SUMMARY

of the PhD thesis by specialty 6D071800 – «Electrical Power Engineering»

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DEVELOPMENT OF THE SYNCHRONOUS COMPENSATOR PROTECTION SYSTEM FROM THE WINDINGS SHORTS

The proposed thesis is devoted to development of the synchronous compensator protection system from the windings shorts.

Relevance of the work. Synchronous compensators (SC) are widely used in electrical power engineering as a regulator of reactive power. Their usage provides a normal level of the voltage in areas of high consumer load concentration, where sufficient-duty synchronous engines are absent and application of static compensators is inefficient for economical or technological reasons. As a result sustainability of energy supply system operation and quality of electrical energy for consumers increase.

International experience of SC application shows that the windings shorts (WS) account for 20-25% of damages in stator and rotor the windings and for 8-10% of all damages in SC depending on the power and operating conditions.

In the field of relay protection of synchronous engines the sufficient contribution was made by Glebov I.A, Korogorodsky V.I., Kuzhekov S.A., Gimoyan G.G., Andreev V.A., Danilevich Ya.B., Novozhilov A.N., Fedoseyev A.M., Vanin V.N., etc. But the research work in this field cannot be considered complete for the following reasons.

Current protection systems, which are traditionally used in SC for protection of stator windings from the shorts, have a low sensitivity to WS in the stator windings. Therefore they turn off a damaged SC not just when WS occurs, but the dimensions of damages reach some sections.

The protection systems of stator windings based on built-in measuring converter are more sensitive to WS. But sometimes some of them can react on WS in rotor windings as well. So the operation of these protection systems doesn’t correspond to the requirements of selectivity that WS occurring in stator windings requires the quick shutdown and WS occurring in rotor windings can be turned off with a significant time delay.

WS in SC stator windings can usually occur through the short circuit of neighboring windings or as a result of occurrence of double rotor WS to ground. If a high-powered SC like a synchronous generator is equipped with the protection system KZR-3 from the short circuits to ground, then the portable protection kit KZR-2 is used to protect the rotor windings in the second point. At the same time protection systems from WS in the rotor windings in SC are not installed. This may reflect the fact that there aren’t any practices providing development of the selective and sensitive protection system.

Thus the work on development of selective and sensitive protection system for synchronous compensator from windings shorts is relevant.

The aim of the thesis is development of the selective and sensitive protection system for a synchronous compensator from WS in stator and rotor windings.

To achieve the aim the following objectives were determined and decided:

- researching the issues of construction features, excitation types, simulation of operation and abnormal modes of synchronous compensators, their operation modes with windings shorts in the rotor and stator windings as well as protection systems from these types of damage;
- developing the current simulation methods in stator and rotor windings of synchronous compensator in operational modes, in the mode of windings shorts as well as in the mode of start and the three-phase short circuit at the output of SC;
- developing the simulation method of magnetic field dispersion in rotor and stator windings in the front-end part of SC to determine a form, location and parameters of measuring converters inside SC;
- developing the construction of measuring converters and recommendations for their allocation and mounting inside SC;
- proposing the method and the device of selective and sensitive protection of SC rotor windings from short circuits in the rotor windings using one single measuring converter;
- proposing the method and a device of selective and sensitive protection system of SC from windings shorts in the stator and rotor windings with using two C-shaped measuring converters.

The object of research is the area of relay protection dedicated to development and research of new selective and sensitive protection systems from windings shorts in rotor and stator windings of SC. It allows installing such protection systems, where unselective operation of protection system can cause the significant material and technical losses.

The subject of research is processes occurring in SC during operation modes and short circuits in rotor and stator windings as well as identification of informative features of these damages and development of selective and sensitive protection of synchronous compensator from windings shorts.

The scientific novelty of the thesis is determined by:

1. Researched disadvantages of traditional devices for stator and rotor windings protection, specified possibilities to mount in the front-end part of measuring converters and methods of parameters estimation as well as clarified causes of unselective operation of famous protection devices based on built-in measuring converters and methods of its removal;
2. Proposed mathematical models of synchronous compensators for simulation of its operation in all operational modes, including the mode of short circuits in rotor and stator windings as well as in the mode of three-phase short circuits on the output of SC;
3. Proposed mathematical model for simulation of magnetic field dispersion in rotor and stator windings in the front-end part of synchronous compensator;
4. Developed approach of determining the shape, allocation in SC and parameters of built-in measuring converters;

5. Developed method of rotor windings protection from windings shorts, based on measurement of a constant component of EMF for one single measuring converter;

6. Developed method of stator and rotor windings protection system from windings shorts, based on measurement of repetition time of EMF and voltage pulses in C-shaped measuring converters.

