of a safety cut off under fault conditions is prevented	X			X		
20	Safety cut off independent from control system	X			X		
21	Level switch is installed and correctly set, if required	X			X		
22	Flow switch is installed and correctly set, if required	X			X		
	INSTALLATION – MOTORS						
23	Motor protection devices operate within the permitted t_E or t_A time limits.				X		
C	**ENVIRONMENT**						
1	Equipment is adequately protected against corrosion, weather, vibration and other adverse factors	X	X	X	X	X	X
2	No undue accumulation of dust and dirt	X	X	X	X	X	X
3	Electrical insulation is clean and dry				X		

In the technical standards [8, 9], are also presented the aspects to be verified for other types of protection applied for electrical equipment (intrinsic safety “i”, pressurization “p” etc.).

An inspection program, comprising the periodical inspections shall be established after installing the equipment / installation [3].

Additional interim sample inspections should be performed to verify if the inspection schedule is adequate or needs adjustments. Sample inspection can be used when many similar items, having the same manufacturer, type, type of protection (electric motors, luminaires, junction boxes, etc.) are installed in the same period, work in the same environment and conditions. But still, each item should be subjected to at least a visual inspection [8].

The factors to be considered when establishing an inspection schedule (program) are: the manufacturer's instructions, type of equipment, deterioration factors, area classification and/or the EPL requirements, results of previous inspections; also, the experience of the personnel on similar installations and equipment can be used in determining the inspection strategy). The time interval between periodic inspections shall not exceed three years without consulting of an expert. Intervals between periodic inspections exceeding three years should be based on an assessment including relevant information [3, 8].

In case of hand-held (portable) equipment the interval between periodic inspections needs to be reduced (because they are more prone to damage than fixed equipment) according to SR EN 60079-17 [8].

It is possible to change the inspection period, if necessary, based for example, on the results of previous inspections.

An inspection shall be performed (on the relevant parts of equipment) after any adjustment, maintenance, repair, reclamation, modification or replacement [8].

The personnel performing specific inspections must be competent personnel (it shall possess knowledge, skills and specific competencies) [3, 8]. In Romania, the personnel performing specific inspection activities must be authorized by INSEMEX according normative NEx 01-06/2007 (considering also the provisions of applicable standards) [2].

In case of equipment having multiple types of protection (there are many equipment with type of protection “d” and “e”) the applicable inspection operations, specific for each type of protection shall be performed. Care shall be taken, in this case, in order to correctly identify the specific compartments and elements for each type of protection. It is very important to verify only what is applicable for each type of protection.

3. FINDINGS FROM THE INSPECTION – EXAMPLES

Inspections are performed to provide evidence that equipment and installations are maintained in good condition regarding the use in explosive atmospheres. To this, it is important to verify all aspects of the specific equipment as presented in the columns of inspection tables (considering the type(s) of protection, the grade and type of inspection) [3].

Some aspects related to the findings that can be revealed when performing inspections (influencing explosion protection of equipment) are included in the following examples:

Fig.1 Equipment in normal construction installed in hazardous area classified as zone 2

Fig. 2 Ex equipment installed in zone 2 but with its label plate being painted

Fig. 3 Bolts missing to an Ex d equipment

Fig. 4 Damaged cable and cable gland of an Ex d equipment

Fig. 5 Ex e blanking element installed to an Ex d equipment

Fig. 6 Damage of rubber elements leading to invalidation of explosion protection for an “Ex de “ equipment

4. CONCLUSIONS

The paper presented some relevant information regarding the inspection of electrical equipment used in explosive atmospheres. The paper was focused on electrical equipment with two types of protection, flameproof enclosure “d” and increased safety “e”. The definitions regarding inspections are also common to other specific types of protection.

In the first two parts of the paper were exposed important features regarding the inspection activity: importance and classification of inspections, verifications needed to be made on inspections according the type of protection, type and grade of inspection; factors that influence the inspection program and competence of personnel.

The third part consisted in some specific examples of non-conformities related to explosion protection that can be found on equipment with type of protection “d” and “e (frequent damages).

These aspects are very important to the personnel performing inspection (and maintenance) activities in installations operating in explosive atmospheres.

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COMPUTATIONAL METHOD AND EXPERIMENTAL MEASUREMENT FOR DETERMINING VOLTAGE STANDING WAVE RATIO

DOBRA REMUS[1], RISTEIU MIRCEA[2], ALDEA MIHAELA [3], FLORIN SAMOILA[4], PAULA CAMELIA STOICA[5]

Abstract: The measuring results and computational methodology is showing that when a transmission line and a waveguide is terminated by an impedance that does not match the characteristic impedance of the transmission line, not all of the power is absorbed by the load impedance. Some of the power is reflected back down the transmission line. The incident signal mixes with the reflected signal to cause a voltage standing wave pattern on the transmission line. The ratio of the maximum to minimum voltage is known as VSWR, or Voltage Standing Wave Ratio. In this paper shows research results dedicated to methods of measuring and calculating the VSWR.

Keywords: Voltage standing wave ratio, transmission line model, impedance, reflect, matched lines, testing transmission lines, waveguide.

1. STANDING WAVE RATIO FUNDAMENTALS

This experiment studies the standing wave basics, voltage standing wave ratio (VSWR) and reflection coefficient (Γ). Standing wave ratio (SWR): it describes the voltage and current standing waves that appear on the transmission line (waveguide). SWR is a measure of impedance matching of loads to the characteristic impedance of a waveguide [6].

Voltage standing wave ratio (**VSWR**): it applies specifically to the voltage standing waves that are set up on a transmission line. Because it is easier to detect the

[1] *Ph.D.Eng. Assoc. Prof., University of Alba Iulia, remusdobra@uab.ro*
[2] *Ph.D.Eng. Assoc. Prof., University of Alba Iulia, mircearisteiu@gmail.com*
[3] *Ph.D. Student, University of Alba Iulia, maldea@uab.ro*
[4] *Ph.D. Student, University of Cluj Napoca, samoila.florin.13@gmail.com*
[5] *Ph.D. Student, University of Pitesti, cameliapaulastoica@gmail.com*

voltage standing waves, the term VSWR is more often used then SWR, especially within radiofrequency (RF) systems [2].

VSWR is defined as the ratio of the maximum voltage to the minimum voltage in standing wave pattern along the length of a transmission line structure. It varies from 1 to (plus) infinity and is always positive. Unless you have a piece of slotted line-test equipment this is a hard definition to use, especially since the concept of voltage in a microwave structure has many interpretations [4].

In figure 1 is described two general cases where the waveguide is terminated with any given complex impedance Z_L (a) and with a shorting plate (b).

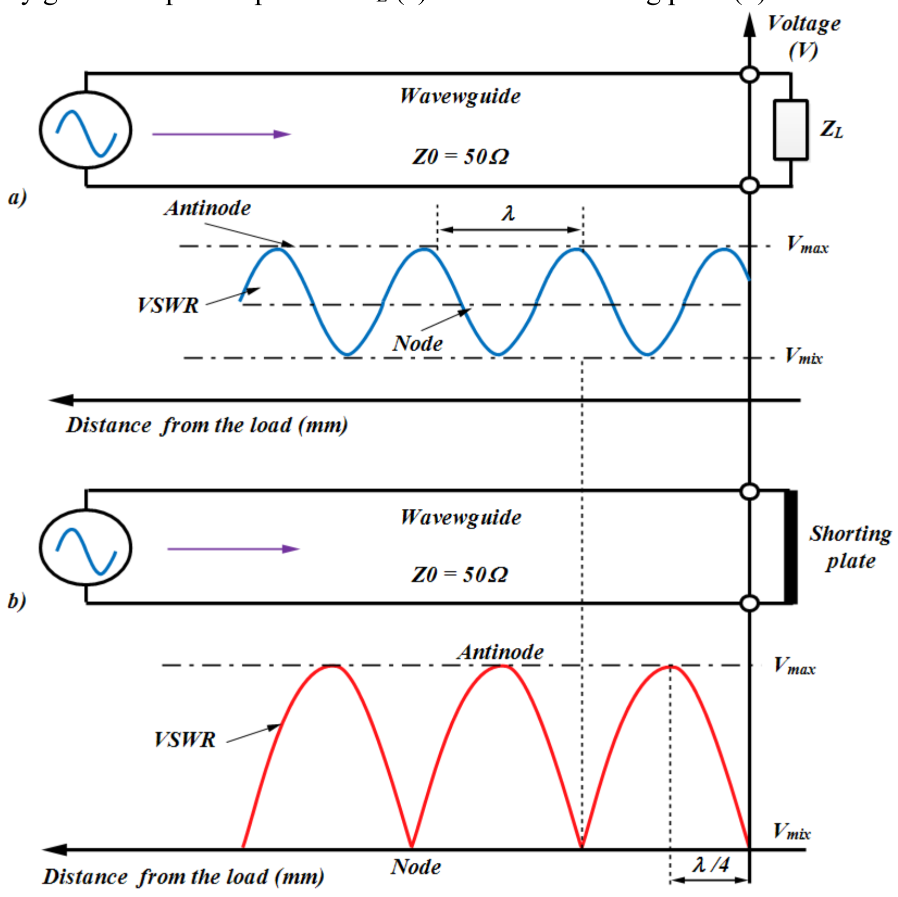


Fig.1. Schematic diagram of matched simulated waveguide at 50 Ω

In radio frequency systems, the power is transferred from the source to the load using a transmission line of feeder (*simulated coaxial cable* in our case). This transmission line has a characteristic impedance $\mathbf{Z_0}$.

Figure 2 shows a system that has the simulated transmission line matched with the load. The characteristic impedance of the simulated transmission line **(Z_0 = 68Ω)** is the same as the characteristic impedance of the load **(Z_L = 68Ω).** In this example, *all the* *power is transferred from the simulated transmission line to the load* (when matched approximatively no power will be reflected to the source).

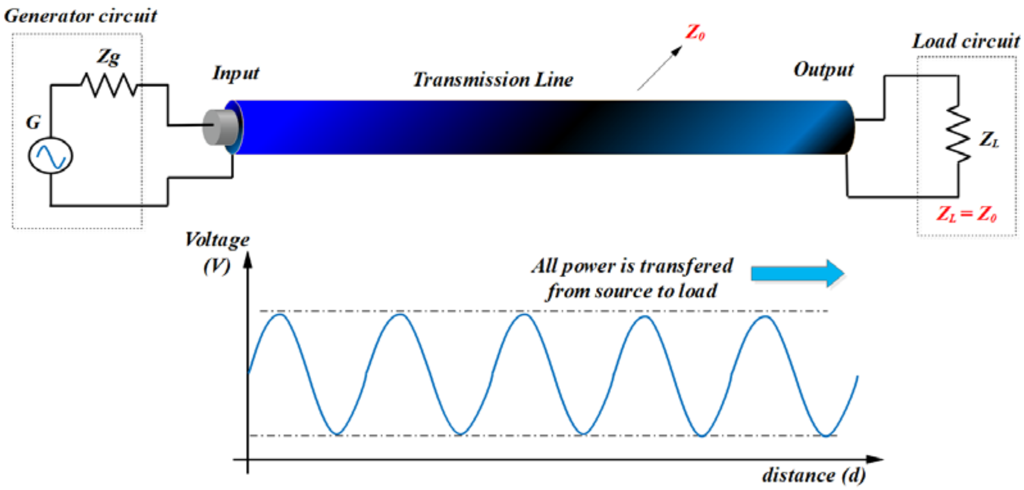


Fig.2. Schematic diagram of matched simulated transmission line and load at 68 Ω (no signal is reflected to the source)

Figure 3 shows a mismatched system where the simulated transmission line impedance (**Z_0 = 68Ω)** and the load impedance (**Z_L ≠ 68Ω**) have different values.

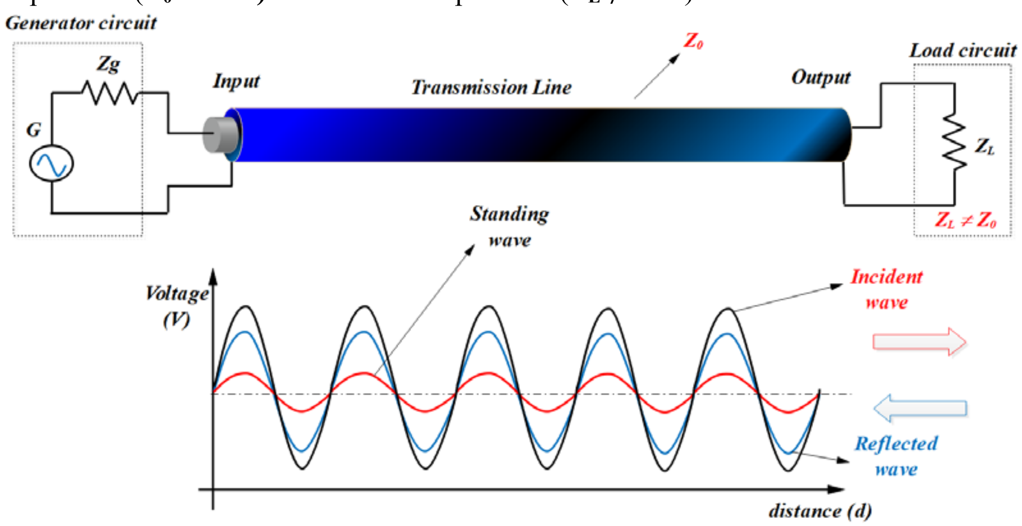


Fig.3. Schematic diagram of mismatched simulated transmission line and load (signal is reflected to the source).

In figures 2 and 3 the notations are: Zg – generator impedance, ZL – load impedance, Z0 – Characteristic impedance of the line, Vin – Input voltage current, Vout – Output voltage, f – variable frequency of the input signal. The maximum power transfer occurs when the load has the same impedance with the simulated transmission line. Technical literature [1], [3], [5] presents that the maximum power transferred into the waveguide occurs when the source has the same impedance with the waveguide.

2. TRANSMISSION LINE MODEL FOR VSWR MEASUREMENT

In figure shows the schematic diagram related to the experiment, where the simulated transmission lines will be supplied with a sinusoidal voltage with variable frequency, from the signal generator (G). One end of the line is closed on the impedance load (Z_L), while on the other end the sine-wave signal generator is connected. At the input stage of the signal generator, the value of input impedance is equal to the characteristic impedance of the line, i.e. 68 ohms.

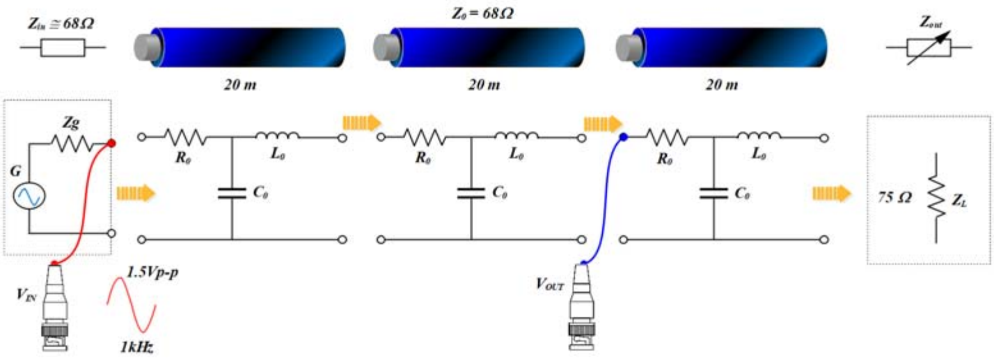


Fig.4. Schematic diagram for measuring the voltage standing wave ratio (VSWR).

VSWR is defined as the ratio of the maximum voltage to the minimum voltage in a standing wave pattern along the length of a simulated transmission line. Theoretically, it varies from 1 to (plus) infinity and it is always positive.

$$\boldsymbol{VSWR} = \left|\frac{V_{max}}{V_{min}}\right| \quad \mathbf{1} \leq \boldsymbol{VSWR} \leq \infty \tag{1}$$

VSWR describes the voltage standing wave pattern that is present in the transmission line due to phase addition and subtraction of the incident and reflected waves.

In a simulated transmission line, with the characteristic impedance of Z_0, the reflection coefficient (absolute magnitude $|\Gamma|$) between the incident and the reflected signal is defined as:

$$|\boldsymbol{\Gamma}| = \frac{\boldsymbol{VSWR}-\mathbf{1}}{\boldsymbol{VSWR}+\mathbf{1}} \tag{2}$$

When the load is perfectly matched to the transmission line:

$$\mathbf{VSWR} = \mathbf{1} \quad \Rightarrow \quad |\boldsymbol{\Gamma}| = \mathbf{0} \tag{3}$$

When the load is a short circuit, an open circuit or a pure reactance:

$$\mathbf{VSWR} = \infty \quad \Rightarrow \quad |\boldsymbol{\Gamma}| = \mathbf{1} \tag{4}$$

In this experiment you will use the frequency selective amplifier and slotted line to measure a matched load a shorting plate load and a variable load.

By perform the circuit configuration shown in the wiring diagram we will measure the amplitude of the signal at the input and output of the line for each different section of the simulated transmission line (i.e. 20 m, 40 m, 60 m and 80 m).

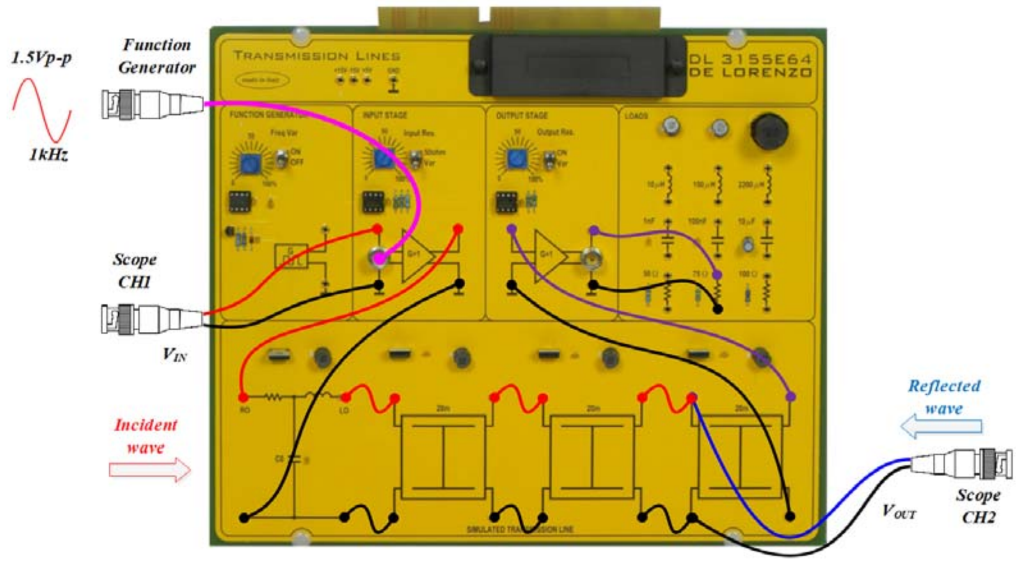


Fig.5. Wiring diagram for measuring the voltage standing wave ratio (VSWR).

For measuring function generator was set up for an amplitude output signal of 750mV and a frequency of 1 kHz. In this configuration the signals will be equal if the input stage potentiometer is at approx. minimum position and the output stage potentiometer is at approx. maximum position. The characteristic impedance of the line is Z_0 = 68 Ω

The SWR is usually thought of in terms of the maximum and minimum AC voltages along the transmission line, thus called the voltage standing wave ratio or VSWR. The MATH menu of the oscilloscope was used to display the standing wave. Selecting the CH1+CH2 to add the incident wave to the reflected wave and to obtain the standing wave ratio.

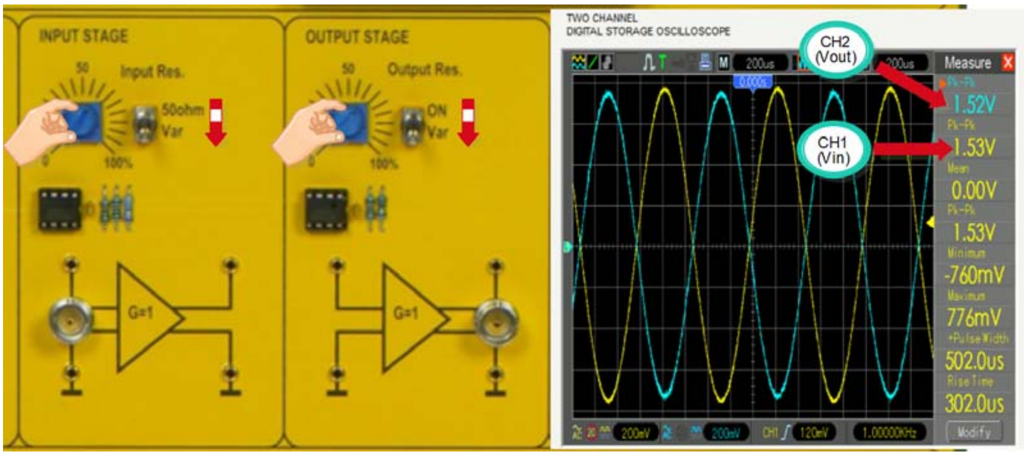
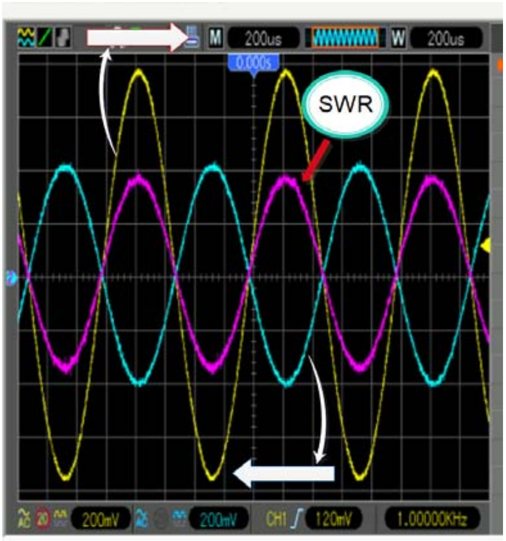


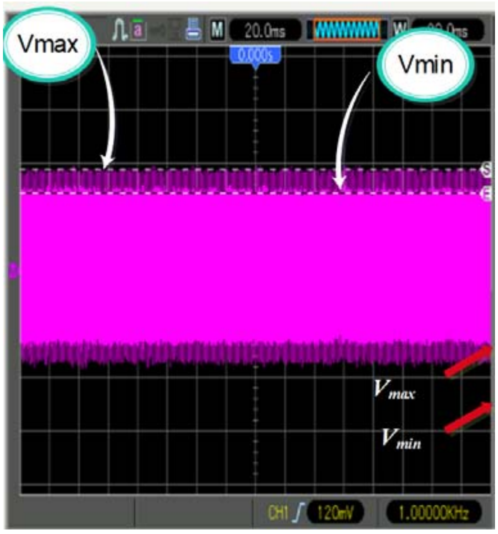
Fig.6. Input/output transmission line voltage measurements

Fig.7. Voltage standing wave ratio (VSWR) determination

The relevant metric is the standing wave ratio (SWR). SWR is defined as the ratio between the amplitude of a partial standing wave at antinodes [max] to the amplitude of the adjacent mode [min]. Thus, a ratio of 1.5:1 means the maximum standing wave amplitude is 1.5 times greater than the minimum standing wave value.

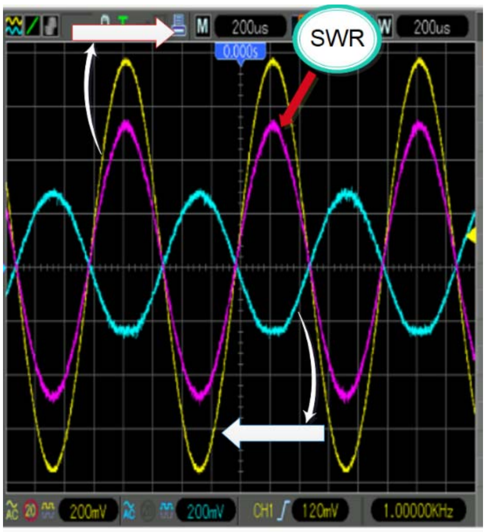
Calculating the Voltage Standing Wave Ratio (VSWR) with mismatched load and the the reflection coefficient (absolute magnitude $|\Gamma|$):

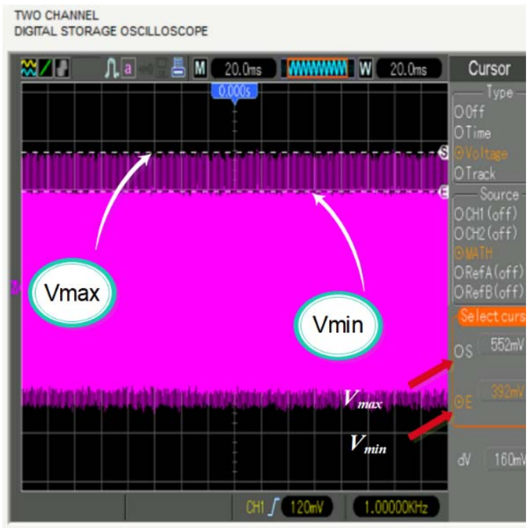




$$VSWR = \frac{V_{max}}{V_{min}} = \frac{376mV}{288mV} = 1.3 \tag{5}$$

$$|\Gamma| = \frac{VSWR-1}{VSWR+1} = \frac{1.3-1}{1.3+1} = 0.13 \tag{6}$$





Calculate the Voltage Standing Wave Ratio (VSWR) with mismatched load:

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{552mV}{392mV} = 1.4 \quad (7)$$

Calculate the reflection coefficient (absolute magnitude |Γ |):

$$|\Gamma| = \frac{VSWR-1}{VSWR+1} = \frac{1.4-1}{1.4+1} = 0.16 \quad (8)$$

3. WAVEGUIDE MODEL FOR VSWR MEASUREMENT

The maximum power transfer occurs when the waveguide transfer power to a load that has the same impedance with the waveguide. Similarly, the maximum power transferred into the waveguide occurs when the source has the same impedance with the waveguide.

The waveguide acts as a high pass filter, where most of the energy above a certain frequency (the cutoff frequency) will pass through the waveguide, whereas most of the energy that is below the cutoff frequency will be attenuated by the waveguide. Waveguides are a special form of transmission line used for microwave applications. Dimensions of the waveguide which determines the operating frequency range. For our testing method, as shown in fig.8, is used a rectangular waveguide and microwave signal source (10GHz), frequency selective amplifier, coaxial adapter, variable attenuator, slotted line, slide screw tuner, shorting plate and a matched termination plate

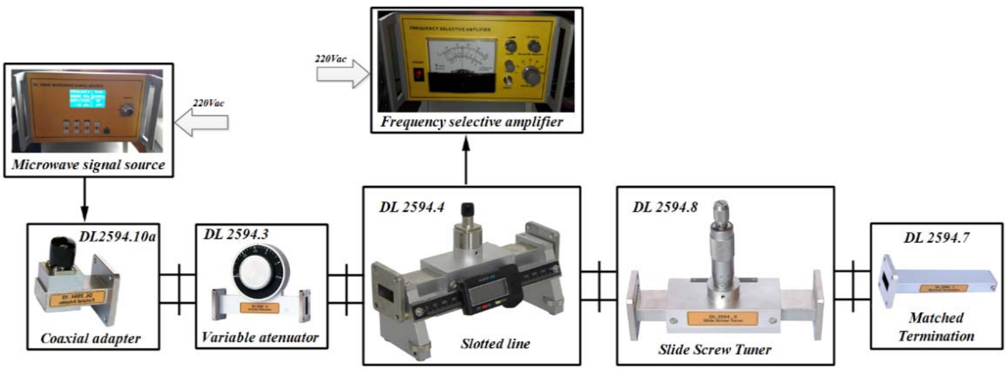


Fig.8. Laboratory setup for measuring VSWR

By moving the slotted line - mobile part to the left until the minimum position Vmin is measured. Continuing to move the slotted line - mobile part to the left until the minimum position Vmax is measured.

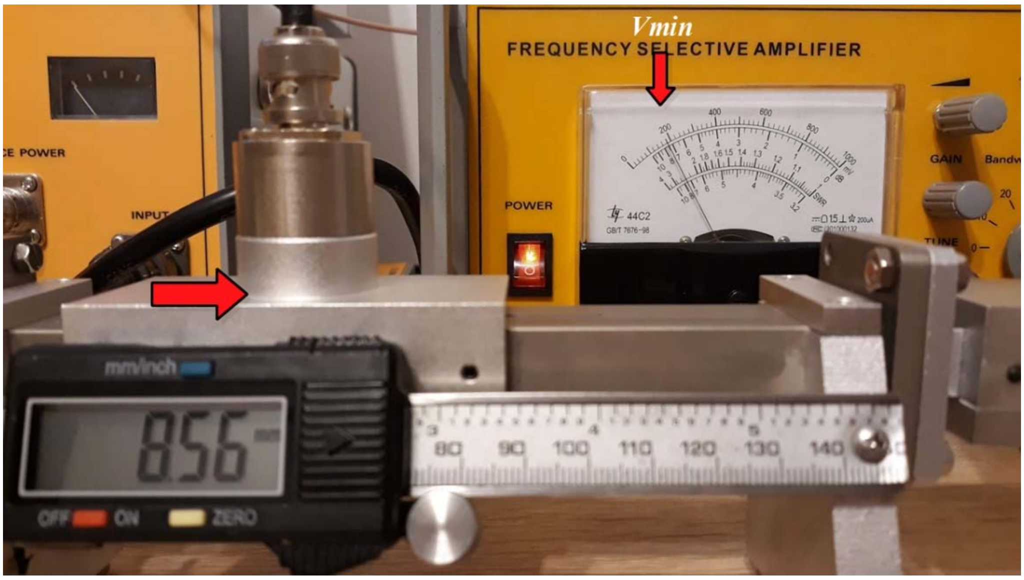


Fig. 9. Measuring the minimum voltage Vmin

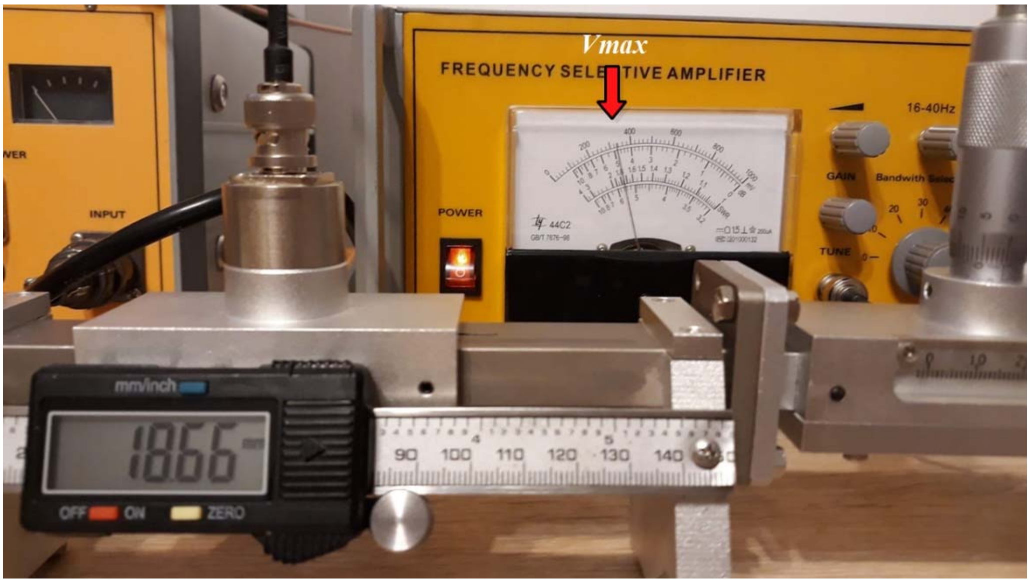


Fig.10. Measuring the maximum voltage Vmax

Calculate the Voltage Standing Wave Ratio (VSWR)

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{420mV}{180mV} = 2.33 \tag{9}$$

Calculate reflection coefficient (absolute magnitude |Γ |)

$$|\Gamma| = \frac{VSWR-1}{VSWR+1} = \frac{3.77-1}{3.77+1} = 0.39 \quad (10)$$

4. CONCLUSIONS

With slotted line module we have studied the standing wave in three cases:

- using a shorting plate (zero impedance of the load)
- matched termination (50Ω)
- by using a waveguide with unknown impedance.

By using the relationships between standing waves and frequencies, using slotted line module we measure minimum and maximum voltages, used to calculate VSWR. Also, VSWR was measured directly using slotted line module and the frequency selective amplifier.

In terms of efficiency, for three situations of mismatched load we have calculated the reflection coefficient. The reflection coefficient as increased as the load impedance increased compared with the characteristic impedance of the transmission line. VSWR is a very important parameter in RF transmission systems where a high VSWR can reduce the power delivered to an antenna or system significantly. This can lead to reduced range, heating of cables, damaged amplifiers, etc.

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DESIGNING VIRTUAL LEARNING ENVIRONMENT FOR ELECTRIC POWER DISTRIBUTION NETWORKS

MIRCEA RISTEIU[1], DOBRA REMUS[2], PASCULESCU DRAGOS[3], MIHAELA ALDEA[4], PAULA CAMELIA STOICA[5]

Abstract: The current paper is the result of research program dedicated to designing new tools and instruments in industrial processes control, optimization and fast learning. The process is replaced by a virtual environment that reacts to the controlled process by using Real Time Unit (RTU) from Supervisory Control and Data Acquisition (SCADA) systems, and answer similar with real process. The software application is designed using specific SCADA developing software, and it is implemented through specific SCADA structure. The designed results will create and understand typical operational restrictions in distribution stations, offer the database status parameters for integrated controls used in the specific SCADA. We have teste the software for both interruptible and non-interruptible regime of load supplying.

Keywords: Process simulation, Electric power networks, SCADA, Control optimization, Learning environment.

1. ENGINEERING EDUCATION- ELECTRIC POWER DISTRIBUTION STUDY CASE

An important research group [1, 2, 3] provided an excellent review report on most frequently used virtual learning methods. In current research paper we are focusing on electric power distribution learning approach.

The documentations follow some study cases scenarios. In the current configurations of electric power networks, we might be "linked" at one moment, by the agreement, to entities like in figure 1.

