Ministry of Education and Science of Ukraine
Ternopil Ivan Puluj National Technical University

Faculty of Applied Information Technologies and Electrical Engineering
(full name of faculty)
Electrical Engineering
(full name of department)

QUALIFYING PAPER

For the degree of

bachelor
(degree name)

topic: **Electrodrives starting mode compensation installation control enhancement**

Submitted by: fourth year student
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specialty 141 Electrical Engineering

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Ternopil 2022___

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Department Electrical Engineering
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ASSIGNMENT

for QUALIFYING PAPER

for the degree of **bachelor**
(degree name)

specialty 141 Electrical Engineering
(code and name of the specialty)

student Khalafalla Sifeldin Kamel Ramadan
(surname, name, patronymic)

1. Paper topic Electrodrives starting mode compensation installation control enhancement

Paper supervisor **Kuzemko Nataliia, PhD, Assistant professor**
(**surname, name, patronymic**, scientific degree, academic rank)

Approved by university order as of « 11 » 01 2022__ № 4/7-8

2. Student's paper submission deadline 27.06.2022

3. Initial data for the paper

1.To improved control systems of devices of dynamic compensation of reactive power, which are based on high-speed measuring channels to obtain information about the spectral conductivity of the load, which provides increased accuracy and speed of compensation of reactive loads.

2.To substantiate the expediency of using spectral conductivities as informative parameters in devices of dynamic compensation of reactive power that allows to maintain voltage during starting modes of operation of asynchronous and synchronous motors

4. Paper contents (list of issues to be developed)
   1. Analytical section
   2. Design section
   3. Calculation section
   4. Job safety section

5. List of graphic material (with exact number of required drawings, slides)

Introduction - 4

Power supply system - 1

Dependeces - 4
Static compensation schemes - 1
Dynamic compensation schemes -1
Dependences for compensators - 5
Conclusions - 1

6. Advisors of paper chapters

Chapter	Advisor’s surname, initials and position	Signature, date	
		assignment was given by	assignment was received by
Job safety	Okipnyi I., Ph.D., Assistant professor		
Standards verified by	Kuzemko N., Ph.D., Assistant professor		

7. Date of receiving the assignment 1.01.2022

TIME SCHEDULE

LN	Paper stages	Paper stages deadlines	Notes
1.	Preparation analytical section	11.01.22-1.02.22	
2.	Preparation design section	10.02.22-27.02.22	
3.	Preparation calculation section	1.04.22-25.04.22	
4.	Preparation occupation health section	17.05.22-20.05.22	
5.	Preparation references	11.06.22-17.06.22	
6.	Preparation assignment, abstract, introduction	20.06.22-25.06.22	
7.	Preparation slides and presentations	26.06.22-29.06.22	
8.	Receiving the response and review of the theses	29.06.22-30.06.22	
9.	Preparation the report for defense	1.07.22-3.07.22	

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ABSTRACT

This bachelor's thesis contains: 60 pages, 23 figures, 2 tables, 14 used references.

The object of the study is the process of compensation of reactive loads of electrical network nodes in the starting modes of asynchronous and synchronous motors.

The subject of research are methods and means of control of compensating installations during starting modes of asynchronous and synchronous motors.

The purpose of the work is to improve the voltage by dynamically compensating the reactive power during the start-up of powerful asynchronous and synchronous motors in power supply systems of limited power.

The following main tasks are solved in the work:

Control systems of devices of dynamic compensation of reactive power are improved, which are based on high-speed measuring channels to obtain information about the spectral conductivity of the load, which provides increased accuracy and speed of compensation of reactive loads.

The expediency of using spectral conductivities as informative parameters in devices of dynamic compensation of reactive power that allows to maintain voltage during starting modes of operation of asynchronous and synchronous motors is substantiated.

Key words: energy saving, energy efficiency, asynchronous motor, synchronous motor, starting mode, reactive energy, compensation.

CONTENT

LIST OF ABBREVIATIONS

AL – air line

AM – asynchronous motor

CT – current transformer

CU – capacitor units

ER – electrical receiver

MC – measuring channel

PL - cable power line

PSS – power supply system

RPC – reactive power compensation

SM – synchronous motor

SPPC – system of pulse-phase control

STC – static thyristor compensator of reactive power

TCR – thyristor controlled reactor

TFS – three-phase source

VT – voltage transformer

INTRODUCTION

Actuality of theme. Starting currents of powerful synchronous (SM) and asynchronous (AM) motors cause a sharp decrease in voltage at the network node. This has a number of negative consequences, which include increasing the start-up time of motors, reducing the stock of static and dynamic stability of electrical network nodes, in particular, in power supply systems (PSS) of limited power.

One of the effective measures to increase the voltage level during engine start-up is dynamic reactive power compensation. At the same time, in order to regulate the power elements of dynamic reactive power compensation devices in transient modes, it is necessary to determine their optimal parameters and evaluate the efficiency of the start-up process.

The task of choosing the optimal parameters in transient modes is complicated because the reactive power of AM and SM is a complex function of load moment, voltage at the network node, which, in turn, depends on voltage at substation buses, network and motor resistance, excitation current of synchronous machines, and also due to the nonlinearity of the magnetization curve of the magnetic circuit AM.

In this regard, there are no equivalent passive parameters that could be unambiguously used as calculated in the starting modes of electric drives, while ensuring minimal impact of static characteristics of load units. In modern conditions of operation of electric networks with a nominal voltage of 6, 10 kV to ensure the compensation of reactive power and to minimize voltage deviations during daily changes in load use unregulated capacitor units (CU) and SM are used to minimize voltage deviations during daily load changes. Devices for dynamic compensation of reactive power in starting modes of electric drives are practically not used.

Therefore, the scientific and applied problem, which is to optimize the process of dynamic compensation of reactive power during the start of powerful asynchronous and synchronous electric drives in the PSS of limited power, is relevant.

The purpose and objectives of the work. The work is dedicated to the problem of stabilization the voltage by dynamically compensating the reactive power during the start of powerful asynchronous and synchronous electric drives in power supply systems of limited power.

To achieve this goal it is necessary to solve the following tasks:

1. Analyze methods and tools for reactive power compensation in starting modes of asynchronous and synchronous electric drives.
2. Develop criteria and propose mathematical models of dynamic reactive power compensation during start-up of induction motors.
3. Analyze the processes of dynamic compensation of reactive power using synchronous motors and static thyristor compensators.
4. Develop a control system for dynamic compensation of reactive power in the starting modes of electric drives.

Object of study- the process of compensation of reactive loads of electrical network nodes in starting modes of asynchronous and synchronous electric drives.

Subject of study- methods and means of control of compensating installations during starting modes of asynchronous and synchronous electric drives.

Research methods.During the work on the thesis research methods were used, which were based on:

a) in the theory of electrical engineering - in obtaining analytical expressions of the criteria for the quality of reactive power compensation;

b) in the theory of electric machines - in the search for mathematical models for the analysis of starting modes of operation of electric drives and control of compensation installations;

c) on the methods of computer modeling - in the analysis of errors in the compensation of reactive loads using mathematical models of asynchronous and synchronous electric drives;

d) on the methods of physical modeling - in the practical implementation of the measuring channel of the control system of compensating installations.

The practical significance of the results obtained work is to use new informative parameters in the creation of systems for dynamic compensation of reactive power in the starting modes of electric drives.

1. ANALYTICAL SECTION

1.1. Analysis of mutual influence of reactive power and voltage deviation

Power supply schemes in the presence of large asynchronous and synchronous electric drives depend on the share of their power in the total load. As a rule, power supply schemes are radial with two voltage transformations and contain several output connections, each of which can be powered by several simultaneously operating technological installations, as well as other electricity receivers. In some networks, deep input is used to power large synchronous electric drives. In general, the power supply scheme (Fig. 1.1) consists of an overhead power line (110 or 35 kV), a transformer 110(35)/10 kV T1, a cable power line (PL), a transformer of 10/6 kV T2, synchronous (SM) and asynchronous (AM) motors. Transformer substations 10/6 kV for power to large AM and SM are powered by transformer substations 110(35)/10 kV PL length of up to one kilometer.

The installed power of power transformers with a voltage of 110(35)/10 is 6300÷25000 kVA, a 10/6 kV – 630÷6300 kVA with the established power- of consumers 250÷3000 kVA. Proportionality of these capacities and the presence of a power line of considerable length loads to a deterioration in the quality of voltage on the clamps of electric receivers.

When working AM and SM in networks of limited power, first of all, such indicators of the quality of electricity as deviations and voltage fluctuations [1, 2], deteriorate.

The voltage quality in the load units of electrical networks is regulated by ГОСТ 13109-97 [3] and is controlled by registering devices and statistical voltage quality analyzers [1, 4]. To determine the integral indicators of electricity quality, statistical research methods have been developed [4-7].

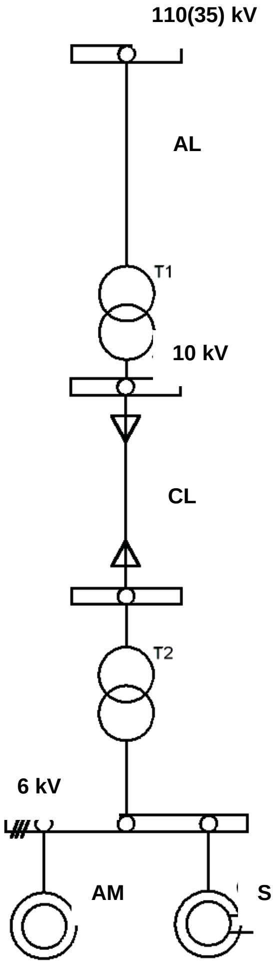

Fig. 1.1. - Power supply scheme in the presence of large electric motors

But the measures that control the quality of electricity alone are not enough. It is necessary to develop and implement special devices for automatic adjustment of reactive power, which ensure the improvement of these indicators in the unit of loading of the electrical network.

The task of improving the quality indicators of electricity becomes especially relevant at the present time saving electricity and controlling its rational use. The conducted studies [2, 8, 9] showed that the function and magnitude of losses from the deviation of electricity quality indicators are an important technical and economic characteristic of a technological object and can be a criterion for optimizing regulation aimed at improving electricity quality indicators [1, 7].

The nature of the consumption of active and reactive capacities of asynchronous and synchronous electric drives is determined by the moment of load.

$$P = -\frac{3U}{\omega_0 L_d}\left(E\sin\theta + \frac{U}{2}\sin 2\theta\left(\frac{L_d}{L_q} - 1\right)\right) = M\omega_0/p_0, \qquad (1.1)$$

where M – mechanical torque of load on the shaft of the machine;

ω_0– angular frequency of power supply voltage;

p_0 – number of pairs of poles;

U – voltage in the node of the electrical network;

E– EMF, directed by the excitation current in the anchor wrapper;

θ – the load angle of the SM;

L_d, L_q– inductance of stator winding, respectively, along the longitudinal and transverse axes.

Reactive power of explicitly polar SM

$$Q = -\ \frac{3U}{\omega_0 L_d}\left(E\,cos\,\theta - U\left(1 + sin^2\ \ \theta\left(\frac{L_d}{L_q} - 1\right)\right)\right). \qquad (1.2)$$

Emf given by the excitation current in the anchor wrapper is determined by the formula

$$E = p_0 \omega M_{sf} I_{f}, \qquad (1.3)$$

where ω– rotor speed;

M_{sf} – mutual induction between stator and rotor windings;

I_f – excitation winding current.

There are a number of analytical methods for accurately determining the reactive power of the SM [11, 12], which take into account the change in the voltage of the network and the active resistance of the engine stator; the saturation of the synchronous machine along the longitudinal axis; taking into account the saturation of the synchronous machine when changing the voltage of the network and linear nonlinear electromagnetic bonds in the machine.

The calculated data show that the reactive power of the SM is a complex nonlinean function of the load and voltage of the network and the excitation current. In the range of changes in loads not exceeding the nominal values for the SM with a short circuit ratio of 0.84, with a decrease in voltage level, the reactive power of the SM decreases. With an increase in the multiplicity of engine load over 1.5 and a nominal excitation current, the reactive power of the synchronous motor becomes inductive regardless of the voltage level of the network.

