MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

National Technical University
"Kharkiv Polytechnic Institute"

Basic Equipment and Technology of Electricity Generation at Industrial Enterprises and Power Plants

Methodical instructions for performing calculation tasks
on the discipline "Fundamentals of the electric power industry"
for full-time foreign students

of specialty 141 – Energy, Electrical Engineering and Electromechanics
in the specialization "Electrical Machines

Kharkiv – 2023

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Reviewer: prof. Lazurenko O. P.

Department of Electric Machines

INTRODUCTION

The methodical publication is devoted to the implementation of the calculation task in the discipline "Fundamentals of Power Engineering" for students majoring in 141 – Power Engineering, Electrical Engineering and Electromechanics, specializing in "Electrical Machines".

The purpose of the individual task is to consolidate students' knowledge of the types of power plants; means of distribution and transmission of electric energy, types of electrical equipment of stations, substations and industrial enterprises: transformers, electrical machines, switching, measuring and protective equipment. That is, the main objects of research are electromechanical devices – transformers and electric machines, which are the basis of electricity and electric drives of various industries.

As a result of these tasks, the student must know the types of power plants, their basic electrical equipment, electrical equipment of industrial enterprises, modern types of renewable energy sources, their disadvantages and advantages.

The student must be able to assess promising areas of electricity development, know the advantages and disadvantages of different types of modern energy sources, know the types of electrical equipment for different types of power plants. The student must be able to assess the technical condition of electrical machines and transformers and transformers, know new series of electrical equipment, take into account economic requirements.

This methodological publication presents tasks for independent work. Each part contains control questions and initial data for tasks, as well as recommendations for their solution. The task consists of the theoretical part and the task, to determine the energy parameters of the transformer.

The specific amount of work and the number of the task option are specified by the professor who lectures.

The individual task is the final document of the student's work. Before the exam, the report must be completely completed and protected. At the end of the report is a list of sources of information that the student used in the process. Schemes and graphs should be built on graph paper with the designation on the axes of standard letter designations of quantities and units of measurement. The report on the implementation of the settlement work begins with the title page, a sample of which is given in *Appendix A*.

In this edition the modern updated system of designations of electric, magnetic, power, mechanical sizes which corresponds to the state standards is applied.

1 CLASSIFICATION OF POWER STATIONS.
LIST OF MAIN ELECTRICAL EQUIPMENT

1.1 Theoretical questions

1) Describe the scheme "Classification of power transformers".

2) Make sketches of the cores and windings structures of power transformers.

3) What are the losses in electrical equipment?

4) What are the categories of reliability of power supply of power receivers? Give examples of power receivers of different reliability categories.

5) To define in writing the concept: transformer ratio; schemes for three-phase transformers windings; idle current. Why are the cores of transformers of electrical machines blended?

6) Describe the scheme "Classification of electrical stations».

7) Describe what are the main sources of electricity in your country. What new directions in the development of the electric power industry do you consider promising?

1.2 Task. Calculation of energy parameters of a three-phase transformer

For a three-phase transformer (m = 3, where m is the number of phases), which operates in a network with a voltage frequency f = 50 Hz and has the data given in table. 1 and in fig. 1, calculate the transformer ratio; nominal and maximum efficiency; load value (in parts of rated power) at which the efficiency of the transformer reaches the maximum value and the magnetizing current (idle current).

Note: the section accepts symbols:

– primary winding – index p;

– secondary winding – index s;

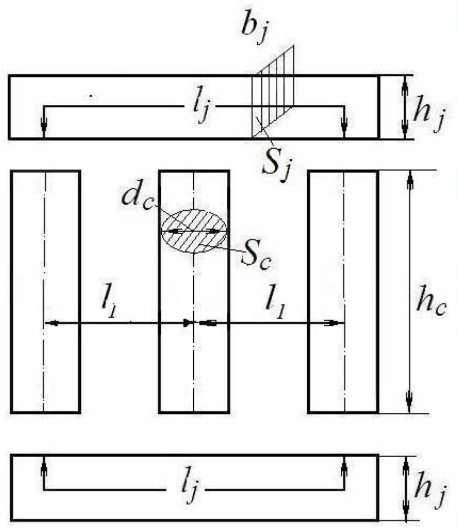
– active resistance R_p and reactive resistance X_p of the primary winding;

– erected active resistance $R_s^{/}$ and reactive resistance $X_s^{/}$ of the secondary winding;

– active resistance R_m and reactive resistance X_m of the magnetization circuit.