[1] *Ph.D.Eng. Assoc. Prof., 1 Decembrie 1918 University of Alba Iulia, mristeiu@uab.ro*
[2] *Ph.D.Eng. Assoc. Prof., University of Alba Iulia, remusdobra@uab.ro*
[3] *Ph.D.Eng. Assoc. Prof., University of Petrosani, pdragos_74@yahoo.com*
[4] *Ph.D. Lecturer, 1 Decembrie 1918 University of Alba Iulia, maldea@uab.ro*
[5] *Ph.D. Student, University of Pitesti, cameliapaulastoica@gmail.com*

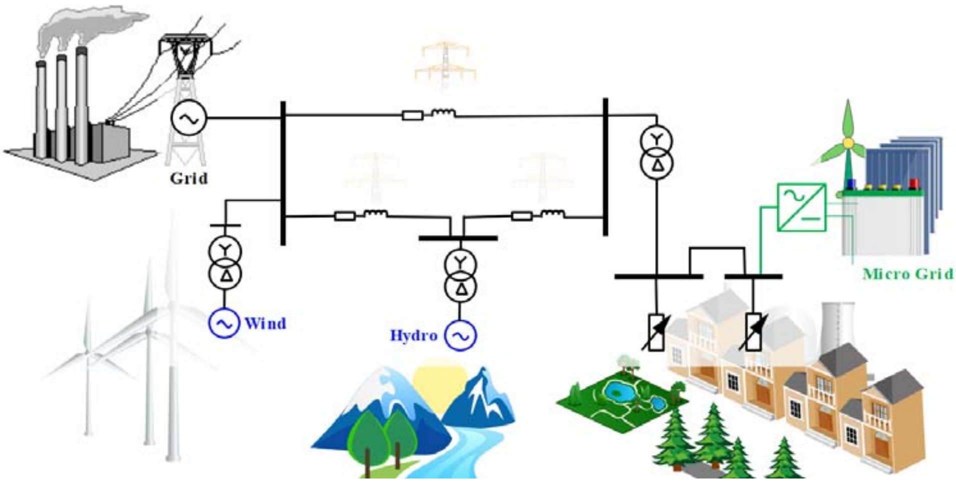


Fig.1. The electric power network model used in current implementation [4]

We say "at one moment" because, depending by the agreement, the configuration might be changed considering that the constrains could be time-variable: security constrained, or cost constrained, or reliability constrained. The consumer "Bistra" is connected through the distribution station to the grid via two main transmission lines paths. From a "faraway" place, Bistra can buy electricity from a hydro plant generator, according with a scheduled program not only to maintain the voltage value at busbar level above .99 pu (see next figure) but also to ensure a high-quality energy. Our electricity invoice will contain a green certificate component of the wind farm connected to the grid, when it is not delivering energy to the grid [10], [12].

In the same time, the consumer "Bistra" is using a local, alternative energy source- a compound of solar, wind, and battery storage systems. The, so- called, micro-grid system is following the grid rules when it works as an on-grid system. Generally speaking we might imagine that micro-grid is also managed to work as off-grid system.

The intention of this approach is to guide users (students/trainers/professors/ researchers) to always imagine their network as an electrical distribution network over which to apply operating rules, market rules, optimization rules [13].

1.1. Busbars general consideration

The industry needs PLC

In this context, one weak part of the power network is the connection point between power line- called also electric power distribution point. High-voltage substations are points in the power system where power can be pooled from generating sources, distributed and transformed, and delivered to the load points. Next figure shows typical power structure focused on distribution stations; where a) Single busbar; Double-busbar (BB – busbar, M-BB – Main busbar, A-BB – Auxiliary busbar, G – Generator, K – circuit breaker, Q – Disconnector, CT – current transformer, VT – voltage transformer, SE – Earthing switch).

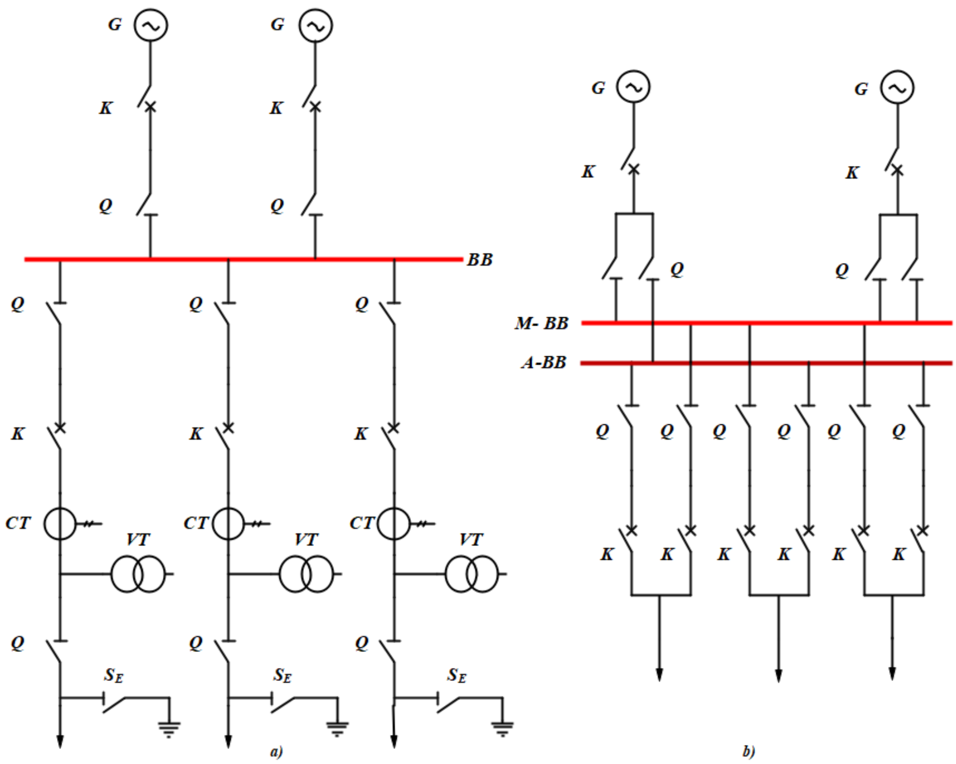


Fig.2. The electric power network model used in current implementation [4, 5, 6]

Above figure (a) shown the single busbar and because it has only one busbar and the minimum amount of equipment, this scheme is a low-cost solution that provides only limited availability. Substations are interconnected with each other, so that the power system becomes a meshed network. Because it has only one busbar and the minimum amount of equipment, this scheme is a low-cost solution that provides only limited availability. In the event of a busbar failure and during maintenance periods, there will be an outage of the complete substation. To increase the reliability, a second busbar has to be added. In double busbar systems, shown in above figure (b), two identical busbars are used in such a way that any outgoing or incoming feeder can be taken from any of the bus. Actually, every feeder is connected to both buses in parallel through an individual isolator. The double busbar arrangement increases the flexibility of the system.

The more complex scheme of a double-busbar system gives much more flexibility and reliability during operation of the substation. For this reason, this scheme is used for distribution and transformer substations at the nodes of the power supply system. It is possible to control the power flow by using the busbars independently, and by switching a feeder from one busbar to the other. Because the busbar disconnectors are not able to break the rated current of the feeder, there will be a short disruption in power flow. To have a load change without disruption, a second circuit breaker per feeder has to be used. The key points of the virtual environment studies related to the busbar operation are:

- Busbar general operation
- Power transfer in a double busbar system with supplying interruption
- Power transfer in a double busbar system with continuous supplying
- Supplying a double busbar system with a backup power line.

2. MODELS IN VIRTUAL LEARNING ENVIRONMENTS

According with technical literature [6, 7] we propose models in progressive approach from the difficulty point of view. Next figure shows the circuit diagram of double busbar basic system. The subject of this experiment is to underline the operation of pairs Q1-K1, and Q2-K2 for supplying/disconnecting the busbars BB1 and BB2 from the distribution station SD.

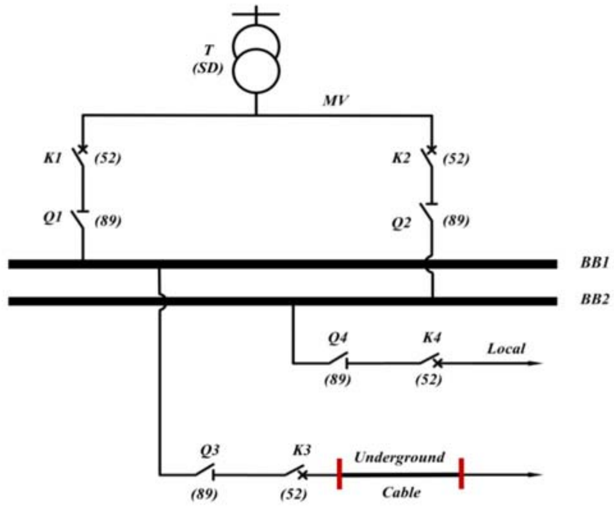


Fig.3. Simplified model for basic operation studies

Then, we are studying the operation of the pair Q3-K3 for supplying/disconnecting the underground cable, and the pair Q4-K4 for supplying/disconnecting the local consumers. Before starting the experiments, we recommend you understand the role of the hardware components of the trainer and how they are arranged and handled. This double busbar basic system is the simplest configuration: one power supply (SD) which in our laboratory configuration is represented by the three-phase power supply, is connected together with a three-phase model of an underground transmission line. Each connection point uses breakers (52) - connected to a double busbar. Special care must be taken to ensure that the individual phases are connected correctly in order to avoid later short-circuits.

High-voltage substations are points in the power system where power can be pooled from generating sources, distributed and transformed, and delivered to the load points. In the main and transfer bus arrangement we have two buses one is the main bus and the other is transfer bus. With the help of isolator switches, it is connected to the transfer bus which is called by pass isolators and with the help of circuit breakers and isolator switches it is connected to the main bus. There is also bus coupler as shown in the following figure.

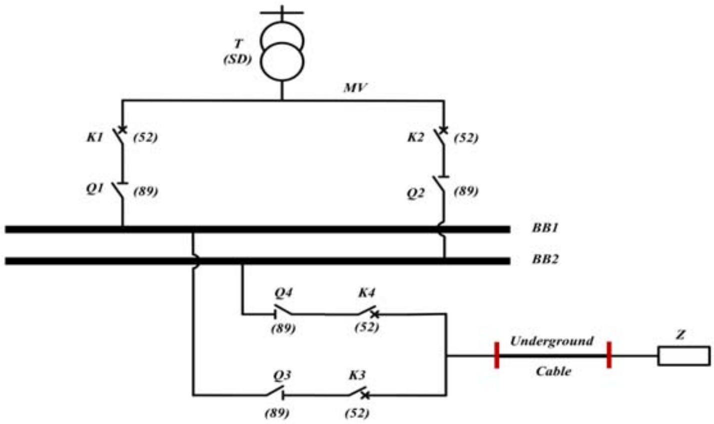


Fig.4. Simplified model for load supplying with interruption

Where, BB1 is main busbar, BB2 is transfer busbar (or reserve busbar). Both according with a procedure will transfer power to the load (Z). As you can see, each busbar can be fully insulated from the electrical powering point of view (see the position of the insulator switches). The subject of this experiment is to underline the operation of pairs Q1-K1, and Q2-K2 for supplying/disconnecting the busbars BB1 and BB2 from the distribution station SD. Then, we are studying the operation of the pair Q3-K3 for supplying/disconnecting the underground cable from one busbar, and the pair Q4-K4 for supplying/disconnecting the underground cable from second busbar. This experiment differs from the previous one because it proposes an improvement in load power supplying:

- Adding at busbar level a busbar coupling system caller busbar coupler
- Completing operational procedure in order to allow continuous power supplying and maintain the security at the busbar's levels.

Technical literature [7, 8, 9] presents two different situations of using busbar couplers. The coupler is used to equalize the voltage potential of the two busbars-preliminary operation for allowing switching between one power path (BB1) and reserve power path (BB2). Second situation of using busbar coupler is also known a busbar sectionalizing system- see next figure.

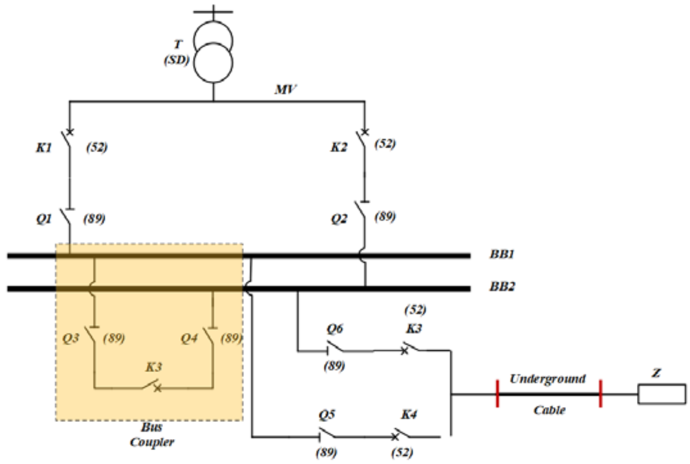


Fig.5. Simplified model for load supplying without interruption- equalizing voltage in first stage

The coupler is used to equalize the voltage potential of the two busbars- preliminary operation for allowing switching between one power path (BB1) and reserve power path (BB2). Second situation of using busbar coupler is also known a busbar sectionalizing system- see next figure. Both couplers have similar structures, but the operational procedure is different- following different purposes. The current experiment will be focused on first situation- as an alternative of previous experiment procedure- to supply continuously a load, when switching from main busbar to the transfer busbar.

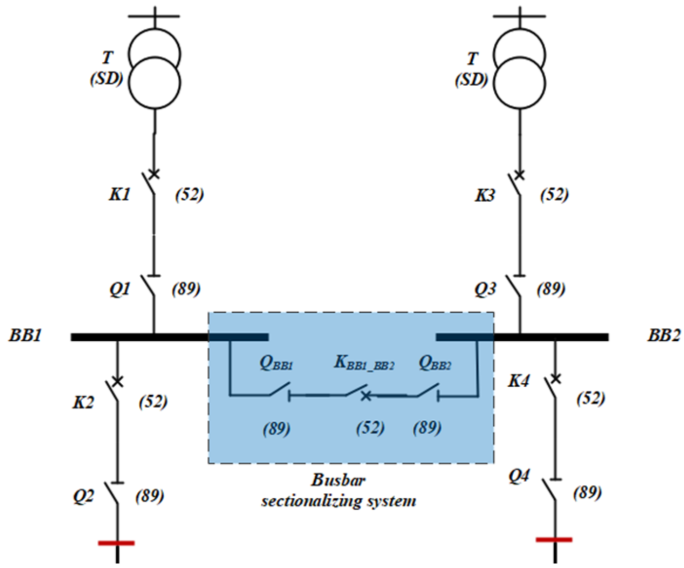


Fig.6. Simplified model for load supplying without interruption- equalizing voltage in first stage- reserve procedure

The subject of this experiment is to underline the operation of pairs Q1-K1, and Q2-K2 for supplying/disconnecting the busbars BB1 and BB2 from the distribution station SD.

Then, we are studying the operation of the pair Q5-K5 for supplying/disconnecting the underground cable from one busbar, and the pair Q6-K6 for supplying/disconnecting the underground cable from second busbar (transfer busbar). To keep continuously the power at the load a coupler is required Q3-K3-Q4.

3. SOFTWARE RESOURCES USED IN MODELS IMPLEMENTATION

3.1 Events triggering considerations

The implementation starts with some control considerations that are used in software model implementation- events triggering. Before creating any program, any flow diagram we must understand:

- What is asked from the automata system?
- What we need to provide to the system in order to "produce" what is asked?

These questions are well symbolized by next figure (systemic representation):

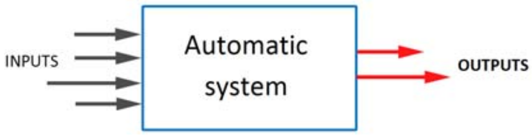
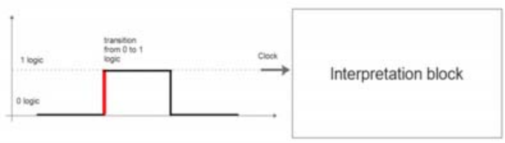
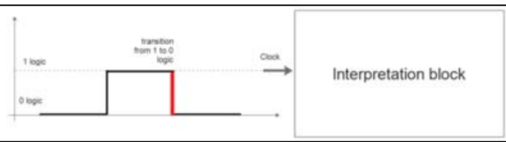
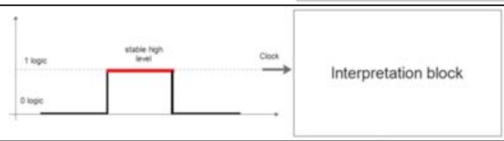
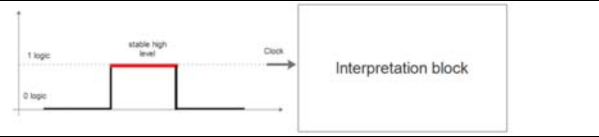
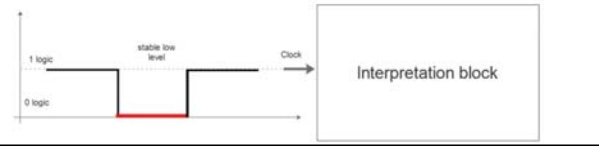


Fig.7. Simplified model of the controlled process; any big practical problem is divided in many simple problems, in many simple systemic representations, with many local working algorithms

Triggering option is referring to the moment of starting understanding the input action. Usually, in automation, there are few options shown in next table.

Triggering on transition from 0 to 1 logic- positive edge triggering	
Triggering on transition from 1 to 0 logic- negative edge triggering	
Triggering on stable high level	

Triggering on stable low level	
Triggering on middle point of the pulse (Manchester code)- the control clock period is double of master clock.	

3.2 Developing software model using SCADA specialized software development

The SCADA project is developed in WinLog programming environment. It is open source technology are based on the provided SCADA software for current trainer, you are able to expand your functions using WinLog.

If you want to re-install/ install SCADA on the new PC, to run SCADA applications two steps are required on the PC:

- Install WinLog
- Import SCADA project in WinLog

If you leave Run Winlog Evo 4.0.15 checked, it will start and project explorer will appear like in figure 8.

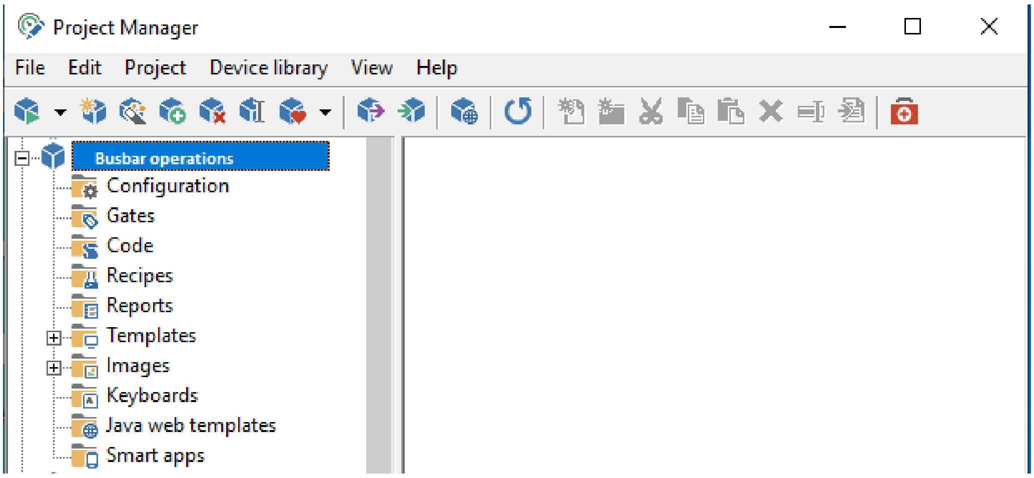


Fig.8. The main window of project explorer in Winlog

4. TESTS AND RESULTS OF VIRTUAL SUPPORT IMPLEMENTATION

When we are running the project, the runtime generates typical SCADA interfaces.

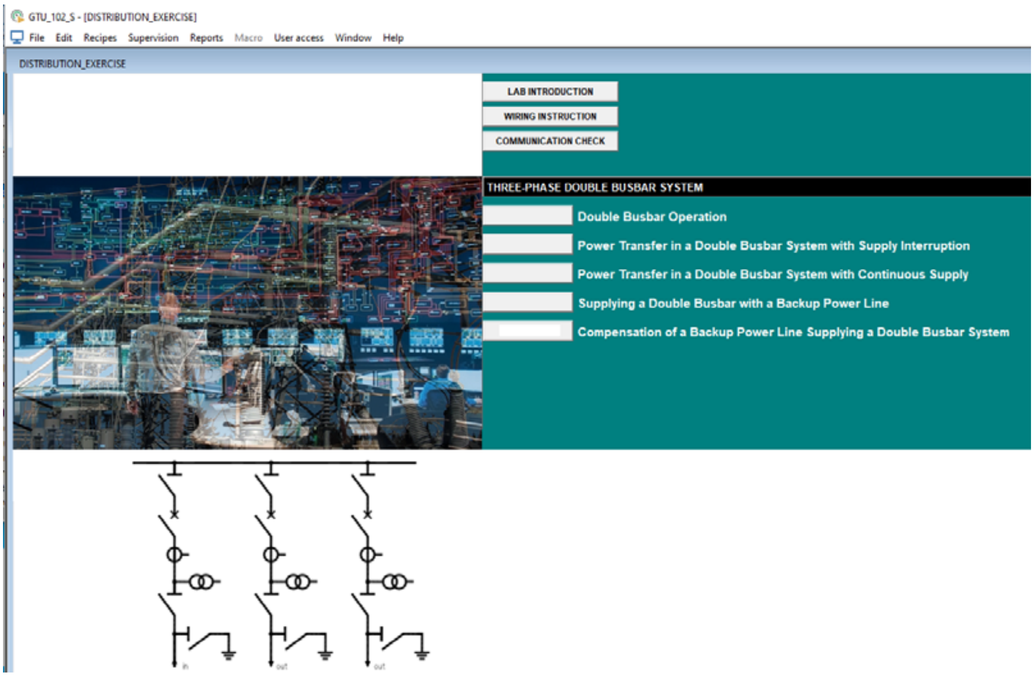


Fig.9. SCADA experiments main window developed in Winlog

4.1 Busbar standard operation implementation

Next figure shows the main SCADA window.

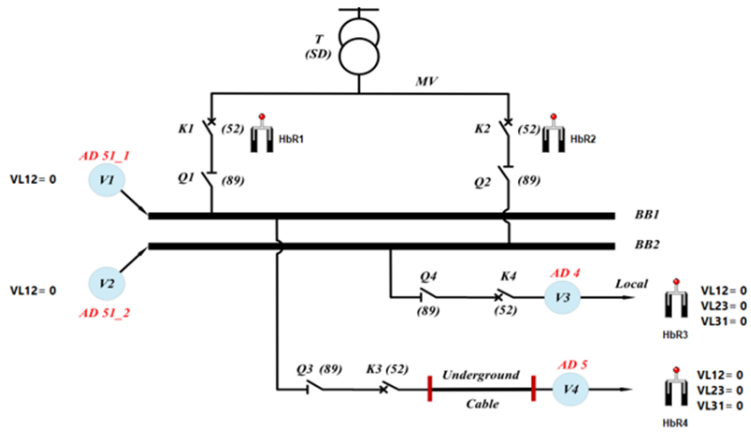


Fig.10. SCADA experiments for basic operations

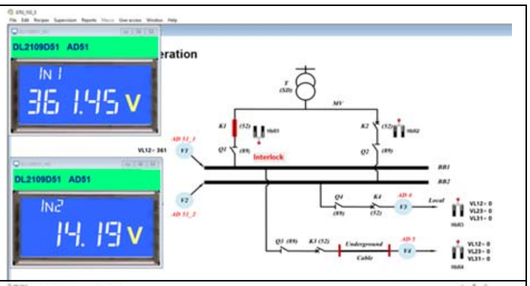
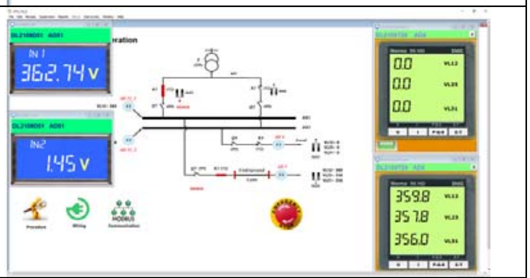
According with the objectives we will supply/ disconnect the power to the underground cable and to the local consumers, independently each other, focusing on the order how to operate devices (insulation breakers (89)- Q1- Q4, power breakers (52)- K1- K4).

A connection point is always composed by one device 89 and one device 52. They are interconnected (according with the law procedures) for correct operation order.

The operation order in one connection point is:

- Closing operation: close 89 than close 52
- Opening operation: open 52 than open 89.

The results are show in next table (by following software implemented procedure).

Closing K1 is on the software	
Close Q3, after that close K3	

In the similar way, the operation of second busbar is controlled by the software. Next figure shows the interface for load supplying in above mentioned conditions.

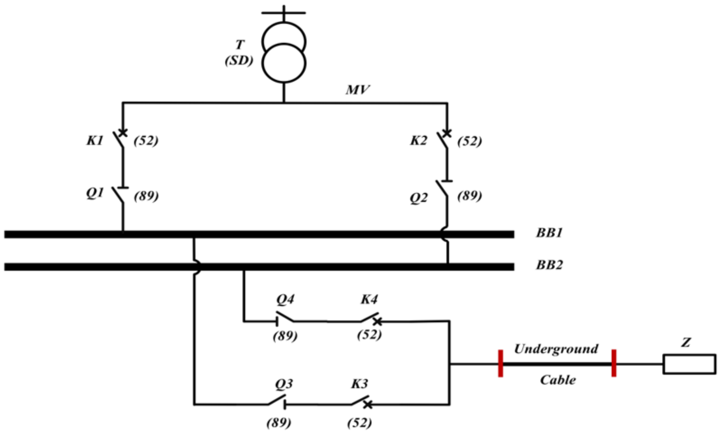


Fig.11. SCADA experiments for basic operations for load supplying

4.1. Busbar operation implementation for non-interruptible power supply and reserve ensuring

Next figure shows typical interface.

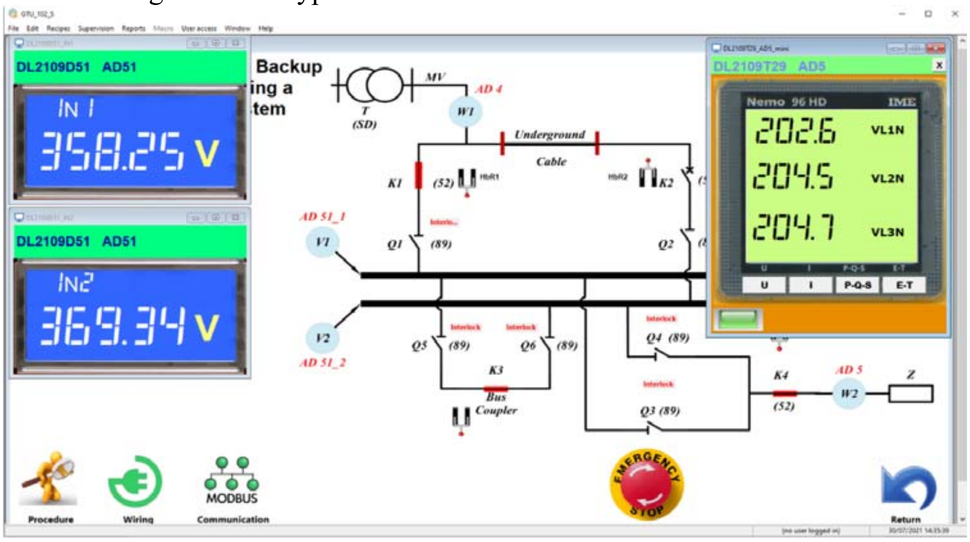


Fig.12. SCADA experiments for non-interruptible supplying

5. CONCLSIONS

The designed SCADA follows the typical power system regulations.

The double system is used to bring to the busbar system power from one/more power supplies through two different power circuits.

The busbar system (simple or double) is a system that defines the voltage lines circuits. It is used to connect/disconnect lines from the voltage presence point of view. A double system creates double line circuits.

The exercise in repeating operations from the previous experiments and continues with power transfer from main busbar to the transfer busbar. The first conclusion is that the order of operating breakers (52 and 89) at busbar level must be always followed.

This operational procedure is transferring the power from main busbar to the transfer busbar by interrupting the power at the load level- this procedure can be used only for the consumers that allow this situation. It is never recommended to be used to supply the consumers where interruption of the power will produce significant losses or victims (hospitals, metallurgical, or transportation industry).

This operational procedure is transferring the power from main busbar to the transfer busbar with continuous the power at the load level- this procedure can be used only for the consumers that allow this situation- being very expensive. It is recommended to be used to supply the consumers where interruption of the power will produce significant losses or victims (hospitals, metallurgical, or transportation industry).

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Annals of the University of Petrosani, Electrical Engineering, 23 (2021)

PRACTICAL METHOD FOR DETERMINATION THE WAVEGUIDE IMPEDANCE USING SMITH CHART

DOBRA REMUS[1], RISTEIU MIRCEA[2], ALDEA MIHAELA[3], GEORGETA BUICA[4], PAULA CAMELIA STOICA[5]

Abstract: The Smith chart is a graphical tool for determination of the reflection coefficient and impedance along a transmission line. The paper presents a practical method for determination the waveguide impedance using Smith chart in a waveguide. From calculating the reflection coefficient and impedance at various points on a transmission line to designing the matching network of a microwave system. The Smith chart is a handy tool that is even included in lots of modern computer-aided design software and test equipment. The Smith chart is based on a polar plot of the complex reflection coefficient Γ(x) overlaid with the corresponding impedance Z(x). A simple transformation is presented which permits the direct use of the standard Smith chart in the study of transmission lines and waveguides.

Keywords: Voltage standing wave ratio, waveguide impedance, reflect, matched lines, Smith chart, waveguide.

1. STANDING WAVE RATIO FUNDAMENTALS

This experiment studies a method to determine the impedance of a waveguide mismatched terminating the line. A mismatched terminating line occurs when a waveguide line is terminated with load impedance with different value than the line's characteristic impedance value [12].

The unknown impedance can be determined by using the Smith chart. In order to get the parameters for Smith chart some processing action should be done by evaluating the standing wave in different situations (without and with unknown impedance) [3], [7]. Typical standing wave is shown in figure 1.

[1] *Ph.D.Eng. Assoc. Prof, University of Alba Iulia, remusdobra@uab.ro*
[2] *Ph.D.Eng. Assoc. Prof, University of Alba Iulia, mircearisteiu@gmail.com*
[3] *Ph.D. Student, University of Alba Iulia, maldea@uab.ro*
[4] *Ph.D. Eng, Institutul Naţional de Cercetare-Dezvoltare pentru Protecţia Muncii "Alexandru Darabont", gbuica@protectiamuncii.ro*
[5] *Ph.D. Student, University of Pitesti, cameliapaulastoica@gmail.com*

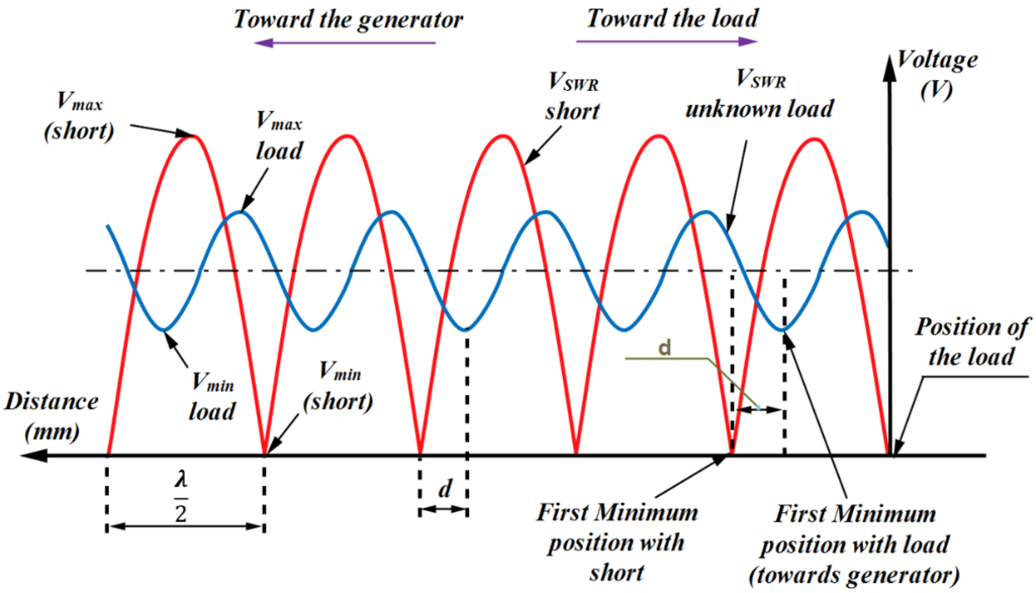

Fig.1. Standing waves on the waveguide line: with shorting plate and with unknown load

By connecting the shorting plate, we identify the first minimum position of the standing wave (**d1**) with the shorting plate inserted, see figure 1.

By disconnecting the shorting plate and connecting the unknown impedance (figure 1), we identify the first minimum position (**d2**) and measure the Voltage Standing Wave Ratio (VSWR), with the load, see figure 2.

The unknown terminating impedance can be determined by measuring standing wave ratio and the distance (**d**) of a convenient minimum (or maximum) from the load.

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{1-|\Gamma|}{1+|\Gamma|} \tag{1}$$

Where: Vmax, Vmin are pick values of Voltage Standing Wave Ratio.

In a waveguide line with the characteristic impedance of Z_o, the reflection coefficient (absolute magnitude |Γ|) between the incident and the reflected signal is defined as [2], [5]:

$$|\Gamma| = \frac{VSWR-1}{VSWR+1} \tag{2}$$

$$\overline{\Gamma} = |\Gamma| \cdot e^{j\theta_r} \tag{3}$$

Where: $\overline{\Gamma}$- is the complex reflection coefficient

θ_R- is the angle of reflection coefficient (degrees)

Using the graphical representation of Smith chart, the load impedance can be determined (load resistance R_L and load reactance X_L) with next equation.

$$Z_L = R_L + jX_L \tag{4}$$

The Smith chart coordinates give the normalized impedance z_L (resistance and reactance).

$$\Rightarrow z_L = \frac{Z_L}{Z_0} \tag{5}$$

For this experiment, the chart coordinates are normalized to **Z_o = 50Ω** (the characteristic impedance of the waveguide).

The value calculation starts from the standing wave processing. To read the standing waves we use the waveguide slotted line and to determine the impedance of the unknown load we use the slide screw tuner, as shown in figure 2.

