ABSTRACT

dissertation submitted for the degree of Doctor of Philosophy (PhD) under the specialty "6D071800 – Electric Power Engineering"

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"Development and research of controlled transformer type shunt reactors with direct current magnetization"

The task of ensuring normal operating modes of the electric power system and electric power quality standards is impossible without controlled means of regulating reactive power and voltage. In addition, maintaining optimal voltage levels on the substation buses minimizes active power losses in power grids and thereby improves the efficiency of power grids. FACTS devices are integral elements of the new generation of power transmissions.

One of the FACTS devices that perform reactive power regulation is a shunt reactor (SR). The main property of the SR is the absorption by charging of the power generated in power lines due to the capacitive component. From the entire line of reactive power control devices, the SR is distinguished by its relative cheapness and simplicity of design and operation. SR can be controlled and uncontrolled.

The issue of limiting excess reactive power is both in long intersystem lines and in urban high-voltage power grids, which are often complex to be closed. Along with the development of cities and accelerating urbanization, the number of overhead lines replaced by cable lines is also increasing. Despite all the advantages of cable lines, they generate more reactive power than overhead lines, which further increases the importance of shunt reactors for the transmission of electricity to the grid. The capacitive conductivity of cable lines is several times higher than that of the same bare wires. For example, the charging capacity of a cable line with a rated voltage of 110 kV is 8.4-18.0 MVAr per 100 km, and for an overhead line of the same voltage rating, this value is 3.4-4.0 MVAr per 100 km.

The demand for voltage and reactive power regulation equipment in the electric grids of the Republic of Kazakhstan with a voltage of 35 kV to 500 kV with a capacity of 25 MVAr to 180 MVAr remains quite high. Despite this, the production of controlled shunt reactors is not implemented in the Republic of Kazakhstan, and their supply is made from foreign countries such as the Russian Federation, Ukraine, Turkey, Spain and others. The price of imported reactors is inflated due to transportation costs and value added.

In accordance with the "Program for the Development of Domestic Value and Export-Oriented Industries", it is possible and necessary to establish the production of controlled shunt reactors. The need for controlled shunt reactors within the country will thus be met. In the future, the supply of reactors to the countries of near and far abroad will be an integral part of the transformer industry of the Republic of Kazakhstan.

The production of controlled shunt reactors of a new generation can be

established at affordable costs at the transformer plants of the Alageum Electric group, since the production of such reactors is fully consistent with the technology of transformer construction. This is important for the country in connection with the completion of the construction of a transformer plant in Shymkent for voltage classes of 500 kV (Asia Trafo JSC) and the promising development of Kentau Transformer Plant JSC, which produces transformers for voltage classes of 110 kV. The advantage of localizing production will provide a significant reduction in the cost of the product.

The practical significance of the work lies in providing controlled reactors to the electrical networks and systems of the Republic of Kazakhstan, expanding the product line of Asia Trafo JSC and Kentau Transformer Plant JSC, increasing the number of jobs, as well as the possibility of supplying controlled shunt reactors abroad.

Domestic production of controlled shunt reactors will increase Kazakhstan's content in solving the problems of building intelligent active-adaptive power grids and systems by optimizing the modes of the national power grid of Kazakhstan and regional power grids.

The listed factors clearly correlate with the tasks set by the head of state and the programs of strategic development of the country. The current attractiveness and, importantly, the cost-effectiveness of solutions for the installation of shunt reactors in power grids, on the one hand, and the continuing growth in demand for economical, reliable and at the same time "affordable" reactive power control devices based on shunt reactors, on the other hand, confirm the relevance of the ongoing research on the development of controlled shunt reactors.

The presented dissertation was carried out on the basis of a complex of research, analytical and experimental works, with the implementation of experiments at the production base of JSC "KazNIPIITES "Energy" and Non-Commercial JSC "AUPET named after G. Daukeyev".

These prerequisites form **the purpose of the dissertation research**, which is formulated as follows:

The aim of the work is to create highly efficient controllable ferromagnetic devices with DC magnetization. In accordance with the goal, a general scientific task is formulated - the development of Controlled SR (CSR) on the basis of experimental studies, simulation modeling and study of electromagnetic characteristics, operating modes, design and technological studies for the technology of transformer production.

In Framework Perform Dissertation To achieve this goal, the following works were carried out **Scientific tasks**:

- To conduct an analysis of scientific literature, patent studies in order to substantiate a new technical solution for controlled shunt reactors, including the design and technological scheme.

- To develop physical models of CSR with a three-rod magnetic core and to experimentally study electromagnetic characteristics.

- To develop a simulation model of CSR in the Matlab software package, at various modes of magnetization with direct current.