The reactive power consumed by the SM at voltage deviations from 0.9 to 1.15 varies depending on the load within 20 ÷ 60%. increase in reactive power, and therefore increase energy losses and voltage deviations, which worsens the technical and economic indicators.

An increase in voltage at the SM clamps loads to a significant deterioration in its compensating capacity (more than twice during the idle course of the engine and voltage changes from 1 to 1.15).

The value of active and reactive power and AE current can be determined by simplified formulas

$$P = \frac{U^2 \frac{R_r}{s}}{\left(\frac{R_r}{s}\right)^2 + X^2}; \; Q = \frac{U^2 X}{\left(\frac{R_r}{s}\right)^2 + X^2}; \; I = \frac{U/\sqrt{3}}{\sqrt{\left(\frac{R_r}{s}\right)^2 + X^2}}, \qquad (1.4)$$

where U – supply voltage;

R_r – rotor resistance;

X – total resistance of the stator and rotor of the engine;

s – sliding of the rotor.

To determine the voltage deviation on the clamps of the installation, which is powered along the line and through the transformer T2 (fig. 1.1), probability characteristics of the load value of the engines are required, depending on the technological modes of operation.

Load factor of the i-th engine by active power β_i may vary in the interval for the following characteristic modes: non-working engine speed, nominal load of the engine $\beta_{nom} = 1$, maximum load of the engine $\beta_{max} = 1{,}8$. At the same time, the engine load factor by reactive power $\alpha_i = \frac{Q_i}{Q_{ном.i}}$ changes within relatively narrow limits $\alpha_{max} = 1{,}2$.

During the start-up of the SM and AM, a significant increase in the consumption of active and reactive capacities, as well as current, is characteristic.

At known values β_i and α_i and voltage losses in the line are

$$\Delta U = \frac{R_л \sum \beta_i P_{ном.i} + X_л \sum \alpha_i Q_{ном.i}}{U_1}, \qquad (1.5)$$

where R_l, X_L – active and reactive support of power line and transformer;

U_1 – voltage value on the part of the supply network.

Summation is carried out by the number of electric drives turned on, taking into account the possibility of their simultaneous start-up.

Voltage value on the installation clamps

$$U_2 = U_1 - \Delta U.$$

Calculations show that the voltage level U_2 at the input of the installation (fig. 1.1) is not a constant value, even with the constant voltage of the transformer and the nominal excitation current of the synchronous motor, and depends on the load and resistance of the power line. The limits of voltage deviation at the installation within the permissible power line poles and specified loads significantly exceed the values allowed in accordance with the standart.

Loss of active Δ_{PL} and reactive ΔQ_L power in the power line and power transformer

$$\Delta P_L = \frac{\sum(\beta_i^2 P_{nom.i}^2 + \alpha_i^2 Q_{nom.i}^2)}{U_1^2} R_L; \; \Delta Q_L = \frac{\sum(\beta_i^2 P_{nom.i}^2 + \alpha_i^2 Q_{nom.i}^2)}{U_1^2} X_L. \quad (1.6)$$

Taking into account the relationship between capacities and voltages, the calculation must be performed by sequential approximations.

The nature of the change in reactive power and voltage at the input of the installation depends not only on the resistance of the power line, but also on the current of excitation of the SM and the mode of operation of other consumers of the installation.

1.2. Analysis of efficiency criteria and methods of research of starting modes of electric drives

The task of maintaining optimal voltage in the load node is a complex optimization task. The criteria for optimality in solving the problem of improving the quality indicators of electricity can be: a minimum of voltage dispersion, a minimum of the consumed reactive power of the load node; minimum losses of active power in the elements of the. Theoretical studies and data on the operation of AM and SM in low-power electrical networks show that their quality indicators of operating modes are low and require significant improvement.

They can be significantly improved or partially optimized by automatically Adjusting the excitation current of the SM, as well as devices for individual and group compensation of reactive power of the AM. Installed in the node load SM can and should be used to improve the quality of electricity. Taking into account the mutual connection of the operating modes of several installations, the voltage level at the installation is not constant, which significantly affects the technical and economic performance of electric drives.

The literature sets and solves the problem of determining the optimal, unregulated excitation current, in which a minimum of reduced costs for the production and distribution of reactive power in the load node is ensured, including a minimum of electricity losses in the synchronous motor and network elements. The optimal excitation current is determined on the basis of total losses that affect the thermal mode of operation of the synchronous motor.

In determining the estimated costs should take into account the cost of regulating and compensatory devices, the cost of losses of electrical energy in the elements of the network along the way of transmission of reactive power from the system to this load node; the cost of electricity consumed by the SM, etc. With an increase in voltage, along with an increase in losses for magnetization (loss in steel), there is an accelerated wear of insulation of electrical machines and transformers and irrationally redistributed reactive power, which causes additional losses in the network.

Existing assessments and criteria for optimizing the operating modes of the SM do not take into account the peculiarities of their work in limited power electrical networks. There is also no justification for choosing and developing the most technical ways to regulate reactive power.

The criteria for regulating the excitation current of the SM can be:

a) in established modes:

– ensuring the transshipment capacity of the engine;

– minimum deviation of voltage from the nominal value with its short-term forcing;

– minimum criterion function proportional to the load and square of voltage deviation;

Minimum of electricity losses.

b) in launch modes:

– limiting the maximum torque;

– limitation of the maximum starting current;

– minimum loss of electricity;

– absence of fluctuations in the moment;

– the duration of the start, which is determined by the average value of the moment.

Analytical methods for the study of start-up modes require a large preliminary work specifically for each type of task and do not provide high accuracy in determining the time of the transition process, instantaneous values of current and voltage at feeding the SM from the PSS of limited power.

When examining the starting modes of asynchronous and synchronous motors, sufficiently accurate results can be obtained using numerical methods. These methods have sufficient accuracy and have been distributed for calculations and design of synchronous machines, but they are time-consuming and require considerable machine time in calculations.

The operation of dynamic reactive power compensation (RPC) devices is based on the use of thyristor keys, thyristor-adjustable reactors and unregulated or discretely adjustable capacitor batteries as sources of reactive power. Dynamic RPC devices differ in the way capacitor batteries are turned on and how they are managed.

Conclusions to section 1

1. Analysis of operating modes of large electric drives and a review of existing methods of their research showed that there are no fairly simple and accurate methods for calculating their compatible modes of operation, which take into account the mutual impact of engines and network parameters. At the same time, insufficient attention is paid to the issues of determining and optimizing the quality indicators of electricity in the starting modes of electric drives.

2. To improve the quality indicators and in particular reduce voltage drops, it is advisable to use dynamic compensation devices for reactive power and synchronous electric drives, which ensure the regulation of reactive power and allow to improve the quality of power supply voltage in the electrical network.

3. When researching the modes of operation of the SM in electrical systems, it is important to identify internal reserves and find ways to rationally and efficiently use the installed electrical equipment and ensure high technical and economic indicators of its work. To do this, it is advisable to use compensatory devices and synchronous electric drives, which ensure the regulation of reactive power and allow you to improve the quality of the power supply voltage in the electrical network.

4. The use of compensatory devices and SM to compensate for reactive power and improve the quality of voltage in the load unit requires to evaluate their use and optimize the compatible mode of operation of electric drives in the electrical network.

5. For the analysis and evaluation of the modes of operation of electric drives, indicators that characterize the operation of electric drives in both transitional and established modes of operation are important. Transitional modes of electric drives in the load nodes of electrical networks often determine the dynamic stability of the load node, and the modes of operation of the electrical network and the parameters of its elements determine the stable and reliable operation of electric drives, and therefore the performance of drive mechanisms. Therefore, it is

necessary to combine the study of the modes of operation of electrical networks and electric drives in their interconnection and mutual influence.

6. To determine the quality indicators of the operating modes of AM and SM, fairly accurate methods for calculating both transitional and established processes are necessary. The study of transients and their accurate calculation by analytical methods is difficult to carry out due to the impossibility of obtaining fairly accurate dependencies. The only possible method of complex studies of the modes of operation of the SM in an electrical system is a method based on nonlinear differential equations solved using computers in phase coordinates recorded in matrix form.

2. DESIGN SECTION

2.1. Characteristics of the reactive power compensation process in the starting modes of asynchronous motors operation using spectral conductivities

The tasks of optimizing the quality of electricity in the load node are mainly related to deviations and voltage fluctuations due to technological features of production, parameters of power lines, the presence of reactive power control devices. With unacceptable values of other indicators of electricity quality - non-sinusoid and voltage asymmetry, optimize the choice of appropriate technical means, based on the minimum cost of their implementation.

Electric drives of consumers work in different modes. The load of each mechanism, its magnitude, duration and nature vary widely and depend on many factors. The values of the average power and its variance are characterized by a wide range of changes. It is impossible to ensure the balance of reactive power with the help of synchronous motors as an unregulated source of reactive power due to the change in the wide range of active and reactive power of electric drives. The use of synchronous motors with unregulated excitation current does not significantly reduce power losses in the power supply network and stabilize the voltage at the input of the receivers.

Starting currents of powerful AM with a short-circuited rotor cause a sharp decrease in voltage at the network node. This, in turn, leads to an increase in the duration of the start-up of the AM and reduce the margin of safety of the load nodes. One of the effective measures to increase the voltage level during the start-up of the AM is the dynamic compensation of reactive power. At the same time, in order to select the power elements of the devices of dynamic compensation of reactive power in transient modes, it is necessary to determine their optimal parameters and evaluate the efficiency of the AM start-up process. The problem of choosing the optimal parameters and estimating the efficiency of AM in transient modes is complicated by the nonlinearity of the magnetization curve of the magnetic circuit of AM and incompleteness of the theory of power in electric circuits with non-sinusoidal voltage and current. In this regard, there are no equivalent passive parameters,

For electric circuits in the case of non-sinusoidal current, the concepts of active and reactive components of spectral resistance and conductivity are introduced

$$R_C = \frac{P}{I^2}; X_C = \frac{Q}{I^2}; g_C = \frac{P}{U^2}; b_C = \frac{Q}{U^2}, \tag{2.1}$$

where P, Q - active and reactive power;

U, I - current values of voltage and current.

In the integral form of the record, the expressions for the active and reactive components of the spectral resistance and conductivity are as follows:

$$R_C = \frac{\frac{1}{T}\int_0^T u(t)i(t)dt}{\frac{1}{T}\int_0^T i^2(t)dt}; X_C = \frac{\frac{1}{T}\int_0^T u(t)H\{i(t)\}dt}{\frac{1}{T}\int_0^T i^2(t)dt} = \frac{-\frac{1}{T}\int_0^T i(t)H\{u(t)\}dt}{\frac{1}{T}\int_0^T i^2(t)dt};$$

$$g_C = \frac{\frac{1}{T}\int_0^T u(t)i(t)dt}{\frac{1}{T}\int_0^T u^2(t)dt}; b_C = \frac{\frac{1}{T}\int_0^T u(t)H\{i(t)\}dt}{\frac{1}{T}\int_0^T u^2(t)dt} = \frac{-\frac{1}{T}\int_0^T i(t)H\{u(t)\}dt}{\frac{1}{T}\int_0^T u^2(t)dt},$$

where $H\{i(t)\}, H\{u(t)\}$- Hilbert transformations instantaneous according to current and voltage; T is the period of supply voltage.

Under the action of non-sinusoidal currents and voltages, the concept of power factor is recommended

$$\lambda = \frac{P}{UI} \; . \qquad (2.2)$$

From expressions (2.1) and (2.2) it follows that the power factor λ can be expressed as the square root of the product of active spectral resistance and conductivity

$$\lambda = \sqrt{R_C g_C} \; . \qquad (2.3)$$

Reactive spectral conductivity and resistance corresponding to the power distribution of S. Friese will be

$$b_F = y\sqrt{1-\lambda^2} \; ; X_F = Z\sqrt{1-\lambda^2} \; ,$$

where y, Z - total conductivity and load resistance.

Spectral resistance and conductivity at non-sinusoidal voltages and currents are analogs of complex resistance and conductivity at sinusoidal voltages and currents and can be represented by series and parallel substitution circuits, respectively (Fig. 2.1). Moreover, series and parallel substitution schemes for non-sinusoidal voltages and currents are not equivalent.