The following shows an explanation of the elements of a three-phase two-winding transformer, which is shown in Fig. 1. On Fig. 1 designations used:

1) **The transformer cores** – designed for the windings mechanical fastening and formation (directions) of a working magnetic flux.



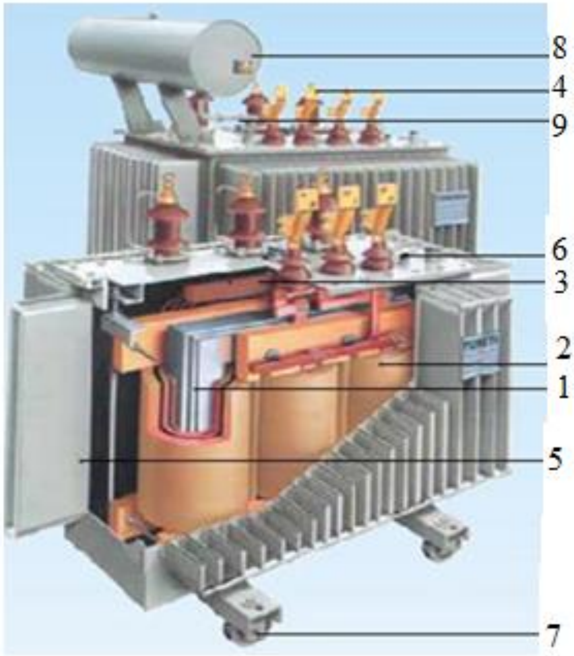


Figure 1 – Core sketch and drawing of a three-phase two-winding oil-cooled transformer

2) The windings of the HV – from round or profiled wire; by LV – mainly from the tape material. Insulation: with high electrical and thermal resistance. Windings axially and radially protected from the forces generated during a short circuit.

3) Switch branch windings designed to equalize the voltage of transformation according to local conditions.

4) Bushings of high and low voltage. From the HV with coordinating spark gap. Protected from contact with the conclusions.

5) Corrugated tank of the transformer with a small number of welds; oil drain device and a screw for attaching the ground wire, sealed construction with flexible corrugated walls. The resulting changes in the operation of the coolant reliably absorbed. Does not require maintenance.

6) Cover pot with loops for attaching and lifting screws for attaching the ground wire and a pocket for a thermometer for the installation of devices for temperature control.

7) Trolley with smooth rollers, possibly both longitudinal and lateral movement.

8) Extender with a magnetic oil level indicator and performed as an exhaust fan filling nipple.

9) Gas Relay – designed to release gases that are released from the oil in the nominal operating mode.

Table 1 shows the data for performing the calculation work.

Table 1 – Parameters of three-phase transformers

Option number	Rated full power S_N, kV·A	Rated voltage of the primary winding U_{pNl}, kV	Rated voltage of the secondary winding U_{sNl}, kV	Number of turns of the secondary winding N_s	The value of the magnetizing current (in% of the rated current of the primary winding) i_0, %	The value of the magnetizing current (in% of the rated current of the primary winding) $\cos\varphi_0$, r.u.	Nominal power factor $\cos\varphi_N$, r.u.	Losses in the mode of laboratory short circuit P_k, kW	Schemes and groups for connecting transformer windings
1	50	6,0	0,525	192	8	0,087	0,82	1,70	Y/Δ-11
2	100	35,0	6,3	200	9,5	0,088	0,82	2,86	Y/Y-0
3	100	35,0	3,6	200	9,0	0,07	0,82	2,86	Y/Δ-11
4	320	35,0	6,3	360	9,5	0,075	0,80	5,60	Y/Y-0
5	5600	110,0	6,0	200	10,0	0,087	0,81	47,8	Y/Y-0
6	1000	35,0	0,69	470	10,5	0,087	0,80	18,54	Y/Δ-11
7	1800	35,0	6,3	640	11,0	0,088	0,85	24,22	Y/Δ-11
8	3200	35,0	3,6	660	10,5	0,07	0,84	36,5	Y/Y-0
9	5600	35,0	6,3	600	11,0	0,075	0,85	49,6	Y/Y-0
10	20	6,0	0,4	100	6,5	0,087	0,83	0,95	Y/Δ-11
11	60	35,0	6,3	200	7,5	0,088	0,83	2,10	Y/Y-0
12	100	35,0	0,69	150	8,7	0,07	0,8	3,26	Y/Y-0
13	180	35,0	3,15	300	7,5	0,075	0,84	4,10	Y/Δ-11
14	180	35,0	3,15	300	8,0	0,087	0,84	4,10	Y/Y-0
15	20	10,0	0,69	380	6,5	0,1	0,83	0,94	Y/ Y-0
16	180	10,0	0,69	388	7,0	0,088	0,83	5,24	Y/Δ-11
17	560	35,0	6,3	400	7,5	0,07	0,80	9,30	Y/Δ-11
18	1000	35,0	10,5	390	9,0	0,075	0,80	15,12	Y/Y-0
19	50	6,0	3,15	400	6,5	0,087	0,85	3,14	Δ/Y-11
20	100	10,0	3,15	600	7,0	0,1	0,84	5,04	Y/Y-0

