MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

National Technical University
"Kharkiv Polytechnic Institute"

EXPLOITATION AND OPERATING MODES OF POWER PLANTS ELECTRICAL EQUIPMENT

Methodical instructions for performing calculation tasks
for full-time foreign students
of 141 specialty – Electric Power Engineering, Electrical Engineering
and Electrical and Technical Engineering

Kharkiv –2021

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ЕКСПЛУАТАЦІЯ ТА РЕЖИМИ РОБОТИ ЕЛЕКТРООБЛАДНАННЯ ЕЛЕКТРИЧНИХ СТАНЦІЙ

Методичні вказівки до виконання розрахункових завдань
для іноземних студентів денної форми навчання
за спеціальністю 141 – Електроенергетика, електротехніка
та електротехніка з дисципліни «Експлуатація і режими роботи
електрообладнання електричних станцій»

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Compilers: V. V. Shevchenko, A. A. Dunev, L. V. Dyomochka

Reviewer: A.P. Lazurenko

Electrical Machines Department

STRUCTURE AND RULES FOR WRITING A REPORT ON PERFORMANCE OF CALCULATION ASSIGNMENT

General information

This work is the final document of student's work during the semester. The report must be fully completed and protected before the exam. The teacher, who conducts the course of lectures, specifies the specific scope of work. The report begins with a cover page, a sample of which is in the Appendix. All calculations need to make in the SI system. The list of the use literature placed at the end of the work. Schemes, vector diagrams and graphs should be built on the graph paper or on the squared paper, indicate the letter designations of the quantities and units of their measurement on the axes. You can use drawings printed on a computer.

Your variant of this work chooses according to the number in the group list or by the teacher instructed. Perform work according to methodological instructions.

<u>The report includes the following parts:</u>

№ 1. Calculation of transformer nominal parameters according to the post-repair test data.

№ 2. Determine the problems and methods of DC motor starting, taking into account the circuit for switching on the field windings

№ 3. Describe the problems and methods of starting asynchronous (induction) motors. How may be regulated the asynchronous motor speed?

№ 4. Determination of the overload capacity of synchronous generators on the power stations and personnel actions in case of an emergency increase in load.

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THEORETICAL AND CALCULATION WORKS

1 CALCULATION OF TRANSFORMER NOMINAL PARAMETERS ACCORDING TO POST-REPAIR TEST DATA

1.1 Theoretical assignments

Answer the questions in writing:

1. List the types of power plants existing in Ukraine and the technological schemes of their functioning.

2. What are the operating electrical equipment modes? Give a brief description of each mode.

3. What do you know the kinds of the electrical machines testing? Describe the advantages and disadvantages of the planned repairs. Why are they currently moving to repairing electrical equipment according to the actual state, and not according to the plan?

4. What are the conditions for switching on transformers in parallel operation? Which of the conditions must be violated if the different capacity transformers are connected into parallel operation? What power deviations are acceptable while choosing transformers for parallel operation?

1.2. Practical assignment

For a three-phase transformer (m = 3, where m is the number of phases), which operates in a network with a voltage frequency of f = 50 Hz and has the data shown in Fig. 1 and tab. 1, calculate the parameters of the transformer in the idle mode (IM), laboratory short circuit (SC). Using the data obtained, determine the transformer data for the rated mode.

On the transformer equivalent circuit in the nominal mode, indicate the numerical values of the elements, Fig. 2.

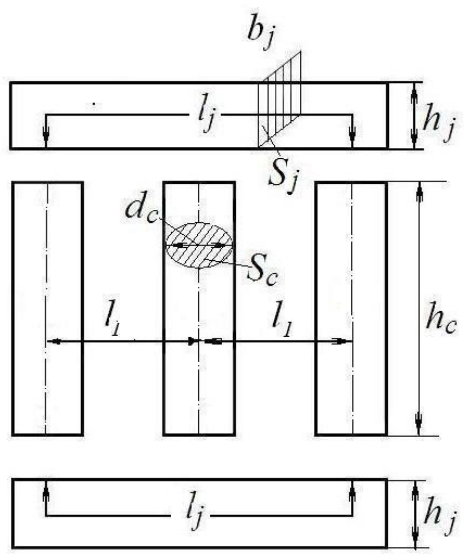

Figure 1 – The dimensions of the transformer core

Calculate the nominal value of the efficiency of the transformer and the value of the load (in parts of the nominal power) at which the efficiency of the transformer reaches its maximum value. Determine the maximum value of the efficiency and compare its value with the nominal value.

