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DETERMINATION OF THE OPTIMUM OPERATING REGIME FOR TWO POWER TRANSFORMERS 35 / 6,3 kV

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Abstract: Power transformers are the basics of power grids because they provide power to large groups of consumers. In the operation of transformers, due to the Joule-Lentz effect and electromagnetic induction (which underlies their principle of operation) electrical energy losses occur, both active and reactive. These losses can be determined by the kilowatt [kW] as a unit of measurement.

Keywords: power loss, energy loss, rated power, electric transformers.

1. INTRODUCTION

In processing stations, system or those supplying category I or category II consumers, more than one transformer is usually installed. In transformer and distribution stations in the electrical power system, two-wrap transformers and three-wrap transformers are used. The most used are the two-wrap ones.

Their operation is possible separately or in parallel. In the case of separate operation, each transformer powers a system of collecting bars. This reduces short-circuit loads, which simplifies sizing conditions for installations. [2], [5], [8]

If the characteristics of the transformers are not known, it can be considered, with very good approximation, that the active power losses represent about 2% of the power at the secondary winding terminals and the reactive power losses about 10%.

The value of these power and energy losses can be rigorously determined when the load curve of the transformer is known or when the average square power and operating time or loss time are known. [1], [11], [14]

Is admitted parallel operation of transformers of different types if their powers do not differ by more than 1:3, their short-circuit voltages, ± 10%, socket voltages ± 0.5%, the connection groups must be identical.

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The maximum economy regime corresponds to a load of transformers, proportional to their nominal powers, which occurs if the transformers have the same parameters. [7], [9], [17]

As the nominal power increases, the short-circuit voltage usually increases, leading to an additional charge of the transformer with lower nominal power. [10], [13]

2. DETERMINATION OF THE OPTIMAL OPERATING REGIME BY MATEMATIC CALCULATION

Next is the determination of the optimal operating regime for an electrical station equipped with two power transformers that can operate in parallel or individually, depending on the charge graph of consumers having the single-line diagram shown in Fig. 1.

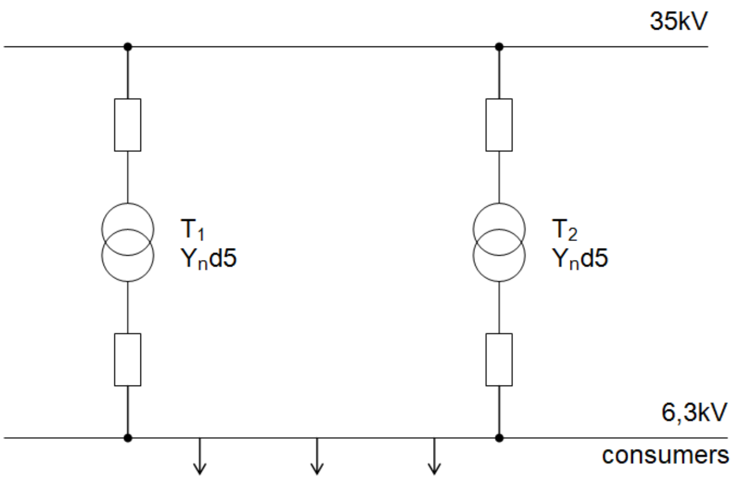

Fig. 1. Single-line diagram of a parallel two-transformer circuit with different powers

The two transformers have the following nominal data:

T1:	S_N = 4 MVA	T2:	S_N = 6,3 MVA
	U_{1N} = 35 kV		U_{1N} = 35 kV
	U_{2N} = 6,3 kV		U_{2N} = 6,3 kV
	ΔP_{sc} = 33,5 kW		ΔP_{sc} = 46,5 kW
	ΔP_{Fe} = 6,7 kW		ΔP_{Fe} = 9,7 kW
	U_{Sc} = 7,5%		U_{Sc} = 7,5%
	i_0 = 1%		i_0 = 0,9%

From the analysis of the recorded energy consumption, it follows that the load on consumers varies between 2 MVA and 8,5 MVA.