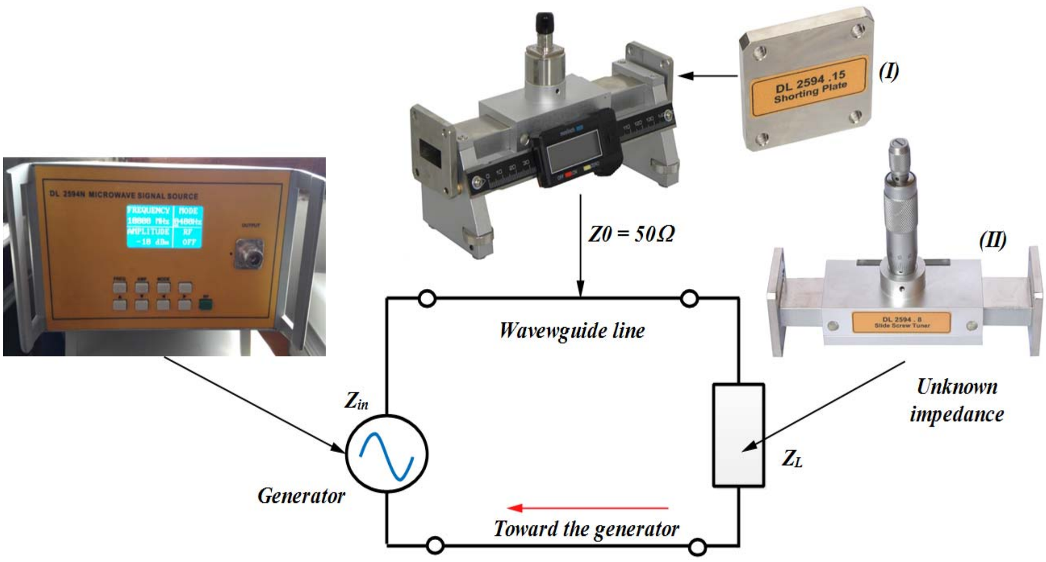

Fig.2. Schematic diagram for impedance measurement

The most common orientation of the Smith chart places the resistance axis horizontally with the short circuit (SC) location at the far left. There's a good reason for this: the voltage of the reflected wave at a short circuit must cancel the voltage of the incident wave so that zero potential exists across the short circuit. In other words, the voltage reflection coefficient must be -1 or a magnitude of 1 at an angle of 180 degrees. Since angles are measured from the positive real axis and the real axis is horizontal, the short circuit location and horizontal orientation make sense [1], [4], [9].

The waveguide post or screw is made from a conductive material. To make the post or screw inductive, it should extend through the waveguide completely contacting both top and bottom walls. For a capacitive reactance the post or screw should only extend part of the way through.

2. WAVEGUIDE IMPEDANCE RESULTS

Ensuring there is a good match between a waveguide and its source and load is essential if the waveguide is to provide optimum operation within and system and ensure that the benefits of its low loss are to be utilised properly [6], [8]. The different methods of providing a good impedance match can be used, the particular approach being dependent upon the system requirements.

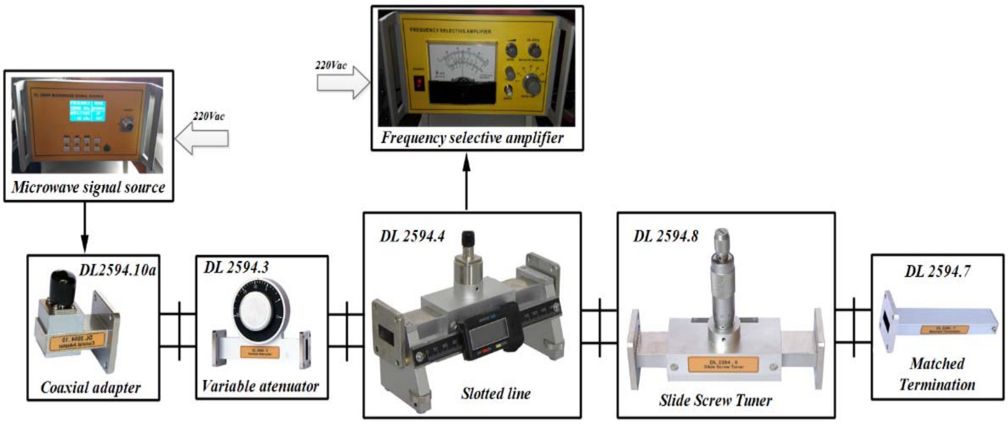

Fig.3. Diagram for measuring unknown impedance (with shorting plate)

Next figure shows the topographical situation for the experiment

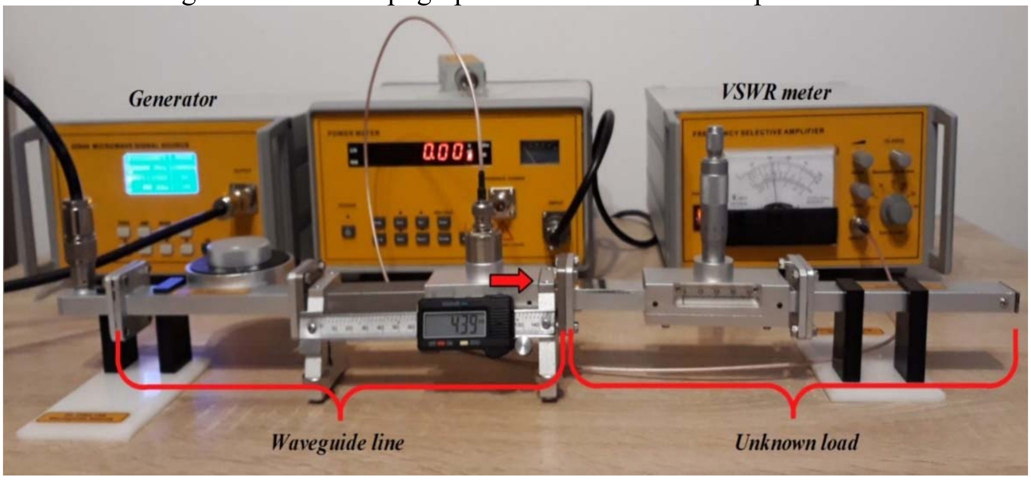

Fig.4. Real representation of the experiment (with load)

The combination of the screw tuner head and the position of the probe cause a reflection in the waveguide at a specific amplitude and phase [10], [11]. Relation between probe's depth and screw tuner scale [mm] is shown in table 1.

Table 1. **Relation between probe's depth and screw tuner scale**

screw tuner scale	3	5	7	9
probe's depth [mm]	7	5	3	1

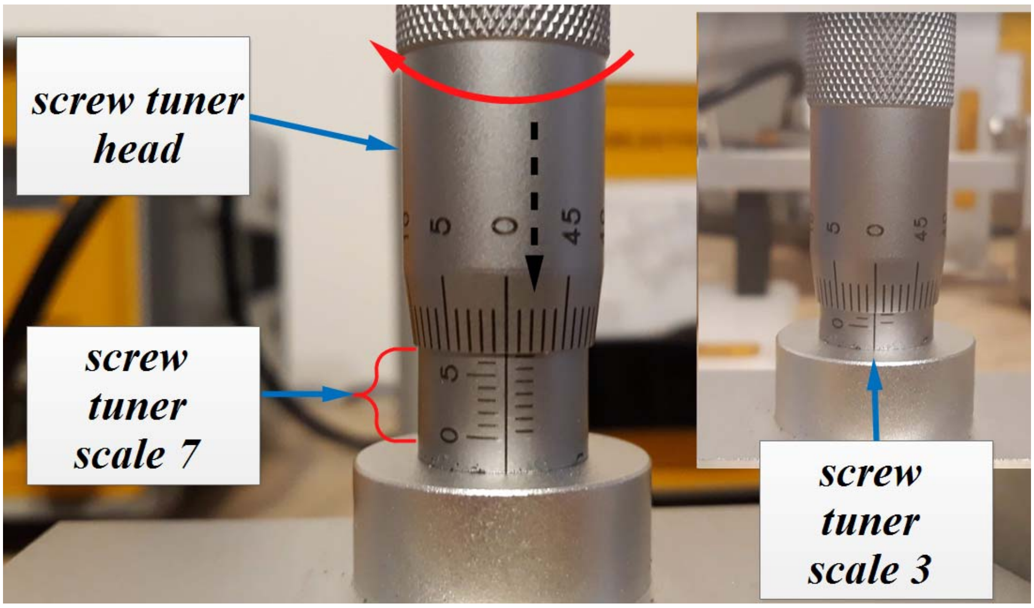

Fig.5. Real representation of the screw tuner scale

By moving *slotted line- mobile part* to the left we will find the first minimum position $Vmin_{load}$. The measured value is 180mV.

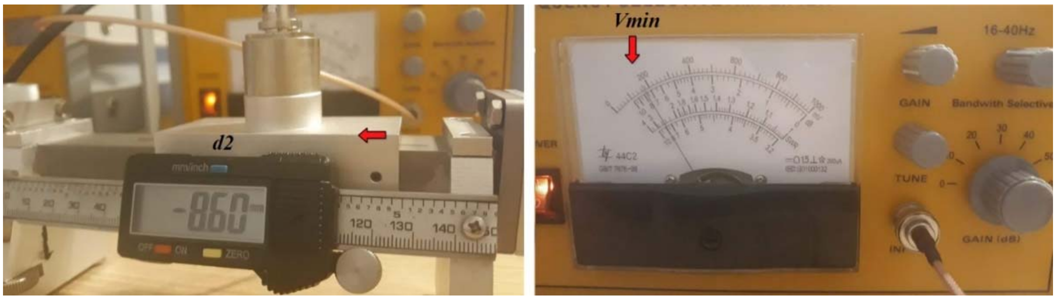

Fig.6. Measuring the minimum voltage

By moving *slotted line- mobile part* to the left we will find the first minimum position $Vmax_{load}$. The measured value is 680mV. The standing wave ratio is:

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{680mV}{180mV} = 3.77 \quad (6)$$

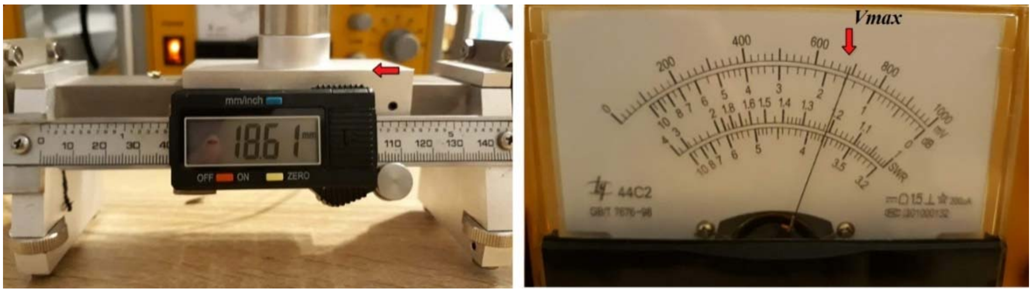

Fig.7. Measuring the maximum voltage

The wavelength toward generator coefficient is:

$$\frac{d}{\lambda_g} = \frac{8.6}{40} = \mathbf{0.21} \tag{7}$$

The reflection coefficient (absolute magnitude |Γ |) is:

$$|\Gamma| = \frac{VSWR-1}{VSWR+1} = \frac{3.77-1}{3.77+1} = \mathbf{0.58} \tag{8}$$

Draw a straight line from the point d/λg calculated to the center of the drawn VSWR circle. The intersection of the circle and the straight line represents the normalized load impedance (Z_L).

From the intersection point (Z_L) read the correspondent value of horizontal axis of resistance component (real part of the impedance), by following the closed circle segment to the horizontal line - record the value.

From the intersection point (Z_L) read the correspondent value from circle of inductive reactance component (imaginary part of the impedance) by following the closed circle segment to inductive reactance component circle - record the value.

For the screw tuner head on position 3 (7mm depth)

The normalized impedance is (Z_L= R+j·X):

$$\Rightarrow z_L = 1.6 + j0.5 \tag{9}$$

The load impedance is:

$$z_L = \frac{Z_L}{Z_0} \Rightarrow Z_L = 50 \cdot z_L \tag{10}$$

$$Z_L = 50 \cdot (1.6 + j0.5) = 80 + j25 \tag{11}$$

By reading the intersection of the straight line with the angle of reflection coefficient circle, this it will be:

$$\theta_R = 29 \tag{12}$$

The complex reflection coefficient is:

$$\overline{\boldsymbol{\Gamma}} = |\boldsymbol{\Gamma}| \cdot \boldsymbol{e}^{\boldsymbol{j}\boldsymbol{\theta}_{\boldsymbol{r}}} = \mathbf{0.58} \cdot \boldsymbol{e}^{\boldsymbol{j}\cdot\mathbf{29}} \tag{13}$$

$$\boldsymbol{e}^{\boldsymbol{j}\cdot\mathbf{29}} = \boldsymbol{\cos} \, \mathbf{2}\,\mathbf{9}^{\mathbf{0}} + \boldsymbol{j} \, \boldsymbol{\sin} \, \mathbf{2}\,\mathbf{9}^{\mathbf{0}} = \mathbf{0.78} + \boldsymbol{j}\mathbf{0.48} \tag{14}$$

$$\Rightarrow \overline{\boldsymbol{\Gamma}} = \mathbf{0.28}(\mathbf{0.78} + \boldsymbol{j}\mathbf{0.48}) = \mathbf{0.21} + \boldsymbol{j}\mathbf{0.13} \tag{15}$$

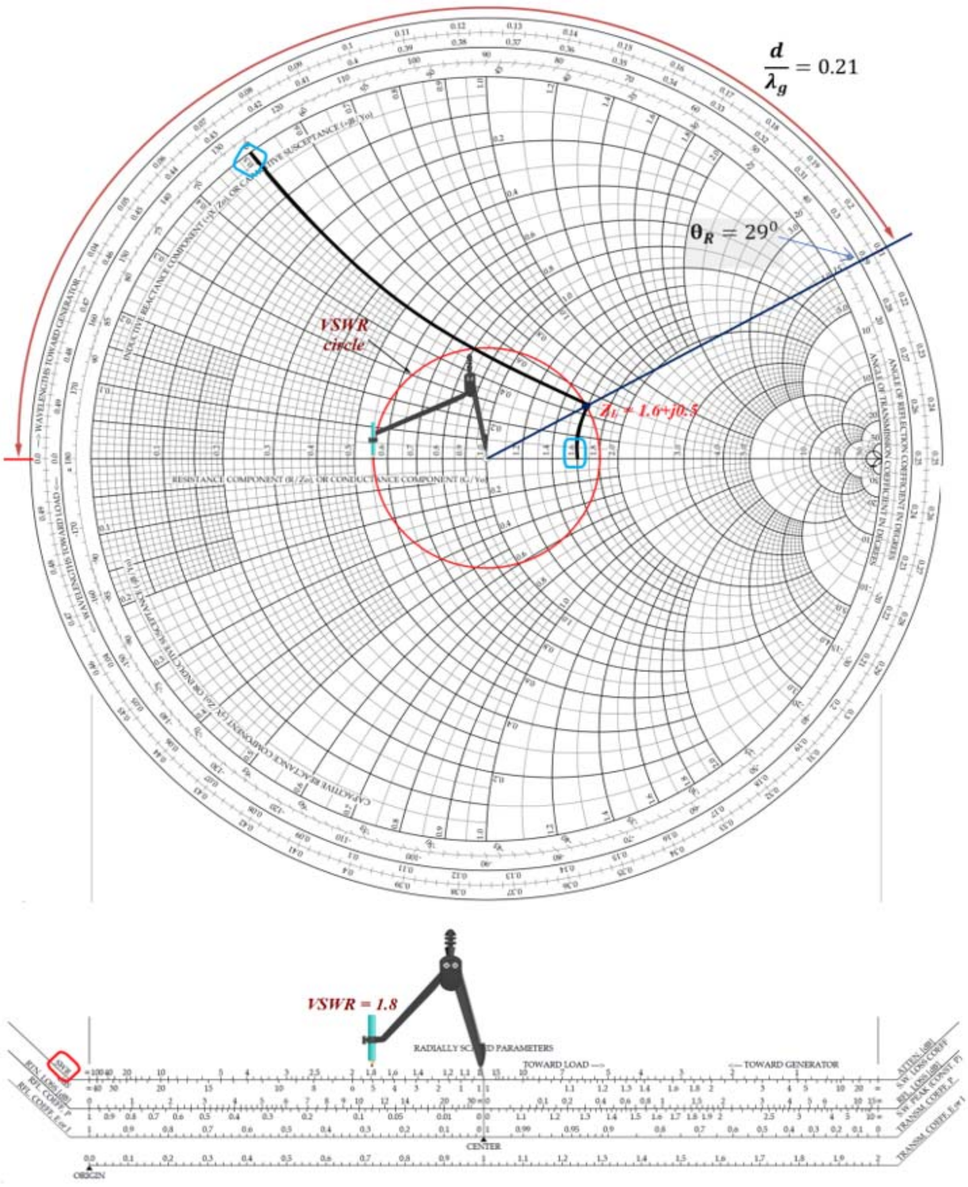

Fig.8. Processed Smith chart diagram for impedance calculation (Screw tuner head on 7 mm depth)

The Smith Chart allows easy calculation of the transformation of a complex load impedance through an arbitrary length of transmission line.

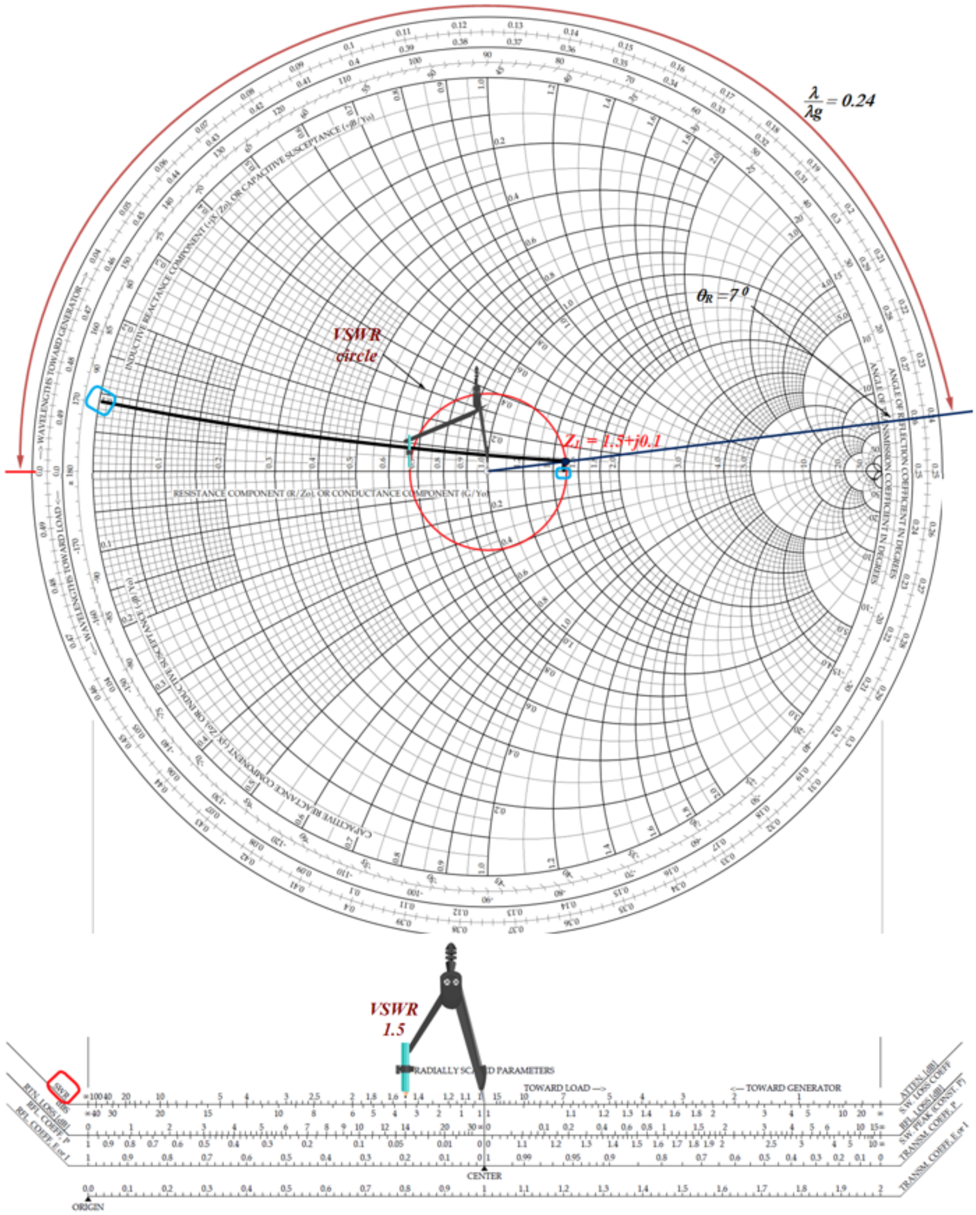

Fig.9. Processed Smith chart diagram for impedance calculation (Screw tuner head on 3 mm depth)

The Smith Chart works with normalized impedance and admittance, where normalization is made with respect to the characteristic impedance of the transmission line**.**

By plotting the normalized load impedance on a Smith Chart, the input impedance as a function of line length can be found. The Smith Chart also provides the value of the reflection coefficient, power delivered to load, as well as the voltage standing wave ratio (VSWR). Distance measurements are given in terms of wavelengths.

4. CONCLUSIONS

With slotted line module we have study the standing wave in two cases- using a shorting plate (zero impedance of the load) and using a waveguide with unknown impedance.

By using the relationships between standing waves and frequencies, using slotted line module we calculate minimum and maximum voltages, used to calculate VSWR. With these values and using Smith chart, we calculate impedances and reflection coefficients.

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ANALYSIS OF FILTERING AND CORRECTION OF THE POWER FACTOR IN DISTORTED BALANCE

FLORIN GABRIEL POPESCU[1], DRAGOS PASCULESCU[2], MARIUS MARCU[3], RAZVAN SLUSARIUC[4], GEORGETA BUICA[5], TEODORA LAZAR[6]

Abstract: The paper presents an analysis of the filtering and correction of the distorted steady state power factor. Due to the example analyzed, it was observed that in the distorted steady state, if the inductances and capacitances of the passive filters are properly sized, it is possible to obtain two additional effects in addition to the harmonic filtering for which they are used, namely the correction of the common power factor at 50 Hz and further reduction of the total current flowing through the network and of the total THD, which means a reduction of the distortion of the waveform of the current itself.

Keywords: Analysis, correction, filters, THD, power factor.

1. INTRODUCTION

Current applications for installation engineering frequently involve the presence of nonlinear loads that generate current harmonics, and therefore it may be necessary to correct the non-sinusoidal steady state power factor. When the presence of harmonics reaches an unacceptable level and consequently the adoption of LC filters is to be envisaged to compensate for one or more of them, the simultaneous suitability of such filters to correct the power factor at the fundamental frequency may be exploited: if properly sized, they can deliver all the required reactive power, thus avoiding the installation of dedicated capacitor banks [2], [7], [13].

Here are analysed and developed such operating conditions and the relevant sizing of the filter, also through an application example; to this end, a preliminary

[1] *Ph.D., Lecturer Eng.,University of Petroşani, floringabriel@yahoo.com*
[2] *Ph.D., Associate Prof. Eng., University of Petroşani, pdragos_74@yahoo.com*
[3] *Ph.D., Associate Prof. Eng., University of Petroşani, mariusmarcu@upet.ro*
[4] *Ph.D., Lecturer Eng.,University of Petroşani, razvansir@yahoo.com*
[5] *Sc. Res. II[nd], PhD.Eng., INCDPM "Alexandru Darabont" Bucharest, georgiana_buica@yahoo.com*
[6] *Ph.D., Asist. Eng., University of Petroşani, teomititica@yahoo.com*

introduction is made to some formulas and definitions of quantities useful for the analysis under consideration [4], [10].

2. QUANTITY ANALYSIS IN DISTORTED EQUILIBRIUM

A periodic, generally continuous and limited quantity can be developed in a Fourier series according to the following relation:

$$f(x) = \frac{a_0}{2} + \sum_{n=1}^{\infty}\left(a_n \cdot \cos nx + b_n \cdot \sin nx\right) \tag{1}$$

where the first term of the right limb represents the average value of the function in period T, it is:

$$\frac{a_0}{2} = \frac{1}{T}\int_0^T f(x)\cdot dx \tag{2}$$

as the coefficients are calculated a_n and b_n of the series of:

$$a_n = \frac{2}{T}\int_0^T f(x)\cdot \cos nx \cdot dx \qquad b_n = \frac{2}{T}\int_0^T f(x)\cdot \cos nx \cdot dx \tag{3}$$

The Fourier series development can also be expressed in terms of cosine only as follows (in the temporal domain):

$$f(t) = \frac{a_0}{2} + \sum_{k=1}^{\infty} A_k \cdot \cos\left(k\omega t - \vartheta_k\right) \tag{4}$$

Switching from general quantities to alternating electrical quantities (average value zero $\frac{a_0}{2} = 0$) such as voltage and current, these, in a distorted state of equilibrium, can be expressed in the harmonic series with frequencies that are multiples of the fundamentals according to the following relations:

$$v = \sum_{k=1}^{\infty} \sqrt{2}\cdot V_k \cdot \cos\left(k\omega t - \vartheta_k\right) \qquad i = \sum_{k=1}^{\infty} \sqrt{2}\cdot I_k \cdot \cos\left(k\omega t - \vartheta_k - \varphi_k\right) \tag{5}$$

whose phase values RMS are defined as the square root of the sum of the squares of the values RMS of unique harmonics:

$$V = \sqrt{\sum_{k=1}^{\infty} V_k^2} \qquad I = \sqrt{\sum_{k=1}^{\infty} I_k^2} \tag{6}$$

In order to obtain information on the harmonic content of voltage and current waveforms and to take action if these values are high, the total harmonic distortion THD is defined:

$$THD_i = \frac{\sqrt{\sum_{k=2}^{\infty} I_k^2}}{I_1} \qquad THD_v = \frac{\sqrt{\sum_{k=2}^{\infty} V_k^2}}{V_1} \tag{7}$$

If $THD_i < 10\%$ and $THD_V < 5\%$, the harmonic ratio is considered low and thus no action will be taken, whereas in the opposite case one or more filters must be used for higher amplitude harmonics so that the values of the harmonic distortion ratios can be brought back to acceptable limits [1], [15], [18].

3. POWERS IN DISTORTED EQUILIBRIUM

In distorted equilibrium conditions, an extension of the sinusoidal steady-state powers is possible. In fact, the total apparent power S, the index of the thermal stress of an electrical component in a three-phase system, is defined as follows:

$$S = 3 \cdot V \cdot I = 3 \cdot \sqrt{\sum_{k=1}^{\infty} V_k^2 \cdot \sum_{k=1}^{\infty} I_k^2} \tag{8}$$

Given the presence of voltage and current harmonics added to the fundamental harmonic, the expressions for active power P and reactive power Q become:

$$P = 3 \cdot \sum_{k=1}^{\infty} V_k \cdot I_k \cdot \cos\varphi_k \qquad Q = 3 \cdot \sum_{k=1}^{\infty} V_k \cdot I_k \cdot \sin\varphi_k \tag{9}$$

Apparent power A is given by the following relation:

$$A = \sqrt{P^2 + Q^2} \tag{10}$$

This power differs from the total apparent power S defined in relation (9); in particular, the following relationship applies:

$$S^2 = P^2 + Q^2 + D^2 \tag{11}$$

where D is the *distortion* power and takes into account the distortion of voltage and current waveforms. The sum of the squares of the reactive power Q and the distortion power D gives the square of the *non-active power* N:

$$N^2 = Q^2 + D^2 \tag{12}$$

which is defined as "inactive" because it is given by the difference between the squares of the total apparent power S and the active power P:

$$N^2 = S^2 - P^2 \tag{13}$$

To explain this concept it is possible to give the graphical interpretation of figure 1, which is a three-dimensional extension of the two-dimensional triangle of power in the sinusoidal steady state. As can be seen, P, Q and D are the vertices of a parallelepiped whose main diagonal is S, A is the diagonal of the face having its edges P and Q, and N is the diagonal of the face whose edges are Q and D [6], [14], [17].

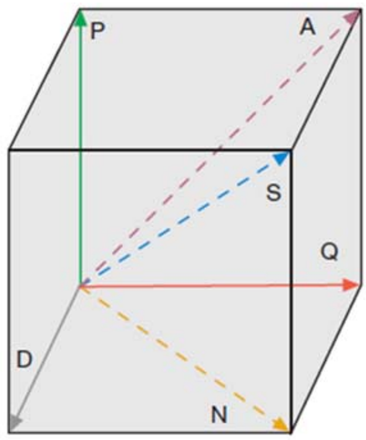

Fig.1. Three-dimensional extension of the two-dimensional triangle of power in the sinusoidal steady state

Along the supply line of a load operating with an active power P in a distorted steady state, the current defined in relation (6) flows with a voltage defined in the same formula; Consequently, the total phase shift factor ($\cos\phi$) between the active power P and the total apparent power S, occurring in the network is given by the relation:

$$\cos\phi = \frac{P}{S} \tag{14}$$

In the correction of the power factor, reference is made to this displacement factor by setting a target value of 0.9; thus, with the same value of the active power attracted by the load, the total apparent power (and, consequently, the current flowing) appeared in the network decreases [3], [11], [16]. The total displacement factor is an extension to the distorted equilibrium state of the normal power factor of the sinusoidal equilibrium state, which also results in this case:

$$\cos\varphi = \frac{P}{A} \tag{15}$$

If there were no distortions of the voltage and current waveforms, the factors appearing in the two equations above would coincide; on the contrary, in the presence of harmonics, they differ and the following relation is valid:

$$\cos\phi = \cos\varphi \cdot \cos\psi \tag{16}$$

in which the distortion factor $\cos\psi$ takes into account the presence of distortion power and is defined as:

$$\cos\psi = \frac{A}{S} \tag{17}$$

4. L-C FILTERS THAT FUNCTION AS CAPACITORS

Consider a branch of a passive L-C series filter resonating at a set frequency and graphically represent, as shown below, the capacitance and inductance of the reactance as a function of frequency, see figure 2.

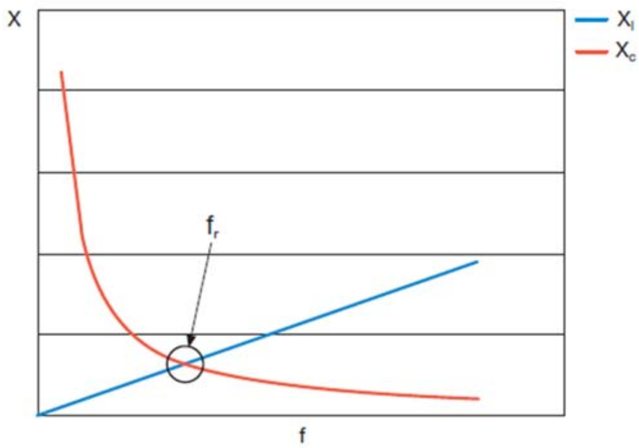

Fig.2. A branch of a passive L-C series filter resonating at a set frequency

As shown in the graph, it can be seen that below the resonant frequency $f_r = \frac{1}{2 \cdot \pi \cdot \sqrt{L \cdot C}}$ capacitive reactance predominates and consequently the generated reactive power prevails over the drawn one:

$$Q = Q_L - Q_C = \omega \cdot L \cdot I^2 - \frac{1}{\omega \cdot C} \cdot I^2 < 0 \tag{18}$$

Therefore, by using passive filters for harmonic filtering at resonant frequencies, the correction of the power factor at lower frequencies is obtained, and this effect is taken into account for the sizing of the capacitive banks of the filters. In other words, when inducing LC filters, it is possible to choose such inductance and capacitance values simultaneously, so that the sum of the reactive power generated at the fundamental harmonic by all filters installed according to the reactive power required to make the total displacement factor observed from upstream network to reach 0.9 [8], [12].

At frequencies higher than the resonant one, the inductive effect predominates, but the amplitude of the harmonics present in the waveforms of the distorted current, in the common engineering applications of the installations, decreases as the frequency increases; as a result, the reactive power drawn by the filter at a frequency value higher than the resonance value decreases as the harmonic order increases, and in addition, for higher frequencies, the compensation bank presents itself to the whole network as an inductance, thus eliminating the possibility of resonance parallel to the inductance of the network [5], [9].

4.1. Case study

Suppose that a three-phase static rectifier Graetz in a fully controlled phase (figure 3) must be powered by a 50 Hz network with a short enough power to make it possible to ignore the distortion of the set of three voltages caused by the distorted current injected into the rectifier network.

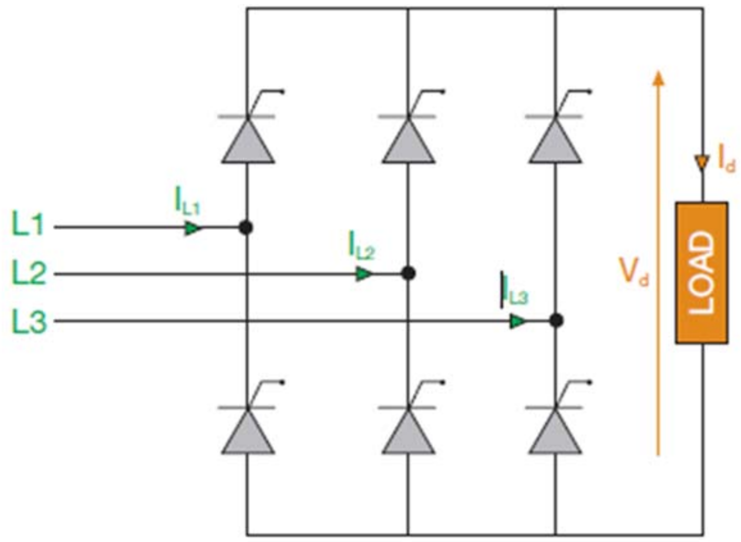

Fig.3. Graetz three-phase static rectifier in fully controlled phase

The current in each phase of the line (assuming a high inductance value on the DC side.) Has a rectangular waveform with the fundamental harmonic frequency equal to that of the sinusoidal voltage. The development in the Fourier series of such a waveform gives only harmonics of the order k = 6n ± 1 (n=0,1,2...), whose theoretical amplitude is inversely proportional to the harmonic of the order k, that is:

$$I_k = \frac{I_1}{k} \tag{19}$$

where I_1 is the amplitude of the fundamental harmonic (in the case examined equal to 50 Hz).