Table 1 - Parameters of the three-phase transformers

Variant number	Nominal total power	Nominal voltage of the primary winding	Nominal voltage of the secondary winding	Number of turns of the secondary winding	Rod diameter	Effective cross-sectional area of the rod	Cross sectional area of the yoke	Core height	Yoke height	Distance between the axes of the rods	Short-circuit voltage	Load power factor	Power loss in the laboratory mode	Schemes and connection groups of the transformer windings
	S_N kV·A	U_{pNl} kV	U_{sNl} kV	N_s, r.u.	d_c, cm	S_c cm^2	S_j, cm^2	h_c cm	h_j cm	l_1, cm	u_k, %	cosφ$_s$, r.u.	P_k, kW	
1	50	6.0	0.525	192	12	89	90	25	12	25	5.5	0.82	1.70	Y/Δ-11
2	100	35.0	6.0	200	16	580	570	41	14	35	6.5	0.82	2.86	Y/ Y-0
3	180	31.5	6.0	280	18	410	400	52	16	39	6.5	0.83	4.52	Y/ Y-0
4	320	35.0	6.0	360	20	330	326	39	18	35	5.5	0.80	5.60	Y/ Y-0

Variant number	Nominal total power	Nominal voltage of the primary winding	Nominal voltage of the secondary winding	Number of turns of the secondary winding	Rod diameter	Effective cross-sectional area of the rod	Cross sectional area of the yoke	Core height	Yoke height	Distance between the axes of the rods	Short-circuit voltage	Load power factor	Power loss in the laboratory mode	Schemes and connection groups of the transformer windings
	S_N kV·A	U_{pNl} kV	U_{sNl} kV	N_s, r.u.	d_c, cm	S_c cm^2	S_j, cm^2	h_c cm	h_j cm	l_1, cm	u_k, %	cosφ$_s$, r.u.	P_k, kW	
5	5600	110.0	10.0	200	22	580	570	72	19	45	6.5	0.81	47.8	Y/ Y-0
6	1000	35.0	0.66	470	30	220	210	83	41	46	5.5	0.80	18.54	Y/Δ-11
7	1800	35.0	6.0	640	32	310	300	85	28	57	6.5	0.85	24.22	Y/Y-0
8	3200	35.0	6.0	660	36	300	310	100	31	62	7.0	0.84	36.5	Y/Y-0
9	5600	35.0	6.0	600	43	320	300	110	37	70	7.5	0.85	49.6	Y/Y-0
10	20	6.0	0.40	100	9	75	72	30	19	21	5.5	0.83	0.95	Y/Y-0
11	60	35.0	6.0	200	13	580	600	41	34	31	6.5	0.83	2.10	Y/Y-0
12	100	35.0	0.66	150	15	86	84	38	34	46	5.5	0.80	3.26	Y/Y-0
13	180	35.0	3.15	300	19	200	180	42	36	49	5.5	0.84	4.10	Y/Δ-11
14	320	35.0	6.0	330	20	350	340	63	47	51	6.5	0.85	7.23	Y/Y-0
15	20	10.0	0.66	380	12	322	316	40	50	20	6.5	0.83	0.94	Y/Y-0

Indicate the numerical values of the elements, currents, electric driving force (EDF) and voltages on Fig. 2.

Note: in the section the following notations are used:

– prime winding is the index *p* (*prime*);

– second winding is the index *s* (*second*);

– active resistance $R_{\sigma p}$ and reactive resistance dissipation $X_{\sigma p}$ of the primary winding;

– reduced active resistance $R^{/}_{\sigma s}$ and reduced reactive resistance dissipation $X^{/}_{\sigma s}$ of the secondary winding;

– active R_m and reactive X_m resistance of the transformer magnetization core.

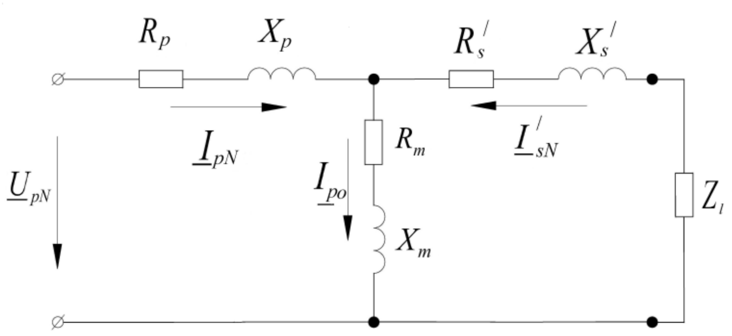

Figure 2 – Equivalent circuit diagram of the transformer in the nominal mode

1.3 Methodological instructions for the practical assignment implementation

Calculate the nominal phase values of the primary U_N and secondary U_{sN} voltages of the transformer according to the line voltage values given in Table 1 (U_{sNl} and U_{nNl}, respectively). In this case, consider the circuit diagrams of the transformer windings. For further calculations, use only phase voltage values.

If the winding is connected in Y, then $U_{p(s)N} = \dfrac{U_{p(s)N}}{\sqrt{3}}$, if in Δ, then $U_{p(s)N}=U_{p(s)Nl}$.

In the following calculations, use the phase voltages of the transformer only.