Solution:

$$\Delta P_T = \Delta P_{Fe} + K_e \cdot \Delta Q_{Fe} + \left(\Delta P_{Cun} + K_e \cdot \Delta Q_{Cun}\right)\left(\frac{S}{S_n}\right)^2 \tag{1}$$

$$\Delta P = \Delta P_{Fe} + \Delta P_{Cun}\left(\frac{S}{S_n}\right)^2 \quad (2)$$

$$\Delta Q = \Delta Q_{Fe} + \Delta Q_{Cun}\left(\frac{S}{S_n}\right)^2 \quad (3)$$

Energy equivalent K_e = 0,02 kW/kVAr for the situation where losses are calculated at transformer terminals connected directly to the generation bars. [3], [4], [6]

With the previous relationship, the losses for each transformer are calculated, giving values between 2 and 4 MVA, respectively between 2 and 6,3 MVA for S.

If the transformers are running in parallel, the powers at which the two transformers are loaded must be calculated, using the relationships: [12], [15], [16], [18]

$$S_1 = \frac{S}{\frac{S_{NT_1}}{U_{Sc_1}} + \frac{S_{NT_2}}{U_{Sc_2}}} \cdot \frac{S_{NT_1}}{U_{Sc_1}} \quad (4)$$

$$S_2 = \frac{S}{\frac{S_{NT_1}}{U_{Sc_1}} + \frac{S_{NT_2}}{U_{Sc_2}}} \cdot \frac{S_{NT_2}}{U_{Sc_2}} \quad (5)$$

Draw the graph ΔP_{T_1}, ΔP_{T_2}, $\Delta P_{T_1+T_2} = f(S)$ resulting in the optimum operating regime.

For transformer T_1:

$$m_1 = \Delta P_{Fe} + k_e \cdot \Delta Q_{Fe} = 6,7 + 0,02 \cdot \frac{1 \cdot 4000}{100} = 7,5kW$$

$$n_1 = \frac{\Delta P_{CuN} + k_e \cdot \Delta Q_{CuN}}{S_N^2} = \frac{33,5 + 0,02 \cdot \frac{7,5 \cdot 4000}{100}}{4^2} = 2,468$$

For:

$S = 0 \Rightarrow \Delta P_{T_1} = 7,5kW$

$S = 2MVA \Rightarrow \Delta P_{T_1} = 7,5 + 2,468 \cdot 2^2 = 17,37kW$

$S = 3MVA \Rightarrow \Delta P_{T_1} = 7,5 + 2,468 \cdot 3^2 = 29,7kW$

$S = 4MVA \Rightarrow \Delta P_{T_1} = 7,5 + 2,468 \cdot 4^2 = 46,98kW$

For transformer T_2:

$$m_2 = 9,4 + 0,02 \cdot \frac{0,9 \cdot 6300}{100} = 10,53kW$$

$$n_2 = \frac{46,5 + 0,02 \cdot \frac{7,5 \cdot 6300}{100}}{6,3^2} = 1,409$$

For:

$$S = 0 \Rightarrow \Delta P_{T_2} = 10,53 kW$$
$$S = 2MVA \Rightarrow \Delta P_{T_2} = 10,53 + 1,409 \cdot 2^2 = 16,16 kW$$
$$S = 3MVA \Rightarrow \Delta P_{T_2} = 10,53 + 1,409 \cdot 3^2 = 23,21 kW$$
$$S = 4MVA \Rightarrow \Delta P_{T_2} = 10,53 + 1,409 \cdot 4^2 = 33,07 kW$$
$$S = 5MVA \Rightarrow \Delta P_{T_2} = 10,53 + 1,409 \cdot 5^2 = 45,75 kW$$
$$S = 6,3MVA \Rightarrow \Delta P_{T_2} = 10,53 + 1,409 \cdot 6,3^2 = 66,45 kW$$

For the case where T_1 and T_2 operate in parallel:

$$S = 0 \quad \Delta P_{T_1+T_2} = m_1 + m_2 = 7,5 + 10,53 = 18,03 kW$$

The results for the rest of the calculation are shown in Table 1. below:

Crt. No.	$S[MVA]$	$S_1[MVA]$	$S_2[MVA]$	$\Delta P_{T_1}[kW]$	$\Delta P_{T_2}[kW]$	$\Delta P_{T_1+T_2}[kW]$
1.	2	0,776	1,223	8,986	12,637	21,623
2.	3	1,165	1,834	10,849	15,269	26,118
3.	4	1,553	2,446	13,452	18,959	32,411
4.	5	1,941	3,058	16,798	23,708	40,506
5.	6	2,330	3,669	20,899	29,497	50,396
6.	7	2,718	4,281	25,738	36,352	62,09
7.	8	3,106	4,893	31,321	44,266	75,587
8.	8,5	3,3	5,199	34,329	48,615	82,944

The graph for determining the optimal regime in figure 2 was drawn based on the calculations and the results obtained.