As, by the initial hypothesis, the voltage waveform is not distorted, its series development is reduced only to the fundamental harmonic and, consequently, the active and reactive powers absorbed by the rectifier (presumed without losses), calculated according to the relation (9), are equal to:

$$P = 3 \cdot \sum_{k=1}^{\infty} V_k \cdot I_k \cdot \cos\varphi_k = 3 \cdot V_1 \cdot I_1 \cdot \cos\varphi_1 = P = V_{d0} \cdot I_d \cdot \cos\alpha = P_d \quad (20)$$

$$Q = 3 \cdot \sum_{k=1}^{\infty} V_k \cdot I_k \cdot \sin\varphi_k = 3 \cdot V_1 \cdot I_1 \cdot \sin\varphi_1 = 3 \cdot V_1 \cdot I_1 \cdot \sin\alpha = Q_1 \quad (21)$$

V_{d0} is the value of the voltage on the DC side;
I_d is the value of the current in DC.

The apparent power that corresponds to these powers is:

$$A = \sqrt{P_1^2 + Q_1^2} = A_1 \quad (22)$$

While the total apparent power observed at the power supply is:

$$S = 3 \cdot V \cdot I = 3 \cdot \sqrt{V_1^2 \cdot \sum_{k=1}^{\infty} I_k^2} \quad (23)$$

a distortion power is present due to the distorted current waveform:

$$D = \sqrt{S^2 - A_1^2} \quad (24)$$

Assuming that the bridge rectifier has a rated power, delivered on the DC side, equal to 140 kW, when it is powered by a grid with undistorted rated voltage and assuming that the switching is instantaneous and the phase control angle is such that $\cos\varphi = \cos\alpha = 0,8$, the following values are obtained for the powers on the AC side:

$$P = P_d = P_{do} \cdot \cos\alpha = 140 \cdot 0,8 = 112 \text{ [kW]} \quad (25)$$

of which a first harmonic current:

$$I_1 = \frac{P}{\sqrt{3} \cdot U_n \cdot \cos\varphi} = \frac{112 \cdot 10^3}{\sqrt{3} \cdot 400 \cdot 0,8} = 202 \text{ [A]} \quad (26)$$

and, consequently, reactive and apparent power is:

$$Q = \sqrt{3} \cdot U_n \cdot I_1 \cdot \sin\varphi = \sqrt{3} \cdot 400 \cdot 202 \cdot 0,6 = 84 \text{ [kVAr]} \quad (27)$$

$$A = \sqrt{P^2 + Q^2} = 140 \text{ [kVA]} \quad (28)$$

By developing in the Fourier series the distorted current waveform on the AC side, according to relation (19), the following values are obtained for the harmonic amplitudes (harmonics up to the 25th were taken into account):

Table 1. ***Values of harmonic amplitudes***

k	I_k [A]	I_k / I_1 %
1	202	100
5	40	20
7	29	14
11	18	9
13	15	8
17	12	6
19	11	5
23	9	4
25	8	4

Therefore, in the upstream network, in the absence of harmonic filters, a current would flow with a total RMS value equal to the square root of the square sum of RMS harmonic values given in the previous table:

$$I = \sqrt{\sum_{k=1}^{25} I_k^2} = 210 \text{ [A]} \quad (29)$$

with a total apparent power:

$$S = \sqrt{3} \cdot U_n \cdot I = \sqrt{3} \cdot 400 \cdot 210 = 146 \text{ [kVA]} \quad (30)$$

and a total harmonic distortion equal to:

$$THD = \frac{\sqrt{\sum_{k=5}^{25} I_k^2}}{I_1} = 29\% \quad (31)$$

Consequently, there would be a distortion factor $\cos\psi = \frac{A}{S} = 0,96$ and, seen in the upstream network, a phase shift factor $\cos\phi = \cos\varphi \cdot \cos\psi = 0,8 \cdot 0,96 = 0,77$.

The goal is to obtain a total phase shift factor equal to $\cos\phi' = 0,9$ and for this purpose it is assumed to dimension and introduce in parallel some L-C filters forthe 5th, -7th, 11th and 13th harmonics as shown in the figure 4:

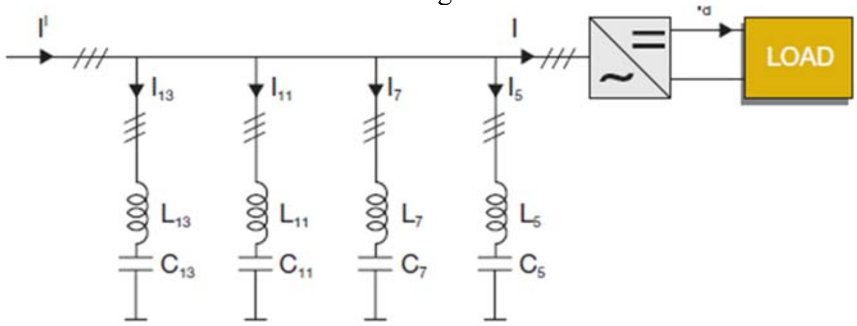

Fig.4. dimension and introduce in parallel some L-C filters

Therefore, the final value of $\cos\phi'$ must exceed 0.9. Assuming that this value is set to 0.91, the compensation of the reactive power obtained is equal to:

$$Q_c = P \cdot \left(tg\varphi - tg\varphi'\right) = 112 \cdot \left(tg\left(\cos^{-1}(0,8) - tg(\cos^{-1}(0,91))\right)\right) = 33\,[\text{kVAr}] \quad (32)$$

from which the final reactive power Q' after application of the power factor correction is:

$$Q' = Q - Q_c = 84 - 33 = 51\,[\text{kVAr}] \quad (33)$$

By conducting tests and determining some inductance values for the harmonics to be filtered, the following capacitance values causing the series resonance are obtained:

$$C_k = \frac{1}{\left(2\pi f\right)^2 \cdot L_k} \quad (34)$$

Table 2. ***Inductance and capacitance values***

k	f[Hz]	L_k [mH]	C_k [μF]
5	250	1	406
7	350	2	103
11	550	1	84
13	650	1	6

The reactive power at 50 Hz provided, for example, by the L-C filter resonating at the 5th harmonic is calculated as follows:

$$I_{1,5} = \frac{U_n}{\sqrt{3}\left(2\pi \cdot 50 \cdot L_5 - \dfrac{1}{2\pi \cdot 50 \cdot C_5}\right)} \tag{35}$$

$$Q_{1,5} = 3\left(\frac{1}{2\pi \cdot 50 \cdot C_5} - 2\pi \cdot 50 \cdot L_5\right) \cdot I_{1,5}^2 \tag{36}$$

Similarly, the contributions of the other harmonics are calculated. The sum of the reactive compensation powers at 50 Hz is very close to the predefined one (with the values of inductance and capacitance shown in table 2); taking into account the value of the apparent power (at the same value of the active power absorbed P):

$$A' = \sqrt{P^2 + Q'^2} = 123 \text{ kVA} \tag{37}$$

the value of RMS of the first harmonic current becomes equal to:

$$I_1' = \frac{A'}{\sqrt{3} \cdot U_n} = \frac{123 \cdot 10^3}{\sqrt{3} \cdot 400} = 177 \text{ [A]} \tag{38}$$

which is approximately 12% lower than the initial value of a, at which the current values of the unfiltered harmonics correspond to:

Table 3. ***Unfiltered harmonic current values***

k	I_k **[A]**	I_k / I_1' **%**
17	10	6
19	9	5
23	8	4
25	7	4

As can be seen when comparing the absolute values of RMS (Root mean square) with the values in Tables 1 and 3, the correction of the power factor to 50 Hz, determines a reduction of the value of the square average of the first harmonic of the current, which leads to the reduction of unfiltered harmonics (because $I_k' = \frac{I_1'}{k}$).

This also implies a further reduction of the total current seen in the upstream network becoming I = 178 A (16% lower than the total initial current I) with a total apparent power S' :

$$S' = \sqrt{3} \cdot U_n \cdot I' = \sqrt{3} \cdot 400 \cdot 178 = 124 \text{ [kVA]} \tag{39}$$

The distortion factor goes from 0.96 to:

$$\cos\psi' = \frac{A'}{S'} = \frac{123}{124} = 0,99 \tag{40}$$

and the total displacement factor results:

$$\cos\phi' = \cos\varphi' \cdot \cos\psi' = 0,91 \cdot 0,99 = 0,906 \tag{41}$$

Thus, the established goal was achieved; otherwise, its set value should have been increased and the previous procedure should have been repeated. The total harmonic distortion ratio decreases to $THD' = 9,9\%$ (less than 10%).

5. CONCLUZII

In conclusion, thanks to this example, it has been observed that in the distorted steady state, if the inductances and capacitances of the passive filters are properly sized, it is possible to obtain two additional effects in addition to the harmonic filtering for which they are used:

- the correction of the common power factor at 50 Hz, because at the fundamental frequency the capacitive effect prevails over the inductive effect and, consequently, over the general reactive power over the absorbed one;
- by reducing, by correcting the power factor, the RMS the value of the fundamental harmonic of the current, consequently and RMS the values of unfiltered harmonics decrease; therefore, a further reduction of the total current flowing through the network and of the total THD is obtained, which means a reduction of the distortion of the current waveform itself.

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CRITICAL ANALYSIS OF THE NATIONAL POWER SYSTEM IN ORDER TO ENSURE EUROPEAN SECURITY

EMILIA GRIGORIE[1], DRAGOS PASCULESCU [2], NICOLAE DANIEL FITA[3], FLORIN GABRIEL POPESCU[4], ALINA DANIELA HANDRA[5], ANDREI CRISTIAN RADA[6], CRISTINA SUCIU (PUPAZA)[7], RAZVAN SLUSARIUC[8]

Abstract: The need for critical analysis of National Power System – NPG, which generates critical infrastructure, comes in the context in which the possible occurrence of black/brown - out cases, generates major issues of national interest, with European and NATO implications. Because the critical infrastructure generated may be vulnerable to internal and/or external threats, it must be critically analysed in terms of ensuring and increasing national and European security in order to prevent possible national crises. The authors consider that the NPG approach is a strictly national security issue because the lack of electricity can cause enormous damage to industry, the economy and state systems, which are almost entirely dependent on electricity.

Keywords: National Power System, European Security, Critical Infrastructure, Critical Analysis.

1. INTRODUCTION

The increasing frequency of cases of energy instability and dynamism in the context of national and regional energy security and the desire of the great economic powers of energy influence, makes the topic very topical and significant, knowing very well that certain critical infrastructures can be vulnerable to internal and external threats, and in this context, the Critical Infrastructure Protection Management must form the most important security system within the National Power System [1], [4], [7], [10],

[1] Ph.D., Student, Eng., University of Petrosani, emilia_grigorie@yahoo.com
[2] Ph.D., Associate Prof., Eng., University of Petrosani, pdragos_74@yahoo.com
[3] Ph.D., Lecturer Eng., University of Petrosani, daniel.fita@yahoo.com
[4] Ph.D., Lecturer Eng., University of Petrosani, floringabriel82@yahoo.com
[5] Ph.D., Assistant, Eng., University of Petrosani, handra.alina@yahoo.com
[6] Ph.D., Assistant, Eng., University of Petrosani, radka_kysto2008@yahoo.com
[7] Ph.D., Student, Ec., University of Petrosani, cristina_suciu27@yahoo.com
[8] Ph.D., Lecturer Eng., University of Petrosani, Eng., razvansir@yahoo.com

[27]. Non-electricity supply to domestic and industrial consumers leads to national crises, as all sectors of the national economy depend on electricity. In this context, the National Power System becomes a strategic objective of national importance by the fact that it generates critical national and European infrastructures [5], [6], [9], [23].

2. CRITICAL ANALYSIS OF THE NATIONAL POWER SYSTEM

2.1. Identification of critical infrastructures

In table 2.1. the critical infrastructures identified within the National Power System are listed [2], [8], [11], [19].

Table 2.1. ***Critical infrastructures identified within the National Power System***

Owner Infrastructure critically	**Responsible Authority Competence**	**Name CRITICAL INFRASTRUCTURE**	**NCI / ECI type** (international / European / national)	**Perimeter Location**
Hunedoara Energy Complex	Minister of Energy	Power Plant Branch DEVA (Mintia)	National	Hunedoara County
Hunedoara Energy Complex	Minister of Energy	Power Plant Branch PAROŞENI	National	Hunedoara County
Oltenia Energy Complex	Minister of Energy	Power Plant Branch ROVINARI	National	Gorj County
Oltenia Energy Complex	Minister of Energy	Power Plant Branch TURCENI	National	Gorj County
Oltenia Energy Complex	Minister of Energy	Power Plant Branch IŞALNIŢA	National	Dolj County
Oltenia Energy Complex	Minister of Energy	Power Plant Branch CRAIOVA II	National	Dolj County
OMV Petrom	Minister of Energy	Thermoelectric plant PETROM BRAZI	National	Prahova County
Romgaz	Minister of Energy	Thermoelectric plant IERNUT	National	Mures County
Termoelectrica	General City Hall Bucharest	Thermoelectric plant BUCUREŞTI SUD	National	Bucharest
Hidroelectrica	Minister of Energy	Hydroelectric Power Plant ŞUGAG	National	Alba County
Hidroelectrica	Minister of Energy	Hydroelectric Power Plant GÂLCEAG	National	Alba County
Hidroelectrica	Minister of Energy	Hydroelectric Power Plant	National	Neamt County

		STEJARU		
		Hydroelectric Power Plant VIDRARU		Arges County
		Hydroelectric Power Plant PORȚILR FR FIER I, II	International	Mehedinti County
		Hydroelectric Power Plant LOTRU	National	Valcea County
		Hydroelectric Power Plant RETEZAT		Hunedoara County
		Hydroelectric Power Plant MĂRIŞELU		Cluj County
Termoelectrica	Minister of Energy	Thermoelectric plant BORZEŞTI		Bacau County
Nuclearelectrica	Minister of Energy	Nuclear Power Plant CERNAVODA	International	Constanta County
National Power Grid Transelectrica	Ministry of Economy and Business Environment	Power substation 400/220 kV ROŞIORI	European	Satu Mare County
		Power substation 400 kV GĂDĂLIN		Cluj County
		Power substation 400/110 kV CLUJ EST		Cluj County
		Power substation 400/110 kV ORADEA SUD		Bihor County
		Power substation 400/220/110 kV ARAD		Arad County
		Power substation 400 kV NĂDAB		Arad County
		Power substation 400 kV RESITA		Caras Severin County
		Power substation 400/220 kV MINTIA		Hunedoara County
		Power substation 400 kV ȚĂNȚĂRENI		Gorj County
		Power substation 400 kV PORȚILE DE FIER		Mehedinti County
		Power substation 400 kV URECHEŞTI		Gorj County
		Power substation 400/220 kV SLATINA	National	Olt County

		Power substation 400/110 kV DRĂGANEŞTI OLT		Olt County
		Power substation 400/110 kV BRAZI VEST		Prahova County
		Power substation 400/220/110 kV BRADU		Arges County
		Power substation 400/110 kV GURA IALOMIŢEI		Ialomita County
		Power substation 400/110 kV PELICANU		Calarasi County
		Power substation 400 kV ISACCEA	International	Tulcea County
		Power substation 400 kV STUPINA		Constanta County
		Power substation 400 kV RAHMAN		Tulcea County
		Power substation 400/220/110 kV LACUL SĂRAT	National	Braila County
		Power substation 400 kV CERNAVODĂ	International	Constanta County
		Power substation 400/110 kV MEDGIDIA SUD		Constanta County
		Power substation 400/110 kV CONSTANŢA NORD	National	Constanta County
		Power substation 400/110 kV TARIVERDE		Constanta County
		Power substation 400/110 kV TULCEA VEST		Tulcea County
		Power substation 400/110 kV SMÂRDAN		Braila County
		Power substation 400/220/110 kV GUTINAŞ		Bacau County
		Power substation 400/220/110 kV SUCEAVA		Suceava County
		Power substation		Bacau County

		400/110 kV BACĂU SUD		
		Power substation 400/110 kV ROMAN NORD		Neamt County
		Power substation 400/220 kV IERNUT		Mures County
		Power substation 400/220/110 kV SIBIU SUD		Sibiu County
		Power substation 400/110 kV DÂRSTE		Brasov County
		Power substation 400/110 kV BRAŞOV		Brasov County
		Power substation 400/220/110 kV BUCUREŞTI SUD		Bucharest
		Power substation 400/110 kV DOMNEŞTI		Ilfov County
		OHL 400 kV ROŞIORI - MUKACEVO	European	Romania Ukraine
		OHL 400 kV (750 kV gauge) ISACCEA - UKRAINA SUD		
		OHL 400 kV NĂDAB - BEKESCSABA		Romania Hungary
		OHL 400 kV ARAD - SANDORFALVA		
		OHL 400 kV RESITA - PANCEVO		Romania Bulgaria
		OHL 400 kV PORŢILE DE FIER - DJERDAP		
		OHL 400 kV ŢĂNŢĂRENI - KOSLODUY		Romania Bulgaria
		OHL 400 kV RAHMAN - DOBRUDJA		
		OHL 400 kV (750 kV gauge) STUPINA - VARNA		
		OHL 400 kV		Romania

		ISACCEA - VULCĂNEŞTI		Republic of Moldova

2.2. Risk scenario identification

Risk scenario: Succession of Technical Incidents 400 kV POWER SUBSTATION - Total decommissioning of the National Power System (black-out) [3], [16], [26].

2.3. Assessment of risk scenarios

Assessment Risk scenario: Succession of Technical Incidents 400 kV POWER SUBSTATION - Total decommissioning of the National Power System (black-out) [12], [14], [20], [25], [29].

Sequential scrolling
SUCCESSION OF TECHNICAL INCIDENTS 400 kV POWER SUBSTATION:
SUCCESSIVE OF TECHNICAL INCIDENTS → MISTAKES OPERATIVE / DISPATCH PERSONNEL → TOTAL OUTPUT FROM THE FUNCTION OF THE NATIONAL POWER SYSTEM (BLACKOUT) → ENERGY INSECURITY → INDUSTRIAL INSECURITY → ECONOMIC INSECURITY → NATIONAL INSECURITY → PROPERTY DAMAGE / LOSS OF LIFE → STATE OF INSTABILITY / CRISIS

The causes and effects are described in *Table 2.2.*

Table 2.2. ***Causes and effects***

Causes:	**Effects:**
- short circuits of energy equipment; - charging of mains overhead power lines; - loads of energy equipment; - precarious condition of energy equipment; - lack of investments in power substations; - system automation malfunctions within energy groups; - lack of revisions to energy equipment; - non-refurbishment of power substations; - wrong configuration of power substations; - wrong maneuvers performed by the substation's operational staff; - lack of specialized and / or trained operational staff; - non-communication or poor communication with Territorial Energy Dispatcher or National Energy Dispatcher;	- stopping the energy market between Romania and the EU; - stopping the energy market between Romania and Serbia, Ukraine, the Republic of Moldova; - non-power supply to neighboring and EU energy systems; - non-supply of electricity to important consumers and NPS main power lines; - enormous material damage due to lack of electricity; - enormous material damage resulting from the interdependence of other systems; - the possibility of a local, regional or national blackout.

- non-specialized Territorial Energy Dispatcher or National Energy Dispatcher staff in times of crisis; - lack of power substation work procedures in times of crisis; - lack / non-compliance / ignorance of national / European procedures in case of serious damage (black out); - lack of training in the field of Risk Management; - failure to close Romania's 400 kV ring - becomes a vulnerability of NPS.	

a) Determining the probability

The following probability scale was adopted to determine the probability of occurrence [13], [15], [17], [21]:

LEVEL/ SCORE ASSOCIATED		DEFINITION PROBABILITY	PERIOD
	1. Very low	It has a very low probability of occurring. Normal measures are required to monitor the progress of the event.	**over 13 years**
	2. Law	The event has a low probability of occurring. Efforts are being made to reduce the likelihood and / or mitigation of the impact produced.	**10 – 12 years**
X	**3. Medium**	The event has a significant probability of occurring. Significant efforts are needed to reduce the likelihood and / or mitigate the impact produced.	**7 – 9 years**
	4. High	The event has a probability of occurring. Priority efforts are needed to reduce the likelihood of mitigating and mitigating the impact produced.	**4 – 6 years**
	5. Very high	The event is considered imminent. Immediate and extreme measures are required to protect the objective, evacuation to a safe location if the impact so requires.	**1 – 3 years**

b) Determining the severity of the consequences

The severity of the consequences is given by the most unfavorable level of vulnerabilities and impact levels [18], [28].

Vulnerability and capability analysis, *according to table 2.3.*

Table 2.3. ***Vulnerability and capability analysis***

VULNERABILITIES AND CAPABILITIES	LEVEL
1. Failure to close the 400 kV ring of Romania: - lack of investment (non-refurbishment of power substations, overhead power lines and new energy targets);	**Very low** **Low** **Medium**

- the unpredictability of the political system;	**High**
- the possibility of a zonal, regional or national blackout, generating the stoppage of the electricity market between Romania and the EU; - economic insecurity generating national insecurity;	**Very high**
2. Degree of specialization and regular training of the personnel with attributions to restore the power supply process: - operative staff; - maintenance staff; - security personnel	**Very low**
	Low
	Medium
	High
	Very high

- ***Impact analysis***

Impact analysis is an analysis of management at certain levels that identifies the impact of the loss of resources of a critical European infrastructure (power substation of national importance) [22].

The severity of all the impacts of the scenario will be taken into account and then the level of severity of the consequences of the occurrence of the hazard / threat in the considered scenario will be established [24].

The highest level of impact severity levels will be chosen, *according to table 2.4.*

Table 2.4. ***Impact analysis***

IMPACTS	LEVEL	
Enormous damage caused by lack of electricity	**1. Very low**	temporary
	2. Low	significant damage
	3. Medium	average damage
	4. High	major damage
	5. Very high	very high damage
Enormous damage caused by the interdependence of other systems	**1. Very low**	0 - 10% of VIC
	2. Low	11 - 20% of VIC
	3. Medium	21 - 30% of VIC
	4. High	31 - 40% of VIC
	5. Very high	over 41% of VIC
Potential environmental damage	**1. Very low**	0 - 20%
	2. Low	21 - 40%
	3. Medium	41 - 60%
	4. High	61 - 80%
	5. Very high	over 81%
Strong social impacts	**1. Very low**	0 - 10% of TP
	2. Low	11 - 20% of TP
	3. Medium	21 - 30% of TP
	4. High	31 - 40% of TP
	5. Very high	over 41% of TP
VIC - the volume of invested capital; TP - trust of the population		

LEVEL/SCORE ASSOCIATED		SEVERITY CONSEQUENCES
	1. Very low	The event causes a minor disruption to the activity, without material damage.
	2. Low	The event causes minor property damage and limited business disruption
	3. Medium	Personal injury and / or loss of equipment, utilities and service delays.
	4. High	Serious personal injury, significant loss of equipment and facilities, delays and / or interruption of service provision.
X	**5. Very high**	The consequences are catastrophic resulting in deaths and serious injuries to staff, major loss of equipment, installations and facilities and cessation of service provision.

c) Calculation of the risk level

PROBABILITY						
	Very high 5					
	High 4					
	Medium 3					**Scenario TECH. INC.**
	Law 2					
	Very law 1					
	0	**Very law 1**	**Law 2**	**Medium 3**	**High 4**	**Very high 5**
SEVERITY / CONSEQUENCES						

Note: The risk is given by the product between the probability of occurrence of a hazard / threat and the severity of its consequences

The calculated risk is 15 (probability 3 x severity 5) therefore there is a HIGH RISK production of the chosen scenario

CALCULATED RISK LEVEL	
NIVEL	**PUNCTAJ**
Very low	**1 – 3**
Low	**4 – 6**
Medium	**7 – 12**
High	**13 – 16**
Very high	**17 – 25**

d) Risk treatment

In order to reduce the risk, measures are required to reduce the following vulnerabilities and / or to improve the following capabilities, *according to Table 2.5.:*

Table 2.5. ***Risk treatment***

VULNERABILITY AND / OR CAPABILITY	PROPOSED MEASURES
Failure to close Romania's 400 kV ring	- major investments in national and European critical infrastructure; - the predictability (security) of the political system; - accessing European funds for the security of European critical infrastructures.
Degree of specialization and regular training of the operative personnel with attributions to restore the power supply process	- training and refresher courses for operational, maintenance and security staff; - analysis of events, incidents, etc.; - control of installations on the operating line and carrying out preventive maintenance.

The application of risk mitigation measures results in:

Table 2.6. ***Measures after risk management***

VULNERABILITY	IDENTIFIED	AFTER THE APPLICATION OF THE MEASURES
- Failure to close Romania's 400 kV ring; - Degree of specialization and regular training of the operative personnel with attributions to restore the power supply process.	**1. Very low**	**1. Very low**
	2. Low	**2. Low**
	3. Medium	**3. Medium**
	4. High	**4. High**
	5. Very high	**5. Very high**

e) Recalculation of the severity of the consequences

LEVEL/SCORE ASSOCIATED		SEVERITY CONSEQUENCES
	1. Very low	The event causes a minor disruption to the activity, without material damage.
	2. Low	The event causes minor property damage and limited business disruption
X	**3. Medium**	Personal injury and / or loss of equipment, utilities and service delays.
	4. High	Serious personal injury, significant loss of equipment and facilities, delays and / or interruption of service provision.
	5. Very high	The consequences are catastrophic resulting in deaths and serious injuries to staff, major loss of equipment, installations and facilities and cessation of service provision.

f) The level of risk after the application of the reduction measures

Probability	**Very high 5**					
	High 4					
	Medium 3			**Scenario TECH. INC.**		
	Law 2					
	Very law 1					
	0	**Very law 1**	**Law 2**	**Medium 3**	**High 4**	**Very high 5**
		SEVERITY/ CONSEQUENCES				
Note: The risk is given by the product between the probability of occurrence of a hazard / threat and the severity of its consequences						

Table 2.6. ***The calculated risk has a value of 9 (probability 3 x severity 3) therefore there is a MEDIUM RISK production of the chosen scenario***

CALCULATED RISK LEVEL	
NIVEL	**NIVEL**
Very low	**Very low**
Low	**Low**
Medium	**Medium**
High	**High**
Very high	**Very high**

3. CONCLUSIONS

The need to identify the risks, threats and vulnerabilities of critical infrastructures within the National Power System results from the following considerations:

- Knowing that the National Power System is of national strategic importance, it must be constantly evaluated and monitored in terms of security risks, in order to identify vulnerabilities, threats, risks and dangers;
- This need to assess the sectorial security risks also comes from the European perspective because Romania is interconnected to the Energy System of the European Union – ENTSO-E, which interconnects the various electricity buses from the Nordic countries to the southern countries or from the western countries to the countries you are what;
- Knowing and identifying vulnerabilities can automatically identify the risks and threats to which the National Power System is subject and engaged and can create national / European measures or strategies to protect and secure critical national / European infrastructures;
- Certain identified, constructed and developed risk scenarios have a very high level of risk with devastating effects on national security, and in this context,

Critical Infrastructure Protection Management must form an integrated, coherent, transparent and convergent security system towards the overall objective TOTAL SECURITY;

- Vulnerability in energy security must be combated and eliminated through major investments in energy infrastructure and staff specialized in critical infrastructure protection and security;
- The issue of critical infrastructure security must also take into account the Human-Infrastructure interaction, ie ensuring the safety and health of workers who use them in the workplace, and the risks, dangers and threats posed by the use of machinery and equipment by workers. critical areas of energy infrastructure, are a particular area of occupational risks, dangers and threats to which they may be exposed and, as a result, cannot be dissociated and treated separately, consider the complex set of conditions and interdependencies specific to modern work systems.

The intended results consist of the development and integration of applicable tools by security liaison officers, security experts or specialists and operational staff working and operating with critical infrastructures to prevent and minimize risks, combat and eliminate vulnerabilities, hazards and threats.

All these aspects support the importance and opportunity of scientific research dedicated to the assessment of sectorial security risks and the development of assessment methods dedicated to minimizing occupational risks, to be used by all actors involved.

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IMPLEMENTATION OF AN INTEGRATED SYSTEM OF INDUSTRIAL SECURITY MANAGEMENT WITHIN AN ENERGY COMPANY OF NATIONAL STRATEGIC INTEREST

CRISTINA SUCIU (PUPAZA)[1], NICOLAE DANIEL FITA[2], EMILIA GRIGORIE[3], FLORIN GABRIEL POPESCU[4], DRAGOS PASCULESCU[5], ALINA DANIELA HANDRA[6], ANDREI CRISTIAN RADA[7], RAZVAN SLUSARIUC[8]

Abstract: The increasing occurrence of cases of industrial insecurity in the context of national, regional and NATO security, makes this paper to be of great importance and topicality, knowing very well that the security, protection and safety strategies of strategic energy companies of national interest must be implemented, due to the interdependencies between the related critical systems. Knowing very well that industrial security is endangered by various vulnerabilities, threats, risks and dangers within strategic energy companies of national strategic interest, the authors propose the need to implement an integrated system of industrial security in the context of ensuring national security.

Keywords: Integrated Management, Industrial Security, Energy Company, National Security.

1. THE CONCEPT OF INTEGRATED MANAGEMENT OF INDUSTRIAL SECURITY

Because the national industry, through its industrial objectives, can have major social and economic effects on society, through jobs, workers, goods, services and infrastructure, the issue of industrial security becomes a fundamental condition of

[1] *Ph.D., Student, Ec., University of Petrosani, cristina_suciu27@yahoo.com*
[2] *Ph.D., Lecturer Eng., University of Petrosani, daniel.fita@yahoo.com*
[3] *Ph.D., Student, Eng., University of Petrosani, emilia_grigorie@yahoo.com*
[4] *Ph.D., Lecturer Eng., University of Petrosani, floringabriel82@yahoo.com*
[5] *Ph.D., Associate Prof., Eng., University of Petrosani, pdragos_74@yahoo.com*
[6] *Ph.D., Assistant, Eng., University of Petrosani, handra.alina@yahoo.com*
[7] *Ph.D., Assistant, Eng., University of Petrosani, radka_kysto2008@yahoo.com*
[8] *Ph.D., Lecturer Eng., University of Petrosani, Eng.,razvansir@yahoo.com*

security and economic efficiency in order to increase national economic security., according to fig.1 [3], [5], [8], [29].

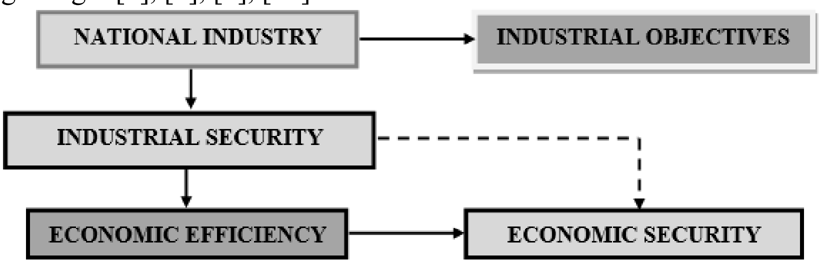

Fig.1. Industrial security – a fundamental component of efficiency and economic security

It is proposed to introduce the concept of Integrated Management of Industrial Security, by implementing in the package the following elements that identify insecurity and generate security [2], [4], [7], [20], [24], according to fig. 1.

1. **Risk Management**:
    a) Risk planning;
    b) Risk identification by S.W.O.T.;
    c) Risk analysis;
    d) Establishing risk approach strategies;
    e) Risk monitoring and control.

2. **Critical Infrastructure Security and Protection Management:**
    a) Preparation of the Security Plan for the critical infrastructure operator;
    b) Measures and strategies for the protection and security of national or European critical infrastructure.

3. **Occupational Health and Safety Management**:
    a) Assessment of the risks of occupational injury and illness;
    b) Assessment (auditing) with the legal provisions and other provisions to which the entity subscribes.

4. **Anti-Bribery Management:**
    a) Certification;
    b) Implementation.

5. **Business Continuity Management:**
    a) Certification;
    b) Implementation.

They must ensure the total security of industrial objectives from all points of view and contribute at all times to the rapid restoration of activity, by increasing resilience, in the following situations [1], [6], [10], [12], [16], [22]: Natural disasters (earthquakes, floods, explosions, fires, etc.); National crises; Special situations; Acts of terrorism; Sabotage; Thefts; Pollution; War, etc.

The critical situations listed above aim at the rapid restoration of production capacity in order to carry out the normal activity of economic activity generating efficiency and economic security [9], [11], [15], [17], [26].

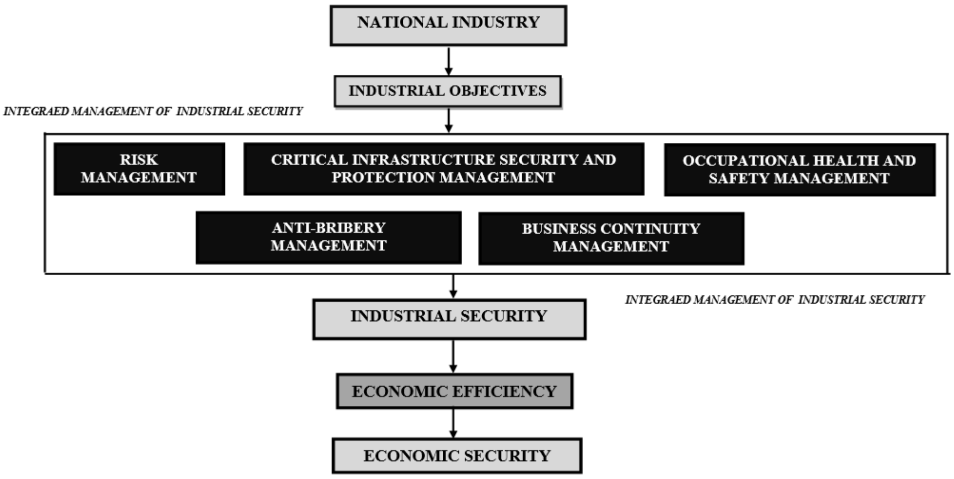

Fig.2. Integrated Management of Industrial Security

Integrated Management of Industrial Security (Fig. 2) include the following 5 stages [13], [18], [21], [25]:

1. **Risk identification by critical analysis (technical) S.W.O.T.:**
    a) Identification of vulnerabilities;
    b) Identification of threats;
    c) Identification of hazards.
2. **Preparation of the national or european Security Plan of the Critical Infrastructure Operator:**
    a) Identification of plausible risk scenarios that threaten the security of industrial objectives;
    b) Assessment of industrial and national security risks;
    c) Development of measures and strategies for the protection and security of national and european critical infrastructure.
3. **Assessment and audit of Occupational Health and Safety risks:**
    a) Assessing the risks of occupational injury and illness by calculating the overall risk level for each place of work and developing the Protection and Prevention Plan.;
    b) Auditing with legal and other provisions to which the entity subscribes by calculating the general compliance level and the level of general security.
4. **Certification and implementation of the ISO 37001: 2016 Standard - Anti-Bribery Management;**

5. Certification and implementation of ISO Standard 22301: 2019 - Business Continuity Management.

The structure of Integrated Management of Industrial Security is based on the following results from the analysis, identification and audit of industrial objectives [14], [19], [23], [: Development of security strategies; Identified threats; Tolerance and minimization of industrial and occupational health and safety risks identified; Identified vulnerabilities; Identified critical infrastructures; Insecurity generating elements; The elements of bad intentions (ill-will).

