ANNOTATION

of the dissertation of Amirbek Dinara Amirbekkyzy "Improving the reliability of power plant circuits by duplication and redundancy", submitted for the degree of Doctor of Philosophy (PhD) in the specialty 8D07103 – "Electric power Engineering"

Relevance

Improving the reliability of the main circuits of power plants (PP), including relay protection (RP), can lead to an increase in electricity supplies (ES), reducing damage and costs due to unreliability of the circuits, and therefore it is relevant. Guk Yu.B., Misrikhanov M.Sh., Nepomnyashchy V.A., Sinchugov F.I., Fedoseev A.M., Smirnov V.A., Figunov E.P., Shalin A.I. contributed to the part of the reliability theory that relates to the main circuits.

The main method of increasing the reliability of these circuits for several decades has been the replacement of air (ASw) and oil switches with more reliable gas (GSw) and vacuum ones, and in the relay protection (RP) of their connections - the transition to a microprocessor element base. There are many articles on determining the reliability of switches. At the same time, it is claimed that GSw is 10-90% more reliable than ASw. However, how this affects the supply of electricity (ES), damage and costs were not found in the articles of journals from Scopus and Web of Science, as well as Russia and Kazakhstan, despite careful study, and we first showed [1] only in 2023. These journals did not evaluate the possibility of further increasing the ES due to the development of more reliable switches than GSw, and which way to go. Maybe, to further increase the ES, it is worth paying special attention to the reliability of the generator-transformer blocks and lines; or try to create new main circuits, more reliable than traditional ones, without replacing switches? The last question for the main schemes of a triangle – hexagon at a voltage of 330-750 kV for Condensing power plant (CPP) and Hydroelectric power plant (HPP) is answered in the doctoral dissertation of Dinmukhanbetova A.Zh. in 2022. But for more common main circuits (3/2 and 4/3 switches per connection) there are no answers to this or any other questions.

As for the RP connections of the main circuits, here, in terms of increasing reliability, high hopes were pinned on the transition to a microprocessor base, which, as the last 20 years have shown, have not been justified [2]. At the same time, the reliability of remote protections and zero-sequence protections in operation does not improve, but their failure as backup is not reserved.

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[1] Barukin, A.S., Kletzel M.Ya., Dinmukhanbetova A.Zh., Amirbek, D.A. Introduction of an Auxiliary Breaker into the Generator-Transformer Block for Energy Saving in Open Switchgear Circuits of Power Plants. // Energetika. Proceedings of CIS higher education institutions and power engineering associations. - Vol. 66. - № 4 (2023). - P. 333–343.

[2] Gurevich V. I. Microprocessor relay protection devices: present and future: // Electricity. – 2007. - No. 4, pp. 30 - 36.

Moreover, the number of accidents, including man-made ones, increased, for example, in 2005 in Moscow and Spain, and in 2015 in Belarus, in 2018 in the USA, in 2019 in the UK and in 2023 in Uzbekistan, which captured Kyrgyzstan and part of Kazakhstan. It can be expected that due to the wear and tear of equipment in the CIS (in Kazakhstan, 75% have already served their time), their number will only increase. Now, to increase the reliability of protections in Kazakhstan, as well as around the world, simple duplication is used. It improves the reliability of operation, but worsens the failure. Both improve majoring (duplication on the principle of two out of three). However, its implementation is hindered at ultra-high voltage by the cost of current transformers and an insufficient number of protections of different operating principles. Therefore, the development of such protection with majoring without current transformers, as well as the answers to all the above questions, will contribute to improving the reliability of the main circuits of power plants.

The object of the research is the schemes of power plants.

The subject of the research is the reliability of the main circuits 3/2 and 4/3 of the switch for connection with a voltage of 330-750 kV at the condensing power plant (CPP) and hydroelectric power plant (HPP).

Connection of the dissertation topic with general scientific (state) programs. The work was carried out in accordance with the priority direction of the development of science "Power Engineering and mechanical Engineering" and the scientific directions of the subcommittee B5 "Relay protection and Automation" of the international organization CIGRE and is associated with obtaining the results of R&D No. 66- 2/1 dated 02/24/2021 " Energy saving through the development of new schemes of open switchgear power plants" (IRN AR09058249) within the framework of grant funding for young scientists on scientific and (or) scientific and technical projects for 2021-2023.