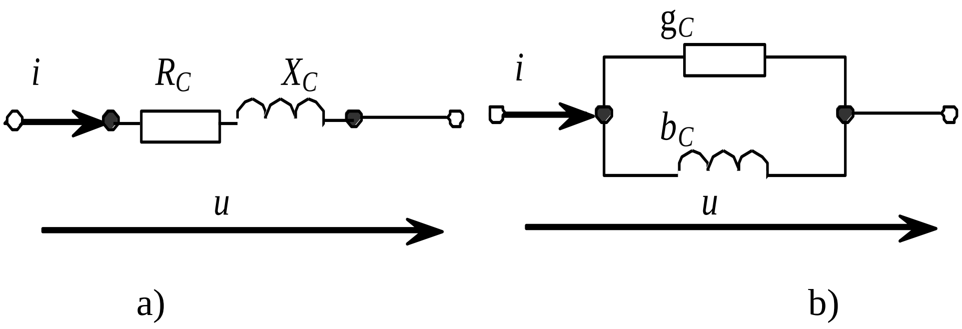

Fig. 2.1. - Two-element substitution schemes

2.2. Analysis of dynamic reactive power compensation in starting modes of induction motors

One of the effective measures to increase the voltage level during the start-up of the AM is the dynamic compensation of reactive power. In fig. 2.2 shows the dependences of active and reactive power during the start of the AM after compensation of reactive power by the criterion $b_C(t) = 0$. The application of this criterion provides full compensation of reactive power during transient electromechanical processes.

Use of reactive conductivity b_K leads to a slight overcompensation of the reactive power when starting the AM with significant non-sinusoidal supply voltage or nonlinearity of the AM. Use of reactive conductivity b_F, leads to even greater overcompensation of reactive power during the start-up of AM and in variable load mode.

The dependences of the current in the line during the start-up of the AM (fig. 2.3) clearly show that the use of dynamic reactive power compensation reduces the current in the line (dependence 2) compared to the current before compensation (dependence 1) almost twice during start-up. Thus, dynamic reactive power compensation significantly improves the starting modes of such engines.

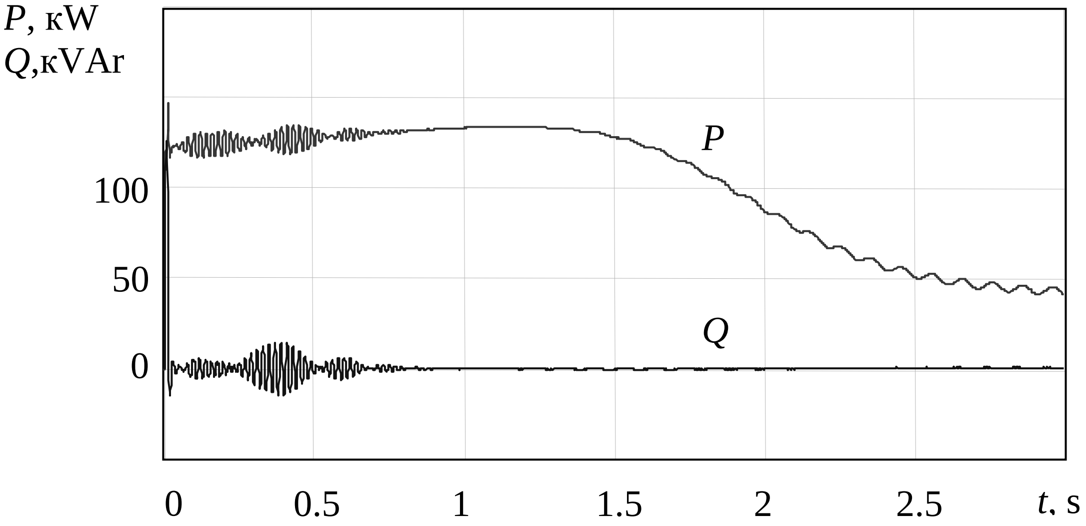

Fig. 2.2. - Dependences of active and reactive power of AM after compensation of reactive power by criteria $b_C(t) = 0$

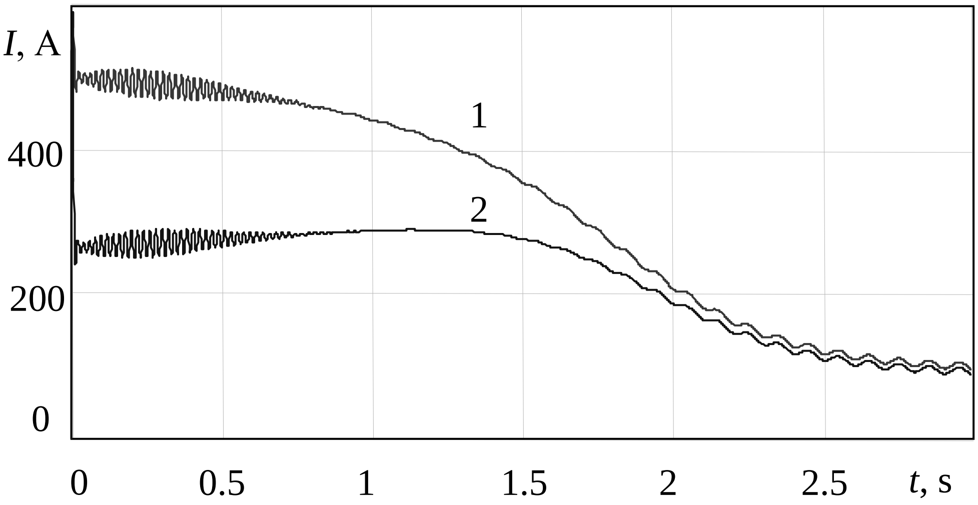

Fig. 2.3. - Dependences of current in the line during start-up of AM

2.3.Analysis of reduction of voltage drops during start-up of induction motors using dynamic reactive power compensation

The operation of induction motors (AM) during their start-up is characterized by significant reactive power consumption, which in some cases exceeds the active power consumption. The starting currents of the AM with a short-circuited rotor cause a sharp decrease in voltage at the network node. This, in turn, leads to a decrease in the margin of stability of the load nodes. Reduced voltage further reduces productivity and often complicates the normal operation of electric drives, especially their start-up. Therefore, to determine the input level of the voltage level and the limits of its change at a given technological loads of electric drives, it is necessary to have fairly accurate calculation methods that take into account the features of the PSS. To determine the quality of electricity requires fairly accurate methods of calculating the reactive power of electric motors,

It is extremely important to take into account the reverse effect of voltage changes in the connection node of the AM on the consumption of active and reactive power. For comparison, in fig. 2.4 shows the graphs of consumption of active and reactive power of the AM in the case of voltage reduction, taking into account the resistance of the line and the transformer. Consumption of active and reactive power during start-up is significantly reduced. Startup is much slower.

In the case of discrete control during the start-up of the AM, it is enough to turn on the power of the capacitor unit is 70 kVAr, which will reduce the amplitude value of the starting current to 340 A (Fig. 2.5). The amplitude value of phase voltage losses during start-up decreases to 35 V.

Activation of CU leads to an increase in the consumption of active and reactive power of the AM. For comparison, in fig. 2.6 shows the graphs of consumption of active and reactive power at the same time AM and CU. Consumption of active and reactive power during the start-up of AM has increased significantly. Start-up is much faster.

And although the application of the criterion $b_C(t) = 0$ provides full compensation of reactive power during start-up of AM and accordingly the smallest voltage losses (amplitude value of losses of phase voltage during start-up (dependence 1 in fig. 2.7) is approximately equal to 10 V), however realization of variable value $b_C(t)$ is a rather difficult task.

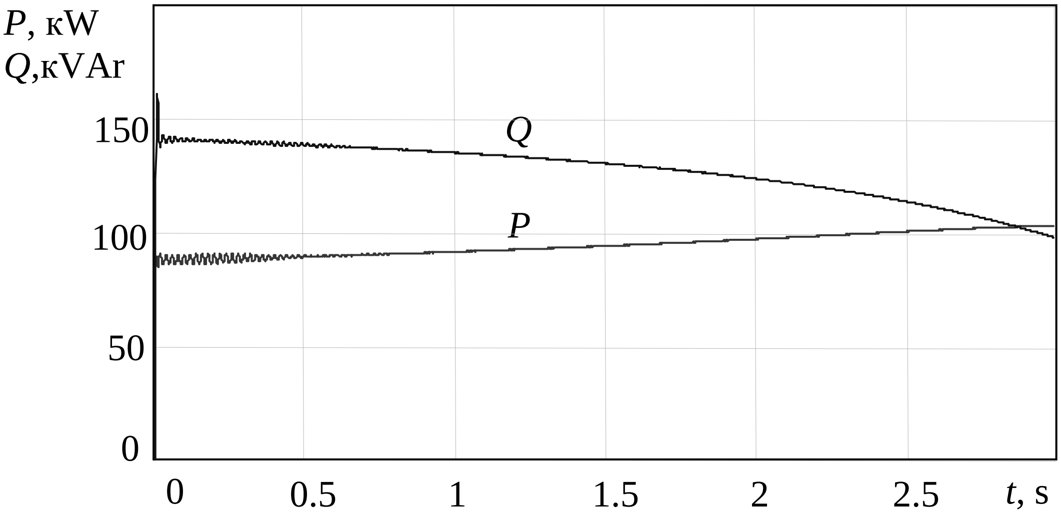

Fig. 2.4. The dependence of active and reactive powers during the start-up of the AM

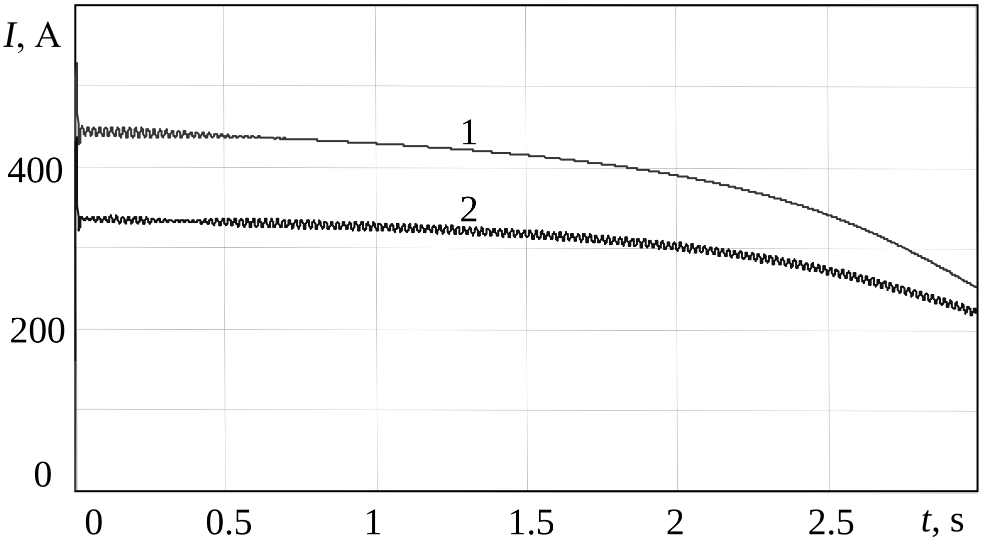

Fig. 2.5. The dependence of the current in the line during the start-up of the AM before (1) and after (2) compensation

Reduction of voltage drops during the start of induction motors can be achieved with the use of capacitor units (CU) with unregulated conductivity (power). To simplify the implementation of dynamic compensation devices, it is sufficient to use a short-term activation of the capacitor unit of such conductivity to ensure approximately the same voltage losses due to the transfer of active and reactive power at the initial start-up time. In the case of short-term switching on the CU with a design conductivity of 1.0 Sm (corresponds to the nominal power of the CU 140 kvar) provides a reduction in phase voltage losses during start-up to 20 V (dependence 2 in fig. 2.7). In the case of switching on the CU with a design conductivity of 0.5 cm, the reduction of phase voltage losses during start-up to 35 V is provided (dependence 3 in fig. 2.7).

