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Development of intelligent electrical network relay protection combined with fast-speed automatic transfer switch

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Abtract

In this article development of intelligent relay protection for electrical networks combined with fast bus transfer is presented. Actuality of research and development in this area is conditioned by problems of earth fault recognition, insufficient usage of modern equipment possibilities, high cost of traditional relay protection and automatic transfer switch. Usage of distance or differential protection in 6-35 kV networks is proposed, algorithms of relay protections were elaborated and their mathematical models in Simulink MATLAB were designed. Modeling of fault work modes has proved fast response and high-speed response of proposed algorithms. Construction of fast-speed automatic transfer switch on the base of vacuum circuit breaker with fast drive is proposed, that is low-cost in comparison with its analogous devices. Electromagnetic calculations have been performed for drive model, which showed actuation time of 15 ms.

Key words: relay protection, electrical network, model, circuit breaker, work mode, equipment.

Introduction.

Modern industry raises demands for the quality of electric energy and reliability of electricity, supplied to consumers. First of all it refers to enterprises with complex continuous technological process, like: chemical, metallurgic enterprises of oil and gas production and refining etc. In electric networks that energize these objects various events may happen, which lead to power supply interruption, like: short circuit faults and single phase-to-earth fault in electric plants, breakdown of electric equipment, shutdown of power sources or electric power lines. For minimization of losses caused by such events electric networks are supplied with relay protection and automation systems (RPA), which recognize emergency modes and shutdown damaged equipment, and also perform automatic switches for power restoration.

Traditional devices of relay protection do not always correctly recognize earth fault modes [1] and are not able to use possibilities of modern equipment in full (digital sensors, microprocessor terminals, systems of data collection and processing). Besides, architecture of RPA system in the view of aggregate of microprocessor terminals of protraction of specific objects, connected with each other by control cables, lead to much too high costs of such system [2, 3]. Building on that, there is an actual need in development of intelligent devices of relay protection, which would have high-speed response to emergency work mode of electric networks and which would sot less at the account of usage of other architecture of RPA system.

Automatic fast-speed automatic transfer switch device (FATS) is an essential element on electric substations that feed locomotive load. Standard automatic fast-speed automatic transfer switch devices at substations that contain high-voltage motors are not able to provide their stable work in conditions of power fails and current failures because of significant time delays. There are known cases of mass shutdown of electric motors and breakdown in the technological process at industrial and public utility companies, caused by too long time of switching to reserve source [4-6]. This issue may be resolved by means of introduction of FATS devices on the base of vacuum commutation or thyristor non-contact equipment, which allow avoiding shutdown of rotating load, which will not allow synchronous motor fall out of synchronism and reduce current strength and moment values during switching process, which influence favorably on motors' resource. Existent development s of FATS [4,5,7-9] are characterized by too high cost or necessity in installation of excessive amount of additional power equipment. That's why the task of finding small-size, cheap and reliable FATS device on the base of domestic components keeps its topicality.

Development of intelligent relay protection.

Power distribution networks that directly feed industrial consumers usually have nominal voltage that equals 6-35 kV. Excess current cut-out are used for such voltages as a mean means of protection from short circuits. However, they have the following disadvantages: necessity to introduce additional time delays for provision of selectivity; difficulties in adjustments in so-called actively adaptive electric networks, where capacity flows in normal mode may vary in wide range and even change their direction. In this connection we offer using other types of RPA devices instead of excess current cut-out, in particular, distant or differential current protection. Distant and differential protections have been widely used in electric networks of 110-330 kV, however their usage at lower voltages hasn't actually been considered because of relative complexity and high costs of implementation at previous element base. Application of digital sensors of current and voltage in combination with microprocessor platform for signal processing makes the usage of such protections in 5-35 kV networks feasible.

Theoretical studies show that connection of discriminating element of resistance, at which resistance values at their output would be proportional to distance to each of closing places, will allow performing protecting elements of starting relays with possibilities of definition of damaged lines, as well as distances to each of fault places [10]. Differential protections provide absolute selectivity and minimal actuation time, which allows reducing the volume of equipment's faults. Within the frameworks of the works performed we have synthesized protective algorithms for main elements of electric circuit (electrical power lines, power converters, electric motors, collecting buses etc) and created mathematic models in Simulink MATLAB modeling environment. For assessment of their efficiency we have performed imitational modeling of various work modes of electric networks. Figure 1 displays an example of Simulink model of electric network's unit with relay protection device of electric power line, and Figure 2 depicts phase current oscillogram at occurrence of double phase short circuit fault at the moment of 0.05.