Determine the magnetic flux in the transformer core, *Wb*,

$$\Phi = \frac{U_{sN}}{4{,}44 \cdot f \cdot N_s}.$$

Determine the magnetic flux density in the rods (B_C) and yokes (B_j) of the transformer:

$$B_c = \frac{\Phi}{k_{Fe} \cdot S_c},\ Tl, \qquad B_j = \frac{\Phi}{k_{Fe} \cdot S_j},\ Tl,$$

where k_{Fe} is the steel filling factor of the transformer core. It is equal to 0.95 when steel sheets are insulated with varnish.

The values of magnetic flux density should be within the interval from 1.3 *Tl* to 1.6 *Tl*.

If the obtained values of magnetic induction are not included in the indicated interval, change the effective cross-sections of the rods and the yokes of the transformer.

To do this:

1) select the values of magnetic inductions from the interval from 1.3Tl to 1.6Tl, recalculate the cross sections of the rods and the yokes of the transformer (S_c and S_j, respectively):

When calculating, the step cross section of the rods is neglected. We consider that Sc is the effective cross-sectional area of the rod:

$$S_c = \frac{\Phi}{k_{Fe} \cdot B_c}, \text{ м}^2; \qquad S_j = \frac{\Phi}{k_{Fe} \cdot B_j}, \text{ м}^2.$$

2) Calculate the diameter of the rods (d_c) and the height of the yoke (h_j) in the obtained values of the cross sections. Recalculate the cross-section of the yoke; accept that its width (b_j) is the new value of the rod diameter (d_c). Specify the height of the yoke. The new values of the rod diameter (d_c) and the yoke height *(h_j)* are:

$$d_c = \sqrt{\frac{4S_c}{\pi}}; \; m \qquad h_j = \frac{S_j}{d_c}, \; m.$$

In further calculations use cross sections obtained.

Calculate the magnetic driving force (MDF) for a single-phase transformer:

$$F_a = H_c \cdot h_c + \frac{2}{3} H_j \cdot l_j + \frac{7}{3} \cdot \frac{B_c}{\mu_0} \cdot \delta, \; A,$$

where μ_0 is the magnetic constant, $\mu_o = 4\pi \cdot 10^{-7}$ *Gn/m*.

The strength of the magnetic field in the rods and yokes (H_c and H_j, respectively) for electrotechnical steel 3411 are presented in Table 2.

Table 2 – Magnetic field strength and specific magnetic power loss for electrotechnical steel 3411

Magnetic flux density, *B*, *Tl*	0,6	0,7	0,8	0,9	1,0	1,1	1,2	1,3	1,4	1,5	1,6
Magnetic field strength, H_c, *A/m*	190	260	318	397	502	647	843	1140	1580	2500	4370
Specific magnetic power loss p_{mag}, *W/kg*	0,54	0,61	0,76	0,96	1,20	1,46	1,76	2,10	2,45	2,80	3,37

When calculating the MDF you must take into account the air gaps in the rods and yokes joints of the transformers. Number of the air gaps (per each phase) is 7/3. The total air gap is assumed to be $\delta = 5 \cdot 10^{-5}$ *m* per phase.

Assume that the magnetic flux density (induction) in the air gaps in the rods and yokes joints is equal to the magnetic flux density in the rods B_c.

The length of magnetic field line in the yoke of the transformer is

$$l_j = 2l_1 + h_j,\ m.$$

Determine the number of turns of the transformer primary winding according to the following formula (Attention! The number of turns must be an integer):

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

Determine the reactive component of the magnetizing current using the formula:

$$I_{or} = \frac{F_a}{\sqrt{2} \cdot k \cdot N_p},\ \text{A},$$

where k is the factor that implies higher harmonics in the magnetizing current. Its value lies within the range from 1.5 to 2.

The weight of steel of the rods (m_c) and yokes (m_j) of the transformer is:

$$m_c = N_c \cdot S_c \cdot h_c \cdot \gamma_{Fe} \cdot k_{Fe},\ \text{kg},$$

$$m_j = N_j \cdot S_j \cdot l_y \cdot \gamma_{Fe} \cdot k_{Fe},\ \text{kg},$$

where l_y is the length of the yoke and can be calculated as following:

$$l_y = 2 \cdot l_1 + d_c,\ \text{m};$$

– N_c and N_j – are the number of rods and yokes of the transformer respectively, that is $N_c = 3$; $N_j = 2$;

– γ_{Fe} - is the specific mass of steel and is $7.8 \cdot 10^3$ kg/m^3.

Determine the magnetic power losses in the transformer core (basic and additional) using formula:

$$P_{mag} = (k_d + 1) \cdot \left(p_{magc} \cdot m_c + p_{magj} \cdot m_j \right),\ \text{W},$$

where p_{magc}, p_{magj} are specific power losses in the rods and the yokes of the transformer. Their values should be selected from Table 2 according to the magnetic flux density, W/kg;

– k_d is the factor of additional losses registration P_{ad} is chosen from the interval from 0.1 to 0.15.