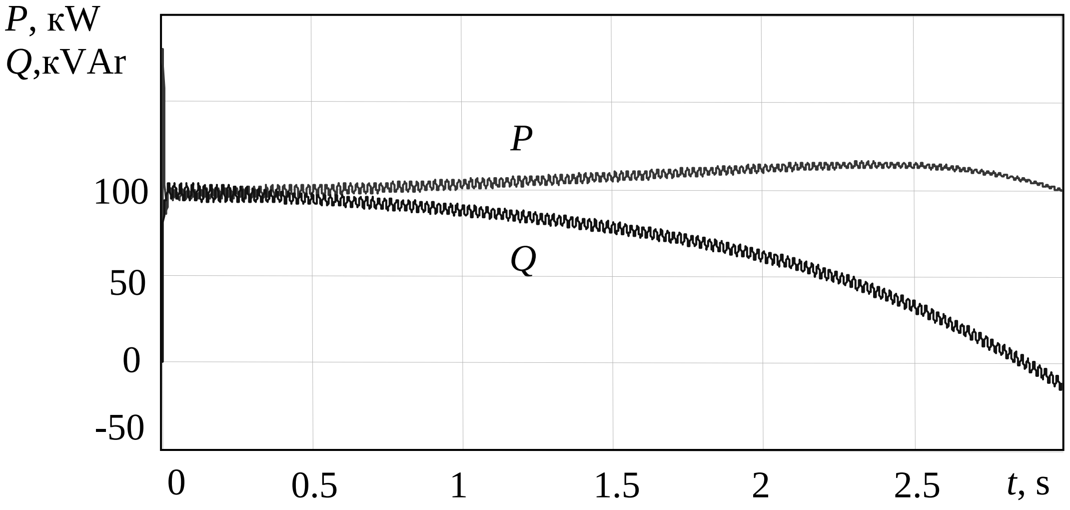

Fig. 2.6. - Dependences of active and reactive capacities of AD and CU

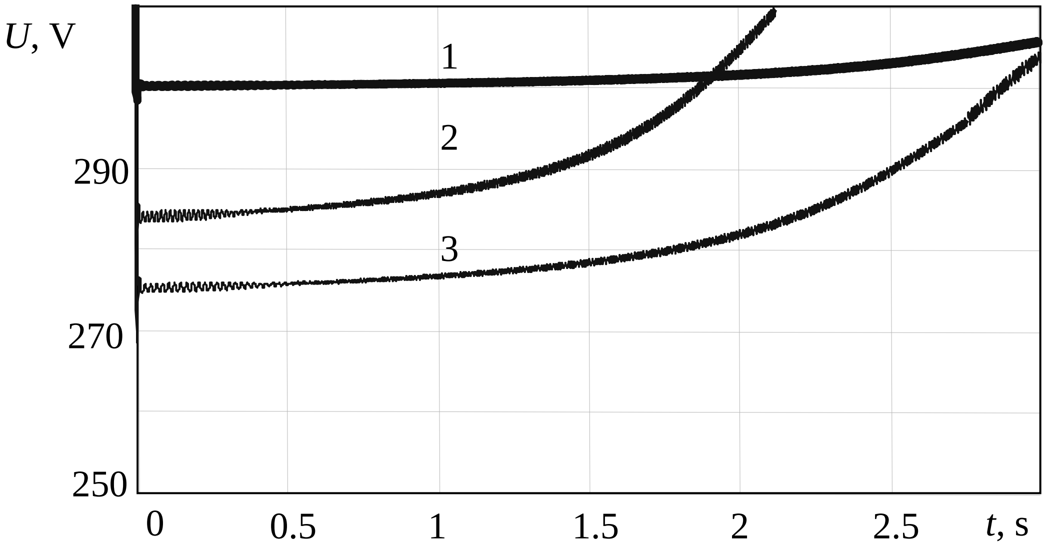

Fig. 2.7. - Dependences of voltage during start-up of AM with CU, corresponding b_C =0 (1), 1 Sm (2) and 0.5 Sm (3)

2.4. Features of the choice of optimality criteria and modeling of synchronous motors starting processes

The choice of the criterion of optimality is an important and difficult task, and the use of unreasonable criteria often leads to decisions that do not provide the desired technical and economic performance of electric drives, including reliability. It should be noted that there is no general, unified approach to the choice of criteria for optimizing electricity quality indicators for large electric drives operating in electric networks of limited capacity.

The optimal criteria for regulating the excitation current of the SM are the efficiency of the machine itself and the best ratio of its electromechanical parameters. The synchronous motor must first of all ensure the efficient operation of the technological installation in the concrete conditions, which is possible with the appropriate automatic regulation of the excitation current of the SM. Automatic control must provide high stability of the SM, its normal thermal regime.

However, this approach is incomplete. The system of automatic control SM must take into account the technological features of the modes of operation of SM and the fullest use of their compensatory capacity, which can significantly improve the quality of supply voltage in the electrical network. Automatic control SM must ensure a minimum of electricity losses in the electricity grid.

The choice of the automatic control SM device is connected with the choice of the optimization criterion. The selected criterion must take into account the mains supply and its parameters, the presence of compensating devices and their use, the peculiarities of the modes of operation of the electrical equipment of the network node and so on.

The main directions of solving the problem of optimizing the modes of operation of electric drives are:

1. The best use of SM as an electric machine, in terms of its performance characteristics (overload capacity β, power factor $\cos\varphi$, efficiencyη) while ensuring high stability and vibration damping.

2. Local regulation of reactive power flows in the load node in order to ensure high technical and economic performance of the network.

3. Ensuring the parameters of the mode (primarily voltage deviations and fluctuations) in the network nodes within acceptable limits.

The optimal use of SM equipped with automatic control devices is considered when comparing two criteria: 1) stability, drive speed; 2) energy and economic performance of synchronous electric drive.

The basis of the control criteria, which improve the quality of electricity and the quality of the modes of operation of the SM, is the provision that the deviation of the voltage level from the optimal value worsens the quality of the modes of operation of the SM and all electrical equipment. It is assumed that when the voltage level deviates from the optimal value, the total losses change, including technological losses, which are determined by the "minimum" or the amount of damage. When implementing such criteria in automatic control devices, it is assumed that during each technological mode, the voltage on the busbars of the transformer and the load node will be maintained optimal, with each instantaneous change in its level.

Automatic control devices that accurately implement the proposed criteria are not only due to technical difficulties, but also their inefficiency, especially in the operation of SM in distribution networks of limited capacity. Existing automatic control, built on simplified criteria, which are based on changes in instantaneous fluctuations of voltage (current) and are invariant, which does not allow to predict or control in advance the voltage regimes and power quality indicators in the PSS.

None of these criteria directly solves the problem of improving the quality of the modes of operation of the SM, so it is necessary to use a combined or selective regulation. In the conditions of operation of the automatic control device which realizes two criteria of regulation, it is expedient to provide independent adjustment of control circuits. You can use a logic switching device for this. To control the system, separate regulators are used, and the system is selectively affected by the regulator, the output of which is currently significant.

Features of the modes of operation of the SM of limited power allow us to identify ways to improve their performance indicators of the modes of operation, the main objectives of which are:

1. Ensuring the required overload capacity of the SM, taking into account the parameters of power lines and possible fluctuations in the supply voltage.

2. Ensuring high quality of electricity at the input of the installation.

Calculations and analysis show that in the devices with the resistance of the power line and the change in engine load, it is impossible to establish the optimal excitation current. Based on these calculations, only one conclusion can be made: the excitation current of a synchronous motor must be automatically adjusted depending on the specific conditions that characterize the load of a synchronous motor. The choice of the automatic control law should be made taking into account possible changes in the voltage level of the transformer, the mutual influence of the operation of the electric drive and the power line.

Methods of research of modes of operation of powerful synchronous electric drives operating in electric networks of limited power are based on the use of analytical dependences and mathematical models for computers. It is generally accepted in solving such problems to divide the study into the analysis of quasi-steady-state modes, the analysis of transients during engine start-up and their dynamic stability.

One of the main assumptions made in the construction of physical models of electric machines is the requirements for the voltage applied to the machine windings. It must be constant or sinusoidal. The two-reaction method is particularly well suited for the analysis of open-pole machines and machines with an uneven air gap. With this method it is convenient to consider transients in electric machines, which is a great advantage over other methods. Using the two-reaction method, it is convenient to analyze electrical machines on a computer.

Consideration of traditional methods of modeling diabetes shows the following:

– transients are calculated by integrating the equations of state in the time domain;

– established processes are calculated in the timeless field, and therefore the methods are not justifiably cumbersome and devoid of accuracy, which is due to the need for human intervention in the computational process;

– the calculation of static stability is based on a mathematical apparatus quite different from that used to calculate both transient and steady-state processes;

– the calculation of parametric sensitivity was out of consideration of these methods;

– the mathematical apparatus used at each stage of the analysis is fragmented and makes it impossible to build unified algorithms, and therefore requires the creation of separate, unnecessarily complex programs;

– mathematical models of electromechanical devices, although focused on numerical methods, but inconvenient for modeling, require an unreasonably large amount of calculations, and therefore lose accuracy;

– analytical methods are difficult to obtain the desired accuracy of the calculation of transients due to the inability to obtain sufficiently accurate dependencies.

The use of general theory of differential equations and a combination of methods of theory of electric and electromagnetic circuits, electromagnetic and thermal fields, equations of mechanical motion in ordinary and partial derivatives made it possible to build mathematical models of complex electromagnetic and electromechanical devices and whole systems. The result is a theory of unified algorithms, which allows on the basis of an identical mathematical apparatus to calculate in the time domain of transients and steady-state processes, to determine static stability and parametric sensitivity as interrelated problems of analysis.

Conclusions to section 2

1. The processes of dynamic compensation of reactive power in starting modes of operation of asynchronous electric drives with short-circuited and phase rotor using spectral conductivities are analyzed. The use of spectral conductivities makes it possible to assess the quality of transient modes of asynchronous electric drives, to obtain criteria for optimizing starting modes and to propose a method of quality control of starting processes of asynchronous electric drives.

2. Based on the analysis of starting modes of AM with short-circuited rotor, as well as AM with phase rotor with the introduction of active resistance in the rotor circuit, it is shown that during the start-up of AM to control dynamic reactive power compensation devices values. A criterion for the quality of AM transients is proposed, which, in contrast to existing methods, increases the accuracy of reactive power compensation and ensures the maintenance of voltage in the electrical network.

3. The influence of dynamic compensation of reactive power during start-up with the use of spectral conductivities as quality criteria of starting modes on reduction of voltage losses and reduction of start-up duration is analyzed.

4. The basis of regulatory criteria that improve the quality of electricity and the quality of the modes of operation of the SM, is the provision that the deviation of the voltage level from the optimal value worsens the quality of the modes of operation of the SM and all electrical equipment. When implementing such criteria in automatic control devices, it is assumed that during each technological mode, the voltage on the busbars of the transformer and the load node will be maintained optimal, with each instantaneous change in its level.

5. When the SM in the network with a satisfactory quality of electricity, increasing the mechanical torque on the SM shaft leads to two cycles of beating and

increases the time of its entry into synchrony; at the same time rather big currents proceed. At some critical value of the mechanical moment, the SM loses synchronicity. The frequency fluctuates at a speed of about 260 s^{-1} and currents flow that far exceed the currents of the normal mode.

3. CALCULATION SECTION

3.1. Dynamic reactive power compensation systems in transient modes of electric drives based on static thyristor compensators

The presence of starting and re-short-term modes of powerful electric drives leads to a sharp decrease in voltage and requires rapid regulation of reactive power. One of the methods of reducing the voltage loss in the power supply network during the start of electric drives is the use of devices for dynamic compensation of reactive power, as well as automatic control of excitation of synchronous motors.

Successes in the development of powerful semiconductor devices and sophisticated electronic control devices have led to the possibility of developing high-speed controlled static thyristor reactive power compensators (STC). These devices are characterized by high dynamic characteristics, ease of use, reliability and virtually unlimited mode flexibility.

There are several methods of generating and regulating reactive power using various semiconductor devices that are used as switches. Currently, almost all compensators are based on high-voltage thyristor valves in combination with reactors and capacitors. Consider the implementation of STC for isolated neutral networks with a connection scheme "triangle" (Fig. 3.1). from the current of other phases. Therefore, the properties and energy characteristics of STC can be identified by considering a single-phase thyristor controlled reactors (TCR).