- To evaluate the effect of the degree of magnetization by direct current on the

composition of current harmonics of the CSR mains winding.

- To study the effect of the height and cross-section of working rods on the current consumption of the CSR, while ensuring the half-period saturation mode.

- Determine the ratio of the working rod cross-section to the yarn cross-section in order to ensure the half-period saturation mode.

- To develop recommendations and assess the possibility of manufacturing CSR based on standard transformers.

Research methods.

In the course of the dissertation, the methods of theoretical electrical engineering were used. Methods of theoretical and experimental study of electromagnetic characteristics of ferromagnetic devices. Methods of harmonic analysis, physical and simulation modeling.

The scientific novelty of the dissertation consists in the following:

1 The parameters of physical models of shunt reactors are substantiated.

2 A simulation model of the reactor was developed in the Matlab Simulink software package. A method for modeling CSR is proposed.

3 The mode of half-period saturation of the CSR is obtained, which is characterized by the minimum harmonic coefficient of the mains winding current and the nominal parameters of the CSR operating mode. Analytical formulas are used to calculate the ratio of the section of the yoke and members.

4 The analysis of electromagnetic processes in the simulation model of the 110 kV CSR was carried out and the possibility of improving the speed characteristics of the reactor without changing its design was revealed.

The reliability of the results obtained is confirmed by the following:

1 The studies were carried out on physical models of the shunt reactor using verified measuring instruments included in the register of the State Examination Institute of the Republic of Kazakhstan.

2 The experimental work was carried out in an integrated manner, and was duplicated by calculations based on the simulation model in the Matlab Simulink software package with high convergence of results.

Based on the results of the work performed and the research carried out, the following provisions are submitted for defense:

1. Experimental physical model of CSR with DC magnetization and substantiated parameters. Results of experimental studies of physical models of reactors.

2. Mathematical models of shunt reactors controlled by direct current magnetization in the Matlab software package. Methodology for modeling CSR.

3. Results of substantiation of the optimal ratio of lengths and cross-sections of rods and rods of the reactor, the number of windings and their tensions to obtain the half-cycle saturation mode at the nominal parameters of the CSR operation.

4. Influence of the third induction harmonic on the fifth and seventh harmonics of the mains winding current.

5. Results of studies of dynamic modes, possible measures to increase the speed of response, as well as a method that allows to significantly increase the speed of a 110 kV CSR of a standard design.

The results of the project may be breakthrough in the implementation of the concept of building intelligent active-adaptive power grids and systems and in the development of new electrical equipment of domestic production.

Consumers of the results obtained may be the system operator of the National Power Grid of Kazakhstan KEGOC JSC, AZhK JSC and other regional power grid companies.

The main provisions are reflected in scientific publications: 4 scientific articles, including: 1 scientific article in a domestic publication from the list of recommended by KOKSON; 2 scientific reports in collections at international scientific and technical conferences, including face-to-face presentation at a foreign scientific conference with the publication of reports in the Scopus database; 1 scientific article indexed in the Scopus database in the journal "Electric Power Systems Research" with a percentile of 78% at the time of publication in the section "Electrical and Electronic Engineering" "Electrical and Electronics". As a co-author, the results of research activities were recorded in: 2 Patents of the Republic of Kazakhstan for a utility model on the design of shunt reactors.

The author's personal contribution to solving the issue under study is determined by:

- Substantiation, formulation and selection of research methods using physical models of shunt reactors;

- Guidance at all stages of creation and direct research (development of the task for the manufacture, participation in measurements and data processing) of physical models of reactors;

- In the formulation and implementation of a mathematical model for calculation using the Matlab Simulink software package in relation to shunt reactors.

The dissertation work was carried out by the author in accordance with the current requirements of design, structure and content. The work consists of 5 main sections, a list of symbols, an introduction, a conclusion, a list of references and appendices.

The first section describes the principle of operation of shunt reactors and the half-period saturation of the reactor magnetic core. A review of the literature and current research in the field of shunt reactor development is given.

The second section describes the physical model of the shunt reactor and the test bench. The results of experimental studies of physical models of reactors are presented.

The third section presents the CSR simulation method in the Matlab Simulink software package, describes in detail the reactor simulation model and the stages of model creation. The results of experimental studies and simulation modeling of the shunt reactor operation at different degrees of magnetization by direct current are compared.

The fourth section contains the analysis and results of calculations of the 110 kV reactor model. Graphs of the dependence of mains winding currents on CSR parameters, harmonic analysis of mains winding currents when changing the cross-section and height of the CSR magnetic core rods are given.

The fifth section presents calculations and research results, technical

documentation for the production of 110 kV CSR with a capacity of 25 MVAr.