Determine the active component of the current in the idling mode using formula:

$$I_{oa} = \frac{P_{mag}}{m \cdot U_{pN}}, \text{ A.}$$

Determine the primary winding current (magnetizing current) in the idling mode and the power factor of the transformer in an idling mode using formulas:

$$I_{op} = \sqrt{I_{or}^{\ 2} + I_{oa}^{\ 2}}, \text{ A;} \qquad \cos\varphi_o = \frac{P_{mag}}{m \cdot U_{pN} \cdot I_{op}}.$$

Define the transformer parameters in the idling mode as following:

– Total resistance of the transformer in the idling mode is:

$$Z_o = \frac{U_{pN}}{I_{op}}, \text{ Ohm;}$$

– Active resistance of the transformer in the idling mode is:

$$R_o = \frac{P_{mag}}{m \cdot I_{op}^2}, \text{ Ohm;}$$

– Reactive resistance of the transformer in the idling mode is:

$$X_o = \sqrt{Z_o^{\ 2} - R_o^{\ 2}}, \text{ Ohm.}$$

The parameters of the transformer in the laboratory short circuit (SC) mode are:

– Total resistance of the transformer in the laboratory SC mode is:

$$Z_k = \frac{U_{pk}}{I_{pN}}, \text{ Ohm;}$$

where U_{pk} is the voltage laboratory SC mode that is:

$$U_{pk} = \frac{u_k}{100\ \%} \cdot U_{pN}, \text{ V;}$$

– Nominal current of primary winding is:

$$I_{pN} = \frac{S_N}{m \cdot U_{pN}}, \text{ A,}$$

– Active resistance of the transformer in the laboratory SC mode is:

$$R_k = \frac{P_k}{m \cdot I_{pN}^2}, \text{ Ohm;}$$

– Reactive resistance of the transformer in the laboratory SC mode is:

$$X_k = \sqrt{Z_k^2 - R_k^2}\text{, Ohm.}$$

The transformer power factor in the laboratory SC mode is:

$$\cos\varphi_k = \frac{P_k}{m \cdot U_{pk} \cdot I_{pN}}.$$

Calculate the parameters of the transformer equivalent circuit in the nominal mode according to the experiments in the idling mode and laboratory short circuit.

– Active resistance of the transformer primary winding equals the given value of reduced reactive resistance of the transformer secondary winding and is:

$$R_p = R_s^{'} = \frac{R_k}{2}\text{, Ohm;}$$

– Reactive resistance of the transformer primary winding equals the given value of the reduced reactive resistance of the transformer secondary winding and is:

$$X_p = X_s^{'} = \frac{X_k}{2}\text{, Ohm;}$$

– Resistance of the magnetizing circuit of the transformer is:

$$R_m = R_o - R_p\text{, Ohm;} \qquad X_m = X_o - X_p\text{, Ohm.}$$

Determine the coefficient of performance of the transformer in the nominal mode using the known values of power losses in the idling mode and in the laboratory SC mode using the following formula:

$$\eta_N = 1 - \frac{P_o + \beta_{Is}^2 P_k}{\beta_{Is} \cdot S_N \cdot \cos\varphi_s + P_o + \beta_{Is}^2 \cdot P_k},$$

where P_o, W is power losses in the idling mode, which are the magnetic losses in the transformer magnetic core, $P_o = P_{mag}$;

– I_s, A is the current of the secondary winding of the transformer (the load current);

– I_{sN}, A is the nominal current of the secondary winding of the transformer;

– β_{Is} is the load factor of the transformer and is:

$$\beta_{Is} = \frac{I_s}{I_{sN}}.$$

$\beta_{Is} = 1$ at the nominal loading.

The transformer maximum coefficient of efficiency is achieved when the constant and variable power losses are equal. The load value (in parts of the nominal capacity), at which the transformer coefficient of performance is maximum, is:

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

Then the maximum transformer coefficient of performance can be calculated as following:

$$\eta_{\max} = 1 - \frac{P_o + \beta^2_{Is\ \max} \cdot P_k}{\beta_{Is\ \max} \cdot S_N \cdot \cos\varphi_s + P_o + \beta^2_{Is\ \max} \cdot P_k}..$$

Compare the nominal and the maximum COP of the transformer. Explain in writing why the transformers are not effective when designed with maximum COP at nominal load ($\beta_{Is} = 1$).

2 ESSENTIAL FEATURES OF STARTING A DIRECT CURRENT MOTOR TAKING INTO ACCOUNT SCHEMES FOR SWITCHING ON THE FIELD WINDINGS

2.1 Theoretical assignments

1. Describe the principle of operation of a DC motor (DCM), indicate its advantages and disadvantages compared with other types of machines. Draw a sketch of a four-pole DCM and possible schemes for switching on the field windings (FWs): independent, parallel, mixed and serial connections, Fig. 3.

According to the plan below, for each option of turning on the field windings, answer the questions in writing:

1) In which drives exactly these engines are used?

2) How to control the speed and reverse the DCM?

3) What are the methods of braking DCM?