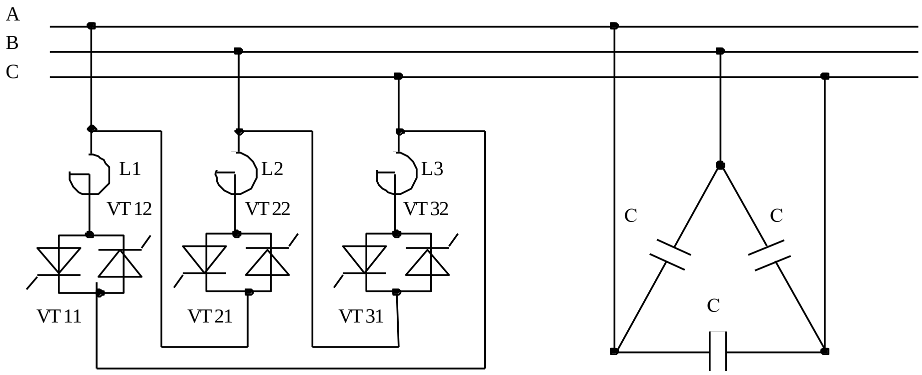

Fig. 3.1. - Scheme of static thyristor compensators (STC)

Each phase of the compensator contains a reactor whose inductance is L_p, active resistance R_p, and bitiristor key, thyristors which are connected counter-parallel.

The scheme of replacement of the network node with STC and load is shown in fig. 3.2. The diagram shows the active and reactive resistance of the system R_C, X_C, load resistance Z_L and capacitor battery X_{cb}.

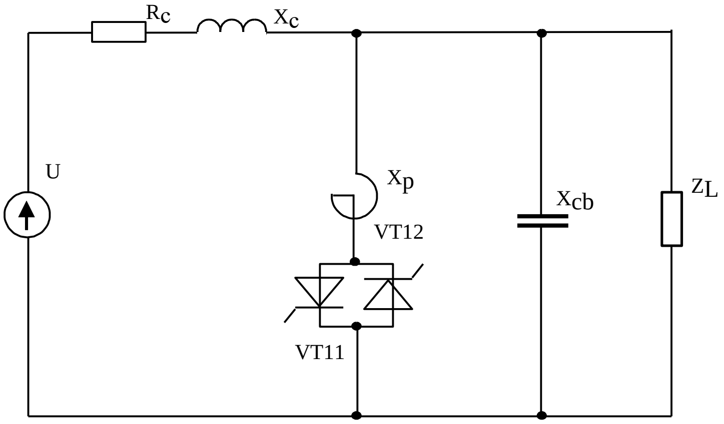

Fig. 3.2. - Scheme of replacement of a network node with STC and loading

Neglecting load supports Z_L and capacitor bank X_{cb}, the expression for the instantaneous current TCR can be obtained as a solution of the differential equation

$$U_m \cdot \cos(\omega t + \gamma) = i \cdot (R_p + R_c) + \omega(L_p + L_c)\frac{di}{d\omega t},$$

where U_m - amplitude value of the line voltage of the network;

γ - angle of opening of thyristors;

L_c - inductance of the system,

which is valid for the current through the thyristor in the range $\gamma \le \omega t \le \gamma_в$, where $\gamma_в$ - the closing angle of the thyristors, which corresponds to the zero value of the current through the reactor.

Solving this equation taking into account the initial conditions $\omega t = \gamma, i = 0$, we obtain the expression for the instantaneous current through the TSR, which is valid for the current through the thyristor in the range $\gamma \le \omega t \le \gamma_в$,

$$i(\omega t) = I_m \cdot \left[\cos(\omega t - \varphi) - \cos(\gamma - \varphi) \cdot e^{-\frac{\omega t - \gamma}{\omega \tau}}\right], \qquad (3.1)$$

where $I_m = \dfrac{U_m}{\sqrt{\left[R_p + R_c\right]^2 + \left[\omega \cdot (L_p + L_c)\right]^2}}$ - amplitude of current through the reactor at $\gamma = 0$;

$\varphi = arctg\dfrac{\omega(L_p + L_c)}{R_p + R_c}$ - phase shift angle of the main harmonic current through the reactor;

$\tau = \dfrac{L_p + L_c}{R_p + R_c}$ - time constant of the circle.

Since the TCR in the general case is mainly an inductive load ($\varphi \approx 90^\circ$), the shape of the current in the TCR with increasing switching angle γ, which is calculated from the maximum value between the phase voltages, reduces its amplitude almost without changing the phase shift (Fig. 3.3).

After turning on the thyristor current through the TCR flows for a period of time not exceeding half the period.

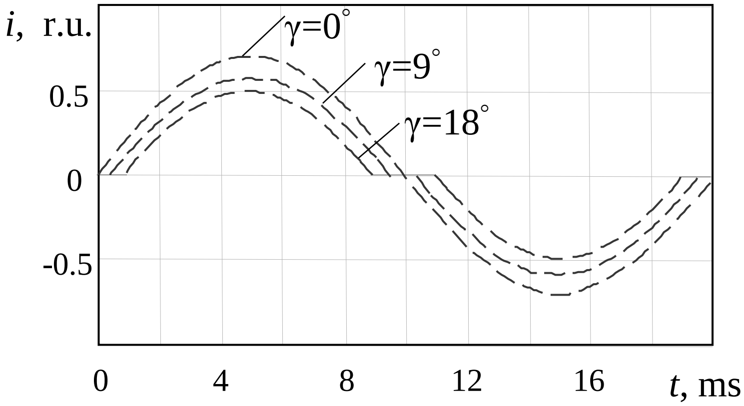

Fig. 3.3. - Graph of current change through TCR

Despite the fact that the TCR is connected to a source of sinusoidal voltage, non-sinusoidal current flows through it.

Decomposing into Fourier series relations (3.1), we obtain the active and reactive components of harmonics

$$i_{\nu a}=\left[\frac{2}{\pi}\cdot\int\limits_{\gamma}^{\gamma_в} i(\omega t)\cos\nu\omega t d\omega t\right]; i_{\nu p}=\left[\frac{2}{\pi}\cdot\int\limits_{\gamma}^{\gamma_в} i(\omega t)\sin\nu\omega t d\omega t\right],$$

where $\gamma_в$ - closing angle of thyristors, which can be determined from the equation

$$\cos(\gamma_в-\varphi)-\cos(\gamma-\varphi)\cdot e^{-\frac{\gamma_в-\gamma}{\omega\tau}}=0,$$

which can be obtained from expression (3.1) provided $i = 0$ at $\omega t = \gamma_{в}$.

The calculation of the harmonic components of the current was performed on a computer using the program MathCad 7.0 Pro. The periodically repeated time function i (t) = i (t ± nT) is presented in the form of convergent trigonometric series:

$$i(t) = c_0 + \sum_{\nu=1}^{\nu=\infty} c_\nu \cos(\nu\omega t + \varphi_\nu) = c_0 + \sum_{\nu=1}^{\nu=\infty} a_\nu \cos\nu\omega t + \sum_{\nu=1}^{\nu=\infty} b_\nu \sin\nu\omega t,$$

where $a_\nu = \frac{2}{T}\int_{-T/2}^{T/2} i(t)\cos\nu\omega t\cdot dt;\ b_\nu = \frac{2}{T}\int_{-T/2}^{T/2} i(t)\sin\nu\omega t\cdot dt;\ c_0 = \frac{1}{T}\int_{-T/2}^{T/2} i(t)\cdot dt;$

$$c_\nu = \sqrt{a_\nu^2 + b_\nu^2};\ \varphi_\nu = \operatorname{arctg}\frac{b_\nu}{a_\nu},$$

T- the period of the function and (t).

The results of these calculations are given in table. 4.1. Analysis of the data shows that with increasing angle γ the reactive current of the fundamental harmonic of the TCR decreases. Simultaneously with the increase of the angle γ reactive components of higher current harmonics appear.

In fig. 3.4 shows the dependences of the TCR current spectrum on the angle γ. The largest is the amplitude value of the third harmonic of the current, which reaches its maximum at $\gamma \approx 30^\circ$. However, given that the third harmonic of the current is closed in the triangle TCR, we can be sure that the effect of higher harmonic components will be less noticeable, because the amplitude of the fifth harmonic is 5.1% of the fundamental harmonic at an angle 18°, and the amplitude of the seventh harmonic does not exceed 2.4%.

Table 3.1 Harmonic current spectrum through a thyristor-regulated reactor

γ	υ	1	3	5	7	9	11	thirteen
0°	a_υ	0.004	0	0	0	0	0	0
	b_υ	0.986	0	0	0	0	0	0
9°	a_υ	0.003	0	0	0	0	0	0
	b_υ	0.790	-0.065	-0.036	-0.024	-0.016	-0.011	-0.001
18°	a_υ	0.002	0	0	0	0	0	0
	b_υ	0.604	-0.113	-0.051	-0.021	-0.005	0.003	0.006
27°	a_υ	0.001	0	0	0	0	0	0
	b_υ	0.436	-0.136	-0.037	0.002	0.013 th most common	0.009	0.001
36°	a_υ	0.001	0	0	0	0	0	0
	b_υ	0.293	-0.131	-0.006	0.020	0.008	-0.005	-0.006
45°	a_υ	0	0	0	0	0	0	0
	b_υ	0.179 th most common	-0.105	0.021	0.015	-0.007	-0.006	0.004
54°	a_υ	0	0	0	0	0	0	0
	b_υ	0.096	-0.069	0.031	-0.002	-0.009	0.005	0.002
63°	a_υ	0	0	0	0	0	0	0
	b_υ	0.042	-0.035	0.024	-0.012	0.002	0.003	-0.004

One of the problems of compensating for the influence of fast-changing loads on the power supply network is to ensure the desired speed of the compensator. Obviously, in real conditions there is always a certain time delay of compensation, which is due to the principles of measurement and processing of control parameters, as well as the features of the power circuit of the static compensator.

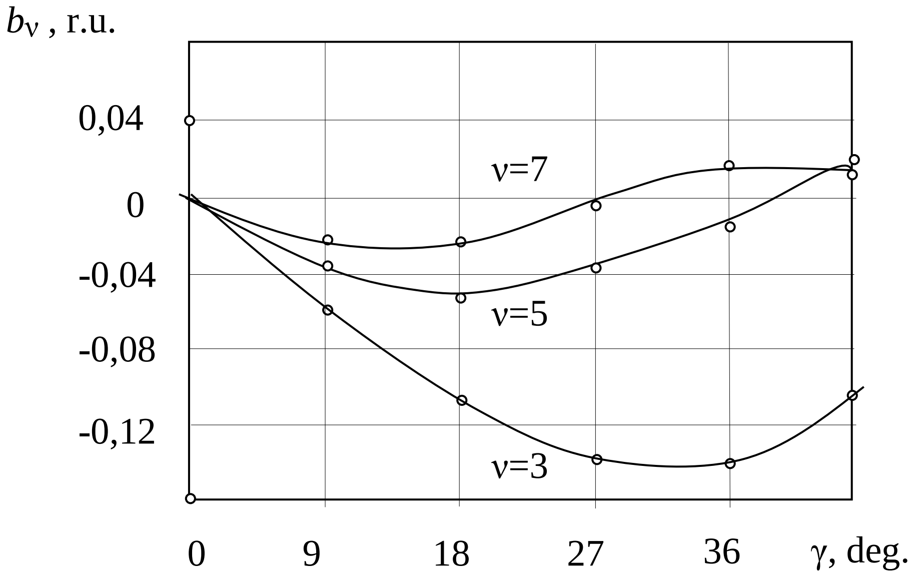

Fig. 3.4. - Dependences of the TCR current spectrum on the angle γ

A frequency method has been developed to estimate the speed of reactive power compensation of variable load. It is shown that if the oscillations of the reactive power of the load occur according to the harmonic law with frequency f and amplitude δQ_f , then, having a compensation delay τ, it is possible to determine the amplitude of the residual relative oscillations of the reactive power by the formula

$$R_Q = \frac{\delta Q'_f}{\delta Q_f} = \sqrt{1 + 1/\alpha^2 - (2/\alpha)\cos\omega\tau},$$

where α is the degree of reactive power compensation;

$\delta Q'_f$ - amplitude of reactive power fluctuations after compensation.

As the frequency of reactive power load fluctuations increases, the amount of uncompensated oscillations of the reactive power of the system will increase in the case of compensation compensation for time τ. Starting from a certain cut-off frequency, the compensator will amplify the oscillations of the reactive power, and the longer the compensation delay time τ, the lower the cut-off frequency value. This worsens the effect of compensation in general.