The aim of the work is to increase the reliability of the main circuits 3/2, 4/3 at the CPP and HPP with a voltage of 330-750 kV by duplication and redundancy.

To achieve the goal, the following tasks were set and solved:

- Find ways to improve the reliability of the schemes of CPP and HPP;
- Predict an increase in electricity supplies from the replacement of switches with more reliable ones on the power plant (PP) for circuits 3/2 and 4/3 by plotting the dependence of the ShSE on the frequency λ_{SW} of switch failures;
- Create PP circuits based on circuits 3/2 and 4/3, duplicating switches;
- To develop an algorithm for the operation of a common resource-saving backup RP of connections of the 4/3 circuit with a voltage of 330-750 kV;
- Create a model of such protection using majoring;
- To develop measuring devices on reed switches for such protections, without using current transformers.

The validity and reliability of scientific statements, conclusions and recommendations are confirmed by: competent use of the fundamentals of reliability theory, relay protection and logic algebra; approbation, which included: Patents of the Russian Federation № 2739971, № 2744255, № 2768976, № 2769277, Patent of the Republic of Kazakhstan No. 35987; scientific journal "Bulletin of Toraighyrov

University"; Materials published in Scopus International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM) (Russian Federation, Sochi, 2021), the International Scientific and Technical Conference "Electrotechnical Complexes and Systems" (Russian Federation, Magnitogorsk, 2021); An article published in the International Scientific and Technical Journal "Power Engineering. News of higher educational institutions and energy. CIS associations." (Republic of Belarus, Minsk, 2023) in Scopus with quartile Q3 (percentile 36).

Scientific novelty of the work:

1. Calculations have proved that it is possible to increase the reliability of the main circuits 3/2 and 4/3, and it is shown that with their help it is possible to predict an increase in the supply of electricity (ES) at power plants as a result of such replacement of switches with hypothetical, more reliable ones. For the first time, the dependences of the short-supply of electricity (ShSE) on the failure rate of the replaced ones were found.

2. New schemes of CPP and HPP have been created, differing from schemes 3/2 and 4/3 by an increased number of switches.

3. It is proposed to increase the reliability of the main circuits of the PP to build a common backup protection of connections using reed switches with windings, which are installed at a safe distance from the phases of connections and are used to simultaneously perform the functions of current transformers (CT) and current relays, and supply the current winding of the power direction relay. An algorithm for the functioning of a common microprocessor protection with reed switches for the 4/3 circuit based on the principle of comparing currents at connections has been created.

4. Models are constructed: backup protection, common to all connections of the hexagon circuit, differing from the known ones by the presence of majoring of the measuring body with reed switches instead of CT; and a design for their attachment near the connection phases of 330-750 kV.

New scientific results of the work:

1. The main PP schemes based on schemes 3/2 and 4/3 have been created, the methodology for calculating the increase in electricity supplies when replacing switches with more reliable ones. The dependences of the ShSE for CPP and HPP on the failure rate of switches and blocks are obtained, and it is determined what increase the proposed schemes give in comparison with traditional ones and the replacement of the latter switches with more reliable ones.

2. The algorithm of the general protection of the 4/3 circuit with reed switches instead of CT and current relays is constructed; as well as a model of such a device with majoring for a hexagon circuit and a design for attaching reed switches near phases with a voltage of 330-750 kV.

Practical significance of scientific results:

1. The developed PP schemes based on schemes 3/2 and 4/3 with GSw will allow, when implemented on a number of CPP, to increase the supply of electricity to the same extent as the replacement of explosives with GSw, and on HPP – only on some;

2. Based on the obtained dependences of the ShSE on the failure rate of switches, it is possible to predict the ES when replacing them with more reliable ones;

3. A way to increase the reliability of relay protection of connections of circuits PP with a voltage of 330-750 kV is outlined. Now, using the proposed methodology, it is possible to create a common backup protection of all connections for PP circuits without current transformers, using majoring and reed switches.