1.3 Methodical instructions for solving the task

1.3.1. Theoretical questions

At first you must answer seven theoretical questions (Point 1.1).

To do this, use the lecture materials of your abstract, which you wrote at the lectures, the literature indicated in these guidelines (p. 15), a study guide and materials from the Internet.

When writing answers to theoretical questions, use diagrams, pictures, graphs, sketches. tables that will help make your answer more complete.

1.3.2 Some materials for compiling answers to theoretical questions

Transformers are classified according to the following indicators:

1) according to intended use: power, measuring and special transformers.

Power transformers are used for power plants and industrial enterprises. Measuring transformers are used for measuring high currents and voltages. These are the current transformers and voltage transformers.

Special transformers are used for the scientific research.

2) Transformers are classified on the design of cores: rod construction, armored construction, armored-rod construction and toroidal construction – in the form of a torus. This name is created from the shape of the geometric figure – torus.

3) Classification by winding design: the concentric (one in the other) and the disc (or «plates»);

4) Classification by number of phases: single-phase and multiphase (usually three-phase)

5) Classification by cooling method: dry (air cooling) and with cooling by oil.

6) Classification by the number of windings per phase: with one winding, with two windings or with three windings.

Draw sketches of cores and windings of power transformers, sign your drawings.

All losses allocated in the form of heat. Therefore, one cannot say "heat" losses.

Losses in the electrical machines and transforms are:

– electrical losses occur when the current passes through the conductor. According to Joule's law, the losses powers are proportional to the current in the second degree $I^2 \cdot R$, where R – is the resistance of conduction, Ohm;

– magnetic losses are when magnetic flux passes through steel cores, Ohm.

The main losses in steel are of two types: from eddy currents (Foucault Фуко currents) and from remagnetization (or from hysteresis). To take into account additional losses in steel, the main losses are increased by 10-15%.

Losses in steel (magnetic losses) depend on the grade and quality of steel, on the quality of stamping and assembly of the core. Of course, they depend on the core size.

Most importantly, they depend on the frequency of voltage and current. In some cases, they depend on frequency to the second power.

$$P_{mag} \sim f^{\beta}, \text{ where } \beta=1.5\text{-}2.$$

The cores of electrical machines, through which an alternating magnetic flux passes, are assembled (mixed) from electrical steel sheets isolated from each other with a thickness of 0.35-0.5 mm. This is done to reduce magnetic losses (losses in steel) from eddy currents and from hysteresis.

All these indicators do not change when the load (current) changes. They are the same in idle mode, in nominal mode, in overload mode. So, it's constant loss.

– mechanical losses – it is the losers from friction in bearings and on air, and ventilation losses. The are no such losses in the transformers, only in the machines.

These losses are from friction in bearings and from friction about the air of the rotor that rotates. Also, that is the ventilation losses.

– additional losses – that are losses which are not taken into account before.