2. IMPLEMENTATION OF THE SYSTEM OF INTEGRATED MANAGEMENT OF INDUSTRIAL SECURITY AT AN ENERGY COMPANY OF NATIONAL STRATEGIC INTEREST

2.1. Elaboration of the Integrated Management Plan of Industrial Security at the National Power Grid – NPG Transelectrica Romania

INTEGRATED MANAGEMENT PLAN OF INDUSTRIAL SECURITY	
NATIONAL / EUROPEAN CRITICAL INFRASTRUCTURE POWER OBJECTIVES FROM NPG TRANSELECTRICA	
Stage 1 – Critical analysis – S.W.O.T. [11]	
STRENGHTS	**WEAKNESSES**
a) The natural monopoly character of the activity of transmission and system operator – TSO and the positive impact on the risk management; b) High level of technical expertise of the staff; c) Important progress in the process of rehabilitation and modernization of the infrastructure of the National Power Grid – NPG; d) Moderate degree of indebtedness for financing investments; e) The legacy of previous decades - a high, very high and ultra high voltage network that carried over 90 TWh per year; f) Membership in ENTSO-E, formation and integration of regional electricity markets and formation of the single electricity market; g) Dualist management system with the Supervisory Board and the Board of Directors and application of the provisions of GEO no. 109/2011; h) The introduction of Law 255/2013 on expropriation for the cause of public utility, necessary to achieve objectives of national, county and local interest; i) Presence on the capital market; j) Trading of TEL shares on Bucharest Stock Exchange.	a) Obsolete or overlapping network elements that have not yet been included in rehabilitation and modernization programs; b) The high value of own technological consumption – OTC with a tendency to increase due to the location of renewables, as a physical percentage, OTC is significantly higher than the regulated one and the real power flows are not likely to help reduce OTC; c) The reduced efficiency of controllable expenditures, especially in the area of maintenance and capital repairs, amid the diminished investment effort in recent years; d) Insufficient financial performance; e) The realized return on capital is still significantly lower than the cost of capital; f) Poor performance than similar TSO listed companies; g) The instability of the management staff and of the organizational formulas with impact on the elaboration of coherent strategies for the development of Transelectrica and the adaptation to the new conditions of the economic environment;

	h) The previously assumed strategies regarding the decreasing evolution of the average number of staff have not been implemented; i) The negative effects of the budgetary constraints, generated in part by the economic crisis, on the financing capacity, accentuated by the fact that Transelectrica manages (does not hold) the assets of NPG; j) Insufficient level of financial expertise of the staff and the partial introduction of a computerized management system; k) The low efficiency of the relationship with the Smart and Teletrans subsidiaries is mainly due to the frequent changes in the group's management.
OPPORTUNITIES	**THREATS**
a) European strategy and legislation, which in principle should be seen as an opportunity - the requirements of Legislative Package 3 on the certification, organization and operation of TSOs; b) Posibilitatea definirii unor programe sectoriale prin care să se aloce fonduri structurale (ajutor de stat pentru activități de serviciu public) pentru realizarea de noi active de transport necesare atingerii unor obiective naționale și pan-europene, cum ar fi integrarea producției necontrolabile din surse regenerabile (Connecting Europe); c) The possibility of defining sectoral programs through which to allocate structural funds (state aid for public service activities) for the realization of new transport assets necessary to achieve national and pan-European objectives, such as the integration of uncontrollable production from renewable sources (Connecting Europe); d) Possible new interconnection infrastructure projects in public private partnership – PPP; e) Development of new business (unregulated regime).	a) High unforeseen electricity costs; b) The decreasing trend of domestic energy consumption (against the background of the prolongation of the economic crisis) with a negative impact on revenues and tariffs for transport and system services; c) Delays in updating the national energy strategy; d) Late application of the European legislative framework both as a transposition into national law, including at the level of secondary legislation, and as implementation (delay in carrying out the certification process) and risks of infringement; e) The structure of the support scheme for renewable energy sources that puts pressure on the company both in investment (connection to NPG) and in operation (with emphasis on the balancing market); f) Vulnerabilities in the electricity production sector (coal area, increase in intermittent production, delay of large investment projects of state-owned companies); g) Changing the centers of gravity of electricity production but even of consumption; h) In Bucharest, obsolete CHPs no longer produce as before and Bucharest is no longer an energy exporter to the rest of the country, becoming an importer, requiring the reconfiguration of the high voltage network, but also the closure of a transmission network ring in the development of consumption in around Bucharest; i) The emergence of electricity producers from renewable energy sources in southeastern Romania, with uncontrollable production,

	leads to reduced production in the southwest and a change in power flows in NPG, with the modification of OTC and threats of congestion when crossing the Danube from Dobrogea - significant network reinforcements are needed; j) Insufficient perspective on the existence and availability of technological system services; k) Different investment rates between new sources of electricity generation using renewables and the development of NPG which should take over and transport this uncontrollable production; l) Insufficient commercial and financial discipline in the electricity markets, non-payment of issued bills and recovery of commercial claims in court; m) Reducing Romania's attractiveness for the investment environment; n) Difficulties of the regulatory framework: insufficient financial balance of the administration of the support scheme for high-efficiency cogeneration and delays in recognizing the costs of technological system services in tariff; o) Transport tariff methodology: insufficient solution of the OTC problem - financing of investments from the transport tariff; p) Deterioration of the energy vocational education system.

Stage 2 – Elaboration of the Security Plan of National / European Critical Infrastructure Operator [11]

SECURITY PLAN AT OPERATOR – S.P.O.
NCI / ECI: POWER OBJECTIVES WITHIN NPG TRANSELECTRICA
400/220/110/20 kV POWER SUBSTATION

DESCRIPTION OF THE WORK SYSTEM WITHIN 400/220/110/20 kV POWER SUBSTATION

General presentation:

Location:

- The 400/220/110/20 kV xxx power substation is located in the village/commune/locality xxx, county xxx, belonging to the Center for the Operation of Electric Transmission Networks xxx - Territorial Transport Unit xxx;
- The 400/220/110/20 kV xxx power substation is/is not an important node for the National Power System;
- The 400/220/110/20 kV xxx power station has/does not have an international interconnection to the European Union Energy System – ENTSO-E.

Organizational structure: x substation manager(s); x shift leaders; x assistant shift leaders; x workers - electrical field (operational staff).

Managed power ebjectives:
- The Territorial Transport Unit xxx carries out its activity on the electric power installations of electricity located in the counties: xxx; xxx; xxx;
- The activity is organized in x centers of exploitation: CE xxx; CE xxx; CE xxx;
- The volume of installations consists of: x power substations with nominal voltages in the range of 20 kV - 110 kV - 220 kV - 400 kV: xxx; xxx; xxx.

Presentation of the 400/220/110/20 kV power substation:

Presentation of the 400 kV power substation:
- The 400 kV power substation has a wiring diagram type xxx.;
- Power cells: x busbars xxx: x OHL (xxx, xxx, xxx); x AT 400/220/110/20 kV; x coupling (transverse/longitudinal/long-transverse); x MVAr compensation coil; x busbar measuring; discharge cells;
- Electrical equipment related to cells: AT/T type xxx, transformation ratio xxx; x switches type xxx; x separators type xxx; x current transformers type xxx; x voltage transformers type xxx; x discharge type xxx.

Presentation of the 220 kV power substation:
- The 220 kV power substation has a wiring diagram type xxx.;
- Power cells: x busbars xxx: x OHL (xxx, xxx, xxx); x AT 220/110/20 kV; x coupling (transverse/longitudinal/long-transverse); x MVAr compensation coil; x busbar measuring; discharge cells;
- Electrical equipment related to cells: AT/T type xxx, transformation ratio xxx; x switches type xxx; x separators type xxx; x current transformers type xxx; x voltage transformers type xxx; x discharge type xxx.

Presentation of the 110 kV power substation:
- The 110 kV power substation has a wiring diagram type xxx.;
- Power cells: x busbars xxx: x OHL (xxx, xxx, xxx); x AT 110/20 kV; x coupling (transverse/longitudinal/long-transverse); x MVAr compensation coil; x busbar measuring; discharge cells;
- Electrical equipment related to cells: AT/T type xxx, transformation ratio xxx; x switches type xxx; x separators type xxx; x current transformers type xxx; x voltage transformers type xxx; x discharge type xxx.

Presentation of the 20 kV power substation:
- The 20 kV power substation has a wiring diagram type xxx.;
- Power cells: x busbars xxx: x OHL (xxx, xxx, xxx); x AT 20/0,4 kV; x coupling (transverse/longitudinal/long-transverse); x MVAr compensation coil; x busbar measuring; discharge cells;
- Electrical equipment related to cells: AT/T type xxx, transformation ratio xxx; x switches type xxx; x separators type xxx; x current transformers type xxx; x voltage transformers type xxx; x discharge type xxx. [4]

RISK SCENARIO IDENTIFICATION:TERRORIST ATTACK → BLACK-OUT
RISC SCENARIO EVALUATION

RISK SCENARIO ***TERRORIST ATTACK → BLACK-OUT***	
Causes: - explosions following a terrorist attack followed by fires; - non-compliance with fire safety regulations; - lack of training / poor training of the staff of the Critical Infrastructure Protection Management; - lack of specialized Fire Protection staff; - lack of physical security personnel; - cyber attacks; - insecurity of hardware systems; - software systems insecurity; - the insecurity of the secret data transmission systems of the critical infrastructures; - lack of specialized cyber security personnel; - insecurity of SCADA (Supervisory Control and Data Acquisition) systems; - operating with insecure and/or non-performing programs; - insecurity of communications with Territorial / National Energy Dispatcher and between cybersecurity responsibles; - lack of cyber investment.	**Effects:** - possible deaths; - possible accidents with serious consequences; - fires; - access to secret informations about National Power System by unauthorized persons; - use of secret informations about the National Power System for military or terrorist purposes; - untimely disconnection of remotely controlled energy equipment by hackers; - enormous material damage due to lack of electricity; - enormous material damage resulting from the interdependence of other systems; - the possibility of a local, regional or national blackout; - energy-economic collapse; - crises.

a) Determining the probability

The following probability scale was adopted to determine the probability of occurrence [27], [28]:

LEVEL/SCORE ASSOCIATED		**DEFINITION OF PROBABILITY**	**PERIOD**
	1. Very Low	It has a very low probability of occurring. Normal measures are required to monitor the progress of the event.	**over 13 years**
	2. Low	The event has a low probability of occurring. Efforts are being made to reduce the likelihood and / or mitigation of the impact produced.	**10 – 12 years**
X	**3. Medium**	The event has a significant probability of occurring. Significant efforts are needed to reduce the	**7 – 9 years**

		likelihood and / or mitigate of the impact produced.	
	4. High	The event has a probability of occurring. Priority efforts are needed to reduce the likelihood of and / or mitigate of the impact produced.	**4 – 6 years**
	5. Very high	The event is considered imminent. Immediate and extreme measures are required to protect the objective, evacuation to a safe location if the impact requires it.	**1 – 3 years**

b) Determining the severity (gravity) of the consequences of the proposed scenario

LEVEL/SCORE ASSOCIATED		**SEVERITY (GRAVITY) CONSEQUENCES**
	1. Very Low	The event causes a minor disruption to the activity, without material damage.
	2. Low	The event causes minor property damage and limited business disruption.
	3. Medium	Personnel injury, and/or certain loss of equipment, utilities, and service delays.
	4. High	Serious personnel injury, significant loss of equipment and facilities, delays and/or interruption of service provision.
X	**5. Very high**	The consequences are catastrophic resulting in deaths and serious injuries to personnel, major loss of equipment, installations and facilities and the cessation of service provision.

c) Risk level calculation

PROBABILITY						
	Very high 5					
	High 4					
	Medium 3					**Scenario BLACK-OUT**
	Low 2					
	Very Low 1					
	0	**Very Low 1**	**Low 2**	**Medium 3**	**High 4**	**Very high 5**

\- **SEVERITY/GRAVITY CONSEQUENCES**

The calculated risk is 15 (probability 3 x severity 5)	**CALCULATED RISK LEVEL**

Risk level is: HIGH RISK	LEVEL	SCORES
	Very Low	1 – 3
	Low	4 – 6
	Medium	7 – 12
	High	13 – 16
	Very high	17 – 25

d) Recalculating the severity (gravity) of the consequences

LEVEL/SCORE ASSOCIATED		SEVERITY (GRAVITY) CONSEQUENCES
	1. Very Low	The event causes a minor disruption to the activity, without material damage.
	2. Low	The event causes minor property damage and limited business disruption.
	3. Medium	Personnel injury, and/or certain loss of equipment, utilities, and service delays.
X	4. High	Serious personnel injury, significant loss of equipment and facilities, delays and/or interruption of service provision.
	5. Very high	The consequences are catastrophic resulting in deaths and serious injuries to personnel, major loss of equipment, installations and facilities and the cessation of service provision.

e) Level of risk after reduction measures have been applied

PROBABILITY						
	Very high 5					
	High 4					
	Medium 3				Scenario BLACK-OUT	
	Low 2					
	Very Low 1					
	0	Very Low 1	Low 2	Medium 3	High 4	Very high 5
	SEVERITY/GRAVITY CONSEQUENCES					

The calculated risk is 12 (probability 3 x severity 4) Risk level is: MEDIUM RISK	CALCULATED RISK LEVEL	
	LEVEL	SCORES
	Very Low	1 – 3
	Low	4 – 6
	Medium	7 – 12

	High	**13 – 16**
	Very high	**17 – 25**

Stage 3 – Assessment and audit in terms of Occupational Health and Safety Risks [11]

ACTIVITY ORGANIZATION OF OCCUPATIONAL HEALTH AND SAFETY

- Activity organization of Occupational Health and Safety – OHS is carried out within the Compartment xxx;
- Within this compartment there is a responsible (specialist) in the field of OHS, together with the occupational medicine doctor;
- The OHS Committee is also organized, which is constituted by: president - the branch director; members - representatives proposed by the branch union; the occupational medicine doctor in the branch; secretary - specialist / expert / assessment in terms of OSH.

Assessment of the risks of occupational injury and illness at a power substation 400/220/110/20 kV

Global risk level assessment

The global risk level of the power substation is calculated as a weighted average of the risk level determined for each workplaces analyzed in the power substation.

$$N_g = \frac{\sum_{p=1}^{n} r_p \cdot N_{rp}}{\sum_{p=1}^{n} r_p} \quad (1)$$

where

Ng *= global risk level of the power substation;*
rp *= workplace rank p, equal to the value of the worplace risk level;*
n *= number of worplaces;*
Nrp *= global risk level of workpace.*

Global risk levels, determined for each worplace at the 400/220/110/20 kV power substation are generally the following:

No.	WORKPLACE	RISK LEVEL (N_{rp})
1	OPERATIONAL SERVICE: 400 kV, 220 kV, 110 kV	X
2	OPERATIONAL SERVICE: 20 kV	X
3	MAINTENANCE OF PRIMARY CIRCUITS: 400 kV, 220 kV, 110 kV	X
4	MAINTENANCE OF PRIMARY CIRCUITS: 20 kV	X
5	MAINTENANCE OF SECONDARY CIRCUITS 20 kV – PRAM	X

DESCRIPTION OF THE WORK SYSTEM

1. Means of production:

- 400 kV power substation: *x busbars xxx:x OHL cells (xxx, xxx, xxx);x AT 400/220/110/20 kV cells; x coupling cells (transversal/longitudinal/longo-transversal);x compensation coil cells x MVAr;x mesuring busbars cells; x discharge cells;etc.;*
- 220 kV power substation: *x busbars xxx:x OHL cells (xxx, xxx, xxx);x AT 220/110/20 kV cells; x coupling cells (transversal/longitudinal/longo-transversal);x compensation coil cells x MVAr;x mesuring busbars cells; x discharge cells;etc.;*
- 110 kV power substation: *x busbars xxx:x OHL cells (xxx, xxx, xxx);x AT/T 110/20 kV cells; x coupling cells (transversal/longitudinal/longo-transversal);x compensation coil cells x MVAr;x mesuring busbars cells; x discharge cells;etc.;*
- 20 kV power substation: *x busbars xxx:x OHL cells (xxx, xxx, xxx);x AT/T 20/0,4 kV cells; x coupling cells (transversal/longitudinal/longo-transversal);x compensation coil cells x MVAr;x mesuring busbars cells; x discharge cells;etc.;*
- system of internal services at alternativ and direct current;
- systems of control, protection and automation;
- systems of cables;
- power plants – discharge on 20 kV;
- building, canals of cables;
- protective equipment and devices.

Risk factors specific to the means of production:

- *mechanical risk* (falling from the same level, slipping or tripping, explosions of equipment with a lifetime exceeded, falls from a height);
- *electric risk* (direct contact with electrical installations);
- *thermal risk* (burns due to electric arc).

2. Workload:

According to the operating regulations, the duties of the operational staff are as follows:

- performing the delivery-receiving operations of the team work;
- supervision activity;
- control activity;
- the activity of executing the maneuvers.

Risk factors specific to the workload:

- *psychic stress in the 400 kV, 220 kV, 110 kV, 20 kV power substations, when installing shortcircuits by hand.*

3. Performer (executor):

The following persons work in the power substation: x power substation manager (s) (engineer); x shift leaders; x assistant shift leader.

Risk factors specific to the performer (executor):

- *wrong action:* incorrect identification of the installation and non-verification of the lack of voltage, when mounting the shortcircuits; non-compliance with neighboring

distances with risk of electric shock by direct contact; uncheck the voltage before installing the shortcircuits;
- *omissions:* omission of operations during maneuvers, with risk of burns caused by electric arc, when closing the earthing knives or mounting the mobile shortcircuits without checking the lack of voltage; non-use and / or non-verification of personal protective equipment and / or electrical insulating means and devices.

4. Work environment:

The operative service personnel carry out their activity in the control room, in the outdoor power substations of 400 kV, 220 kV, 110 kV and 20 kV.

The specificity of the workload requires the development of exploitation and control activities regardless of climatic conditions.

As a result, the main risk factor for the work environment is air temperature and exposure to high or low temperatures during work.

Risk factors specific to the work environment:
- *physical risk factors:* exposure to adverse weather conditions (low / high temperatures, rain, snow, drafts) during the inspection of installations;

CALCULATION OF THE GLOBAL RISK LEVEL

1. Global risk level for workplace: OPERATIONAL SERVICE: 400 kV, 220 kV, 110 kV

$$N_{400kV-110kV} = \frac{\sum_{i=1}^{7} R_i \cdot r_i}{\sum_{i=1}^{7} r_i} = \frac{2\cdot(1\cdot 1)+2\cdot(3\cdot 3)+3\cdot(4\cdot 4)}{2\cdot 1+2\cdot 3+3\cdot 4}\,\frac{68}{20} = 3{,}4 \quad (2)$$

2. Global risk level for workplace: OPERATIONAL SERVICE: 20 kV

$$N_{20kV} = \frac{\sum_{i=1}^{11} R_i \cdot r_i}{\sum_{i=1}^{11} r_i} = \frac{11\cdot(3\cdot 3)}{11\cdot 3} = \frac{99}{33} = 3{,}00 \quad (3)$$

3. Global risklevel for workplace: MAINTENANCE OF PRIMARY CIRCUITS: 400 kV, 220 kV, 110 kV

$$N_{MENT.EP400/220kV} = \frac{\sum_{i=1}^{14} R_i \cdot r_i}{\sum_{i=1}^{14} r_i} = \frac{1\cdot(1\cdot 1)+3\cdot(2\cdot 2)+8\cdot(3\cdot 3)+2\cdot(4\cdot 4)}{1\cdot 1+3\cdot 2+8\cdot 3+2\cdot 4} = \frac{101}{39} = 2{,}58 \quad (4)$$

4. Global risklevel for workplace: MAINTENANCE OF PRIMARY CIRCUITS: 20 kV

$$N_{MENT.EP20kV} = \frac{\sum_{i=1}^{16} R_i \cdot r_i}{\sum_{i=1}^{16} r_i} = \tag{5}$$

$$= \frac{3\cdot(2\cdot 2)+2\cdot(3\cdot 3)+2\cdot(4\cdot 4)+4\cdot(5\cdot 5)+5\cdot(6\cdot 6)}{3\cdot 2+2\cdot 3+2\cdot 4+4\cdot 5++5\cdot 6} = \frac{342}{70} = 4{,}8$$

5. Global risk level for workplace: MAINTENANCE OF PRIMARY CIRCUITS – PRAM

$$N_{EP} = \frac{\sum_{i=1}^{17} R_i \cdot r_i}{\sum_{i=1}^{17} r_i} = \frac{13\cdot(3\cdot 3)+3\cdot(2\cdot 2)}{13\cdot 3+3\cdot 2} = \frac{129}{45} = 2{,}87 \tag{6}$$

GLOBAL RISK LEVEL OF THE 400/220/110/20 kV POWER SUBSTATION

The global risk levels determined for each workplace in the 400/220/110/20 kV power substation are as follows:

No.	WORKPLACE	RISK LEVEL (N_{rp})
1	**OPERATIONAL SERVICE: 400 kV, 220 kV, 110 kV**	**3,4**
2	**OPERATIONAL SERVICE: 20 kV**	**3**
3	**MAINTENANCE OF PRIMARY CIRCUITS: 400 kV, 220 kV, 110 kV**	**2,58**
4	**MAINTENANCE OF PRIMARY CIRCUITS: 20 kV**	**4,8**
5	**MAINTENANCE OF SECONDARY CIRCUITS 20 kV – PRAM**	**2,87**

The global risk level of the 400/220/110/20 kV power substation is:

$$N_{rg} = \frac{\sum_{p=1}^{n} r_p \cdot N_{rp}}{\sum_{p=1}^{n} r_p} = \tag{7}$$

$$= \frac{(3{,}4\cdot 3{,}4)+(3\cdot 3)+(2{,}58\cdot 2{,}58)+(4{,}8\cdot 4{,}8)+(2{,}87\cdot 2{,}87)}{3{,}4+3+2{,}58+4{,}8+2{,}87} = \frac{49{,}48}{16{,}65} = 2{,}97$$

$$N_{rg-statie} = 2{,}97$$

Assessment (auditing) of compliance with legal and other provisions at a 400/220/110/20 kV power substation

Program for assessing (auditing) compliance with legal and other provisions

GENERAL LEVEL OF COMPLIANCE

Sheet Code	Name	Scores		Level of compliance
		Maximum (PM)	Obtained (PO)	
A	**Obligations of the employer**	168	168	**100 %**
B	**Workers' rights and obligations**	48	47	**97,91 %**
		TOTAL		**NC_g**
		216	**215**	**99,53 %**

GENERAL LEVEL OF COMPLIANCE

Sheet Code	Name	Scores		Level of compliance
		Maximum (PM)	Obtained (PO)	
C. General provisions				
C.1	Minimum provisions at OHS	300	300	100 %
C.2	Minimum safety and health provisions for sign at work	90	90	100 %
C.3	Minimum safety and health provisions for use equipment by workers	120	120	100 %
C.4	Minimum safety and health provisions for use of display screen equipment	27	27	100 %
C.5	Minimum safety and health provisions for use of personal protective equipment by workers at work	18	18	100 %
C.14	Minimum safety and health provisions regarding the exposure of workers to the risks posed by electromagnetic fields	30	30	100 %
C.21	Monitoring healt of workers	45	45	100 %
C.22	Measures that may be applied in periods of extreme temperatures for the protection persons at work	12	12	100 %
D. Specific provisions				
D.1	Own Instruction of OHS in electrical installations of exploitation (operating)	30	30	100 %
D.2	Own Instruction of OHS for work under voltage	54	54	100 %
D.3	Own Instruction of OHS regarding how to complete the work permit under voltage	30	30	100 %
		TOTAL		**NC_g**
		756	**756**	**100 %**

GENERAL LEVEL OF SECURITY

Sheet Code	Name	Scores		Security level	Risk level
		Maximum (PM)	Obtained (PO)		
A	**Obligations of the employer**	408	408	100 %	Small
B	**Workers' rights and obligations**	99	96	96,96 %	Small
C. General provisions					
C.1	Minimum provisions at OHS	672	672	100 %	Small
C.2	Minimum safety and health provisions for sign at work	249	249	100 %	Small
C.3	Minimum safety and health provisions for use equipment by workers	360	360	100 %	Small
C.4	Minimum safety and health provisions for use of display screen equipment	60	60	100 %	Small
C.5	Minimum safety and health provisions for use of personal protective equipment by workers at work	54	54	100 %	Small
C.14	Minimum safety and health provisions regarding the exposure of workers to the risks posed by electromagnetic fields	90	90	100 %	Small
C.21	Monitoring healt of workers	132	132	100 %	Small
C.22	Measures that may be applied in periods of extreme temperatures for the protection persons at work	36	36	100 %	Small
D. Specific provisions					
D.1	Own Instruction of OHS in electrical installations of exploitation (operating)	90	90	100 %	Small
D.2	Own Instruction of OHS for work under voltage	162	162	100 %	Small
D.3	Own Instruction of OHS regarding how to complete the work permit under voltage	90	90	100 %	Small
		TOTAL		**NS_g**	**NR_g**
		2502	**2499**	**99,88 %**	**Small**

LEVEL OF SECURITY	LEVEL OF RISK
91-100 %	Small
81-90 %	Medium
71-80 %	High
under 71 %	Very high

Stage 4 – Certification and implementation of the ISO 37001: 2016 Standard - Anti-Bribery Management [11]

Stage 5 – Certification and implementation of ISO Standard 22301: 2019 - Business Continuity Management [11]

3. CONCLUSIONS

The frequent occurrence of cases of industrial insecurity in the context of economic, national and regional security, makes the topic addressed very topical and of great significance, knowing very well that the security strategies of strategic companies of national interest must be implemented, due to the interdependencies between the systems. Such an approach must start with industry decision-makers and top management of companies of strategic interest who own and operate critical national and european infrastructure.

The paper aims to identify the threats and vulnerabilities of critical infrastructures within the strategic company of national interest National Power Grid Transelectrica in order to combat and eliminate possible risks that threaten its proper functioning and be applicable by security liaison officers, experts, specialists and assessors on industrial safety and occupational health and safety issues, responding to the current needs and competencies of them.

The advantages of such an Integrated System at Industrial Security are the following:

- Identification of Strenghts– by SWOT technique, by the risk manager;
- Identification of Weaknesses– by SWOT technique, by the risk manager;
- Identification of Opportunities– by SWOT technique, by the risk manager;
- Identification of Threats– by SWOT technique, by the risk manager;
- Identification of national or european critical infrastructures – through the importance and facility of critical infrastructure, by the responsible public authorities;
- The level of criticality of critical infrastructures – criticality assessment, by the responsible public authorities;
- Interdependencies between critical infrastructures and systems – industrial and national security risk assessments, by the responsible public authorities;
- Identification of plausible risk scenarios with insecurity effect – by drawing up the Security Plan at the Critical Infrastructure Operator, by the security liaison officer – SLO;
- Assessment the risks of Occupational Health and Safety – by Assessing the risks of occupational injury and illness, by the Head of the Internal/External Prevention and Protection Plan Service – INCDPM (The National Research and Development Institute of Occupational Safety) Bucharest Method;
- Auditing of Occupational Health and Safety – by the method of Assessment of compliance with legal provisions and other provosions, by the Head of the Internal/External Prevention and Protection Plan Service – INCDPM (The National Research and Development Institute of Occupational Safety)Bucharest;

- Development of security and protection strategies regarding critical infrastructures – by drawing up the Security Plan for the Critical Infrastructure Operator, by the security liaison officer – SLO;
- Development of security and protection strategies for workers (personnel), by developing the Prevention and Protection Plan, by the Head of the Internal/External Prevention and Protection Service;
- Diminishing and stopping the bribery phenomenon (corruption) – by certifying and implementing the ISO 37001: 2016 Standard - Anti-Bribery management, by decision makers or the management of the strategic company of national interest;
- Diminishing and stopping the phenomenon of stopping the activity of industrial processes – by certifying and implementing the ISO 22301: 2019 Standard - Business Continuity Management, by decision makers or the management of the strategic company of national interest.

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CURRENT ASPECTS OF ENERGY SYSTEMS IN ACHIEVING DECARBONIZING OBJECTIVES

STOCHITOIU MARIA DANIELA[1]

Abstract: The sustainable development is based on secure access to clean and affordable energy for human security. Sustainable development is a balance between energy security, equity and affordability for environmental sustainability. Fossil fuels are by far the most widely traded primary energy sources. Energy transition is in a strong tie with wider set of decarbonizing due to the main challenge of world for climate change.

Key words: decarbonizing, sustainable development, climate, efficiency.

1. INTRODUCTION

The key for a modern life is representing by clean power, clean heat and clean fuel as a modern energy. The sustainable development is based on secure access to clean and affordable energy for human security. Sustainable development is a balance between energy security, equity and affordability for environmental sustainability. [1]

Energy transition is in a strong tie with wider set of decarbonizing due to the main challenge of world for climate change. The electricity is representing more than 20% of final demand. Sequestration retrofitting and utilization of carbon capture are representing a rough way and requires a major injection of capital and a long period of time to retrofitting with unproductive downtime for power plants. There is necessary to think for re-purposing or re-using the existing power plants than building new infrastructures. The nowadays trends are representing of decarbonizing, digitization, decentralization, electrification. [2]

For many transmission companies as well as for energy companies in general, the pandemic has accelerated digital transformation.

International cooperation and concerted action are necessary to reinforce useful energy access and simultaneously develop, diversify and decarbonize whole economies.

2. PROPOSALS FOR CLIMATE 2030

[1] *Ph.D, Associate Professor Eng., University of Petroşani, danielastochitoiu@upet.ro*

The 2030 climate and energy framework establish points of view for reducing through cutting greenhouse gas emissions and rising the share of clean energy and energy efficiency. Under the energy union, UE is working to integrate Europe's energy markets for ensuring security in power energy, improving the energy efficiency and decreasing carbonize of economy. International cooperation and concerted action are necessary to reinforce useful energy access and simultaneously develop, diversify and decarbonize whole economies. [3]

The ultimate target is essential to reach the objectives in the climate field (figure 1).

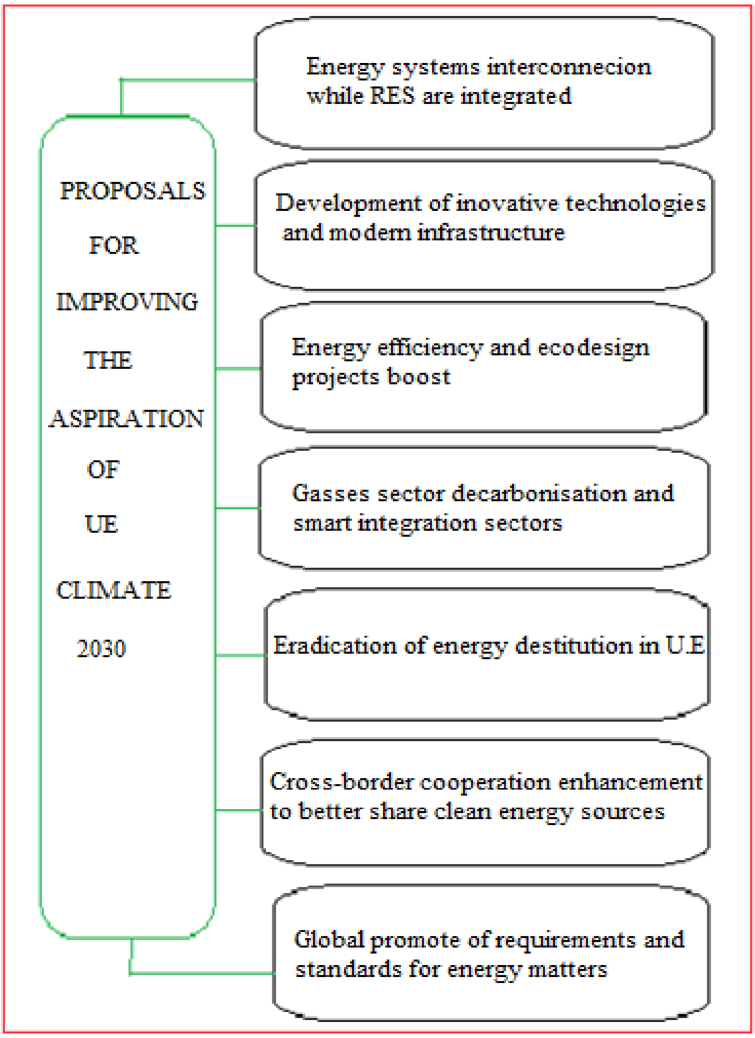

Fig.1 Some proposals for climate 2030

The three main directions are [4]:

- Priority statute grant for energy efficiency and develop the energetic sector based on renewable sources because the energy production and operating represent about 75% from CO_2 emissions; the pressure on the fossil fuel industry will be increased due to regulatory of limiting the Carbon emissions.
- UE supplier with secure energy security at accessible and competitive prices; in according with Renewable Energy Agency the cost of renewable sources energy will be cheaper than fossil fuel worldwide.
- An integrated, interconnected and digitalized UE energy market.

Final energy consumption reached about 18% in EU from renewable sources, up from 17% in 2018 and about double 2004 (8,5)%. Sweden has the highest consumed energy from renewable sources (54,8%), followed by Finland (41,2%), Latvia 40,3%, Denmark (36,1%) and Ostrich (33,4%). Romania has 0,1% away from own national framework objectives.

Romania will reach 27,9% of final consumption from renewable energy and improve the energy efficiency with 37,5% (Integrated National Plan in the field of Energy and Climate Change).