The practical value of the work:

1. The dependences of the ShSE on the failure rate of the switch λ_{Sw} and the block λ_{bl}, obtained on the basis of the calculations carried out, make it possible to determine in Russia and Kazakhstan for the vast majority of known schemes 3/2 and 4/3 of power plants with a voltage of 330-750 kV an increase in ES when replacing ASw with GSw and GSw with a more reliable hypothetical switch (HSw), as well as how much it is necessary to lower the frequency of λ_{bl}, to get the same magnification. It is possible that the replacement of ASw with GSw will increase the ES at CPP by 4-9% and at HPPs by 15-44%, and the introduction of new schemes at most CPP - by 2-7% and about half of all HPPs by 1-7%.

2. The proposed measuring bodies for general protection of connections of the main circuits make it possible not to use current transformers (CT), saving high-quality copper, steel and insulating materials. They will improve the reliability of the main circuits, duplicating not only protection, but also CT, which is not currently being done;

3. The general protection built according to the created model with a new measuring body after testing and implementation will allow reserving the operation of all autonomous protections currently used and being developed, thus increasing the reliability of the main circuits.

To the defense are presented:

1. The developed schemes of PP, the dependence of the ShSE on λ_{Sw} and λ_{HSw}, as well as the results of comparing the ShSE, damage and costs when using them and when replacing switches with more reliable ones with the same for traditional schemes 3/2 and 4/3;

2. The algorithm of functioning of the general relay protection of connections of the main circuit PP 4/3 with new measuring bodies on reed switches and a model of such protection for hexagon circuits.

Approbation of the work. The main content of the dissertation was presented at the International Conference on Industrial Engineering, Applications and Production (ICIEAM) (Russian Federation, Sochi, 2021), the International Scientific and Technical Conference "Electrotechnical Complexes and Systems" (Russian Federation, Magnitogorsk, 2021), the plenary session of the International Scientific and Technical Conference "VII readings Sh. Shokina" (Pavlodar, 2023) and at a meeting of the Department of "Electro-Energetics" of NAO Toraigyrov University.

Publications. The results of the work have been published in 9 scientific papers, including: 6 publications in publications recommended by COQAES, including 1 patent of Kazakhstan, 4 patents of the Russian Federation, an article in the scientific journal "Bulletin of Toraigyrov University"; 2 publications in the materials of

international conferences (in Scopus), an article in the journal "Energetika. Izv. higher. studies. institutions and energy associations of the CIS" in Scopus with quartile Q3. In 7 works, the share of my contribution is at least 70%, and in two – 25-30%.

The structure and scope of the dissertation. The dissertation consists of an introduction, three sections, a conclusion and two appendices. The work is presented on 74 pages of computer text, includes 16 figures, 7 tables. The list of sources used consists of 73 titles.

In the first chapter "Reliability of ultra–high voltage circuits at power plants (PP) and their relay protection", the traditional main circuits of PP type 3/2 are considered - two bus systems with three switches for two connections (one and a half), and 4/3 - two bus systems with four switches for three connections and their reliability, as well as the main methods calculation of the reliability of PP schemes such as probabilistic, logical – probabilistic (failure tree); logical-analytical, topological and tabular-logical method of Guk Yu.B.. Their features and disadvantages are analyzed. The well-tested tabular-logical method chosen by us for a comparative assessment of the reliability of PP schemes is described in detail.

To assess the reliability of relay protection of connections of ultrahigh voltage circuits PP, the types of traditional main and backup protections and their features were considered.

As a result of the review, the following conclusions were made:

1. The traditional main circuits 3/2 and 4/3 of the connection switch have disadvantages that have a significant impact on their reliability. Ways to improve the reliability of the main circuit of electric PP are currently reduced to replacing switches with more reliable gas-fired ones. What this gives in terms of reducing the short supply of energy W, damage Y and costs Z in schemes 3/2 and 4/3 has not been quantified. There is no work on predicting W, Y, Z when replacing gas switches with more reliable ones and on evaluating the possibilities of using such well-known methods as duplication and redundancy to increase their reliability.