When all losses have been determined, the efficiency of electrical equipment can be calculated:

$$\eta = \frac{P_2}{P_1} = \frac{P_1 - \Sigma P_i}{P_1}, \text{ r.u.} \quad \text{or } \times 100\%$$

where ΣP_i – is the sum of all losses, W.

The transformer ratio; schemes for three-phase transformers windings; idle current.

Transformer ratio, r. u.:

$$k_{tr} = \frac{E_p}{E_s} = \frac{w_p}{w_s},$$

where w_p – the number of turns of the transformer primary winding;

w_s – the number of turns of the transformer secondary winding;

E_p – electromotive force (EMF) self-induction, V;

E_s – EMF of mutual induction, V.

When $k_{tr}<1$ – a step-up transformer.

When $k_{tr} >1$ – a step-down transformer.

Schemes for three-phase transformers windings

A three-phase transformer has two three-phase windings – high (*HV*) and low (*LV*) voltage. Thus, a three-phase transformer has six independent phase windings and 12 leads. The initial conclusions of the phases of the higher voltage winding are denoted by the letters *A, B, C*, the final conclusions are *X, Y, Z*, and for similar conclusions of the phases of the low voltage winding, the designations *a, b, c, x, y, z* are used. Each of the windings of a three-phase transformer – primary and secondary – can be connected in three different ways, namely: star; triangle; zigzag.

In most cases, the windings of three-phase transformers are connected either in a star or in a triangle (Fig. 2).

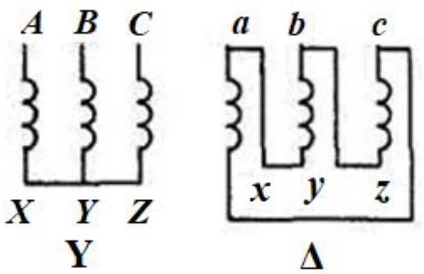


Figure 2 – Schemes for connecting the windings of three-phase transformers to «a star» Y and «a triangle» Δ

The choice of wiring diagram depends on the operating conditions of the transformer.

The idle current of the primary winding (the secondary winding open) is called the magnetizing current, because it is almost completely reactive and is needed to create a magnetic flux that closes along the steel core and induces EMF in the secondary and primary windings

Describe what are the main sources of electricity in your country. What new directions in the development of the electric power industry do you consider promising?

In this question, analyze the state of the electric power industry in your country. Describe the geographic location, what minerals are on the territory of your country (coal, gas, oil). Assess the prospects for using electricity from renewable energy sources: wind, sun, geysers, sea currents, bio-gases, etc.

In your work, you need to propose the most promising directions for the development of the electric power industry in your country. Write which power plants operate in your country; which stations are promising to build in your opinion.

What electrical equipment is needed for these power plants? Indicate if your country has its own production of electrical equipment

The main directions of the energy development:

1) demand for long-term sustainable energy sources;

2) environmental safety of electricity generation.

In different periods, energy sources changed all the time, fuel at thermal power plants changed. At first there was only coal. Since the 40s of the 20th century, gas and fuel oil have been used at the stations. Since the 70s, the nuclear power industry began to develop, and since the 90s, stations using renewable energy sources have been added to thermal and nuclear power plants. The global economic crisis, and especially the war, negatively affected the state and development of the electric power industry.

Consider the problems that are common to all countries:

1) ecological problems;

2) limited mineral resources (coal, gas, oil);

3) continuous population growth and increase in the need for electricity;

4) increase losses of electricity;

5) old electrical equipment.

Ways to increase electric power generation

1) Increase in the unit installed capacity of turbogenerators (up to 1500 MW).

2) Increasing the efficiency of turbogenerators – main sources of energy on Earth.

3) Develop nuclear power.

4. Install renewable energy sources (wind, sun, sea currents and others).

5) The use of high-temperature superconductors in the electric power industry.

This became possible with the discovery and production of the first industrial high-temperature superconductors with a critical temperature above 77.3 K.

Equipment for power plants: these are generators, motors and transformers. All machines and transformers work a different time. This is called the «operating mode». These modes mean S1, S2-S8: S1 – long operation mode. S2-S7 – re-short-term mode operation mode; S8 – short-term operation mode.

Power stations are of different types, for example, fig. 3: the classic (conventional) power plants and power plants that operate from renewable sources. Basically, we can say that there are thermal power plants, hydroelectric power plants and nuclear power plants.