Summarizing the above, it can be argued that due to the high speed of the STC can reduce the starting currents.

Let's consider two variants of realization of systems of dynamic compensation of reactive power of electric drives by means of STC for networks with the isolated neutral with the scheme of connection "triangle" (Fig. 3.5) where the three-phase source (TFS), the electric receiver (ER) consisting of reactors L1, L2, L3 and counter-parallel thyristors VS11, VS12, VS21, VS22, VS31, VS32, filter unit consisting of capacitors C1, C2, C3 and filter reactors L4, L5, L6. STK control is carried out by means of system of pulse-phase control (SPPC), information on loading of ER on inputs which arrives from outputs of the measuring channel (MC) which, in turn, is connected to the power supply line of PSS through measuring current (CT) and voltage transformers (VT).

The system of dynamic compensation of reactive power (Fig. 3.5 a) provides control of perturbation, and the system (Fig. 3.5 b) - deviation. The system of dynamic compensation of reactive power with perturbation control (Fig. 3.5 a) is characterized by higher speed, but for its construction it is necessary to obtain the control characteristics of the STC.

If the higher harmonics of the supply voltage are zero, then there are no active and reactive powers on any of the higher harmonics. Therefore, the active and reactive power will be determined by the fundamental harmonics of the current

$$P = U \cdot I_1 \cdot \cos\varphi_1 = U \cdot I_{1a}, Q = U \cdot I_1 \cdot sin\,\phi_1 = U \cdot I_{1r}.$$

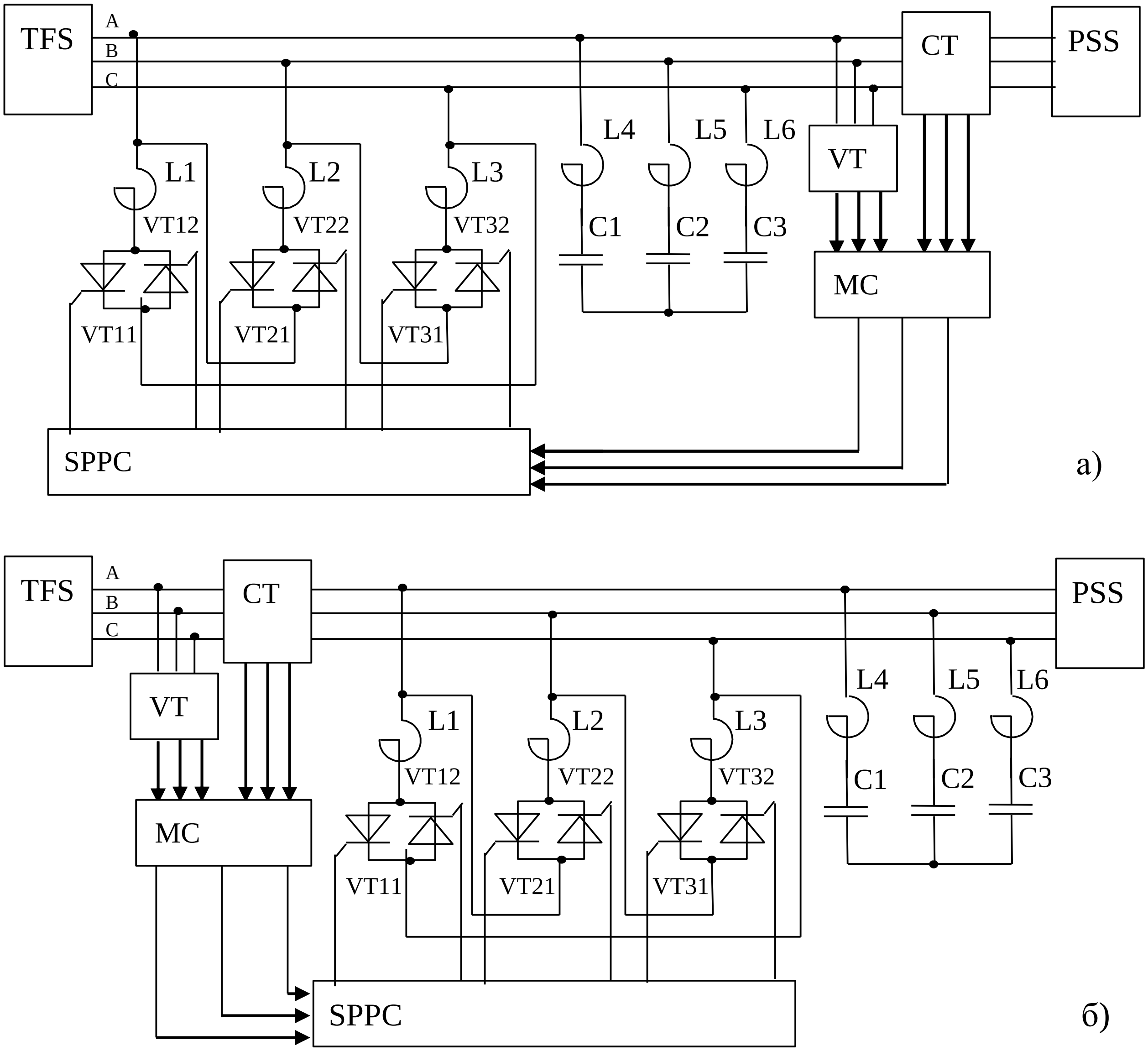

Fig. 3.5. - Reactive power dynamic compensation schemes electric drives using STC

In fig. 3.6 shows the dependence of the reactive power Q (γ) TCR, which allows to obtain the control characteristic of the STC by reactive power

$$Q_{STC}(\gamma) \approx Q_{CB} - Q(\gamma), \qquad (3.2)$$

where Q_{CB} is the power of the capacitor unit.

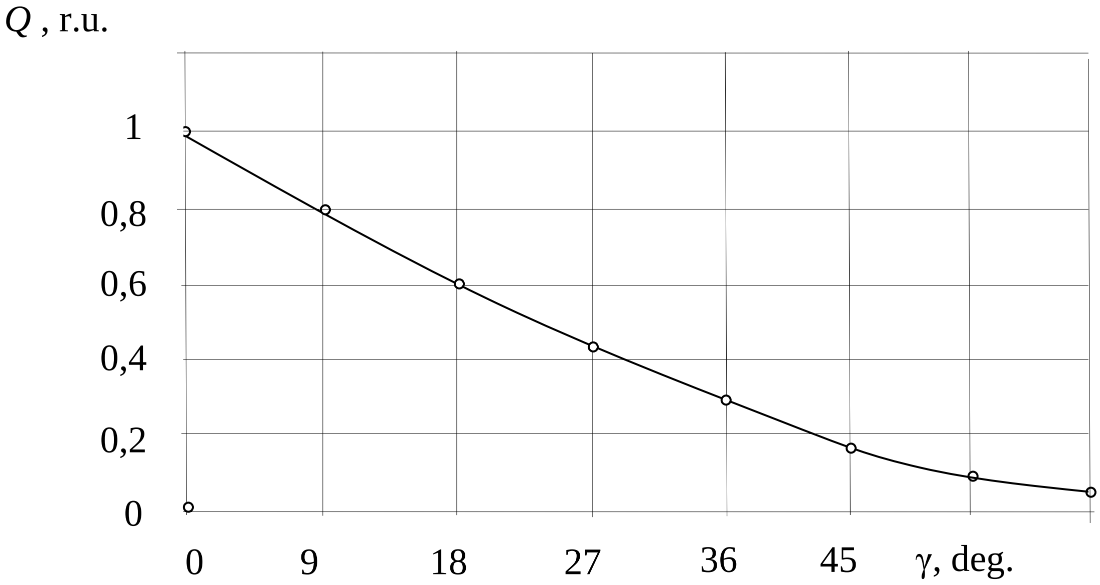

Fig. 3.6. - Change in reactive power Q (γ) STC

To obtain the $Q_{STC}(\gamma)$ dependences, we consider the analytical dependences for the reactive current of the STC. Dependence of the amplitude value of the TCR current on the angle γ can be obtained from expression (3.1) by substituting $\omega t = \varphi$:

$$I_m(\gamma) = I_m(0) \cdot \left[1 - \cos(\gamma - \varphi) \cdot e^{-\frac{\varphi - \gamma}{\omega\tau}} \right]. \qquad (3.3)$$

Dependence $I_m(\gamma)$ shown in fig. 3.7 (curve 1). For comparison, the same figure shows the experimentally removed dependence of the amplitude of the first harmonic $\tilde{I}_{1m}(\gamma)$ current TCR (curve 2). Dependence of the amplitude of the first harmonic $\tilde{I}_{1m}(\gamma)$ (curve 2) current TCR is much lower than the theoretical dependence of the amplitude value of non-sinusoidal current $I_m(\gamma)$ (curve 1), which can be explained by the content of higher harmonics (see fig. 3.4).

In the table. 4.2 shows the experimental data of the amplitude values of the current TCR $\tilde{I}_m(\gamma)$ obtained using the MEMOBOX 300-smart network analyzer, which differ slightly from the theoretical $I_m(\gamma)$. Experimental data on the amplitude values of the first harmonic of the TCR current are also given here $\tilde{I}_{1m}(\gamma)$.

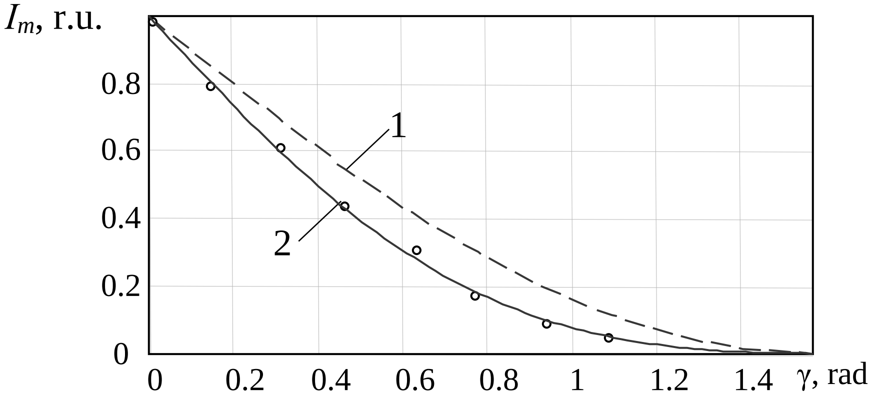

Fig. 3.7. - Dependences of amplitudes of non-sinusoidal current (1) and its first harmonic (2) through TCR

Table 3.2 Data of amplitude values of current through TCR

γ	0°	9°	18°	27°	36°	45°	54°	63°
$I_m(\gamma)$	1	0.844	0.692	0.548	0.414	0.295 th most common	0.193 th most common	0.110
$\tilde{I}_m(\gamma)$	1	0.839 th most common	0.693	0.538 th most common	0.405	0.293	0.186 th most common	0.107

$\tilde{I}_{1m}(\gamma)$	0.986	0.790	0.604	0.436	0.293	0.179 th most common	0.096	0.042

Analytical dependence of amplitude values of the first harmonic of current $\tilde{I}_{1m}(\gamma)$ can be obtained from the expression for the current (3.3) by decomposing it into a Fourier series

$$I_{1m}(\gamma) \approx \frac{I_m(0)}{\pi} \cdot \left[(\pi - 2\gamma) - \sin(\pi - 2\gamma)\right].$$

Therefore, the control characteristic of the reactive power of the STC can be represented as

$$Q_{STC}(\gamma) = F(\gamma) = Q_{CU} - Q(\gamma) = Q_{CU} - \frac{Q(\gamma=0)}{\pi} \cdot [(\pi - 2\gamma) - sin(\pi - 2\gamma)].$$

Thus, the control law of the STC for the system of dynamic compensation of reactive power by perturbation (Fig. 3.5a) can be presented as follows:

$$Q_{STC}(t) = b_C(t)U^2(t);$$

$$\gamma(t) = F^{-1}(Q_{STC}(t)). \qquad (3.4)$$

To implement the inverse nonlinear dependence F^{-1} you can use a functional converter or you need to perform its approximation.

A much more difficult task is to obtain current values of load conductivity $b_C(t)$. Therefore, we will dwell in more detail on this issue.