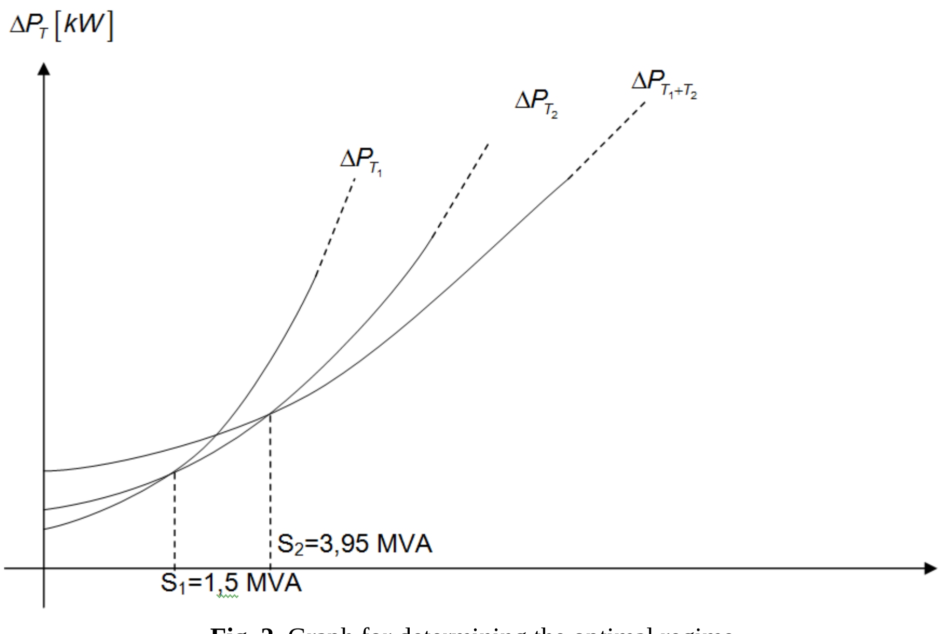

Fig. 2. Graph for determining the optimal regime

From the graph it is noted that for:

- $S < S_1 = 1{,}50$ MVA it is economical to operate only the T_1 transformer,
- 1,50 MVA < S < 3,95 MVA is economical to operate only the T_2 transformer,
- S > 3,95 MVA the two transformers must operate in parallel.

Technological measures to reduce (optimize) power and energy losses in electrical energy systems are the specific measures that can be applied in the design and construction phases, having in most cases, a much more important role than those in the operational phase of the installations. It should be made clear that these measures adopted in the initial stages require additional investment, for which a well-founded technical and economic justification is required.

The main operating measures leading to the reduction of losses are:

- limiting idle time for all electricity consumers;
- increasing the time to use the maximum charge or flattening the charge curve (i.e. achieving the highest possible coefficient of use);
- the correct choice of voltage control sockets for power transformers;
- ensuring optimal operating regime for power lines and power transformers.

Automatic connection and disconnection of transformers can be achieved by tracking the current absorbed by consumers and comparing it with an imposed value (established by adjusting a current relay or by a specialized comparator circuit). The information element is a current transducer or a current relay. The system of commanding the connection and disconnection of transformers, in principle, is similar to those of the lines. In general, the reduction of energy losses by automatically connecting and disconnecting power transformers according to charge is considered to be significant because all transformers have a long service life.

3. CONCLUSIONS

The optimal maximum load, expressed as a percentage of the rated power, decreases with the increase in the number of transformers in operation.

In general, the optimal maximum load is greater than 50% of the rated power of the transformer.

Consideration of active power losses related to the transformer's apparent power losses, depending on the technical characteristics of the transformers, has different effects.

For the high-power transformer where the share of losses in reactive power load is greater than that of reactive power losses when idle, the maximum optimal load decreases with the increase in the value of the equivalent.

The economic working arrangements result from the graph, corresponding to the minimum power losses.

As noted, they correspond to certain transformer loads.

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