All consumers of electricity can be divided into categories, in accordance with the need for constant provision and supply of electricity.

The first category includes energy consumers, the interruption of the supply of electricity to which can lead to a danger to the life of the population, to serious material damage (failure of expensive equipment, violation of a complex technological process), as well as to negative social processes. This category is represented by the most responsible consumers:

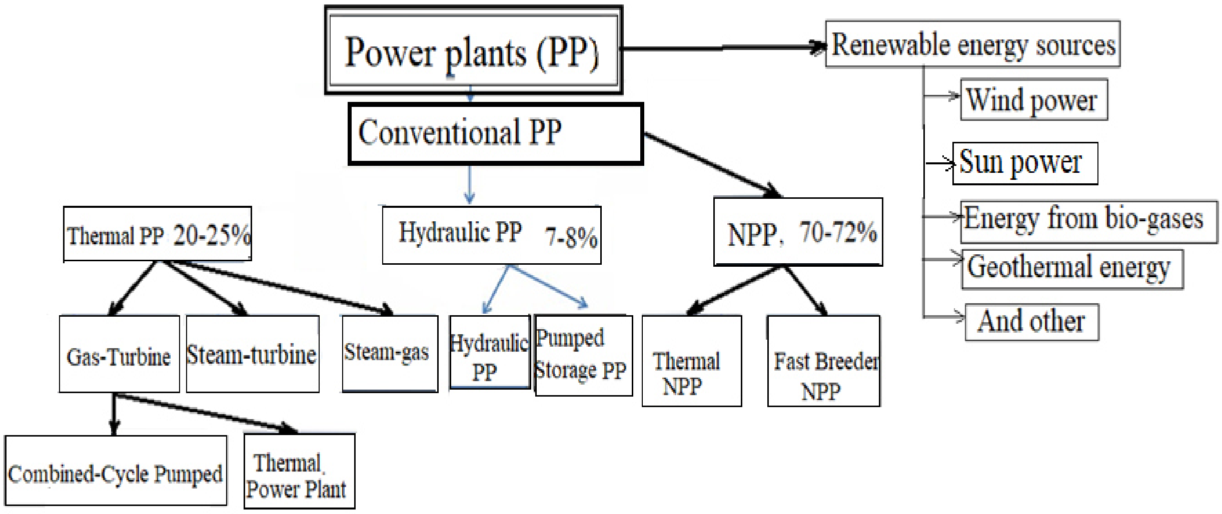


Figure 3 – Power plants classification

The main categories of power supply reliability are shown in Fig. 4.

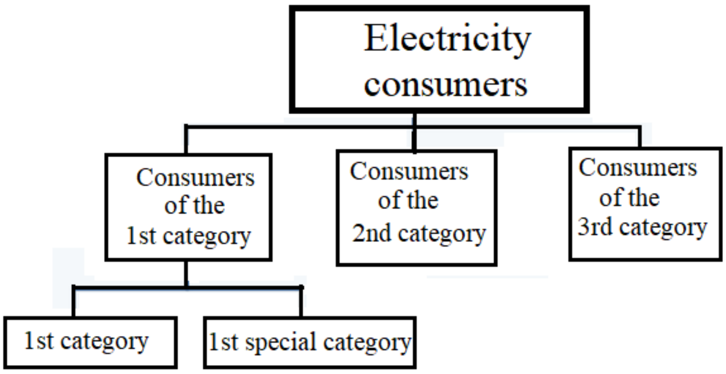


Figure 4 – The main categories of power supply reliability

The first special group is electrical receivers, the uninterrupted supply of electricity to which reduces the risk of serious fires, explosions and human casualties.

Electric receivers of the first special category of power supply reliability include electrical equipment of nuclear power plants, accelerators, tokomaks, complex chemical industriesю

Electric receivers of the power supply reliability first special category include electrical equipment of nuclear power plants, accelerators, tokomaks, complex chemical industries.

The second category (important electrical receivers) includes electrical consumers for whom a sudden power outage can lead to mass defects in production, to long downtime of expensive equipment, to disruption of the normal mode of life of large groups. Category 2 includes the bulk of various administrative buildings.