2. The most proven method of calculating the reliability of the main circuit of the PP was the tabular-logical method. In addition, it lacks the disadvantages of other methods. For these reasons, it is used in this work. At the same time, as in the calculation program, they were eliminated (with the decisive participation of A.S. Barukin).

3. The reliability of relay protection (RP) of the connections of the main circuits of the PP can have a great impact on the reliability of the circuit itself, leading to major accidents in case of failures in the RP, especially due to the presence of a large number of equipment that has worked its life on the PP (75% in Kazakhstan).

4. Duplication and redundancy, but due to the mentioned accidents - obviously to an insufficient extent. So when duplicating, current transformers are not duplicated, and when reserving, failures of backup protections are not taken into account.

5. It follows from the above: answers and solutions to the questions and tasks that this dissertation is devoted to will contribute to improving the reliability of schemes 3/2 and 4/3.

In the second chapter "Improving the reliability of the main circuits 3/2 and 4/3 on the PP by duplicating, reserving and replacing switches," the power plant's short supply of electricity is predicted due to the unreliability of the circuits, the share of circuit elements in the short supply of electricity (ShSE) is determined and the impact of the input of additional switches is estimated. New schemes are considered to increase the reliability of the circuits by connecting an additional switch between the transformer of the block and its switches, connecting an additional switch in series to each of the existing ones in the traditional and with the connection of the switch to the hot reserve, in parallel with two consecutive ones according to the previous method. The modes of their operation are described, and the results of calculations for reducing the short supply of electricity, the damage from this short supply and the costs of constructing power plants are presented. The influence of the generator switch on the supply of electricity (ES) in the main circuits of the PP is estimated. The dependences of the ShSE on the failure rate of the switches λ_{Sw} and the blocks λ_{bl} are constructed. Analyzing the results obtained, the following conclusions are made:

35 main circuits of power plants (PP) with a voltage of 330-750 kV, λ_{ASw}, λ_{GSw}, λ_{HSw} and λ_{bl} are considered – the failure rates of air, gas, hypothetical switches (ASw, GSw, HSw) and the block, and all the values of the digits depend on the power of the blocks, the type and voltage of the circuits.

1. The greatest impact on the damage caused by the short supply of electricity (ShSE) due to unreliability in circuits with GSw is exerted by λ_{BL}: 83-93% (37-86%) on CPP (HPP); λ_{Sw} of switches is 4-14 times (2-10 times) less; and λ_{VL} of lines is 7-7600 times (4-318 times). The introduction of a generator switch into the blocks allows you to increase the supply of electricity by 7 to 9 (4 to 9) times, and reduce the cost of building an PP by 1,2 to 6,5 times.

2. The constructed dependences of the ShSE on λ_{GSw} and λ_{BL} make it possible to predict its decrease when replacing switches with more reliable ones and a decrease giving the same decrease. The formula derived on the basis of these dependencies makes it easy to calculate ΔW depending on the decrease in the failure rate of switches.

3. Replacing ASw with GSw with $\lambda_{GSw} = (0{,}65 \div 0.7)\ \lambda_{ASw}$ will reduce the ShSE at the HPP by 13-44%, at the CPP by 4-9%. Damage during reconstruction and construction costs at the HPP - by 4.4-31% and 0.4-2%, and at the CPP by 1-7%. The same can be obtained by reducing the λ_{BL}. at the HPP by 22-93%, at the CPP by 4-10%.

4. Replacing the GSw with a hypothetical more reliable switch with ($\lambda_{HSw} = 0{,}1\lambda_{GSw}$) can increase the ES at the CPP by 2-4% (5-11%), and at the HPP by 1-10% (13-27%). This can be obtained by lowering the λ_{BL}. So, if , then the λ_{BL} should be 2-20% lower than the original one. If you create a switch 100 times more reliable than GSw, then the increase in ES will not exceed 12% at the CPP, and 30% at the HPP.