Practical value of the thesis concludes that:

1. Analysis of traditional devices for stator and rotor windings protection in SC as well as protection systems, based on built-in measuring converters, provided determining the direction of researches, which allow developing new selective and sensitive protection systems for synchronous compensators from windings shorts;

2. Proposed mathematical models of synchronous compensator allows simulating currents in rotor and stator windings in all operational modes, with short circuits in rotor and stator windings as well as with three-phase circuit short at the output of SC with an error which does not exceed 5-20%, being a sufficient parameter for relay protection device development;

3. Proposed mathematical model allows simulating magnetic field dispersion of rotor and stator windings in the front-end part of synchronous compensator with sufficient accuracy to provide reliable determination of parameters of built-in measuring converters;

4. Developed approach of parameter determination for built-in measuring converters gives opportunities to determine with sufficient accuracy shape, allocation in SC and parameters, which are necessary for development of SC protection device from short circuits in stator and rotor windings;

5. The device of SC rotor protection from windings shorts which is selective and provides high sensitivity to windings shorts with operation mode, based on measurement of the constant component of EMF in one single measuring converter;

6. Device for protection of rotor and stator windings of SC from windings shorts is selective and provides high sensitivity to windings shorts both in rotor and stator windings, based on measurement of repetition time of EMF and voltage pulses in C-shaped measuring converters;

7. Developed on the base of synchronous compensator and personal computer with software “Elena-2012” experimental complex and approach for its usage provide reliable and accurate executing of experimental researches, which are necessary for testing the theoretical statements of the thesis and experimental researches of developed devices of SC relay protection.

The outcomes of the thesis are methods of current simulation in stator and rotor windings of synchronous compensator in operational modes, with windings shorts in stator and rotor windings as well as in the start mode and three-phase short circuit at the output of SC, method of magnetic field dispersion simulation in rotor and stator windings in the front-end part of SC, construction of measuring converters and recommendations for its allocation and mounting inside SC, the method and the device of selective and sensitive protection of SC rotor windings from short circuits in the rotor windings using one single measuring converter, the

method and a device of selective and sensitive protection system of SC from windings shorts in the stator and rotor windings with using two C-shaped measuring converters.

The basic content of the thesis.

Introduction proves relevance, aim of the thesis and way to achieve this aim. Its scientific novelty and practical value are reflected there. Research methods and defended statements are specified. Approbation of research outcomes is provided. Conclusion on need for development of the synchronous compensator protection system from windings shorts is made.

First chapter includes issues of construction features, excitation types, simulation of operation and abnormal modes of synchronous compensators, their operation modes with windings shorts in the rotor and stator windings. In addition analysis of protection systems from stator and rotor windings shorts was made.

It was found that synchronous compensators are structurally synchronous engines with the rotor and a lightweight shaft without dampener windings. The maximal values of currents in stator and rotor windings are reached during three-phase short circuit at the output, while starting and decreasing of rotor magnetic field. It's also shown that main causes of WS in SC stator windings are the short circuit of two elementary conductors and WSC. Analysis of known technical solutions for stator and rotor protection systems was made. As it was found, there are no any sensitive and selective protection systems of SC from windings shorts, and the sensitivity problem can be solved only by measuring of changes in magnetic field of front dispersion using new types of induction measuring converters.

In the second chapter mathematical models of SC for simulation of operational and abnormal modes were developed as well as SC modes during stator and rotor windings shorts, starting and short circuit at the output.

As a result of simulation of SC operation in these modes it was found, that proposed mathematical models allows modeling currents in stator windings with the error, not exceeding 5-10%. The adequacy of the mathematical model was being determined through start time $t_{пуск}$ till fixed value or rotor slip s_f as well as through ratio of stator current values at the beginning and the end of start. Within these researches difference between simulation results and experiments didn't exceed 15-20%. It was found that during the simulation of the three-phase short circuit the integration interval Δt should be equal to 0,001-0,006 s, and current in stator and starting windings should be determined as a sum of periodic and aperiodic current components. At the same time difference between simulation results and experiments doesn't exceed 10-15%.

In the third chapter the method of magnetic field simulation in the front part of SC was considered, then magnetic field dispersion simulation of one winding of stator and rotor pole with the current value, equaled to one, was executed. Then using the known allocation of stator sections and rotor poles as well as their currents, magnetic field is simulated in all aforementioned modes. Then basing on the analysis of these magnetic fields construction and mounting of

new C-shaped measuring converter was developed. Its main advantage is equality to zero of EMF in each mode without windings shorts in stator or rotor. This modernized approach of magnetic field dispersion simulation in the front-end part of rotor and stator windings allowed developing the method to determine parameters of the converter, and then to develop methods and devices of selective and sensitive protection from windings shorts in rotor and stator based on this approach.

Publishing activity. Within the thesis research 9 papers were published, including: one - in the journal from Scopus Database, three – in journals, recommended by Control and Appraisal Committee in the Area of Education and Science of MES RK, four papers - in the proceedings of international conferences, including 2 – in the proceedings of foreign international conferences. One innovation patent of Republic of Kazakhstan was acquired as well.

Structure and size of the thesis. Thesis contains introduction, 3 chapters, conclusion and 2 appendices. The thesis's volume is 99 pages, including 48 figures and 10 tables. The list of used sources consists of 87 titles.