4) What problems arise when starting DCM and how to solve them?

2. Describe the design of the collector of a DC machine. What function does the collector in the MPT perform depending on the operating mode?

3. Indicate the causes of sparking on the DC machine collector. How can such sparking be eliminated (or reduced) given its appearance?

2.2 Methodical instructions for the assignment

2.2.1. When answering the first question, follow the plan given for each option of turning on the field windings.

2.2.2. Describe the design of the manifold on plastic and on steel pressure cones. Indicate for which machines each type of structure is used.

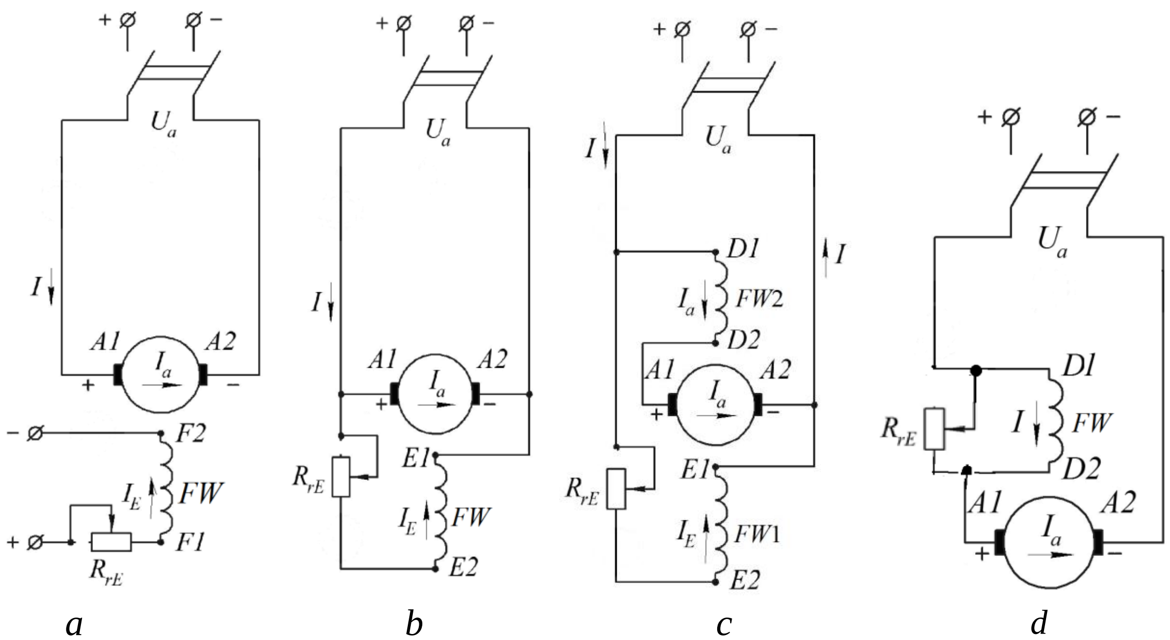

Figure 3 – Schemes for including the excitation windings of DC machines
a – independent excitation; *b* – parallel excitation;
c – mixed excitation; *d* – sequential excitation

2.2.3. Describe the three causes of sparking on the manifold. For each cause, suggest ways to reduce sparking. When describing the occurrence of switching sparking, describe how to improve switching in the DC machine. For better understanding, use diagrams and sketches.

3 THE FEATURES OF STARTING AND REGULATION OF AN ASYNCHRONOUS MOTOR ROTATION FREQUENCY

3.1 Theoretical assignment

3.1.1. Describe the design and principle of operation of an asynchronous motor (AM) and an asynchronous generator (AG). Where are asynchronous machines used in motor mode and in generator mode?

3.1.2. What are the problems of starting AM? What is done to improve the starting characteristics of an asynchronous motor?

3.1.3. Explain why AM has the smallest air gap. What characteristics of an asynchronous motor will affect the increase in air gap?

3.1.4. List and explain the ways of frequency rotation regulation of an asynchronous motor.

3.1.5. Describe how to diagnose the state of an asynchronous motor in the terms of the spectrum of the stator current.

3.2 Methodical instructions for the assignment

3.2.1. When completing a task, use drawings, graphs, and specifications. The use of computer versions of the drawings is possible.

3.2.2. To answer question 3.1.5, use data from the Internet and/or [8].

4 DETERMINATION OF THE OVERLOAD CAPACITY OF SYNCHRONOUS POWER PLANT GENERATORS AND URGENT ACTIONS WHILE OVERLOADING

4.1 Theoretical assignment

Describe the design of the synchronous generators (SG) rotor, which are used in thermal power plants (including nuclear power plants) and in hydroelectric power plants. Explain the difference in rotor designs of these generators. Give sketches of explicit and implicit pole rotors. Describe the methods of excitation, the main stages of starting, and the conditions for turning on the SG for parallel operation in the network with accurate and rough synchronization. How to start and stop the turbogenerators (TG)? What types of repairs are used for turbogenerators (TG)?