3.2. Analysis of the influence of supply voltage on starting and steady-state currents of induction motors

Operation of asynchronous electric motors at industrial enterprises is complicated by high voltage levels during periods of load reduction, which leads to frequent damage to their stator and rotor windings and requires identification and elimination.

Experimental studies of voltage performed on the substation of an industrial enterprise showed that in addition to the inflated voltage level, there is also a decrease (landing) voltage and a sharp increase (emissions) (fig. 3.8).

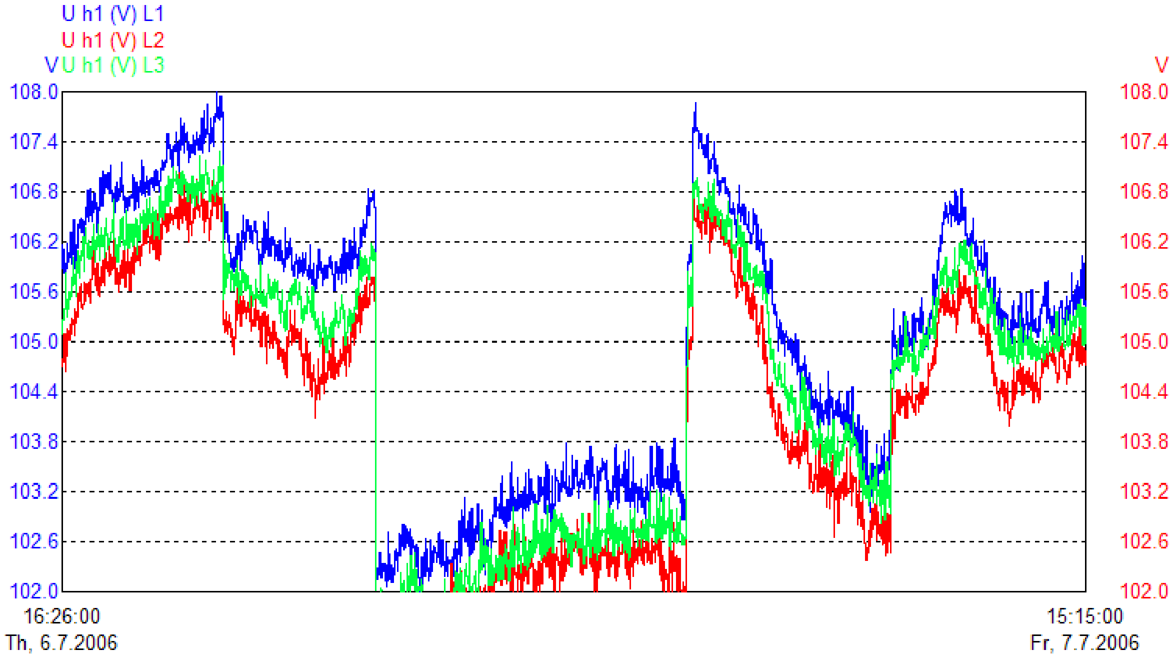

Fig. 3.8. Dependences of voltage on the substation of an industrial enterprise

Let's analyze the possible causes of engine failure. In fig. 3.18 shows the dependences of the rotor current during the start-up of the substation at normal temperature in the case of nominal (curve 1) and inflated (curve 2) supply voltage.

Thus, the cause of the destruction of the rotor may be an increase and fluctuations in current at the initial moment of starting the substation, which causes a sharp increase in dynamic loads on the rotor cage.

The increase in blood pressure has almost no effect on the mode of consumption (fig. 3.19).

Replacing motors with more powerful ones will provide a relative reduction of current in steady state (fig. 3.20). Increasing the voltage leads to a decrease in the steady state current and to its increase in the starting current (fig. 3.21).

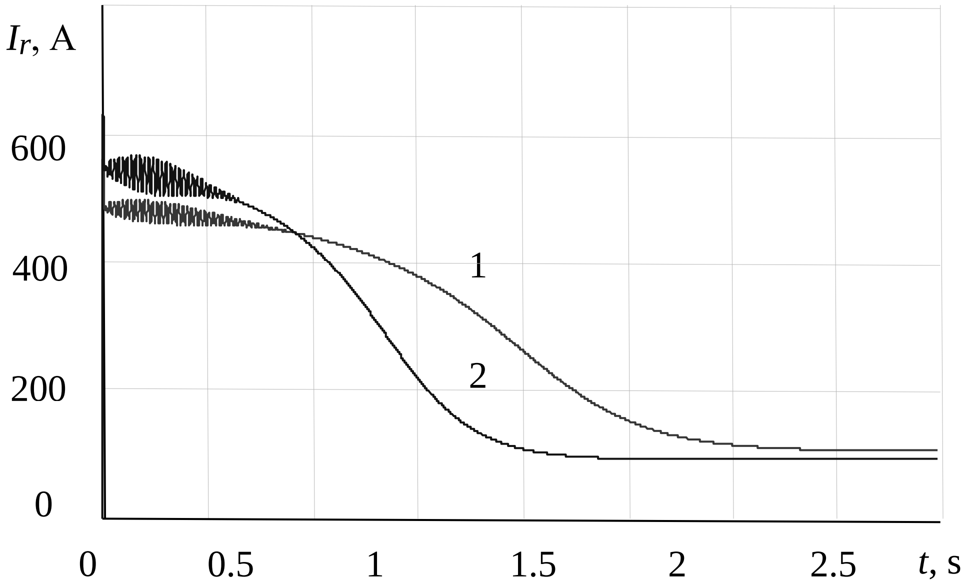

Fig. 3.9. -Dependences of rotor current during start-up of substation at normal temperature in case of nominal (curve 1) and high (curve 2) voltage

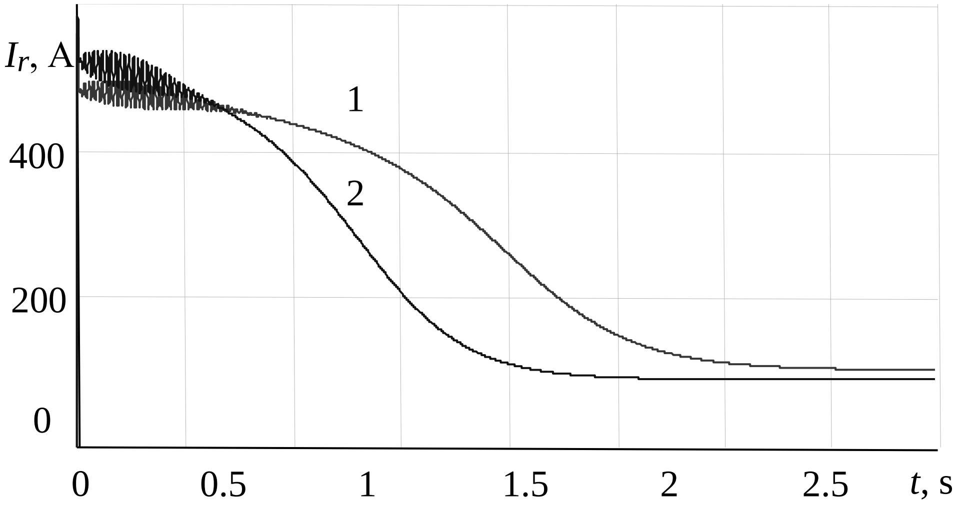

Fig. 3.10. - Dependencies of rotor current during AM start-up at high temperature in case of nominal (curve 1) and high (curve 2) voltage

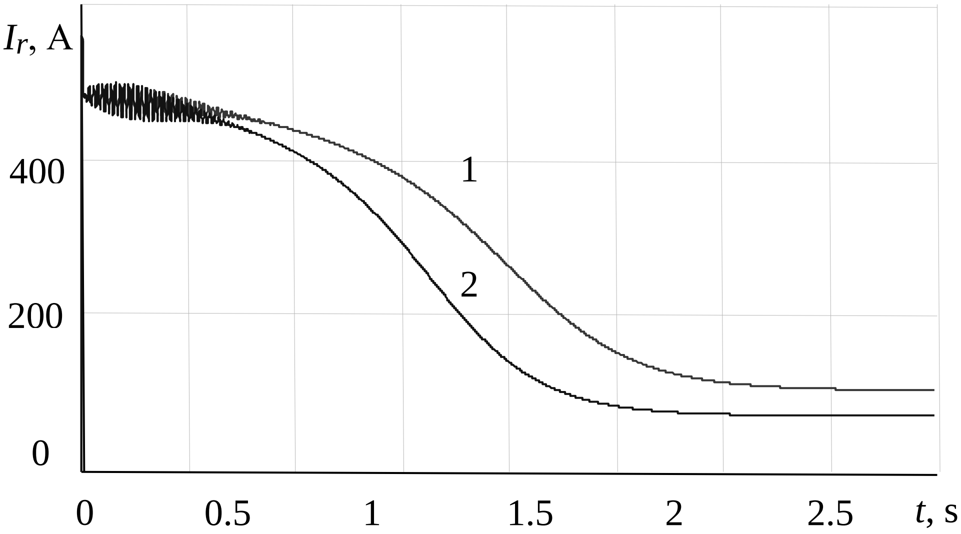

Fig. 3.11. - Dependences of rotor current during start-up of substation at nominal (curve 1) and reduced (curve 2) load in case of nominal voltage

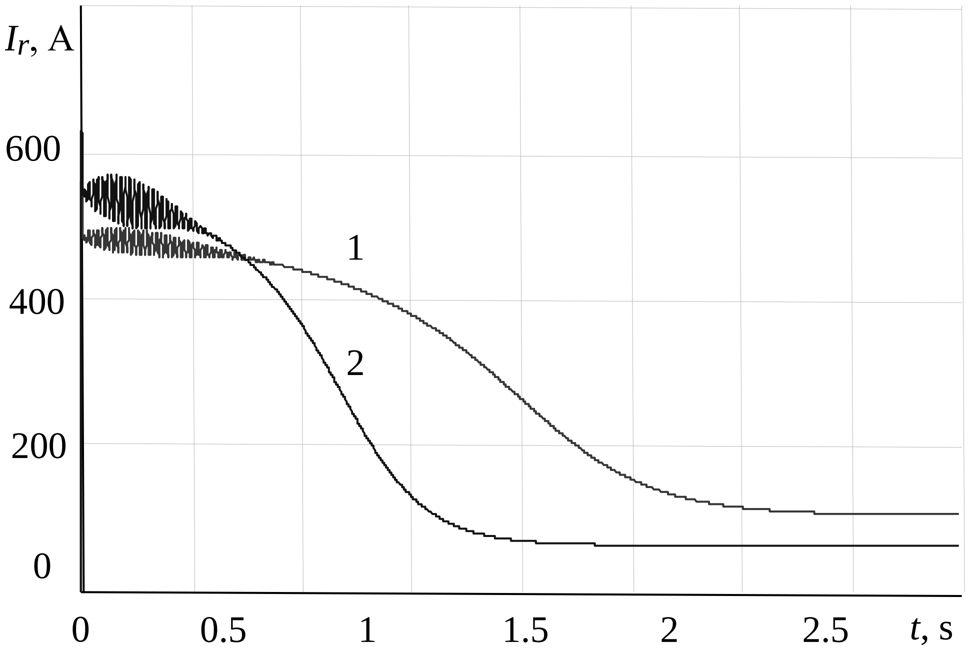

Fig. 3.12. - Dependences of rotor current during AM start-up at rated load and rated voltage (curve 1) and reduced load and overvoltage (curve 2)

Consider the effect of existing capacitor installations on voltage values. In fig. 3.22 shows the power supply circuit of the load unit with connection to the terminals of the condenser unit CU. When starting the motor in the supply line flows the current I, formed by the difference between the starting I_{start} and the current of the capacitor unit I_{CU}.

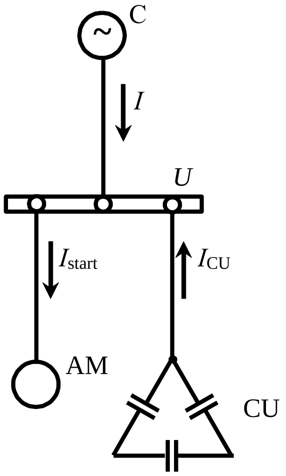

Fig. 3.13. - Power supply circuit

In fig. 3.23 shows the dependences of the supply current during the start-up of the AM without CU and with CU in the case of nominal supply voltage. In steady state, reactive power compensation leads to an increase in current, especially in high voltage mode, due to the influence of static characteristics of capacitor banks (Fig. 3.24).