The third category includes all other consumers.

Table 2 shows the required number of channels for backing up the supply of electricity to consumers and the allowable time for switching on the backup channel for supplying electricity.

Table 2 – The required number of channels for reserving the supply of electricity to consumers and the allowable time for switching on the backup channel for supplying electricity

Category	Number of redundancy channels	Backup channel activation time	Note
First special category	3	Backup channel activation – automatic response time	The third (independent) source can be a neighboring power plant (satellite station), a diesel generator set, an uninterruptible power supply
First category	2	Backup channel activation – automatic response time	
Second category	1	For the period of manual activation of the backup channel by the personnel – one hour	A break in the power supply is allowed up to 1 hour (for the time of manual switching). It is recommended to set the automatic switching on of the reserve, as for the first category
Third category	-	No spare channels	Power supply must be restored within 24 hours

1.4. Task. Calculation of energy parameters of a three-phase transformer

From Table 1, select the data for your transformer according to your option.

A transformer is an electromagnetic device that has two (or more) inductively coupled windings and is designed to convert one AC system to another. The most widely used in electrical installations are power transformers, through which the values of alternating voltage and current are changed.

It must be remembered that a transformer is not an electrical machine. An electrical machine is an electromechanical converter. But transformers are studied in the discipline "Electrical Machines", because the physical processes in the transformer and the mathematical apparatus used in its study are similar to the physical processes and mathematical apparatus of electrical machines (in particular, induction motors).

This means that in an electric machine, energy changes its form:

– if at an electrical machine is supplied the electrical energy, the machine converts it into mechanical energy. This is an engine (motor);

– if at a mechanical energy is applied to an electric machine, the machine converts it into electrical energy. This is a generator.

This is called the "principle of reversibility of electrical machines": any electrical machine can be a generator and a motor.

The simplest power transformer consists of a magnetic circuit made of sheet electrical steel and two windings located on its rods (see Fig. 1). One of the windings, which is called the primary, is connected to an alternating current source with a voltage U_p. An electrical receiver is connected to the secondary winding.

Calculate the nominal phase values of the primary U_{pN} and secondary U_{sN} voltages of the transformer. In table. 1 shows the values of line voltages (U_{pNl} and U_{sNl}, respectively).

If the transformer winding is connected in a "star", then the phase value of the voltage must be calculated:

$$U_N = \frac{U_{Nl}}{\sqrt{3}}$$

If the transformer winding is connected in a "delta", then the phase voltage is equal to the line voltage $U_N = U_{Nl}$. And you don't have to count the voltage.

In subsequent calculations, use only the values of phase voltages.

Determine the number of turns of the transformer primary winding

$$N_p = \frac{N_s \cdot U_{pN}}{U_{sN}}.$$

Remember that the number of turns must be an integer.

Determine the magnetizing current of the transformer (full current of the inoperative primary winding of the transformer), A:

$$I_{p0} = i_0 \cdot I_{pN},$$

where i_0 – is the value of the magnetizing current (from Table 1, in the calculations used in r.u.);

I_{pN} – is the primary winding rated current, A:

$$I_{pN} = \frac{S_N}{m \cdot U_{pN}};$$

Magnetic losses in the transformer core (together the main and additional), W:

$$P_{mag} = (1 + k_{ad}) \cdot m \cdot U_{pN} \cdot I_{p0} \cdot \cos\varphi_{p0}$$

where k_{ad} – is the coefficient of additional losses (P_{ad}). This coefficient varies within k_{ad} = 0,1–0,15.

Efficiency of the transformer at rated load, r.u.:

$$\eta_N = 1 - \frac{P_0 + \beta_{Is}^2 \cdot P_k}{\beta_{Is} \cdot S_N \cdot \cos\varphi_N + P_0 + \beta_{Is}^2 \cdot P_k}$$

where P_0 – losses in idling mode are magnetic losses in the transformer magnetic circuit. Magnetic losses are constant, they do not depend on the load, W:

$$P_0 = P_{mag};$$

β_{Is} – is the transformer load factor, r.u.:

$$\beta_{Is} = \frac{I_p}{I_{pN}}.$$

At rated load $\beta_{Is} = \beta_{IsN} = 1$;

I_p – is the transformer primary winding current, A;

I_{pN} – is the rated current of the transformer primary winding, A.