Describe the actions of the operational personnel of the power plant unit in case of a sharp increase in the load on a running generator due to an accident in the network. In which system is the excitation boost unit installed? Describe this system briefly.

4.2 The assignment

Construct the angular characteristics of three-phase explicit and implicit pole SGs (m_s = 3, where m_s is the number of phases) according to the data given in Table. 3, and calculate their overload capacity. Indicate in writing how to maintain the generator's overload capacity when the load increases. Compare the angular characteristics of three-phase explicitly polarized and non-polarized superconductors; explain why they are different.

4.3 Methodical instructions for the assignment

Calculate the nominal phase voltage of the stator winding, V, using the following formula:

$$U_{sN} = \frac{U_N}{\sqrt{3}}.$$

In synchronous machines, the electromagnetic moment M_{em} is proportional to the electromagnetic power P_{em}. Therefore, it is possible to construct an angular characteristics, as a dependence $M_{em}(\theta)$ or $P_{em}(\theta)$, where θ is the load angle (“take-off” angle), the angle between the rotor winding flow vector and the anchor reaction vector, or between the vector EMF, that is E_{so}, and the stator voltage vector U_s. When constructing the angular characteristics of a non-polar three-phase SG, assume that $X_q = X_d$. The data for the TG with the explicit poles are given in Table 3. Build the angular characteristics of the synchronous generator $P_{em}(\theta)$ using the following formula:

$$P_{em} = \frac{m_s \cdot U_{sN} \cdot E_{so}}{X_d} \cdot \sin\theta + \frac{m_s \cdot U_{sN}^2}{2} \cdot \left(\frac{1}{X_q} - \frac{1}{X_d}\right) \cdot \sin 2\theta, \qquad (4.1)$$

Table 3 – Data for a three-phase synchronous generator

variant number	Stator winding nominal voltage	Nominal power factor	Relative value of EMF in the idling mode	Cross inductive resistance	Longitudinal inductive resistance	The angle between the vector stator current and	Scheme connections of the

						the vector stator EMF	stator winding
	U_{sN}, kV	$\cos\varphi_N$	$E^*_{so} = \dfrac{E_o}{U_{sN}}$	X_q, Ohm	X_d, Ohm	ψ_N, el. degr.	
1	6.0	0.90	1.30	4.21	6.42	52	Y
2	0.4	0.91	1.33	0.935	1.42	54	Y
3	10.0	0.92	1.31	5.35	8.82	53	Y
4	6.0	0.93	1.34	2.48	3.82	52	Y
5	6.0	0.90	1.32	3.12	5.04	54	Y
6	0.4	0.89	1.36	5.20	7.46	54	Δ
7	0.4	0.89	1.30	4.02	6.18	52	Y
8	6.0	0.90	1.33	2.12	3.44	53	Y
9	6.0	0.91	1.37	1.96	3.12	52	Y
10	10.0	0.90	1.30	5.00	7.36	54	Y
11	10.0	0.91	1.44	3.18	6.84	50	Y
12	6.0	0.92	1.20	5.10	7.44	51	Y
13	6.0	0.93	1.35	4.18	6.54	52	Y
14	6.0	0.92	1.22	5.24	7.85	54	Y
15	0.23	0.91	1.35	3.36	5.68	55	Δ

Where E_{so} is EMF, which a magnetic flux field winding induces in the stator winding, and is $E_{so} = E^*_{so} \cdot U_{sN}$, V.

The synchronous generators angular characteristics of with explicitly expressed and with implicitly expressed rotor poles are different, because the generators with explicitly expressed poles have the following characteristics: $X_q<X_d$, while the generators with implicitly expressed rotor poles are considered to have the following characteristics $X_q=X_d$.

The critical load angle, at which the electromagnetic power peaks, is:

$$\theta_{cr} = \arccos(\sqrt{\beta^2 + 0{,}5} - \beta), \text{ el. degr,}$$

where the design factor is:

$$\beta = \frac{E_{so}}{4 \cdot U_{sN} \cdot \left(\frac{X_d}{X_q} - 1 \right)}.$$

The data of calculations of the angular characteristics should be put in Table 4.

The nominal load angle is $\theta_N = \psi_N - \varphi_N$, el. degr,

where ψ_N is the angle between the vector stator current (I_s) in the nominal mode and the vector EMF in the stator winding (E_{so}) in the idling mode, el. degr;

– φ_N is the angle between the vector voltage (U_{sN}) of the stator and the vector current (I_{sN}) of the stator in the nominal mode, el. degr.

Its value can be calculated from the value of $\cos\varphi_N$ (Table 3).

For the explicitly polar SG, the angular characteristic is graph 3, Fig. 4. It is actually the sum of two characteristics: the first (graph 1) and the second (graph 2), or the first and second terms in the formula (4.1), and it can be constructed analytically using the entry in Table 4.