The influence of static characteristics of capacitor banks is described by the quadratic dependence

$$Q = Q_{CU}\left(\frac{U}{U_L}\right)^2,$$

where Q_{CU} - capacity of the condenser battery;

U_L - rated voltage.

As a result, an increase in current may occur.

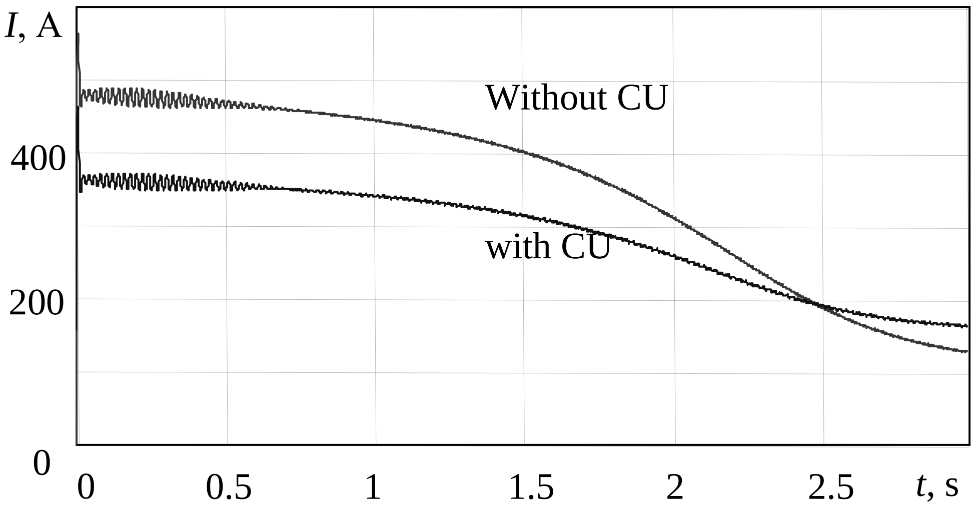

Fig. 3.14. - Dependences of supply current during start-up of AM without CU and with CU in the case of rated voltage

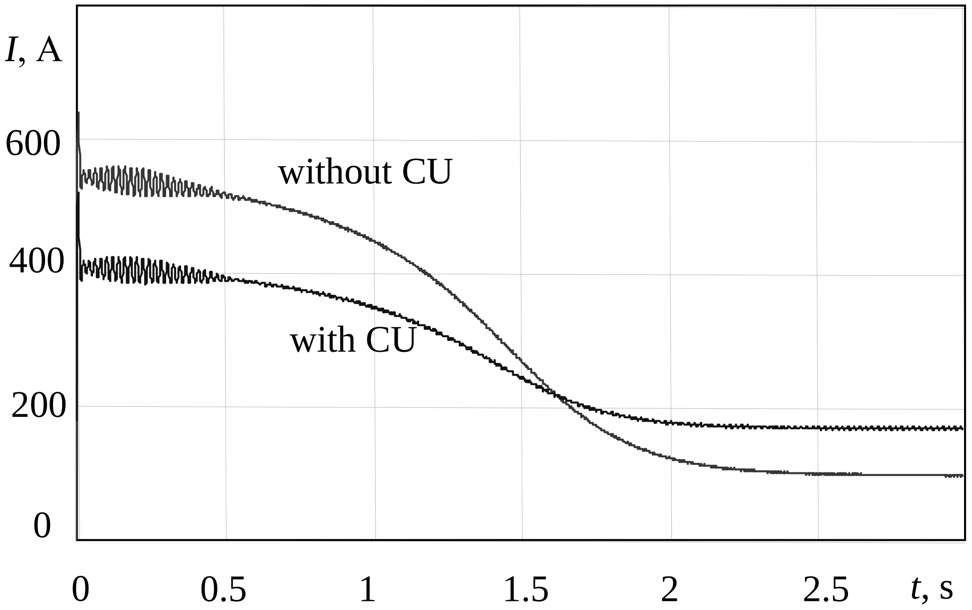

Fig. 3.15. - Dependences of supply current during start-up of AM without CU and with CU in case of overvoltage

Conclusions to section 3

1. Structural schemes of systems of dynamic compensation of reactive power on perturbation and on deviation are considered. Analytical expressions for the control characteristics of static thyristor compensators are obtained. For practical implementation, the regulatory characteristics are approximated by a simpler analytical dependence. The harmonic spectrum of the current through the thyristor-regulated STC reactor is analyzed. The law of control of the system of dynamic compensation of reactive power by perturbation is formulated.

2. On the basis of the analysis of starting characteristics of AM it is established that the reason of damage of windings of AM is starting currents at the overestimated pressure on their clamps. It is recommended to reduce the voltage level while using dynamic reactive power compensation in the starting modes of AM.

SECTION 4 . JOB SAFETY

4.1. Electrical safety and zprotective earthing of electrical equipment

The operation of compensating electric drive units is inevitably associated with the use of electricity. Electrical safety is a system of organizational, technical measures and means that protect people from the harmful and dangerous effects of electric current.

Electric current, passing through the human body, causes thermal, electrolytic and biological effects, causing local and general electrical injuries. The effect of electric current on the human body is accompanied by external damage to tissues and organs in the form of mechanical damage, electrical signs of electrometallisation of the skin, burns.

To ensure the safety of people from electric shock, protection of electrical equipment and electrical installations from overvoltage, the electric drive must have earthing devices to which securely connect metal parts of electrical installations and electrical equipment, which may be energized due to insulation failure.

Grounding of electrical installations must be performed:

- at a voltage of 500 V and above AC and DC in all cases;
- at voltage of alternating current above 42 V and direct current above 110 V, in rooms with the increased danger, especially dangerous and in external electric installations;
  - at all voltages of alternating and direct current in explosive rooms. To the parts which are subject to grounding, concern:
- housings of electric machines, transformers, devices, lamps, etc .;
- secondary windings of measuring transformers;

- frames of switchboards, control panels, panels and cabinets;
- metal structures of switchgear, metal cable structures, metal housings of cable glands, metal sheaths of wires, steel pipes and other metal structures related to the installation of electrical equipment;
- metal housings of mobile and portable electric receivers;
- metal supports of overhead lines.

Each earthing element of the installation must be connected to the earthing conductor or earthing line by means of a separate branch. Serial connection of several earthing parts of the installation to the earthing conductor is not permitted.

The connection of earthing conductors to earthing conductors and earthing structures must be made by welding or a reliable bolted connection. At the same time in damp rooms contact surfaces should have protective coverings. The ends of the earthing flexible conductors used for connection to the housings of appliances, machines, etc. must have lugs.

In the presence of shock or vibration, measures must be taken to loosen the contact (lock nuts, lock washers, etc.).

Earthing conductors located in the premises must be available for inspection. These requirements do not apply to neutral conductors and metal sheaths of cables, concealed wiring, metal structures in the ground, or earthing conductors laid in pipes.

Each earthing device in operation must have a passport containing earthing diagrams, its basic technical data on the results of the inspection of the earthing device, the nature of repairs and changes made to the earthing device.

In electrical installations with grounded neutral, when short-circuited to grounded parts, it is necessary to ensure automatic disconnection of damaged sections of the network with a minimum connection time. For this purpose in electrical installations with voltage up to 1000 V with grounded neutral the metal connection of the case of electric equipment with the grounded neutral of installation should be necessary.

4.2. Fire safety requirements for extinguishing electrical installations

Electrical installations are usually saturated with plastic elements, and some have a large amount of oil or work with gas, oil, fuel oil. In the event of a fire, the products of combustion emitted from them can cause serious injuries to both personnel and people involved in extinguishing it. The smoke emitted contains a variety of gases, which differ in the degree of adverse effects on humans. Therefore, protective measures to prevent the harmful effects of smoke on the human body should be carried out taking into account the gases contained in it.

Protecting human health from toxic gases when extinguishing fires in electrical installations can be active and passive. Active protection involves rapid ventilation of the premises that need to be penetrated to help people or perform any action. This method of protection is effective if the resulting air flow does not increase combustion.

Passive (defensive) respiratory protection is used when active is not possible. It involves the use of regenerative devices (insulating gas masks).

If the burning electrical installation is not switched off and is energized, its extinguishing is an additional risk of electric shock to personnel. Therefore, as a rule, you can start extinguishing the fire of the electrical installation only after removing the voltage from it. If for some reason it is impossible to relieve the voltage, and the fire develops quickly, it is allowed to extinguish the fire of live electrical equipment, but with special electrical safety measures.

To extinguish the fire of electrical equipment (oil-filled transformers, electric machines, cable lines laid in tunnels, etc.), you can use water (sprayed or compact jet), air-mechanical foam, inert gas, powders and other fire extinguishers. dry sand, etc.).

If it is necessary to extinguish a fire of unplugged electrical equipment to eliminate the possibility of electric shock, the following rules must be observed:

- the head of fire extinguishing in the electrical installation before the arrival of the first fire department caused by the alarm is the senior of the electrical personnel on duty or responsible for the electrical industry (chief power engineer, head of the electrical department). Upon arrival of the fire department, the senior commander takes over the management of the fire;
- disconnection of connections on which the equipment burns, is carried out by the next electrotechnical personnel without the prior permission of the higher person who carries out the operative management on operation of electric installation, but with the subsequent message it after the shutdown operation;
- extinguishing fires with compact and sprayed water jets without removing the voltage from the electrical installation is allowed only in open for inspection electrical installations, including cables at rated voltages up to 10 kV. The trunk of the fire water supply must be grounded, and the trunk must work in dielectric boots and gloves and be at a distance of at least 3.5 m from the fire with a water jet diameter of 13 mm at voltages up to 1 kV and 4.5 m at voltage up to 10 kV. With a jet diameter of 19 mm, these distances increase to 4 and 8 m, respectively;
- It is not allowed to use heavily contaminated water to extinguish live electrical equipment. Extinguishing fires in live electrical installations is prohibited by all types of foam, as foam and a solution of foaming agent in water have high electrical conductivity. In exceptional cases with reliable grounding of the generator of high-frequency foam and pumps of fire engines it is allowed to extinguish fires in

electrical installations under voltage up to 10 kV, air-mechanical foam;

- in case of fire, the power transformer must be disconnected from both windings, after which it must be immediately extinguished by any means (sprayed water, air-mechanical foam, fire extinguishers). Burning mineral oil should not be extinguished with a compact jet to prevent an increase in the area of the fire. When extinguishing the fire of transformers installed in the chambers, it is necessary to take measures to prevent the spread of fire through ventilation and other channels. Ventilation of the room at this time can be turned on only at the request of the fire department;
- in case of ignition of cables placed in tunnels, canals and other premises, it is necessary to turn it on in the presence of a stationary fire extinguishing system. When extinguishing burning cables with a voltage higher than 1000 V in a cable tunnel, the person working with the barrel must direct a stream of water through an open door or hatch without entering the cable compartment. Simultaneously with the extinguishing of cables, it is necessary to take measures to remove the voltage from them as soon as possible.

Extinguishing fires of non-live electrical installations is allowed by any fire extinguishing means, including water.

GENERAL CONCLUSIONS

Theoretical and experimental research performed in the thesis can be summarized by the following conclusions:

1. Improved dynamic reactive power compensation systems with perturbation control, based on high-speed measuring channels to obtain information on active and reactive spectral conductivity of the load, which increases the accuracy and speed of reactive load compensation and reduce voltage dips (delay time during regression) does not exceed half of the supply voltage period).

2. Starting modes of SM in normal, asymmetric and non-sinusoidal modes of supply voltage are analyzed. It is shown that forcing the excitation of the SM provides the possibility of dynamic compensation of reactive power. However, there are fluctuations in active power, which requires damping.

3. A mathematical model of an induction motor is proposed, which takes into account saturation and losses in steel, and stator and rotor currents are used as state variables. The new mathematical model of the electric machine differs from the traditional one in that its application will allow to determine more precisely the control parameters during the transient processes of the AM with short-circuited and phase rotor.

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