5. The proposed introduction of GSw between the transformer of the unit and its two switches from the high voltage side into the traditional main circuits of the ES with GSw can increase the supply of electricity to the CPP by 1÷7%, and reduce it at the HPP. To get the same effect from replacing GSw with HSw, it is necessary to develop a switch with $\lambda_{HSw} = (0.9 \div 0.4)\ \lambda_{GSw}$.

6. New circuits with GSw connected in series to each of the available GSw in circuits 3/2 and 4/3 and one more in parallel to the hot reserve will increase the supply of electricity no less than from replacing the ASw with GSw.

7. The results of this work and the methods for obtaining them can be useful not only in predicting the reduction of ShSE on the main circuits of the considered and similar power plants with any initial data, but also in determining the strategy for improving switches.

In the third chapter "Construction of resource-saving common protections for connections of ES circuits to increase their reliability", the principle of construction and the algorithm of functioning of resource-saving backup protections common to all connections are considered. Their main difference is in the use of reed switches with winding instead of current transformers (CT) and a current relay at the same time. The synthesis of algorithms for the functioning of the general protection of the 4/3 scheme is presented. They allow you to build such protection on microprocessors or logic elements of any nature, and current relays, and power direction relays on electromechanical elements. This will make it possible, using both implementations, to maximize (in accordance with the theory of reliability) the reliability of the entire relay protection system of the main circuit of power plants, if the autonomous protections installed there are reserved by the general principle of majoring, without using current transformers. The results of the research led to the following conclusions:

1 The use of reed switches with windings proposed in this paper in the construction of common connection protections of the main PP circuits allows to increase the reliability of their RP not only by reserving autonomous connection protections, but also by reserving their CT and simplifying the implementation of general protection. In addition, copper, steel and high-voltage insulation are saved. Due to the exclusion of CT in the general protection, the savings when performing it without majoring for the 4 /3c scheme with six connections is approximately 500 thousand dollars, and with majoring 1 million dollars.

2 The algorithms developed jointly with Shahaev for the operation of the general protection of connections of the 4/3 circuit (without majoring) with reed switches instead of CT make it possible to perform protection using a two-way power direction relay and a logic block on any logic elements or on microprocessors when the latter controls the direction of power on all connections.

3 The model developed in this paper, a general backup protection with reed switches and a microprocessor for a hexagon, thanks to majoring after implementation, testing and positive operational experience, can be recommended for widespread implementation at power plants to increase the reliability of the entire RP system.

4 The proposed model of structures for mounting reed switches at a safe distance from the phases of the electrical installation can serve as the basis for the development of a measuring body with reed switches for voltages 330 - 750 kV.

The results of the work are as follows:

1. Models of the main PP circuits with a voltage of 330-750 kV are constructed, differing from the 3/2 and 4/3 circuits by an increased number of the same type of

switches. It is shown that the short supply of electricity (ShSE), damage and costs, when introducing new schemes at CPP decrease in comparison with traditional schemes no less than when replacing ASw with GSw (by 1-9%). At the HPP, when replacing ASw with GSw, the figures reach 44%, and the introduction of new switches is impractical.

2. The obtained dependences of the ShSE on the failure rate of switches and the block, which turned out to be straight lines, make it possible at CPP and HPP to predict the reduction of ShSE - ΔW, damage and costs when replacing explosives with GSw and GSw with hypothetical, more reliable switches, as well as to determine what the frequency of the block λ_{bl} should be in order to obtain the same reduction. The formula derived from these dependencies makes it easy to calculate ΔW.

3. The developed models of measuring bodies on reed switches that do not use current transformers (CT) and the design for their attachment make it possible to build common protections using majoring. This will increase the reliability of the entire relay protection system (RP) for ultra-high voltages, while saving high-quality copper, steel and high-voltage insulation in unprecedented sizes for RP.

4. A model of such a general protection with reed switches without CT has been created for the hexagon circuit based on the principle of comparing the current in the damaged connection with the sum of all the currents of the other connections in operation. The algorithm of the general protection action for 4/3 circuits based on the principle of comparing the power direction is presented. The technique of constructing these protections is simple and can be used to create similar protections for any main PP circuits.