Build a table (Table 5) similar to Table 4 with necessary edits for implicit pole TG, and build the angular response for the generator with implicit poles. The example of the angular characteristic of an SG with an implicit pole (turbogenerator, graph 1) and explicit pole (hydrogenerator, graph 3) rotor designs is shown in Fig. 4.

The electromagnetic power (P_{max}) at the critical load angle (θ_{cr}) is maximum. Usually θ_{cr} =75-80 el. degrees for the synchronous generator with explicit poles rotor.

Calculate the coefficient of static overload (overload capacity) of the synchronous generator with explicit and implicit poles rotors using the following formula:

$$K_{Mm} = \frac{P_{em.max}}{P_{em.N}} /$$

The value of K_{st} should be within the particular range for hydro generators, that is K_{Mm} = 1.3–1.5; and for turbogenerators, that is K_{Mm} = 1.7–1.8.

Table 4 – Calculation of angular characteristics of three-phase synchronous generator with explicit rotor poles

Parameters	Values of load angle θ, el. degr.									
	0	θ_N	30	60	θ_{cr}	90	120	135	150	180
$\sin\theta$										

$\frac{m \cdot U_{sN} \cdot E_{s0}}{X_d} \cdot \sin\theta$, W										
$\sin 2\theta$										
$\frac{m \cdot U_{sN}^2}{2} \cdot \left(\frac{1}{X_q} - \frac{1}{X_d}\right) \cdot \sin 2\theta$, W										
$P = \frac{m_s \cdot U_{sN} \cdot E_{so}}{X_d} \cdot \sin\theta + \frac{m_s \cdot U_{sN}^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right) \cdot \sin 2\theta$, W										

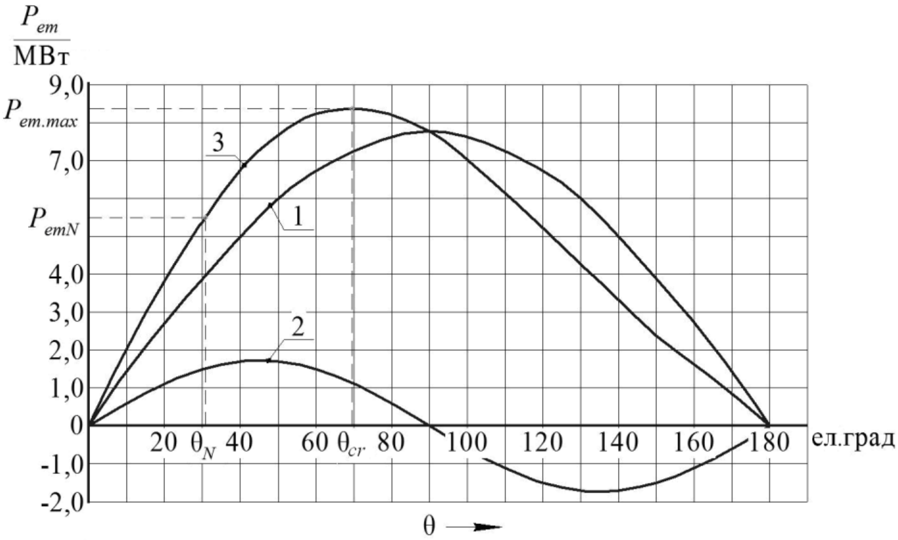

Figure 4 – The angular characteristics of the three-phase synchronous generator with explicit rotor poles

4.4 Actions of the power plant operator when changing the load on the generator

In case of accidents in the power system, when one or several generators accidentally stops, their load is taken by TGs that work side by side in the same power system.

In this case, TGs operate with overload and their overload capacity decreases ($K_{Mm} = P_{\max}/P_N$), which is unacceptable. To preserve the overload ability of the TG, it is necessary to force its excitation, i.e. sharply increase the current in the field winding. Forcing excitation is the transition of the excitation system to the mode of issuing the maximum voltage and excitation current of the TG (hydro generator, synchronous compensator). This is usually done automatically by the excitation system. Automatic excitation regulator

(AER) is carried out by changing the voltage of the field winding. In this case, the strength of the excitation current and, as a consequence, the main magnetic flux and EMF of the stator windings change. Automatic regulation of excitation in synchronous generators is used to ensure a given voltage in the electrical network, as well as to increase the stability of their parallel operation in the common network, to maintain the necessary voltage for coordinated work with the network. AER of proportional and strong actions are distinguished.

AER is a device which is a part of the excitation system and acts on the exciter of a synchronous machine in order to maintain voltage in the electrical network at a given level. The proportional-action AER is characterized by a change in the excitation current strength in proportion to the deviation of the voltage at the machine terminals from the set value (negative voltage feedback). The proportional-action excitation regulators can contain compounding devices (positive feedback on the current of the machine) and stabilization (flexible negative feedback on the excitation voltage). A proportional-action AER does not provide sufficient accuracy to maintain the voltage of power plants operating on long-distance power lines and in cases when the system has abruptly variable loads leading to significant voltage fluctuations.