The main source of electricity, located in the Oltenia basin, produces about 40 TWh / year, based on an excavation of about 21 million tons of lignite per year. All the plants in the Oltenia basin are modernized. There are still many challenges for these plants, as to the impossibility of giving up this energy source but also by the financial difficulties caused by an uncontrolled evolution of the price of green certificates from 7€ /tons CO_2 to 29 - 30€/tons CO_2. Practically 45% of the benefits obtained by coal producers, are used to purchase green certificates that limiting the possibilities for investment and modernization. To face the competition in the market the operator has adopted a clear strategy to reduce emissions in which it is obliged to reduce by 1600 MW the capacity on lignite. [5]

The gross final energy consumption of all energy sources, covers total energy delivered for energy purposes to final consumers as well as the transmission and distribution losses for electricity and heat. National energy security has traditionally been characterized by the robustness of energy systems and strategic oil stocks. The shift to digital, decarbonized, and decentralized energy systems raises new energy security challenges – including extreme weather, grid visibility, reliability and resilience. In the next few years, the decisions which taken in Europe will influence in the strongly way the model of the world responds to the challenges of climate.[6]

In order to ensure a fair and just transition to E.U ambitions, some aspects must highlight:

- The coal regions must be founded in specific boost for facing the toughest challenges;
- Energy efficiency is a vital principle for the clean energy transition;

- Smart sector integration with stronger integration of the electricity, heating and cooling, transport, gas, industry is efficiency through incorporate renewables into all parts of the energy sector.

The world needs to capture as much as 6 billion metric tons of CO_2 by 2050, according to modeling done by the International Energy Agency, the energy giant's shareholders are pressuring the company to take steps to ensure climate change doesn't convert their investments into stranded assets. And to scale up, the cost of carbon capture needs to come down.

For example, in 2020, the electrical energy production from wind and solar farms has increased with 64TWh at 600 TWh and for the first time has overtaken the electrical energy production produced in coal power plants with 100 TWh. The wind farms supplied with 14% more energy in 2020 than 2019, while solar farms recorded a growth of their production with 7%. On the other hand, the electrical energy production has decreasing with more than 6% due to dryness weather. Viewing the new annual capacities about 16,8 GW was installed in wind farms and more than 16,5 GW in solar farms.

Energy transition is in a strong tie with wider set of decarbonizing due to the main challenge of world for climate change. Key trends and uncertainties affecting electricity transmission determine some features as (fig.2) [7]:

The transition to a low carbon involves:

- penetration of variable renewables such the wind and solar;
- new technologies such as utility scale batteries and hydrogen;
- fossil fuel powered generators close and disconnect from the system.

The point of view of decentralization:

- connecting a range of new technologies and new prosumers;
- changes in supply and demand patterns;
- prosumers and electricity being produced closer of where is consumed.

Customers as active elements of the system:

- electrification of end-uses as industry, heat and mobiles;
- demand response programs included smart devices and distributed energy storages;
- new demand patterns with the emergence of flexibility providers.

More automated operation of the system:

- the evolution and using the intelligent or smart metering, remote control and automation system;
- forecasting capabilities development;
- optimization and aggregation platforms as future trends.

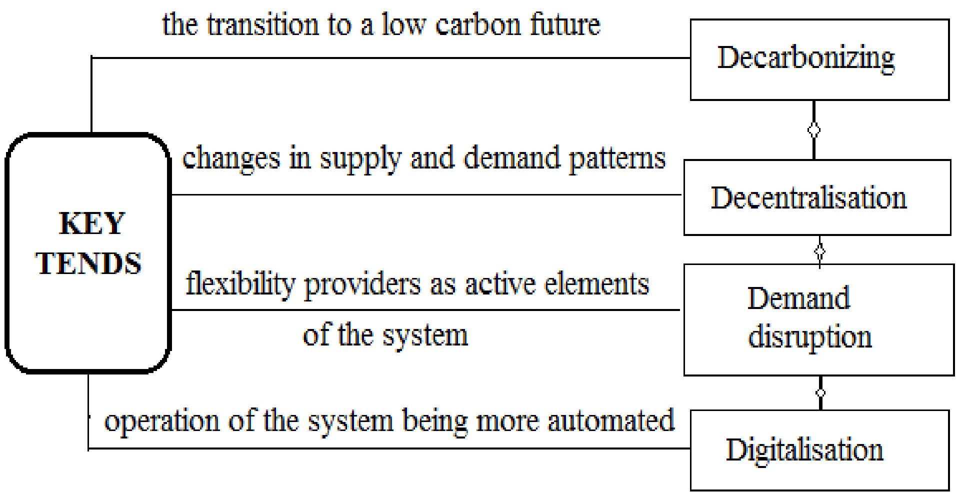

Fig.2. Key trends and uncertainties affecting electricity transmission companies

In 2020, global investment in the low-carbon energy transition summed \$501.3 billion, up from \$458.6 billion in 2019 and just \$235.4 billion in 2010. This figure includes investment in projects, such as renewable power, energy storage, EV charging infrastructure, hydrogen production and CCS projects – as well as end-user purchases of low-carbon energy devices, such as smalls solar systems, heat pumps and zero-emission vehicles.[8]

For Romania are necessary huge harmonize efforts through coordination the national policies with neighboring countries. Next new challenges can be regulated for assuring the real participation to market mechanisms and climate reduction:

- The appearance of energy agregators;
- The evolution of energy storage units;
- The appearance of prosumers;
- Efficient renewable sources integration.

3. CONCLUSIONS

Among all, two valid solutions for reducing CO_2 emissions have been identified as being most relevant: energy efficiency improvements and generation by renewable energy sources. The sustainable development is based on efficient energy using. The energy efficiency increasing in different operations of energy and decreasing the harmful emissions level help the human society to have a cleaner atmosphere, a better health and more related comfort.

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ENERGY EFFICIENCY REQUIREMENTS TO OPTIMISE THE INDUCTION MOTORS OPERATING

MARIA DANIELA STOCHITOIU[1], ILIE UTU[2]

Abstract: The paper presents the improvements of electrical drives. In nowadays industry, electrical motors are using almost 80% of used energy, as the aspects of their efficiency has an important weight in the engineering concerns for electrical energy reduction.

Key words: power factor, efficiency, losses

1. INTRODUCTION

Electric motors and electric drive systems use more than half of the electricity production, in the industrial processes, transmission, residential applications. Electrical motors, usually have η about 90% which determine the energy losses, so an increase with 2% of η, which is possible for energetic efficiency motors, has an important effect viewing the electrical energy economy.[1]

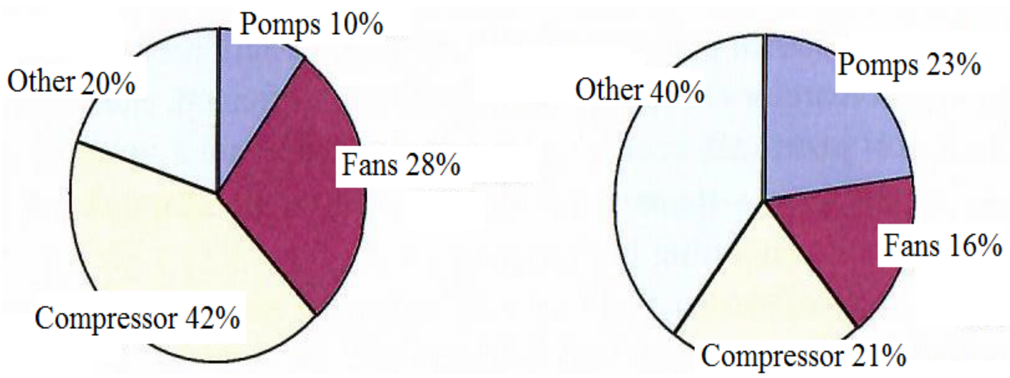

Fig.1. The weight of driven motors in industry and residential applications

[1] *Ph.D, Associate Professor Eng., University of Petroşani, danielastochitoiu@upet.ro*
[2] *Ph.D ., Associate Professor Eng., University of Petroşani, ilieutu@yahoo.com*

The efficiency of the drive motor is defined through η as the ratio between mechanical active power P_m and the input electrical active power:

$$\eta = \frac{P_m}{P_{el}} \tag{1}$$

The difference between input electrical power and the mechanical power represents the following losses:

- Stator winding losses ΔP_1;
- Rotor winding losses $\Delta P_{2;}$
- Magnetic circuit losses ΔP_{mg};
- Ventilation and friction losses $\Delta P_{m,y}$;
- Release losses ΔP_σ.

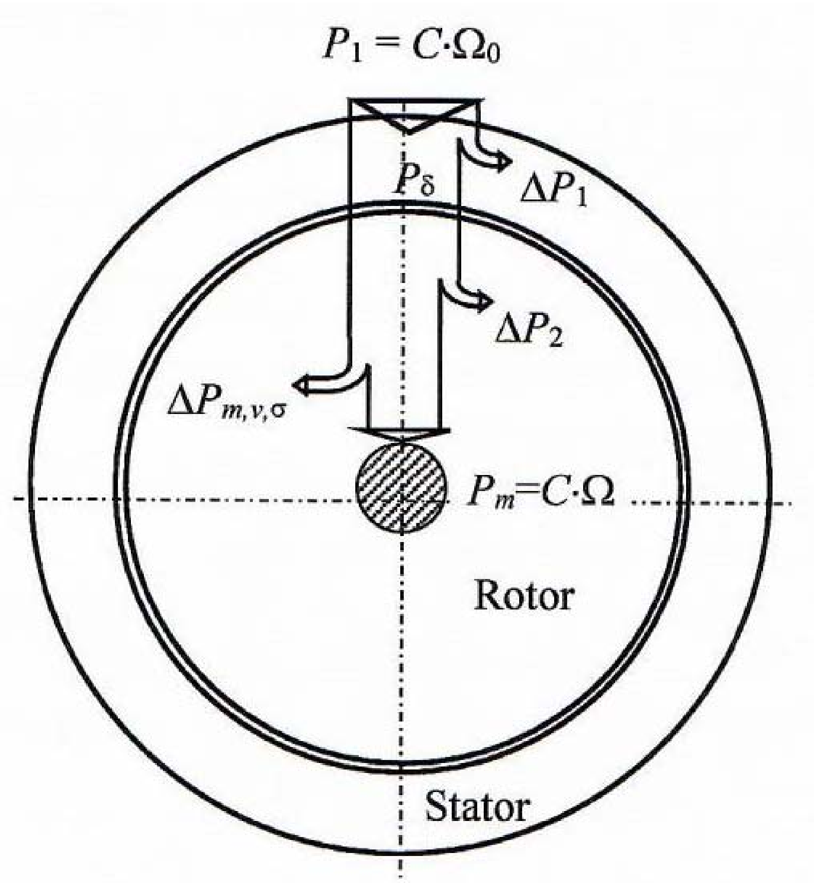

Fig.1 Simplified energetical balance for asynchronous motor

For an asynchronous motor, the loss of active energy ($\Delta\ p_a$) is calculated by the following relation:

$$\Delta\ p_a = (1-\eta)\cdot\frac{P_N}{\eta} \quad \text{(kW)} \tag{2}$$

where: η = nominal efficiency; P_N =nominal power

The loss of reactive energy (Q) is calculated by the following relation:

$$Q = P_N \cdot tg\varphi \quad \text{(kVAR)} \tag{3}$$

Out of the losses generated in an asynchronous motor, the mechanical losses Pm are practically independent from the charging power, and only the losses from the wrappings and the ferromagnetic core remain variable according to the electrical and mechanical variations.

The losses from the wrappings are practically dependent only on the charge and the quantity of the materials.

The losses in the stator $\Delta P_1 = 3R_1\ I_1^2$ are the losses with caloric effect, determined by the current I_1, the energetic parameters of the asynchronous motor are defined by efficiency (η) and power factor (cosφ), which help calculating the loss of active power and the loss of reactive power.

$$I_1 = \frac{P_{el}}{\sqrt{3}U cos\varphi} = \frac{P_m}{\sqrt{3}U\eta cos\varphi} \tag{4}$$

we can notice that for a given current, the only measure is to increase the section of the conductor, and so to decrease the density of electricity.

The losses wight for three phases asynchronous motor, on nominal load, is shown in the below table. The losses adjustment in dependence of shaft load is shown in the (figure 2).

Table 1 ***The losses in the asynchronous motor***

Type of losses	**Losses weight**
Joule losses in stator	37
Joule losses in rotor	18
Magnetic circuit losses	20
Mechanical and friction losses	9
Release losses	16

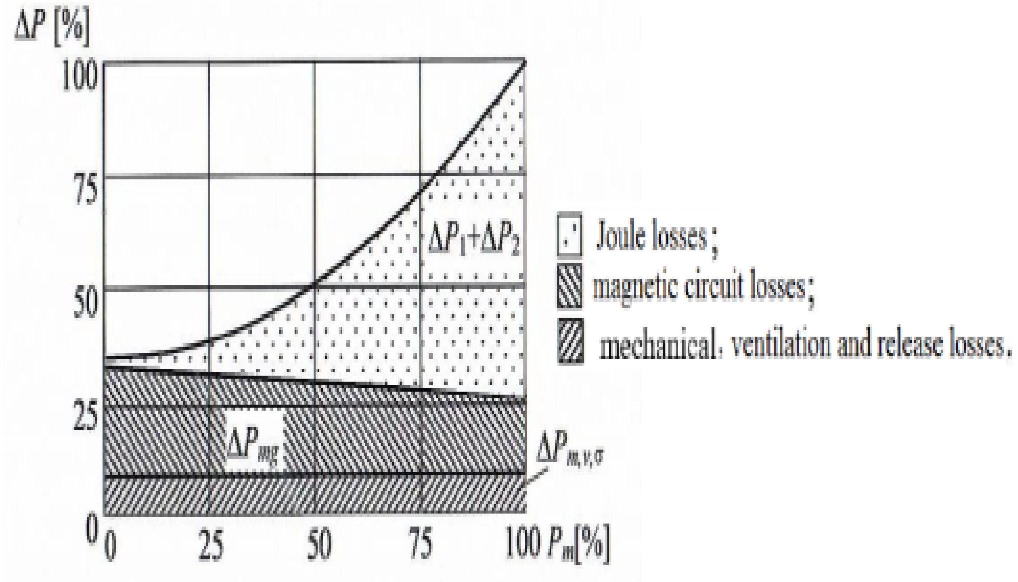

Fig. 2 The losses variation for asynchronous motor

For the asynchronous motors with contact rings, this measure can be applied for both rotor and static armatures. The limit is given only by the possibility to place spires, limited by the exterior diameter of the machine.

In the case of asynchronous motors with a caged rotor, the measure can be applied only at the static wrapping. The rotor wrapping must satisfy other requests corresponding to the rotation moment necessary to accelerate and the starting current, as compared to the one with rings, so the degrees of freedom for this motor are lower.

Usually, the asynchronous motor with a squirrel cage rotor requires relatively big starting moments and low starting currents. This requires a certain shape of the rotor notch, which must have a pronounced refutation of the current from the rotor bar, in order to increase the apparent resistance.

2. ABOUT HIGH EFFICIENCY MOTORS

New EU eco-design measures for electric motors and variable speed drives enter into force on 1 July 2021, aimed at improving the energy efficiency of these products across the EU. Applicable to AC induction motors (such as those that can be found in washing machines, air conditioners, or heat pumps and are also commonly used in many types of industrial applications), the new rules update the previous regulation from 2009. The new regulation has a significantly broader scope, covering motors with a power range from 0.12 kW until 1000 kW. The energy efficiency requirements have also been reinforced, reflecting technological progress and market evolution in the past decade. For example, the new rules will now regulate the efficiency of variable speed drives. This will help engineers to optimize the efficiency of entire systems.[3],[4]

The induction motors with power between 0,12kW – 1000kW and voltage till 1kV, are classified in three efficiency classes:

a. Standard Efficiency IE1;
b. High Efficiency IE2;
c. Premium Efficiency IE3;
d. Hight premium efficiency IE4

Table 2 ***The efficiency of regular motor and efficiency of efficient motor***

Power domain [kW]	**Efficiency**	
	Regular motor [%]	**Hight efficient motor [%]**
0,75÷7,5	80	86
7,5÷37	86	90
37÷75	90	93
>75	95	96

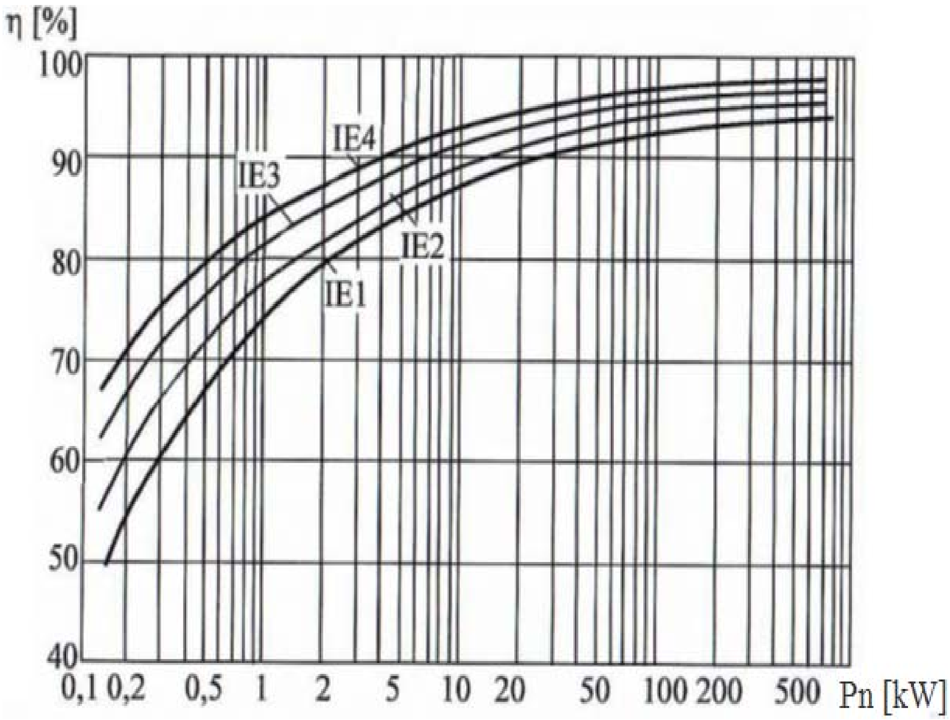

Fig.3 The η adjustment of electrical motors with two poles in dependence of efficiency classes and nominal power

From above diagram, it can notice that an electrical motor with 7,5kW from IE3 has an efficiency about 90,1% in compatation with the corresponding motor from IE1 which has an efficiency is 86%, so the losses reduction is about 20%.

These motors must be executed respecting the standard power-frame size assignment. To increase the efficiency of induction motors there were looked methods to reduce the losses. In the conductors of the stator winding appear principal and supplementary losses.

The IE class and nominal efficiency has to clear subscript on the identify motor plate.[3],[5]

The annual energy economy ΔE from replacing the regular motor (η_r) with an efficient motor (η_e) is calculated with the below relation:

$$\Delta E = P_n \cdot \lambda \cdot t_a \cdot (1/\eta_r - 1/\eta_e) \quad (5)$$

P_n – nominal power, λ – load factor equal with the ratio between real power and nominal power, t_a – the annual duration of operating at nominal power time.
The annual reduction of CO_2, is C_t:

$$C_t = \Delta E \cdot f_c \text{ [kg } CO_2\text{/an]} \quad (6)$$

Where f_c (kg/kWh) is the pollutant emissions factor for different resources are shown in the below table.

Tabel 3 ***The values of emission factor f_c***

Resources	**f_c (kg/kWh)**			
	CO_2	**SO_2**	**NO_x**	**CO**
coal	1,18	0,0139	0,0052	0,0002
petroleum	0,85	0,0164	0,0025	0,0002
natural gas	0,53	0,0005	0,0009	0,0005
hydro	-	-	-	-
Wind, photovoltaic	-	-	-	-

To reducing of the principal losses in the stator winding was achieved by reducing the stator winding resistance. To this aim the winding diagram with concentric coils was replaced with a winding diagram with equal, displaced coils. The losses in the magnetic core are the main losses (which are taking place only in the stator) and supplementary losses. For the reducing of the losses in the core the use of electromagnetic steel sheet, having lower specific losses ps=1.1W/kg (M270-50) and ps=1.7 W/kg (M400-50) instead of that with specific loss of ps=3.6 W/kg (M800-50).

By adopting certain constructions and design methods, one can obtain motors with high energetic indexes.

The supplementary losses in the core appear both at no load and full load status of the machine. According to the literature, the supplementary losses can reach up to 8-25% from the total losses.

The supplementary losses in the induction motor are [6]:

- surface losses (representing 40%from the total supplementary losses);
- losses caused by transversal currents between the rotor bars (30% from the total supplementary losses;
- pulsation losses (represent 17% from the total supplementary losses);
- losses produced by the high frequencies (10%); losses produced by the stray fluxes.

Therefore, in order to reduce the supplementary losses and implicitly to increase the efficiency, first of all must be reduced the surface losses and the losses produced by the transversal currents between the rotor bars.

It was shown above theoretically that the decreasing of the supplementary surface losses and of those produced by the transversal currents can be achieved by the increasing of the resistivity of the rotor surface respectively by the increasing the resistance between the bars. [7]

This treatment is made as follows: the rotor (with machined shaft, but not finished on the bearing-seats) having the surface of the rotor core machined, is introduced in an oven and the temperature is increased at 400 ^{o}C and then maintained for 2 hours.

Then the rotor is cooled suddenly in water up to maximum 30̊C. Using copper instead of aluminum in the execution of the squirrel cage leads to the decreasing of the rotor resistance, of the losses in cage and, also, leads to increasing of efficiency. For increasing the efficiency, it was worked on the ventilation losses by using fans with smaller external diameter.

3. CONCLUSIONS

The energetical efficiency growth in the electrical drives could determine a reduction of energy necessary with 6,5%. If estimate that every saved kWh leads to reduce the CO_2 emissions with one kg of CO_2 , for Romania, to a energy production of 45TWh/year , the gross energy necessary is less with 3,25% and is corresponding about $1,45\cdot10^6$ tons of CO_2.

Worldwide, electric motors represent around 50% of electricity consumption. Promoting market uptake of efficient motors and drives is an important contribution to the fight against climate change.

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USING SENSORS WITH MODBUS COMMUNICATION RTU INTO A DATA ACQUISITION SYSTEM

NICOLAE PĂTRĂȘCOIU[1], COSMIN RUS[2], CECILIA ROȘULESCU[3] , NICOLETA NEGRU[4]

Abstract: In this paper we propose an application written in LabVIEW through which a number of transducers or sensors are controlled so that the data from them are taken according to a certain algorithm and also this application realize the data processing. Control consists in selection for each of these transducers, their inputs selection and retrieves information from them. The physical connection between used transducers and master is made through RS-485 bus and the transmission protocol used is Modbus RTU.

Keywords: RS-485 interface, environmental sensors, Modbus RTU, LabVIEW.

1. INTRODUCTION

It is known that a data acquisition system can be defined as a measurement system that allows both visualization and recording of the evolution over time of several analog or numerical quantities.

The traditional operator's control function has been replaced by instruments and sensors that give very accurate measurements and indications, making the control function totally operator-independent. The processes can be fully automated. Instrumentation and sensors are an integral part of process control, and the quality of process control is only as good as its measurement system [1].

The instrumentation and sensors send the collected data, representing the controlled quantities' values through electrical signals. The current practice involves their digital transmission, that's means the transfer of binary codes to the equipment that allows the visualization or processing of this acquired data.

Here are many solutions both in terms of the hardware configuration of the data transmission structure and software solutions for their implementation. One of

[1] Associate Prof. Eng. Ph.D. at the University of Petroşani, nicolaepatrascoiu@upet.ro
[2] Eng.,Ph.D. student at the University of Petroşani, cosminrus@upet
[3] Professor, Grigore Geamănu School, ceciliarosulescu@yahoo.com
[4] Ph.D. student, Systems engineering, University of Petrosani, nicoletanegru@upet.ro

these possibilities is to use the RS-485 serial transmission bus together with the Communication Modus protocol [2].

Data collection, from different environments, can be done by manual measurements and their subsequent manual or computerized processing [3]. Their real-time data acquisition brings a new perspective to the scientific analysis of the information contained [4].

Different methods and structures are been developed following the different aspects of environmental monitoring systems. Thus a very important aspect is related to the distance between the measurement points and the data processing location. If these distances are large, different radio technologies are used for data transmissions, such as GSM and wireless standards as IEEE 802.15.4 or ZigBee protocols [5].

However, if these distances are of the order of tens or hundreds of meters, it is possible to use transmission technologies using various physical environments. This second variant has the advantage that it also offers the possibility of remote powering of nodes and sensors.

The solution that we propose through this paper comes to complete the known solutions, by the fact that the data collection is done according to a specific algorithm. This algorithm aims to obtain functional characteristics of the input-output type based on predefined values of the input quantities. Thus, automatic measurements are performed and graphs of the evolution of the quantities subject to observation under predetermined conditions are provided to the user.

The algorithm is validated by means of a laboratory stand in which various transducers are used for various physical quantities connectable on the RS-485 bus with data transfer via Modbus RTU protocol.

2. HARDWARE STRUCTURE

The used sensors are a family of environment sensors with an RS-485 interface and these communicate using standard Modbus RTU protocol. We used the Tibbo four types of sensors:

1. temperature sensor (BP#01),
2. combined temperature and humidity sensor (BP#02),
3. light sensor (BP#03),
4. 3-axis accelerometer (BP#04).

All of these are typically wired to a twisted pair cable, which distributes power and carries RS485 "+" and "-" lines and sensors accept the supply voltage in the 4V to 15V range.

Each of the 4 sensors used in the acquisition system is made using the measurement integrated circuits specific to the controlled quantities. The structure circuits of the four sensors used, as well as their main measurement parameters, are presented in the table 1 [6]:

Table 1. ***The structure circuits of the four sensors used***

Type of sensor	Measurement IC	Measurement specifications
BP#01 – ambient temperature sensor	MCP9808 Microchip	➢ Measurement range: -40°C to + 125°C ➢ Measurement resolution: 0.25°C ➢ Measurement accuracy: ± 0.5 °C
BP#02 – ambient temperature and humidity sensor	HIH6130 Honeywell	1. Temperature measurement ➢ Measurement range: -25°C to 50°C ➢ Measurement resolution: 0.5°C ➢ Measurement accuracy: ± 0.5 °C 2. Humidity measurement: ➢ Measurement range: 10 to 90% RH ➢ Measurement resolution: ±0.1% RH ➢ Measurement accuracy: ±5% RH4 ➢ Temp. range for valid humidity measurements: 5°C to 50°C
BP#03 – ambient light sensor	BH1721FVC Optical Sensors	➢ Measurement range: 1 to 65528 lux ➢ Measurement resolution: 1 lux ➢ Measurement accuracy: 1 lux
BP#04 - 3-axis accelerometer	ADXL312 Analog Devices	➢ Independent X, Y, and Z axes ➢ Measurement range for each axis: ±6G ➢ Measurement resolution for each axis: 0.003G ➢ Measurement accuracy for each axis: 0.1G

Figure 1 shows the sensor capsule, with the specification that it is common to all 4 types of sensors used.

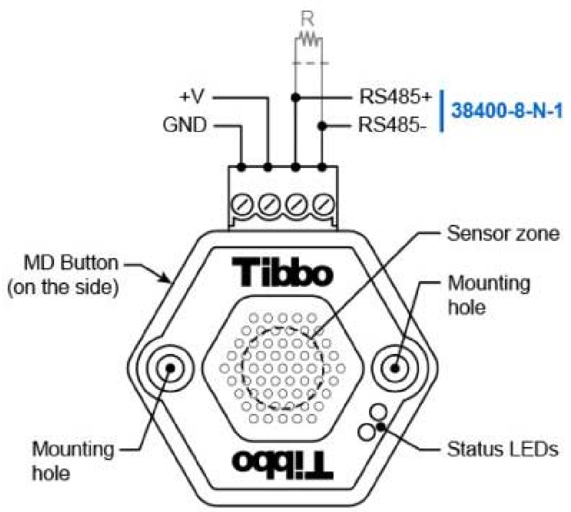

Fig.1. The connector and control elements of the used sensor

The RS-485 applications use data communication over twisted-pair cable because the noise from external sources couple equally into both signal lines as common-mode noise, which is rejected by the differential receiver input.

Using only one signal pair means half-duplex communication mode and that implies the data driving and receiving to occur at different times and necessitate the controlled operation of all nodes via direction control signals, such as Transmitter/Receiver Enable signals.

RS-485 standard conforms transmitters provide a differential output of a minimum 1.5 V across a 54-Ω load, whereas standard conform receivers detect a differential input down to 200 mV.

The two values provide a sufficient margin for a reliable data transmission even under severe signal degradation across the cable and connectors. This robustness is the main reason why RS-485 is well suited for long-distance networking in a noisy environment.

Based on these considerations is build the experiment configuration with the sensors connected to the RS-485 bus and this configuration is shown in Fig. 2

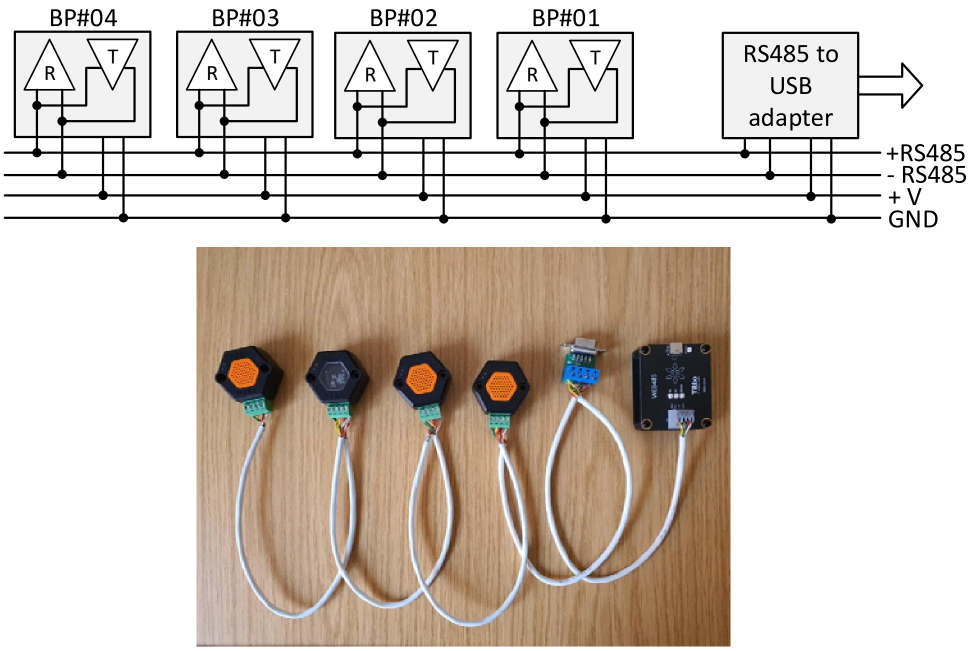

Fig.2. The diagram and the setup of the experiment.

Because the sensors, which represent the slave devices, communicate with a master device or equipment through RS-485 serial bus and when the master device is a PC or laptop they should have a compatible port for connection to this serial bus.

The current and usual PC or laptop communication port is the USB port and in these cases for connecting the sensors is required a USB to RS-485 adapter. In developing this application is used the UT-850 converter (a Data Communications product), which ensures a data transfer rate of up to 921.6 Kbps. This RS-485/422 to USB converter adds a virtual serial port on a desktop or laptop so that the outputs are automatically configured as additional COM ports [7], [8].

Parameters of the data communication through RS-485 bus are:

- Half-duplex (two-wire) RS-485 interface
- Communications parameters: 38400-8-N-1
- Modbus RTU protocol
- Sensors powered via the USB port and RS-485 adapter [9]

3. SOFTWARE IMPLEMENTATION

The software used to control the data acquisition from the sensors and also the data processing that we propose in this paper is built in the LabVIEW graphical programming environment and like all applications builds in LabVIEW is named virtual instrument.

A virtual instrument has three components, i.e., a front panel that is the user interface, a block diagram that is the proper program and icon used in the hierarchical structure of the virtual instrument.

The virtual instrument build for this application consists of the main program and a number of subprograms, called SubVI used to simplify the diagram block configuration.

This programming environment was chosen due to its ease of use, the multitude of functions and libraries available and even due to the fact that in the current context of the development of IoT technologies there are more and more implementations of specific IoT programs in LabVIEW. Also, this programming environment is widely used in terms of creating hardware and software platforms that allow the development of online laboratories both in the IoT context and especially in the current pandemic context.

3.1. Front panel

The front panel consists of three components through which the user can interact with the virtual instrument.

The first component is dedicated to the necessary settings for communication with the sensors on the bus via the Modbus protocol. The parameters are set according to the previous specifications [9].

The second component is used for the selection of one of the two working modes, namely: manual query (acquisition), figure 4, or automatic query (acquisition), figure 5. For the manual query, the user has a TAB control to choose the sensor to be read (BP # 01 ... BP # 04).

For the automatic query, all the 4 sensors will be interrogated cyclically, thus 7 values of the measured quantities will be displayed simultaneously: temperature from the BP # 01 sensor, temperature and humidity from the BP # 02 sensor, light intensity from the BP # 03 sensor, as well as the movements along the X, Y and Z axes from the BP # 04 sensor (Giro).

The third component offers the user the processed data in the form of a graph with every quantity evolution in time for the manual query, (figure 3) respectively these quantities in the form of a table which is displayed all the values and the time stamp of their acquisition (figure 4).