Figure 1. Fragment of Simulink model of electric network's unit with relay protection device at power supply line

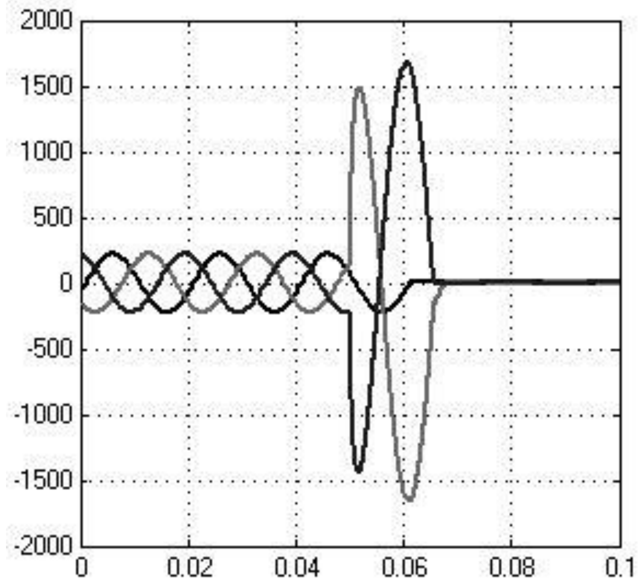

Figure 2. Oscillogram of double phase short circuit fault at power supply line

As it can be seen from Figure 2, full time of analysis of emergency mode and disconnected of faulty line from power source equaled only 0.02 s, which is indicative of fast response time of relay protection. Similar investigations of other mathematic model showed that they provide fast response time and high-speed response to various emergency work modes.

One of the most frequent emergency modes of electric networks that work with insulated neutral is single phase-to-earth fault (SFEF). Considering that almost in all cases of SFEF there are higher harmonics in spectrum of current and voltage [11-13] (while some of them may increase at the account of resonance characteristics of power supply lines), in developed RPA system identification of SFEF is suggested, as well as identification of its location in the network according to results of analysis of higher harmonics in dependencies of current and voltage. For confirmation of conclusions made from theoretical studies we have created mathematic models of electric networks' units with SFEF. Basing on created models we have performed imitational modeling of this emergency mode. As an example, on Figure 3 the model of power supply line is demonstrated, and Figure 4 shows spectrum of voltage higher harmonics at this type of damage.

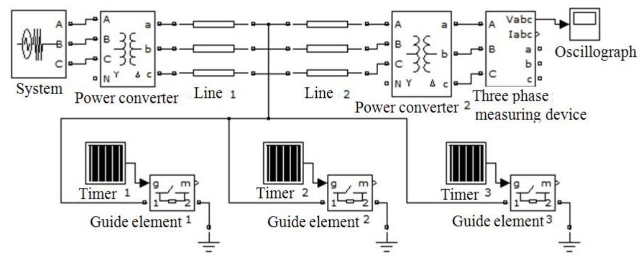

Figure 3. Simulink model of electric supply line with SFEF

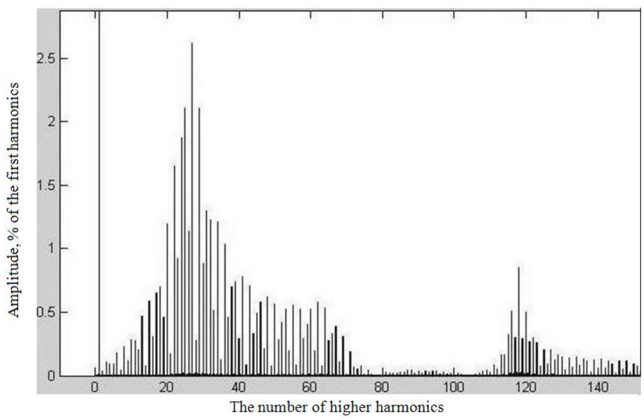

Figure 4. Spectrum of voltage higher harmonics SFEF at power supply line

Figure 4 implies that SFEF, accompanied by intermitted bow, is a source of higher harmonics with wide ranges (up to 200 and including), while harmonics with number from 15 to 70 have the amplitude that exceeds the level of 0.5% main harmonics, which is enough for launch of algorithms of protection from SFEF. Results of modeling for various network configurations confirmed that analysis of the level of higher harmonics allows univocally indicate damaged element of electric network, as well as to define the distance to the faulty point in most of cases.