Sometimes in the technical literature and in the price lists, the efficiency is indicated at a percentage (%). But in calculations, you should always use the efficiency value in relative units.

The maximum value of the transformer efficiency is reached when the constant losses are equal to the variables. There are two types of losses in the transformer: magnetic (basic and additional) P_0 and electrical losses (losses in the transformer windings).

Note. In all type electrical equipment, the maximum efficiency will be when the constant losses are equal to the variable losses. But in electrical machines, in addition to magnetic and electrical losses, there are mechanical and additional losses. This is also an irretrievable loss.

Electrical losses are variable losses. At enterprises and power plants, they are determined during a laboratory short circuit experiment. Determination of losses in this experiment is performed with the nominal value of current. Therefore, the losses of the

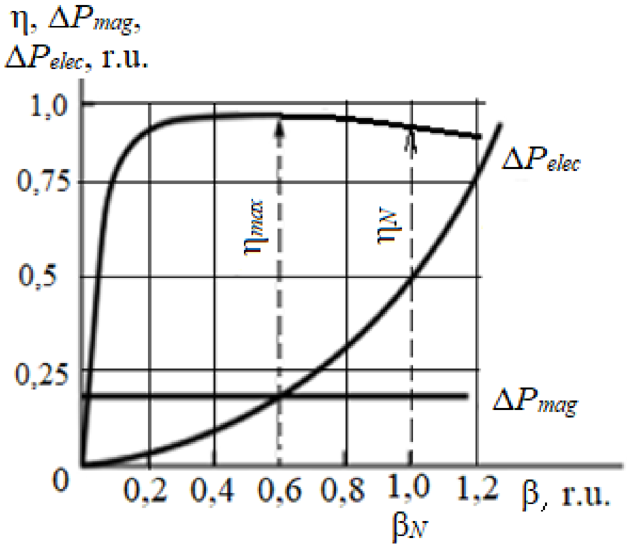


Figure 5 – The efficiency characteristic of a transformer:
ΔP_{elec} – is the electric losses in the transformer; ΔP_{mag} – is the magnetic losses in the magnetic circuit of the transformer

laboratory short circuit experiment are electrical losses in the nominal mode. Their value ($P_{el} = P_k$) given in table. 1.

The value of the load factor at which the transformer efficiency is maximum:

$$\beta_{Is\max} = \sqrt{\frac{P_0}{P_k}}.$$

Fig. 5 shows the efficiency characteristic of a transformer.

Then the maximum value of the transformer efficiency:

$$\eta_N = 1 - \frac{P_0 + \beta_{Ismax}^2 \cdot P_k}{\beta_{Ismax} \cdot S_N \cdot \cos\varphi_N + P_0 + \beta_{Ismax}^2 \cdot P_k}.$$

Compare the nominal and maximum efficiency of the transformer.

Explain the inexpediency of designing transformers with maximum efficiency at rated load ($\beta_{Is} = 1$).

RECOMMENDED LITERATURE

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APPENDIX A

Example of the title page of the calculated jobs

Ministry of Education and Science of Ukraine

National Technical University
"Kharkiv Polytechnic Institute"

Department of Electric Machines

THE ESTIMATED WORKS ON THE DISCIPLINE
« FUNDAMENTALS OF THE ELECTRIC POWER INDUSTRY»

by a first-year student
group ______________________________

____
(Student's full name)

Section name	Date of completion mark the teacher's signature
1.1 Theoretical tasks	
1.2 Task. Calculation of energy parameters of a three-phase transformer	

Kharkiv – 20___ р.

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Навчальне видання

ОСНОВИ ЕЛЕКТРОЕНЕРГЕТИКИ

Контрольні питання, розрахункові завдання
методичні вказівки з дисципліни
«Основи електроенергетики»

для студентів за фахом 141 «Електроенергетика, електротехніка і електромеханіка» за спеціалізацією Електричні машини
(Англійською мовою)

Укладачі: ШЕВЧЕНКО Валентина Володимирівна
ЮР'ЄВА Олена Юріївна

Відповідальний за випуск проф. В. І. Мілих
Роботу до видання рекомендував проф. Б. Г. Любарський

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