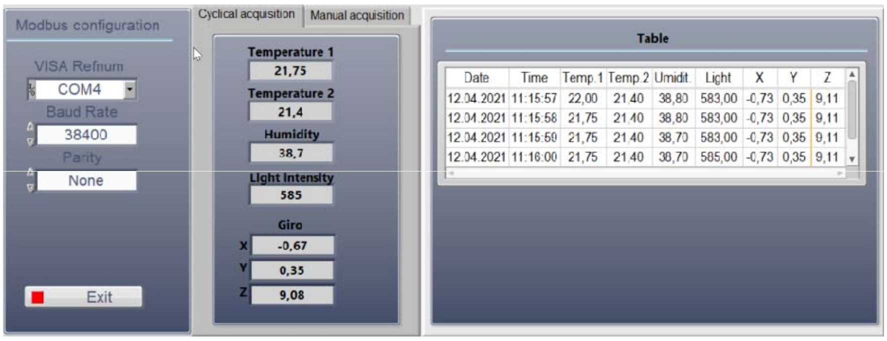

Fig.3. Front panel in the Manual Acquisition mode

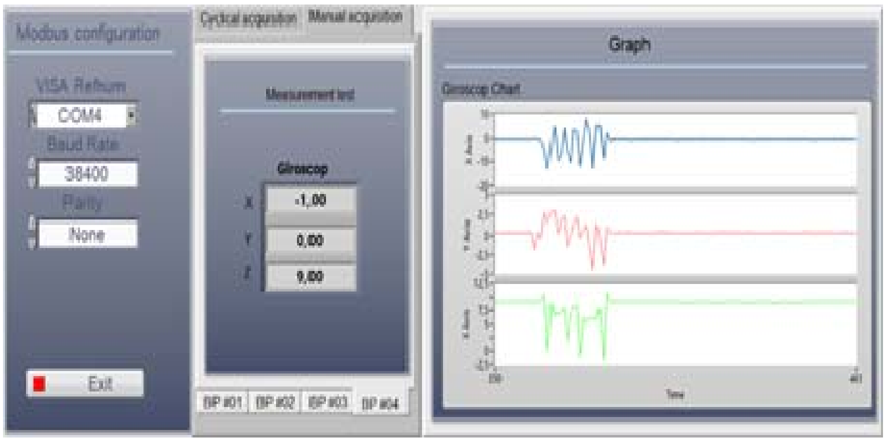

Fig.4. Front panel in the Cyclical Acquisition mode

3.2. Block diagram

The block diagram represents the program itself and is built with operations, functions, and programming structures from LabVIEW libraries.

The main programming structure in making the virtual instrument is a **WHILE** loop that makes the program work until the user presses the **STOP** button. While running the program, the user can always switch between the two operating modes of the virtual instrument, namely, **Manual Acquisition** mode or **Cyclic Acquisition** mode.

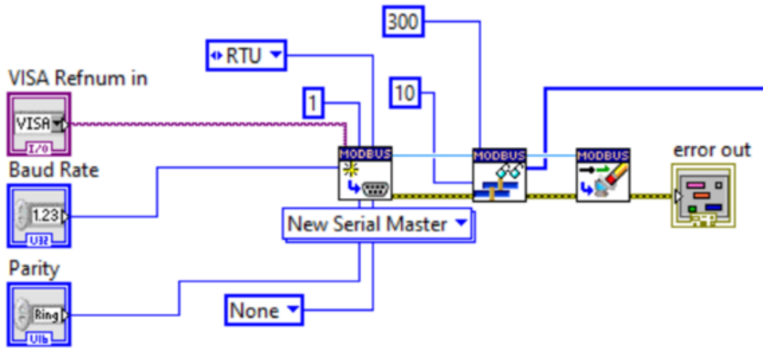

Fig.5. Modbus reading functions

Switching between the two working modes is performed by means of a Case structure controlled with **TAB Control**.

For the **Manual Acquisition** mode, the user has another tab control, **Select Device**, with which he can select any of the four sensors on the bus. The selection is made by the ID of each sensor and to read the information available to it is chosen is used the list of Modbus registers for each sensor. Based on the two identifiers, subVIs are made for each of the 4 sensors using Modbus functions from the NI Modbus library, as shown in fig.5.

The measured values are thus taken over and transmitted to **Chart** type indicators to represent their evolution over time. Each graphical indicator is activated with the selection of the respective sensor and for this their **Property** type nodes are used with the choice of the **Visible** property. The block diagram of the virtual instrument for the operation corresponding to the **Manual Acquisition** mode is presented in figure 6.

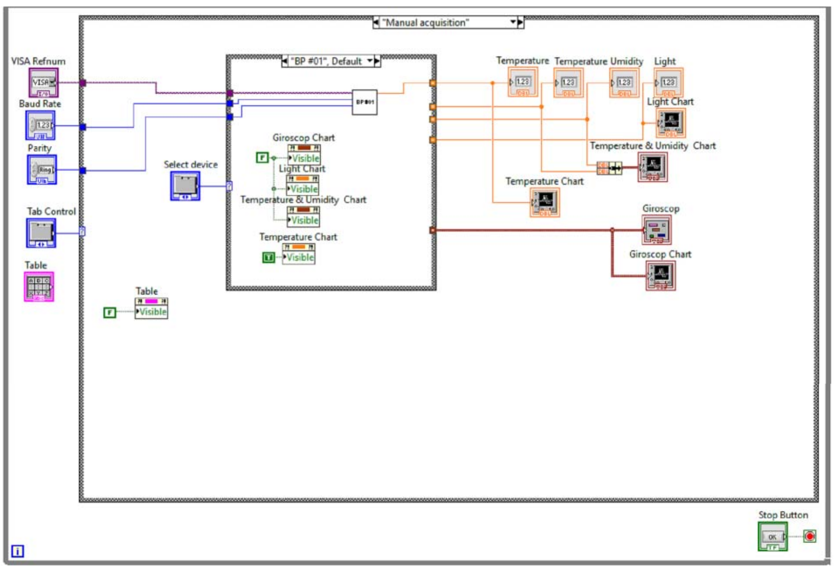

Fig.6. Block diagram of the **Manual acquisition** mode

By choosing the **Cyclic Acquisition** operation mode on the front panel, indicators for each size will be available and their values are read by including a **FOR** loop in the structure of the block diagram. The number of cycles required to read the sensors is set so that constant 4 is connected to the **Count terminal**. The block diagram of the virtual instrument for the operation corresponding to the **Cyclical Acquisition** mode is presented in figure 7.

The selection of each sensor is made by using the iteration variable of this structure which also controls a **CASE** structure by connecting that to the **Case selector**. Thus, in each cycle, the iteration variable is incremented and, by default, the next sensor is selected. This selection procedure is resumed after each reading package of all sensors.

The iterative reading of each sensor is done by calling the same SubVI used in the manual acquisition mode.

Because the values read on the bus correspond to a single sensor at a time, all other sensors send the value 0 at that time, in order to retain all the values, read in a cycle of the **FOR** loop, a displacement register associated with this **FOR** structure is used.

The values read from each sensor are taken through local variables and converted from numeric format to string format via the **Number to Fractional String Function**. These functions convert a number to an F-format (fractional notation), floating-point string at least width characters wide or wider if necessary.

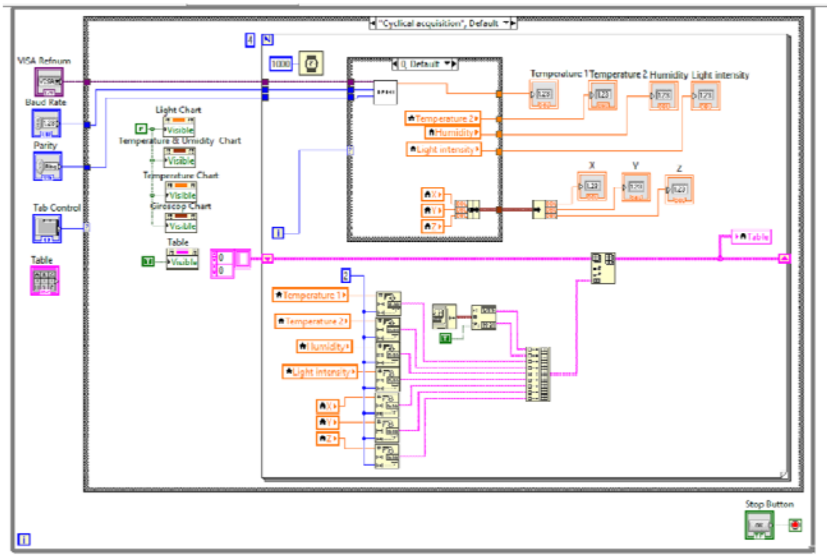

Fig.7. Block diagram of the **Cyclical acquisition** mode

The strings representing the read values are added with the information about the time (date and time) of their acquisition obtained with the **Gate Date/Time in Seconds** function and all are grouped in an array using the **Build Array** function.

Each new data packet is inserted into the array containing data from previous acquisitions, retrieved through the **Shift Register**, using the **Insert into Array** Function. All these data are sequentially displayed in **Table**.

Although it has imposed constraints since its inception more than 40 years ago, related to the speed of data transmission, the maximum number of devices that can be interconnected and possible problems caused by potential sources of interference, the Modbus protocol is widely used, especially in energy consumption monitoring applications and as seen in the present case and in terms of managing a network of sensors].

Even though there is more and more talk these days about wireless sensor networks (WSN), wired sensor networks have not yet reached their maximum potential and are still widely used, especially in environments where it is not possible to provide good protection against any type of interference. Thus, we will always try to find the simplest and reliable solutions to improve technologies that allow the acquisition of various data from different sensors to achieve high-performance monitoring systems, especially in the context of new IoT technologies.

4. CONCLUSIONS

This paper presents its own contribution related to the Modbus communication protocol and its use in a network of sensors. Thus, through its own algorithm implemented in LabVIEW, a manual and automatic reading of 4 types of sensors was achieved (temperature sensor, temperature and humidity sensor, light sensor and accelerometer). In the manual operation mode of the program, it allows the user to select the type of sensor from which he wants to take the data so that later they can be processed and displayed as a graph. In the automatic reading mode, an automatic reading of all the sensors is performed and the results are displayed in the form of graphs specific to each sensor.

Thus, an overview can be made of some important physical parameters in a certain area proposed to implement such a monitoring system using a network of sensors that use the Modbus communication protocol.

The hardware structure can be expanded to 255 sensors with the appropriate settings for their identifiers. The length of the bus, according to RS485 specifications, can be extended up to 1200 meters, which ensures a relatively large coverage area. Any addition of sensors in the structure implies a minimal intervention in the program regarding only the number of sensors that will be read either manually or cyclically.

The entire system of acquisition, processing and display of results implemented and presented in this paper has a special reliability being tested both in the laboratories of the University of Petrosani and in external environmental conditions and has proven its effectiveness and accuracy.

The major advantage of this system is that it can be included extremely smoothly and quickly in other specialized programs due to its modular structure, the entire program is built around a central core that deals only with data processing while for communication with the four sensors four subprograms (SubVI) are used which can be modified or used as desired.

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A NEW GAIN MATRIX OF THE ROTOR FLUX LUENBERGER OBSERVER FOR INDUCTION MOTORS – ROTATING METHOD OF THE EIGENVALUES

OLIMPIU STOICUTA[1]

Abstract: In this article presents a new gain matrix of the rotor flux Luenberger observer obtained based on the rotating method of the eigenvalues. In order to determine the gain matrix of the Luenberger observer, the mathematical model of the induction motor with iron loss, is used. The Luenberger observer estimates the position and modulus of the rotor flux space vector. The validation of the new gain matrix is done by numerical simulation in Matlab-Simulink.

Key words: induction motors, numerical simulation, Luenberger observer.

1. INTRODUCTION

In present, direct rotor field-oriented control (RDFOC) of induction motors, require estimation of the position and modulus of the rotor flux space vector [1] – [3].

The dynamic performances of vector control systems are closely linked of the quality of estimating the position and modulus of the rotor flux space vector [1] – [3].

In order to increase the quality of the estimation of the position of the rotor flux space vector, of the induction motor mathematical model with iron core losses is used [4], in the design of the gain matrix of the Luenberger observer. In this sense, the method of rotating the eigenvalues, proposed by R. Maceratini and G. Barba is used [5].

The essential contribution of this article is related to the presentation of a new gain matrix of the rotor flux Luenberger observer. In the final part of the article, the dynamic performances of the Luenberger observer, based on the new gain matrix, are evidenced by numerical simulation in Matlab-Simulink.

[1] *Ph.D. Associate Proffesor Eng., University of Petroşani, stoicuta_olimpiu@yahoo.com*

2. LUENBERGER OBSERVER

For a better understanding of the method for determining the new gain matrix of the Luenberger observer, in the following are presentation two mathematical models of the induction motor.

- *the stator currents-rotor fluxes model* (in which the iron losses are neglected) [1]:

$$\frac{d}{dt}\begin{bmatrix} \underline{i}_s \\ \underline{\psi}_r \end{bmatrix} = \begin{bmatrix} a_{11} & a_{13} - j \cdot a_{14} \cdot z_p \cdot \omega_r \\ a_{31} & a_{33} + j \cdot z_p \cdot \omega_r \end{bmatrix} \cdot \begin{bmatrix} \underline{i}_s \\ \underline{\psi}_r \end{bmatrix} + \begin{bmatrix} b_{11} \\ 0 \end{bmatrix} \cdot \underline{u}_s \tag{1}$$

where $\underline{i}_s = i_{ds} + j \cdot i_{qs}$; $\underline{\psi}_r = \psi_{dr} + j \cdot \psi_{qr}$; $\underline{u}_s = u_{ds} + j \cdot u_{qs}$; $j = \sqrt{-1}$;

$$a_{11} = -\left(\frac{1}{T_s \cdot \sigma} + \frac{1-\sigma}{T_r \cdot \sigma}\right);\ a_{13} = \frac{L_m}{L_s \cdot L_r \cdot T_r \cdot \sigma};\ a_{14} = \frac{L_m}{L_s \cdot L_r \cdot \sigma};\ a_{31} = \frac{L_m}{T_r};\ a_{33} = -\frac{1}{T_r};$$

$$b_{11} = \frac{1}{L_s \cdot \sigma};\ T_s = \frac{L_s}{R_s};\ T_r = \frac{L_r}{R_r};\ \sigma = 1 - \frac{L_m^2}{L_s \cdot L_r}$$

- *the stator currents-rotor fluxes-air-gap fluxes model* (the parallel model in which iron losses are taken into account) [4], [6]:

$$\frac{d}{dt}\begin{bmatrix} \underline{i}_s \\ \underline{\psi}_r \\ \underline{\psi}_m \end{bmatrix} = \begin{bmatrix} \alpha_{11} & \alpha_{13} & \alpha_{15} \\ 0 & \alpha_{33} + j \cdot z_p \cdot \omega_r & -\alpha_{33} \\ \alpha_{51} & \alpha_{53} & \alpha_{55} \end{bmatrix} \cdot \begin{bmatrix} \underline{i}_s \\ \underline{\psi}_r \\ \underline{\psi}_m \end{bmatrix} + \begin{bmatrix} \beta_{11} \\ 0 \\ 0 \end{bmatrix} \cdot \underline{u}_s \tag{2}$$

where $\underline{i}_s = i_{ds} + j \cdot i_{qs}$; $\underline{\psi}_r = \psi_{dr} + j \cdot \psi_{qr}$; $\underline{\psi}_m = \psi_{dm} + j \cdot \psi_{qm}$; $\underline{u}_s = u_{ds} + j \cdot u_{qs}$; $j = \sqrt{-1}$;

$$\alpha_{11} = -\frac{R_s + R_f}{L_{\sigma s}};\ \alpha_{13} = -\frac{R_f}{L_{\sigma s} \cdot L_{\sigma r}};\ \alpha_{15} = R_f \cdot \frac{L_r}{L_{\sigma s} \cdot L_{\sigma r} \cdot L_m};\ \alpha_{33} = -\frac{R_r}{L_{\sigma r}};\ \alpha_{51} = R_f;$$

$$\alpha_{53} = \frac{R_f}{L_{\sigma r}};\ \alpha_{55} = -R_f \cdot \frac{L_r}{L_{\sigma r} \cdot L_m};\ \beta_{11} = \frac{1}{L_{\sigma s}};\ L_r = L_{\sigma r} + L_m;\ L_s = L_{\sigma s} + L_m$$

The following notations were used in the mathematical models presented above: R_r, R_s – rotor/stator resistances; L_r, L_s– rotor/stator inductances; L_m – mutual inductance; R_f – iron loss resistance; T_r, T_s – rotor/stator time-constants; σ – leakage factor; z_p – number of pole pairs; ω_r – mechanical angular speed; $\underline{u}_s$ – stator voltage space vector; $\underline{i}_s$ – stator current space vector; $\underline{\psi}_r$ – rotor flux space vector; $\underline{\psi}_m$ – space vector air-gap flux.

Under these conditions, the relations that define the Luenberger observer are [6]:

$$\frac{d}{dt}\begin{bmatrix} \hat{\underline{i}}_s \\ \hat{\underline{\psi}}_r \end{bmatrix} = \begin{bmatrix} a_{11} & a_{13} - j \cdot a_{14} \cdot z_p \cdot \omega_r \\ a_{31} & a_{33} + j \cdot z_p \cdot \omega_r \end{bmatrix} \cdot \begin{bmatrix} \hat{\underline{i}}_s \\ \hat{\underline{\psi}}_r \end{bmatrix} + \begin{bmatrix} b_{11} \\ 0 \end{bmatrix} \cdot \underline{u}_s + G \cdot C \cdot \left(\begin{bmatrix} \underline{i}_s \\ \underline{\psi}_r \end{bmatrix} - \begin{bmatrix} \hat{\underline{i}}_s \\ \hat{\underline{\psi}}_r \end{bmatrix} \right) \quad (3)$$

where the estimated variables are denoted by "^"; $C = \begin{bmatrix} 1 & 0 \end{bmatrix}$ and G is gain matrix Luenberger

$$G = \begin{bmatrix} g_{11} + j \cdot g_{12} \\ g_{21} + j \cdot g_{22} \end{bmatrix} \quad (4)$$

To determine the elements of the matrix G, in the following we will define the following matrix

$$\Gamma = \begin{bmatrix} \alpha_{11} & \alpha_{13} \\ 0 & \alpha_{33} + j \cdot z_p \cdot \omega_r \end{bmatrix} \quad (5)$$

From the above relationship, we notice that Γ is a submatrix of the state matrix (first 2 rows and 2 columns), from the component of the mathematical model defined by the relation (2).

Following the tests, it observed that the spectrum of eigenvalues of the matrix Γ is located to the left of the complex plane. The spectrum of the eigenvalues of the Γ matrix is obtained from the following relation

$$\det\left[\lambda_m \cdot I_2 - \Gamma\right] = 0 \quad (6)$$

where I_2 is the second order unit matrix and $\lambda_m = \lambda_{m1} + j \cdot \lambda_{m2}$ is the spectrum of eigenvalues of the matrix Γ.

Under these conditions, the elements of the gain matrix (G) are determined from the following imposed relation

$$\lambda_e = k_L \cdot \lambda_m ;\ \ k \in £ \quad (7)$$

where: $\lambda_e = \lambda_{e1} + j \cdot \lambda_{e2}$ is the spectrum of the Luenberger observer eigenvalues; $k_L = k_1 + j \cdot k_2$ is the proportionality coefficient; £ is the set of complex numbers.

The relation of determining the spectrum of the Luenberger observer eigenvalues is

$$\det\left[\lambda_e \cdot I_2 - \left(A - G \cdot C\right)\right] = 0 \quad (8)$$

where $A = \begin{bmatrix} a_{11} & a_{13} - j \cdot a_{14} \cdot z_p \cdot \omega_r \\ a_{31} & a_{33} + j \cdot z_p \cdot \omega_r \end{bmatrix}$.

Taking into account the relation (7), following the calculations we obtain the elements of the matrix G.

$$g_{11} = a_{11} + a_{33} - k_1 \cdot (\alpha_{11} + \alpha_{33}) + k_2 \cdot z_p \cdot \omega_r \tag{9}$$

$$g_{12} = z_p \cdot \omega_r \cdot (1 - k_1) - k_2 \cdot (\alpha_{11} + \alpha_{33}) \tag{10}$$

$$g_{21} = a_{31} + \frac{a_{11} - g_{11}}{a_{14}} + \frac{\alpha_{11}}{a_{14}} \frac{(k_2^2 - k_1^2)(z_p^2 \cdot \omega_r^2 + \alpha_{33} \cdot a_{33}) + 2 \cdot k_1 \cdot k_2 \cdot z_p \cdot \omega_r (a_{33} - \alpha_{33})}{z_p^2 \cdot \omega_r^2 + a_{33}^2} \tag{11}$$

$$g_{22} = \frac{\alpha_{11}}{a_{14}} \cdot \frac{(k_2^2 - k_1^2) \cdot z_p \cdot \omega_r \cdot (a_{33} - \alpha_{33}) - 2 \cdot k_1 \cdot k_2 \cdot (z_p^2 \cdot \omega_r^2 + \alpha_{33} \cdot a_{33})}{z_p^2 \cdot \omega_r^2 + a_{33}^2} - \frac{g_{12}}{a_{14}} \tag{12}$$

If in the above relations, we impose $k_2 = 0$ and $k_1 > 1$, we obtain the elements of the matrix G based on the method of H. Kubota (proportional eigenvalues method) [7]. The elements of the matrix G in this case are identical to those proposed by O.Stoicuta [6].

On the other hand, if $k_1 = k \cdot \cos(\theta)$ and $k_2 = k \cdot \sin(\theta)$, the matrix G e is obtained based on the method proposed by R. Maceratini and G. Barba (method of rotating the eigenvalues) [5].

In this case, the proportionality coefficient from relation (7) becomes [5]:

$$k_L = k_1 + j \cdot k_2 = k \cdot e^{j \cdot \theta};\ 0 < \theta \le \pi/4\ ;\ k > 1 \tag{13}$$

From the above relation, it is observed that the method proposed by R. Maceratini and G. Barba is identical with the method proposed by H. Kubota, with the difference that simultaneously with the amplification of the eigenvalues by means of the proportionality coefficient k, there is also a rotation of the eigenvalues with an θ angle.

In the above relation, the θ angle can be chosen either constant or depending on the mechanical angular speed. (V. Bostan proposed this idea [8])

$$k_L = k_1 + j \cdot k_2 = k \cdot e^{j \cdot \theta};\ \theta = k_m \cdot \omega_r\ ;\ k > 1 \tag{14}$$

where $k_m = \theta_{\min} / \omega_{r_{\max}}$.

If in relation (7), we choose $\Gamma = A$, we obtain the elements of matrix proposed by G. R. Maceratini and G. Barba [5]. The matrix G in this case is defined by the following elements [5]

$$g_{11} = (1 - k_1) \cdot (a_{11} + a_{33}) + k_2 \cdot z_p \cdot \omega_r \tag{15}$$

$$g_{12} = (1 - k_1) \cdot z_p \cdot \omega_r - k_2 \cdot (a_{11} + a_{33}) \tag{16}$$

$$g_{21} = (1 - k_1^2 + k_2^2) \cdot (a_{31} + \gamma \cdot a_{11}) - \gamma \cdot g_{11} \tag{17}$$

$$g_{22} = -2 \cdot k_1 \cdot k_2 \cdot (a_{31} + \gamma \cdot a_{11}) - \gamma \cdot g_{12} \tag{18}$$

where $\gamma = 1/a_{14}$.

On the other hand, if in the above relations we impose $k_2 = 0$ and $k_1 > 1$, we obtain the elements of the matrix G, proposed by H. Kubota [7].

3. SIMULATION RESULTS

The validation of the gain matrix Luenberger - proposed (defined by relations (9) - (12)), is done by numerical simulation of the Luenberger observer in Matlab-Simulink. In this sense, a 1.5[kW] induction motor is used [6], [9]. The Luenberger observer is tested in open loop. In the numerical simulation, the induction motor starts based on the DOL (Direct On-Line) method, in load ($T_L = 10[N \cdot m]$).

The simulation results are presented in the following figure.

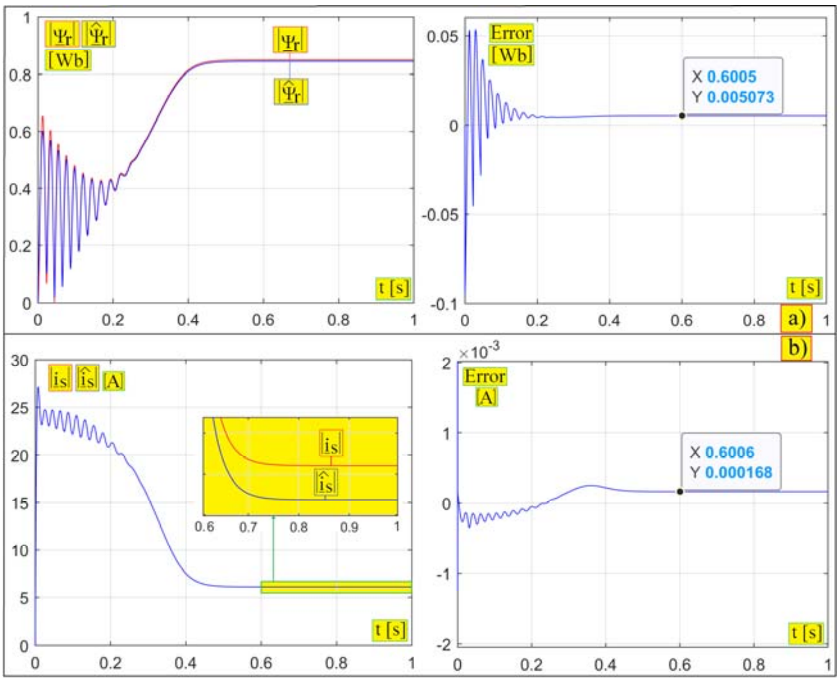

Fig.1 The time variation of the rotor flux space vector (a) and stator current space vector (b)

In the numerical simulation, formula (13) was used, in which: $k = 1.2$; $\theta = 30^{o}$. Based on the results in Fig. 1 we can say that the Luenberger observer estimates the state vector of the induction motor very well (the errors being very small). Tests have shown that the errors increase as the θ angle decreases. The optimal choice of the parameters k and θ in formula (13), as well as the study of the stability of the Luenberger observer, will be the subject of another article.

4. CONCLUSIONS

The article extends the field of research of the full-order state observers for the induction motors. The article presents a new gain matrix of the Luenberger observer.

Numerical simulation tests have shown that the new gain matrix of the observer allows the state vector estimation with very good errors. The Luenberger observer presented in this article successfully can be used in the vector control systems of induction motors.

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DETERMINATION OF THE BASIC PARAMETERS OF A PERFORMING FILTER FOR COMPENSATION OF THE DEFORMING REGIME

ILIE UTU[1], MARIA DANIELA STOCHITOIU[2]

Abstract: In this paper were elaborated the sizing procedures for the main power components of the parallel active filter. The procedures are a set of automated tools that allow an optimal and quick choice of components. First of all, the filter load is established, starting from the parameters of the non-linear consumer to be compensated (nominal current, harmonic content), the proposed compensation level and the compensation strategy to be applied. Then the criteria for sizing inductiveness from the output of the active filter are established.

Particular attention is paid to the passive filter for the switching waving. Different ways of location and their implications are reviewed, different filter topologies are identified, the advantages and constraints of each are examined.

Key words: *Harmonics, filters, adjustable electric drives*.

1. INTRODUCTION

In modern energy systems, nonlinears have an increasing share; the widespread use of adjustable AC drives, having rectifiers with diodes as the first floor of conversion, of DC drives based on rectifiers with thyristors, of cycconverters has as a consequence the increase of the harmonic content of the current absorbed by consumers.

The disadvantages of these current harmonics are well known [1], [6]:

- increased power dissipation in cables, transformers, electric machines, and capacitors.
- in three-phase systems with null, the multiple harmonics of three gather in the null conductor so that the current in this conductor reaches unacceptable values.
- the current harmonics cause the distortion of the supply voltage of all consumers, so linear consumers are also affected, which does not generate

[1] *Associate Professor Eng., Ph.D. at the University of Petrosani, ilieutu@upet.ro*
[2] *Associate Professor, Eng., PhD, University of Petrosani, branaliliana@gmail.com*

current harmonics.

- harmonics accelerate the processes of aging of insulation and reduce the life of installations.

The limitation methods can be divided into three groups:

- passive filters,
- harmonic isolation and reduction transformers,
- active filters

Active filters are static power converters that can perform various functions. The current filtration schemes allow the synthesizer of any form of current with harmonic components of relatively high frequencies, sufficient for most practical cases and at increasing power levels [2], [5].

2. FILTER OUTPUT INDUCTANCE

The procedure for sizing the inductance at the filter output is based on the following criteria:

- A *lower limit* of the inductance of **LF(min)** is set so as to limit the flow of current due to the components with the switching frequency and its multiplies (e.g. to 5...15% of the injected current).
- An *upper limit* of the inductance of **LF(max)** is set so that the minimum rate of variation of the current generated by the filter is higher than the maximum speed of variation of the consumer's current; only in this way is an adequate compensation of the harmonics possible.

Following the performance of some simulations, the variation of the ratio between the apparent power of the filter and the apparent power of the nonlinear consumer can be determined in case both the reactive power and the current harmonics are compensated (fig.1), [3], [4]. Similarly, the variation of the ratio between the apparent power of the filter and the apparent power of the nonlinear consumer can be determined if only the current harmonics are compensated (fig.2.)

Lower limit of inductance LF(min)

A relationship of general character is obtained by relating the waving to the maximum value of the current of the $\hat{I}_F$ filter, as in the relation (1); for $\hat{I}_F$, the maximum value of the consumer current can be adopted, i.e. I_d (direct current at the rectifier output)

$$\frac{\hat{I}_{F,ripple}}{\hat{I}_F} = \frac{V_{dc}}{12 \cdot L_F \cdot f_{sw} \cdot I_d} \cdot 100 \quad [\%] \tag{1}$$

Upper limit of inductance LF(max)

$$\frac{di_F}{dt} = \frac{\frac{2}{3}V_{dc} - \sqrt{\frac{2}{3}}V_{LL}}{L_F} \tag{2}$$

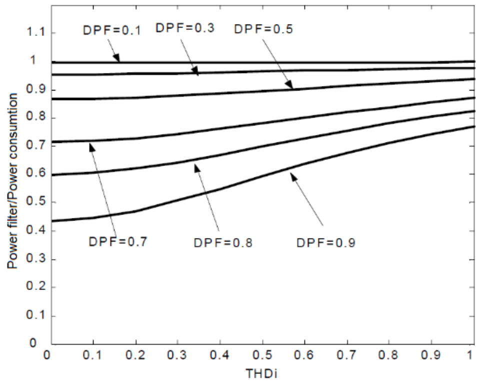

Fig.1. Variation of the ratio between the apparent power of the filter and the apparent power of the nonlinear consumer in case the reactive power and the current harmonics are compensated

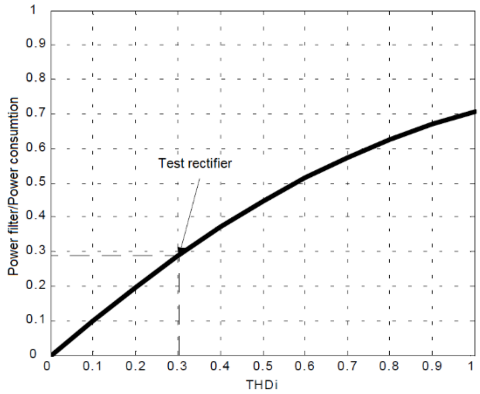

Fig.2. Variation of the ratio between the apparent power of the filter and the apparent power of the nonlinear consumer in case only the current harmonics are compensated

In fig. 3 is represented the relation (1) for f_{sw} = 10 kHz, having as parameter V_{dc} and in fig. 4 is represented the relation (2), having as parameter Vdc.

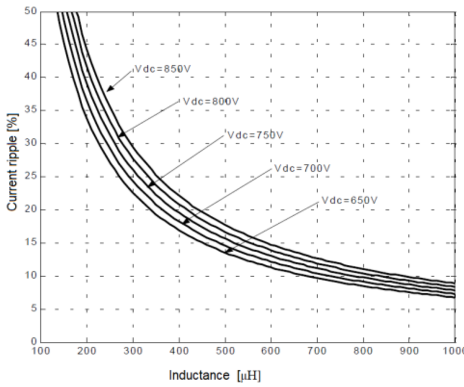

Fig.3. Curves $i_{F,\,ripple}$=f(L_F) for determination the minimum inductance of the L_F inductance (min)

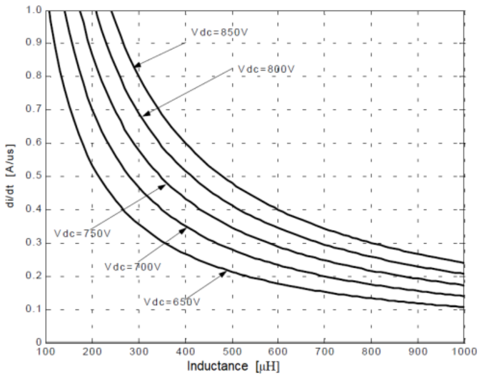

Fig.4. Curves di_F/dt = f (L_F) for the determination maximum inductance limit

3. FILTER CAPACITOR

The procedure for sizing the filter capacitor is based on the balance of powers. The calculation assumptions are as follows:

- The active power dissipated in the converter is negligible.
- The energy stored in the output inductiveness is negligible.

- The continuous voltage is kept constant with the help of the specially designed adjustment loop, so the undulating component of the continuous voltage $v_{dc,\sim}(t)$ is much lower than the mean value V_{dc}

$$v_{dc}(t) = V_{dc} + v_{dc,\sim}(t) \cong V_{dc} \quad (3)$$

- Since the chosen switching frequency - f_{sw} (10kHz) is much higher than the frequency of the network, f_s the undulating component at the switching frequency and its multiplies of the current absorbed by the capacitor $i_{C,sw}$ is negligible in relation to the low frequency undulating component of the current absorbed by the capacitor $i_{C,\sim}$ (multiples of the network frequency)

$$i_c(t) = I_c + i_{c,\sim}(t) + i_{c,sw}(t) \cong i_{c,\sim}(t) \quad (4)$$

In relation (4) the mean component I_C is null as a consequence of the fact that the losses are neglected in the converter – the first calculation hypothesis.

- Only the current harmonics are compensated, the reactive power is not compensated.

It is useful to express the curling component Δv_{dc} relative to the mean value V_{dc}

$$\frac{\Delta v_{dc}}{V_{dc}} = \frac{THD_I}{\sqrt{1+THD_I^2}} \cdot \frac{S_L}{C_d \cdot V_{dc}^2 \cdot \omega_S} \quad (5)$$

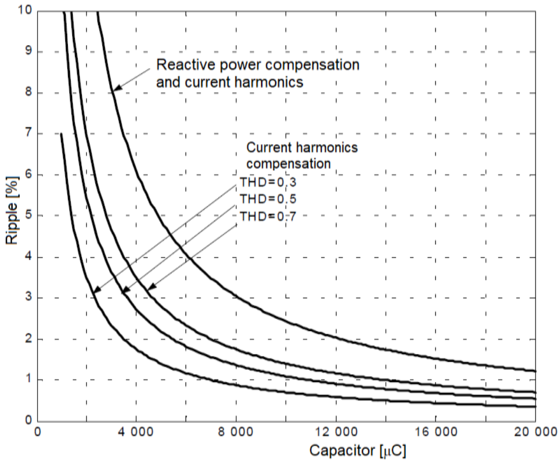

Fig.5. Condenser value curves filtering

A useful form of materialization of the sizing procedure is the representation of the relationship (5) as in Fig. 5.
The dependence of the relative ripple on the value of the filtering capacity is highlighted. It is observed that if it is desired to compensate the reactive power, the required value of the filtering capacity is much higher at the same ripple percentage, [4], [5], [6].