Then a strong-action AER is used, in which an increase in efficiency is achieved by introducing regulation of the excitation according to the voltage deviation, according to the derivatives of current, voltage, frequency, etc., selected in certain ratios; characterized by high speed and high power excitation system. For the first time, AERs of strong action were used at the Volga Hydroelectric Power Station named after V.I. Lenin in 1955-57.

High-power AERs of synchronous generators with a capacity of 60 MW or more, as well as high-power AERs installed as part of the excitation systems of synchronous generators of lower power must meet the requirements of GOST 21558-2000 and provide the following functions that affect the stability of the parallel operation of the synchronous generator in the power system:

– damping of oscillations of rotors of synchronous generators in normal, repair and post-accident modes of the power system, excluding occurrence of undamped oscillations in the power system;

– relay forcing excitation;

– blocking of stabilization channels or a system stabilizer when the frequency changes at a speed of 0.05 Hz/s or more with adjustable delay time for input and prohibition of blocking operation when synchronous fluctuations of the parameters of the electric power regime occur in the energy system;

– stable operation of synchronous generators in the mode of limiting the minimum excitation;

– limitation to a twofold value of the rotor current (for thyristor excitation systems;

– using for brushless excitation systems, the AERs of strong action which have an appropriate limiter with an entry delay of not more than 0.6 s^{-1}. The time delay is introduced to prevent the limitation of free currents during a short circuit in the generator stator circuit. It should be adjustable; the control range should provide the ability to set the time delay values from 0.1 to 0.6 s;

– having stabilization channels or a system stabilizer;

– carrying out voltage regulation on the tires of a synchronous generator or generator-transformer unit according to the proportional integral-differential or proportional integral law of voltage regulation;

– providing regulation of the rotor current and stator current relative to the settings of the corresponding limiter according to the proportional-integral law.

In AERs of strong action of a TG with a system stabilizer, the voltage frequency of the synchronous generator or the shaft rotation speed, the generator electric power can be used as input parameters of the system stabilizer.

When the synchronous generator is first turned on in the network until the verification and adjustment of the strong action ARE settings are completed, the system operator limits the electric power of the power plant according to the calculated data of transient modes and dynamic stability. If the selected magnitude of the excitation voltage boost does not ensure the preservation of dynamic stability, then the magnitude should be increased to a value that ensures a stable dynamic transition to the post-accident mode.

Verification and adjustment (if necessary, identified during the verification) of the selected parameters of settings of the AER of strong action of synchronous generators should be carried out on the model of the power system and according to the verification procedure determined in accordance with the requirements of Table 6.

Table 6 - Selection of a method for checking AER settings and a model of the power system, on which verification and adjustment (if necessary, identified during the verification) of selected AER settings for strong synchronous generators, depending on the type and installed capacity of generating equipment, is carried out.

Type of generating equipment	Type of power system model and methodology by which verification and adjustment of AER settings should be carried out, depending on the installed capacity of generating equipment	
	The mathematical model of the power system	Physical model of the power system
Synchronous hydrogenator	100 MW and more, but less than 500 MW	100 MW and more
Synchronous TG	–	500 MW and more
Combined cycle power unit	–	500 MW and more
Synchronous TG for nuclear power plant	–	600 MW and more

Checking and adjusting (if necessary) the settings of powerful automatic controllers are carried out before the commencement of complex tests of turbine generators in power plants. When you first turn on the synchronous generator in the network before completing the test of automatic controllers of strong action, its electric power must be limited. The system operator determines the load of each synchronous generator by its dynamic stability. To determine the influence of the voltage frequency in the field winding, a digital model of the power system is used.

When determining the range of voltage changes on the field winding using an automatic field controller, the changes in loads in winter and summer should be taken into account.

Appendix

Example of the title page

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

National Technical University
"Kharkiv Polytechnic Institute"

EXPLOITATION AND OPERATING MODES OF POWER PLANTS ELECTRICAL EQUIPMENT

By the fourth-year student of the group ____________________________

____
(surname, first name, middle name of the student)

The assignment	Date of performance, assessment, teacher’s signature
№ 1. Calculation of the transformer nominal parameters according to post-repair test data	
№ 2. Essential features of starting a direct current motor taking into account schemes for switching on the field windings	
№ 3. The features of starting and regulation of an asynchronous motor rotation frequency	
4. Determination of the overload capacity of synchronous power plant generators and urgent actions while overloading	

Kharkiv – 2020

CONTENTS

Навчальне видання

ЕКСПЛУАТАЦІЯ ТА РЕЖИМИ РОБОТИ ЕЛЕКТРООБЛАДНАННЯ ЕЛЕКТРИЧНИХ СТАНЦІЙ

Методичні вказівки до виконання розрахункових завдань
для іноземних студентів денної форми навчання
за спеціальністю 141 – Електроенергетика, електротехніка
та електротехніка з дисципліни
«Експлуатація і режими роботи електрообладнання електричних станцій»
(на англійській мові)

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