Architecture of developed intelligent system of RPA and FATS will be similar to architecture of "digital substation", which has been being developed during the recent years [14,15]. In comparison with existing RPA systems it will allow reduce costs and enhance reliability of functioning.

Information about work mode of electric network is recorded by measuring current and voltage transformers are digitized and transmitted to central device of RPA system for processing. Central device of RPA also receives information about actual state of switching devices, which gives possibility to analyze topology and mode of electric network in real time mode, as well as adaptive tuning of RPA installations depending on current network configuration. Set of protective algorithms for all network objects are processed by central processing device, which in case of necessity gives commands for shutting down of damaged elements' switches and turning on reserve power sources. Application of standard data communication protocols of (МЭК 61850) allows using accumulated experience of development of other RPA devices [3,8,16] in this system, and also to provide its interconnection with superior RPA systems, if necessary.

Development of FATS.

Analysis of literary sources [4,5,7,17-18] shows that thyristor FATS, despite of fast response time and limitation of current rushes and electric motor's moment at restoration of power by means of managing opening angles of thyristors, have major deficiencies, like: necessity to have two to three switchgear cells of distributing gear at substations (instead of one cell for FATS on the base of vacuum breakers); limited overload capacity; high cost; necessity of upgraded protection from commutation and lightning overvoltage.

Implementation of FATS on the base of serial vacuum breakers doesn't allow obtaining required fast response. Basing on analysis of oscillograms it has been stated that for guaranteed recovery of normal work mode of locomotive load after power failure its duration time shouldn't exceed 30-40 ms. Meanwhile, proper time for turning on serial vacuum breakers equals minimum 50 ms. Considering that for analysis of mode and definition of necessity of transfer to automatic load 10 to 20 ms is required, proper time for turning on breakers should equal about 20 ms. Thus, is is necessary to use special fast-speed switchers. Such devices (for example, VM1-T produced by ABB), however, are extremely expensive.

In this connection FATS on the base of vacuum breaker with special fast-speed driving device is being developed. Such construction would have required high speed and at the same time it would cost less, which would provide certain competitive advantages at market of electric equipment. Additionally, such device would have small size, which would allow integrating such switcher into any cell of distributing device.

FATS management system forms an integral part of general system of RPA of electric network, obtaining information about mode parameters and analyzing it on a real-time basis. In case of loss of failure of voltage at working supply source, RPA system sends command to simultaneously disconnect working source and connect reserve one, which additionally reduces time of breaking of current, supplied to consumers.

Construction of high-speed drive unit is a variety of magnetic drive with locking device. Presence of permanent magnet allows securely hold the anchor in "on" and "off" positions without power costs; turning the switcher in is performed by short-time current supply into corresponding bobbin.

Using Elcut program we have build up the model of breaker drive, for which the range of calculations was made, which allowed optimizing geometrics of drive and main constructive parameters (material of magnetic circuit, wire section and number of winding turns). Optimization criterion was reaching minimum time for actuation of drive. Actuation time that has been reached as of today (15 ms) is acceptable for realization of FATS. Further stages of work imply creation of physical model of breaker with fast-response drive and its testing.

Conclusion.

The system of intelligent relay protection that is currently being developed and FATS provides possibility of analysis of topology and electric network mode in real time and adaptive settings of RPA installations depending on current network configuration. We have created and investigated mathematic models of relay protection in Simulink MATLAB program, which confirmed high-speed response and response time of protection algorithms. Implementation of FATS on the base of vacuum breaker with fast-response drive as an element of RPA network system has been suggested. Modeling of FATS drive showed that actuation time equals 15 ms, which is enough for realization of FATS.

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