4. PASSIVE FILTER FOR SWITCHING RIPPLE

In the absence of measures to limit the switching wave of the current absorbed by the active filter, these harmonics enter the non-line consumer to compensate and the supply network, which may result in the deformation of the supply voltage in the CCP.

Simple active filter structures use the output inductances of the L_F filter as the only interface between the converter and the network [7].

But in order to have a good dynamic of the active filter, a maximum limit is imposed for the value of the L_F inductance; thus, a very high switching frequency is required to maintains the switching ripple of the absorbed current within acceptable limits, only with a low output L_F inductance. In order to achieve good dynamic performance and eliminate current ripple at a lower switching frequency, a passive filter, located between phases, is required [4], [8].

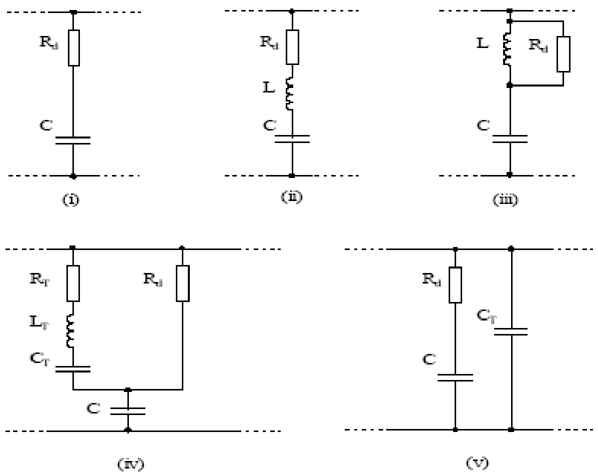

Fig.6. Passive filter topologies for switching waving

The objective of this filter is to remove the current harmonics with the switching frequency and its multiples, produced by the converter. If properly designed, the passive filter for the switching ripple can also attenuate the upper harmonics in the current absorbed by the nonlinear consumer, located above the frequency band of the active filter regulator, [6].

Some of the more widespread typologies for passive filters are shown in Fig. 6.

The approach in Fig. 6, consists in creating two separate paths: one path LT, C_T, C on the switching frequency of the converter (fig. 7a) and another of broadband R_d, C (fig. 7b). The resistor R_d shall be sized to ensure the damping of any resonance possibility with the network or consumers, at frequencies above the active filter band.

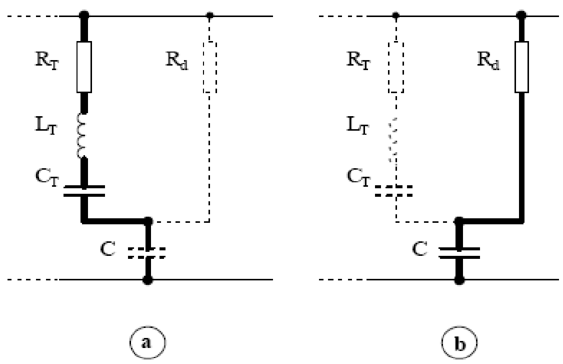

Fig.7. Topology in Fig. 6,
(a) The path for the switching frequency.
(b) Broadband path.

Therefore, it is not necessary to increase the frequency band of the converter, in order to achieve active damping of the resonances.

The value of the network frequency current is determined by the capacitor C. At the network frequency the impedance of the capacitor C is much higher than the resistance R_d and, as a result, the fundamental voltage is found on the capacitor C, and on the circuit granted to L_T, C_T the amplitude of the fundamental component of the network voltage is very low (fig. 8).

5. SIZING THE BASICS

5.1 Task specification

The active filter shall compensate the non-linear consumer's current harmonics so that the distortion factor of the total current absorbed is within the limits imposed. The inverter on which the active filter is implemented is a deck with IGBT transistors of 200 A, 1700 V, SKM type 200GB173D1, cooled with an axial fan type SKF16B. A current capability of the inverter of 55 A at 16 kHz has been estimated (fig.9).

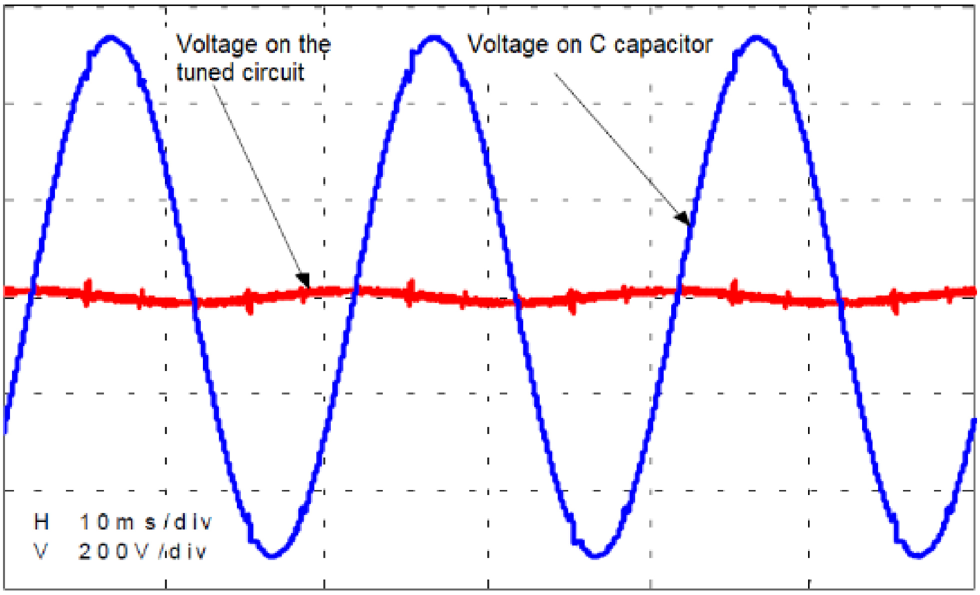

Fig.8. Topology from Fig. 6,
The fundamental voltage is found on the C capacitor

5.2. Passive filter sizing for switching waving

The purpose of the passive filter is to create a way of deflection of the waving current so that it does not penetrate the power supply network, [1], [4]. The efficiency of the passive filter can be assessed by means of the current transfer factor with the output in short circuit $\mathbf{H_{21}}$. The (ideal) efficiency criteria of the passive filter are:

- module | $\mathbf{H_{21}}$| to be unitary throughout the frequency band and null to the frequency f_{SW} and
- the phase shift inserted to be zero throughout the frequency band.

Of course, an achievable physical filter will partially meet these requirements. It is chosen for the passive filter the topology in fig. 6, which has an optimal structure. Let the value of the capacitor C capacity of 60 μF; its impedance at 50 Hz is about 53 Ω and, if you want to reduce the voltage on the circuit granted {L_T, C_T} toabout 10 V, it results in a resistance R_d of about 1.3 Ω. (Table no.1)

Table 1. ***Parameters of the filter***

f_{SW}	10.8	kHz
L_T	32	μH
C_T	50	μF
R	60	mΩ
C	60	μF
R_d	1.5	Ω

Fig.9. IGBT transistor bridge

Choose C_T=6.8μF and result in L_T=32μH. The parameters of the passive filter with the structure in fig. 5.9, are recapitulated in the table above; the resistance R_T is the resistance of the winding of the inductance L_T of about 50...100 mΩ, which leads to a quality factor of 50...100 for the circuit granted L_T , C_T.

6. CONCLUSIONS

All modern electrical and electronic equipment has switching sources or controls the power absorbed in one way or another and thus results in non-linear loads. Linear loads are relatively rare, uncontrolled incandescent lamps and uncontrolled heating systems are the only examples.

This class of equipment causes most of the problems caused by harmonics, encountered in industry and commerce, on the one hand due to the large number installed and on the other hand due to the type of harmonics they produce - with a multiple of three.

Due to the increase in the number of equipment and without the application of strict rules, followed by drastic measures, it is likely that harmonic pollution will increase. It is a risk for companies that have invested, based on good design practice, in the right equipment and in the right maintenance.

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CONSIDERATIONS ON THE EVOLUTION OF ELECTRICITY PRICES IN EUROPEAN UNION COUNTRIES IN RECENT YEARS

BRANA LILIANA SAMOILĂ[1], ILIE UTU[2]

Abstract: The last years have brought profound changes in the electricity sector materialized through: restructuring, liberalization, regulation, privatization. The late few years, significant electricity price increases took place in the electricity market, all over Europe and worldwide, which recorded record price increases almost every month.. the paper addresses an analysis of the increase in electricity prices in recent years in the countries of the European Union, seeking to identify its causes. we have detailed aspects related to the evolution of prices in romania, taking into account the price components.

Keywords: electricity, price, energy market

1. INTRODUCTION

From July 1st, 2007, when the energy market became competitive, all non-household customers have the right to opt for a free electricity supplier.

Starting January 1st, 2021 prices for supplying electricity to customers households are no longer regulated by ANRE (National Energy Regulatory Authority) [8].

The advantages of liberalizing the electricity market are:

- encouraging the increase of energy efficiency and improving the quality of the services provided;
- the possibility for consumers to negotiate electricity supply contracts;
- ensuring services in conditions of transparency, objectivity and non-discrimination;
- new mentalities, specific to the competitive environment.

2. ELECTRICITY RATES COMPONENTS FOR CONSUMERS

[1] *Associate Professor, Eng., PhD, University of Petrosani, branaliliana@gmail.com*
[2] *Associate Professor Eng., Ph.D. at the University of Petrosani, ilieutu@upet.ro*

In order to exercise the right of eligibility, the National Energy Regulatory Authority, ANRE, elaborates, establishes and monitors the application of the set of mandatory regulations at national level necessary for the functioning of the electricity sector and market.

The electricity produced in different types of power plants is introduced into the national energy grid (SEN) with the help of specialized equipment, is then transported through the high voltage networks of Transelectrica [7], and afterwards it is extracted from the grid, distributed through the medium and low voltage networks of distribution operators, which deliver it to consumers (households and non-households) and, in the end, consumed by them.

The price of electricity includes the following components (tab. 1) [3], [8]:

a) a component resulting from the application of regulated tariffs (ANRE), for the activities of transport, system services and distribution;

b) a negotiable tariff component, which represents the offer of the supplier to the consumer.

Table 1. ***Electricity price components***

Supplier offer price	**Rates regulated by ANRE**					
	Transport		**System services**	**Distribution**		
Negotiable rate	TG	TL	TS	HV	MV	LV

These rates are approved by order issued by ANRE and include [2],[8]:

- networking tariff (TG)

It requires a series of equipment with the help of which some energy will be transformed before it is introduced in a transport network. This tariff covers the costs for the purchase, maintenance and operation of such electrical equipment.

- system service rate (TS)

Once introduced, the electricity is transported through the transmission network, through the electrical networks, to the border with one of the 8 territorial electricity distribution networks in Romania. All this operation is done with costs that are covered by this tariff.

- network withdrawal fee (TL)

Then, also with the help of specific equipment, the electricity is extracted from the transmission system and delivered to the distribution networks. The equipment is bought and maintained with money from this tariff.

- distribution tariff (TD)

Once they have received the energy, the distributors have to pass it through the transformer stations, in order to bring it from high (HV), to medium (MV) and then to low voltage (LV). And all these costs are paid out of the money raised from this distribution fee.

The path of electricity from producer to consumer represents several transactions which means, for the consumer, the payment of the tariffs listed above. The money from these rates is divided. Specifically, the tariffs for network introduction, system service and network extraction go to Transelectrica, and the distribution tariffs reach the 8 operators of the existing regional distribution networks in Romania.

3. LAST YEARS EVOLUTION OF THE ELECTRICITY PRICE IN THE EUROPEAN UNION COUNTRIES

The world faces a global energy crisis. Demand for energy is climbing rapidly, but supply is down, [5].

The EU has been working to liberalize the electricity market since the second half of the 1990s. The directives adopted in 2003 laid down common rules for the internal markets in electricity and natural gas. Deadlines have been set for the opening of electricity markets, so that from 1 July 2007 customers were allowed to choose their supplier. In 2014, in response to a request from the European Council, the European Commission developed an in-depth analysis of energy prices and costs in Europe to help policymakers understand the underlying context, the impact of recent consumer price increases and policy implications. Data deficiencies have led to the recommendation to improve the detail, transparency and consistency of the collection of energy price data, as well as to the Commission proposal and the adoption of Regulation (EU) 2016/1952. Transparency in electricity prices is more effective when it is published and disseminated as widely as possible, i.e., at EU level.

Increased transparency in electricity prices should help to promote fair competition by encouraging consumers to choose between different suppliers. The price of electricity is a key element in a country's strategy for electricity supply, but also for consumers in order to manage costs as efficiently as possible. Electricity prices are of particular importance for international competitiveness, as electricity is usually a significant percentage of total energy costs for industrial consumers and service providers. Unlike the price of fossil fuels, which are usually traded on global markets at relatively uniform prices, electricity prices vary widely between countries around the world.

The price of energy in the European Union countries depends on a range of different supply and demand conditions, including the geopolitical situation, the national energy mix, import diversification, network costs, environmental protection costs, severe weather conditions, or levels of excise and taxation.

For household consumers in the EU (defined for the purpose of this article as medium-sized consumers with an annual consumption between 2 500 kWh and 5 000 kWh), electricity prices in the first half of 2021 were highest in Germany (EUR 0.3193 per kWh), Denmark (EUR 0.2900 per kWh), Belgium (EUR 0.2702 per kWh) and Ireland (EUR 0.2555 per kWh); see Figure 1. The lowest electricity prices were in Hungary (EUR 0.1003 per kWh), Bulgaria (EUR 0.1024 per kWh) and Malta (EUR 0.1279 per kWh). The price of electricity for household consumers in Germany was more than three times higher than the price in Hungary and 45.6 % higher than the EU average price.

In European Union countries, the rates of energy depend on a number of different supply and demand conditions: geopolitical state, energy mix, diversification of imports, grid costs, environmental protection costs, weather conditions, taxes amount.

To analyze the evolution of electricity prices for household consumers, we specify that in this category we refer to those whose annual consumption is in the range of 2500 kWh to 5000 kWh.

For household consumers the weighted average price for electricity in the first semester of 2021 was 0.2192 EUR/kWh, comparing to 0,1173 EUR/kWh in the second half of 2019. That mean an increase of 1.869 times during the last two years.

If we look at the price in 2020, average household electricity price was 0.213 EUR/kWh, meaning that in the first half of 2021 the price increased slightly compared with the same period of 2020.

As it can be seen in figure 1, prices were the highest in Germany - 0.3193 EUR/kWh (more than three times higher than the Hungarian price and 45.6% higher than the EU average price), Denmark -0.2900 EUR/kWh, Belgium - 0.2702 EUR/kWh and Ireland - 0.2555 EUR/kWh. The lowest prices were in Hungary - 0.1003 EUR/kWh, Bulgaria - 0.1024 EUR/kWh and Malta - 0.1279 EUR/kWh.

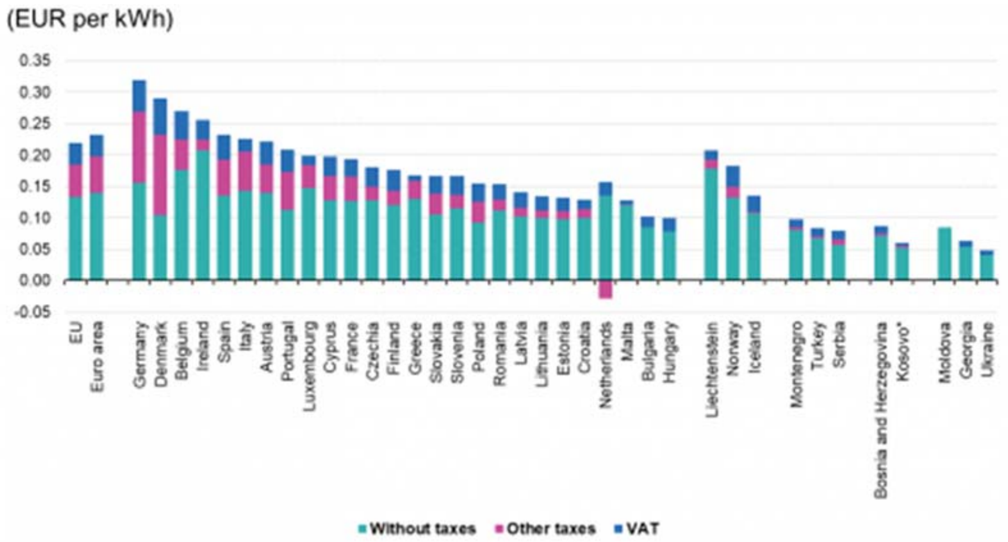


Fig.1. Electricity prices for household consumers in the first semester of 2021 (source Eurostat, [4])

In Romania, electricity price rose in the first half of 2021, compared with the first half of 2020 by 7%, one of the highest icrements in EU. Household electricity prices rose in 16 EU Member States

Household electricity prices rose in 16 EU Member States in the first half of 2021, compared with the first half of 2020. The largest increase (expressed in national currencies) was registered in Slovenia (+15%), ahead of Poland (+8%) and Romania (+7%).

In June 2021, in Romania, the electricity prices were:

- For households: 0.151 EUR/kWh; the average price in the world is 0.121 EUR/kWh.
- For business: 0.121 EUR/kWh; the average price in the world is 0.110 EUR/kWh.

The evolution of electricity prices for domestic consumers in EU countries since 2008 is shown in figure 2. The energy price, for electricity and grid only, rose rather more than the global inflation rate getting to 0.1338 EUR/kWh in the second half of the year 2013. From 2014 to 2019 it was quite constant. In the first half of 2021 it was 0.1339 EUR/kWh, a bit higher than the 0.1282 EUR/kWh at the end of 2020. The share of taxes increased by 8.8 % in the last 13 years, from 31.2% in 2008 to 39.4% in 2021.

For inflation-adjusted prices, the total price for domestic consumers, all taxes included, was 0.1914 EUR/kWh in the first semester of 2021 compared to 0.1604 EUR/kWh in the first half of 2008. We conclude the actual price without taxes is quite the same as the 2008 inflation-adjusted price.

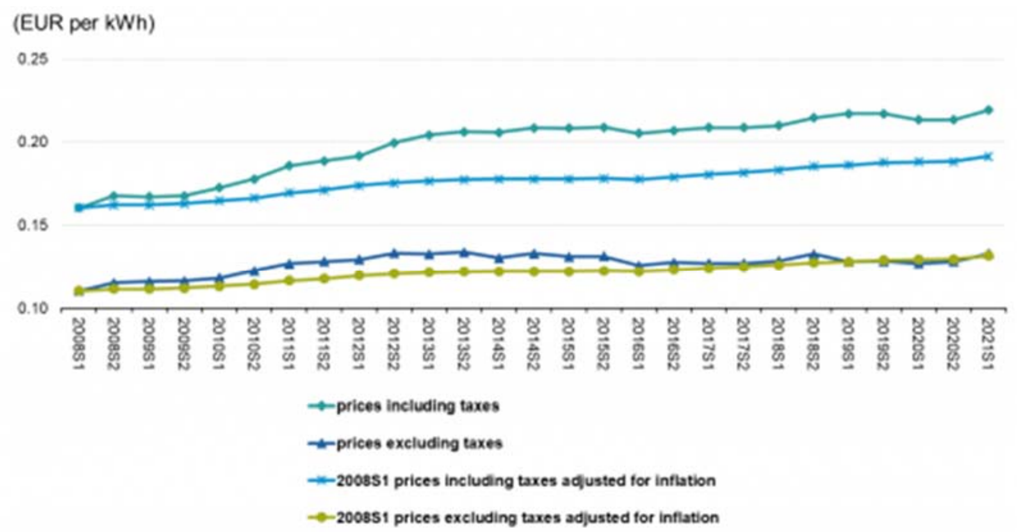


Fig.2. Development of electricity prices for household consumers, EU, 2008-2021 (source: Eurostat, [4])

Figure 3 shows the ratio between taxes and fees and the total retail selling price of residential electricity. As it can be seen, among EU countries Netherlands had the lowest tax rate in the first half of 2021, where the values are actually negative (-5.5%),[1], [4]. The average weight of taxes and duties at EU level was 39.4%. VAT is 15.5% of the total price in the EU. It ranges from 4.8% in Malta to 21.3% in Hungary.

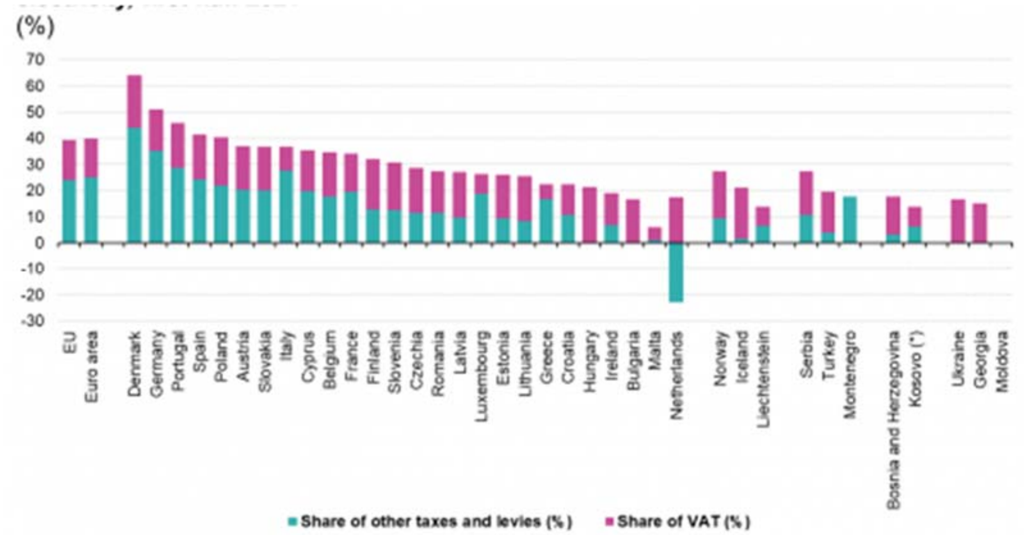


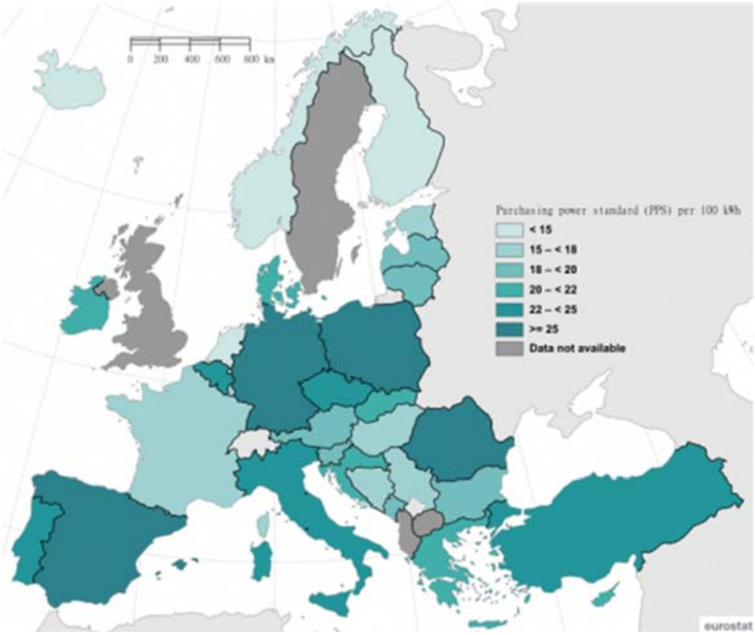
Fig.3. Weight of Taxes and duties paid by household consumers for electricity, first half of 2021 (source Eurostat, [4])

The maps in figure 4.a show the prices of electricity for residential customers in the Purchasing Power Standard (PPS- that is an artificial currency unit; which can buy the same amount of goods and services in each country) in the first half of 2021, classifying the EU countries into six categories, with categories of electricity prices ranging from over 25 PPS / 100 kWh to under 15 PPS / 100. kWh. Romania (29) and Germany (28) have the highest electricity prices according to the purchasing power standard. According to the purchasing power standard, the lowest electricity prices are in the Netherlands (11) and Finland (14).

If we refer to the EU countries for non-household consumers and we look at the evolution of electricity prices during the last two years, we can see that there were fluctuations form country to country and from a year to another, so the electricity market was changing a lot.

The electricity prices in the second half of 2019 reached the highest values in the EU Member States in Cyprus and Italy (figure 5). The average price for the EU in the second half of 2019 (a weighted average based on the latest 2018 data on electricity consumption for non-household customers) was EUR 0.173 per kWh.

The change in electricity prices for non-household consumers, including all non-refundable taxes and duties, between the second half of 2018 and the second half of 2019 is shown in figure 5. These prices have fallen in six EU Member States. The largest decreases were recorded in Denmark (-13.4%), followed by Poland (-6.3%) and Portugal (-2.1%). In 21 other EU Member States, prices have risen. The highest increases were recorded in Romania (19.5%), Hungary (18.4%), Italy (12.7%), the Netherlands (11.1%) and Slovenia (10.0%).



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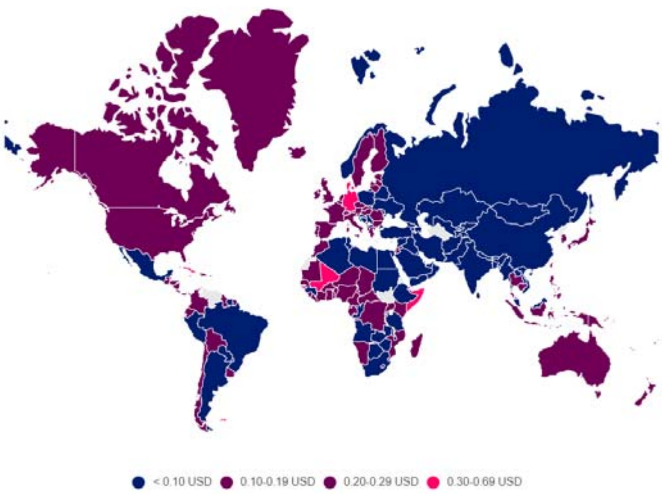

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Fig.4. Electricity prices for household consumers, first half 2021, (PPS per 100 kWh) - (a.) (Source: Eurostat, [4]); interactive map for electricity prices worldwide - (b) [10]

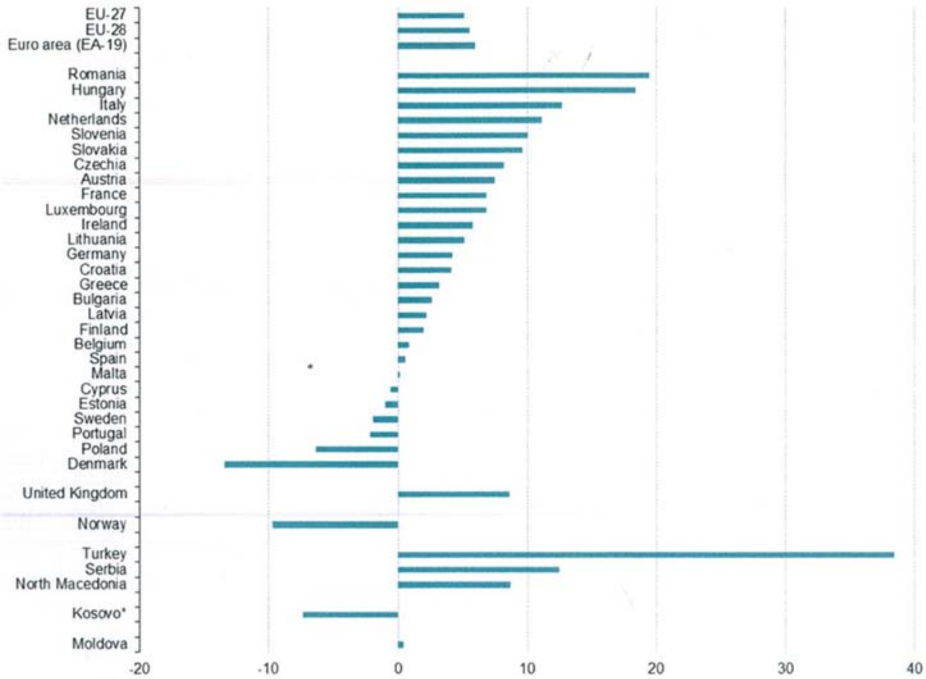

Fig.5. Change in electricity prices in the EU for non-household consumers in the second half of 2019 compared to the previous year, same semester (%)

As for electricity prices in the second half of 2021, they reached the highest values in the EU Member States in Germany (0.1813 EUR/kWh) and Italy (0.1584 EUR/kWh). (Fig. 6). The average price for the EU countries in the second half of 2021 (a weighted average based on the latest data on electricity consumption for non-household customers) was 0.1283 EUR/kWh.

Figure 6 shows how electricity prices change for non-domestic consumers (including taxes and duties) from the first half of 2020 to the first half of 2021. We can see that they decreased the most in Slovenia (-6.5 %) and Portugal (-5.2 %), followed by Romania (-5.1 %). They increased in the other sixteen EU Member States (for example in Denmark (29.8 %), Bulgaria (18.0 %), Estonia (16.3 %)).

In Romania, in the late few years, the electricity market has recorded a continuously rising price that increases almost every month. Thus, July 2021 came with prices two and a half times higher than in the same month of 2020, with August and September reaching new records, increasing three times higher than the same periods in 2020. In August 2021, the average closing price of the market for the next day in Bucharest increased by 93 lei / MWh compared to the one in July, reaching 555 lei/MWh, and in September it was 662 lei/MWh. In November, the market reached new highs - over 1,200 lei/MWh, on DAM (Day Ahead Market), and over 1,000 lei/MWh quotations for the first quarter of 2022. Prices also increased on all spot markets in

Europe, Romania being in the top half of ranking. Also, the unprecedented increase in the levels at which carbon certificates are traded, exceeding the threshold of 70 euro/t CO_2 in November, has led to an increase in the price of electricity, all over Europe.

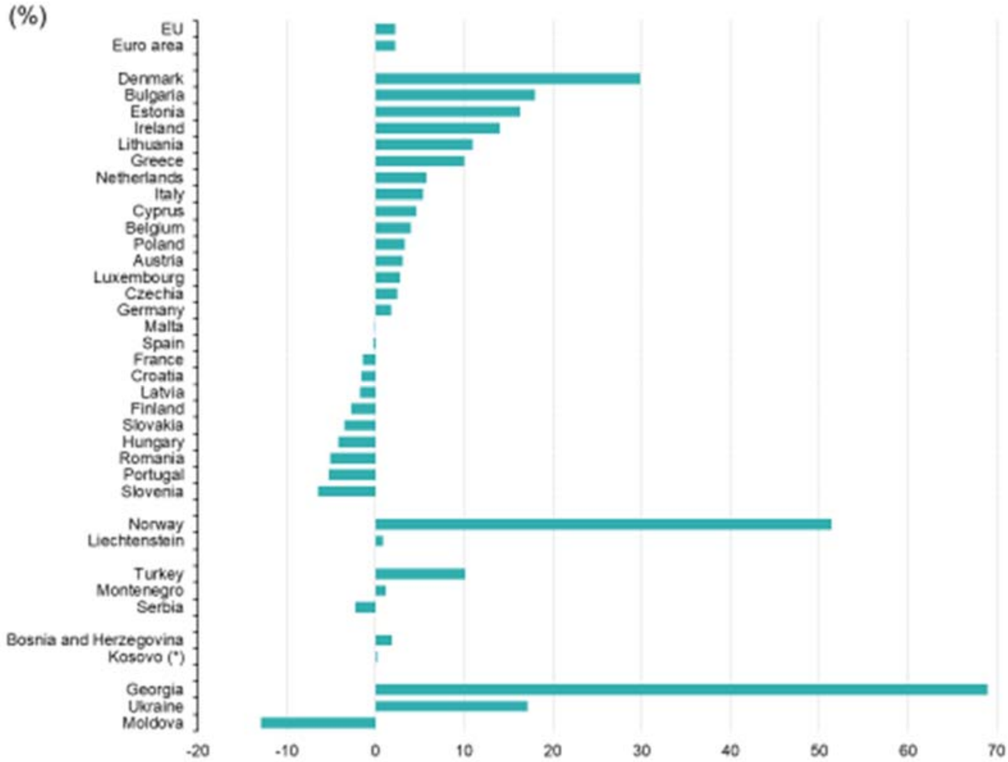

Fig.6. Change in electricity prices for non-household consumers compared with previous year's same semester, first half 2021, % (Source: Eurostat, [4])

Association of Energy Suppliers in Romania - AFEER states that electricity prices borne by consumers recently reflect the evolution of energy markets, internal and international, lack of investment in Romania in production capacity in recent years, and high costs of certificates CO_2, according to a press release, [6], [9].

4. CONCLUSIONS

The current situation on the energy market is complicated: the prices of fuels, coal, natural gas, oil have increased in all European markets and, in addition, due to the EU's clear commitment to decarbonisation, the price of emission allowances has reached around 50 euro/ton (compared to a price of 21 euro/ton in June 2020), and, for the future, an upward trend is also estimated.

All these increases are also found in the price of electricity and that is why we cannot expect the prices of electricity and natural gas to be close to those of 2020. For example, at the beginning of June 2020, on the spot electricity market in Romania, as well as on the spot markets with which we are connected - Hungary, Czech Republic and Slovakia - the prices were 20-25 euros/MWh. At the middle of 2021, in all these markets the prices vary between 65 and 90 euro/MWh.

Romania can no longer ensure from internal sources the necessary consumption of electricity, at competitive prices. For natural gas, we almost always resorted to imports. Thus, all this has influenced and will continue to influence internal market prices. That is why we need investments in both natural gas and electricity production.

Stable and predictable legislation is also needed to ensure security in the supply of secure, sustainable, competitive and affordable energy.

Both end-customer supply and energy trading (electricity and natural gas) are activities which, by their nature, involve a high degree of risk, which increases all the more in an unpredictable legal framework.

In addition, the biggest competition in the energy market is in the supply segment. There are no less than 58 suppliers to the final customers of electricity and over 70 to the final customers of natural gas in Romania, which makes, practically, almost impossible agreements or concerted practices, coordinated between them.

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