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Smart Relay Protection of Electric Networks: Response Speed, Sensitivity and Selectivity Test with Use of a Physical Network Model

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Abstract: This study presents issues on experimental testing os response speed, sensitivity and selectivity with use of the breadboard for smart relay protection of electrical networks that was developed in the University "Dubna". Testing was performed using a physical model of an electrical network comprising transmission lines, power transformers, electric motors, generalized load and substation buses. Method of emergencies simulation in the model, key points of the investigation tests to determine response speed, sensitivity and selectivity are described. Specific examples of determining these parameters for the electrical network model are shown.

Key words: Relay protection, breadboard, model electric network, response speed, algorithm, sensitivity, short circuit, selectivity, switch, network operation mode

INTRODUCTION

The State University "Dubna" conducts research works on the development of smart protection for smart electrical networks. As part of these studies, the relay protection algorithms have been developed that have a high sensitivity to changes in a topology, parameters and modes of electrical networks as well as algorithms for improving the safety and adaptive properties of the energy system through the use of a Fast Automatic Transfer Switch (FATS) device using a fast actuator. The breadboard for smart relay protection of electrical networks was made that implements the algorithms mentioned.

Smart relay protection breadboard investigation tests are scheduled at the final stages of the research. Their purpose is to confirm compliance with the requirements to a breadboard specified in the terms of reference for the scientific research. The principal characteristics of relay protection for which there were formulated requirements are response speed, sensitivity and selectivity (Kopiev, 2009; Bass and Doroguntsev, 2006; Kireeva, 2010). According to the number of analog and digital inputs as well as the functionality, the smart relay protection breadboard differs significantly from the known Relay Protection and Automation (RPA) terminals what causes the peculiarities of investigation tests. This study deals with consideration of these features and the formulation of recommendations for conducting the investigation tests.

MATERIALS AND METHODS

Breadboard for smart relay protection of electrical networks (Fig. 1) is a set of feature boards placed inside the case made of the components manufactured by Rittal company. The case has 19 inches width and 4U height what provides both the ability to mount within a standard 19" rack and to be used as a stand-alone device.

Fig. 1: Appearance (above) and a computer model in COMPASS (below) of the breadboard for smart relay protection of electrical networks

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The operator panel Weintek MT8071iE (2007) equipped with 7” touch screen (800×480 pixel resolution) capable of displaying 16 million colors is used to implement HMI. Due to this, it is possible to show not only text information (the values of relay protection setup, current mode settings) but also images such as a simplified diagram of a protected electrical network. The panel is a single control element located on the breadboard front panel. Due to the high protection degree (IP65) it can be used not only for the smart relay protection breadboard but further as a part of pilot or industrial products.

The following boards are installed within the breadboard: a motherboard (1 pcs.); a digital signal and information processing board (1 pcs.); a power board (1 pcs.); an analog input signal board (its number depends on the number of processed current and voltage signals from the electrical network). Since, the size of electric networks to be protected and therefore, the number of processed signals on its mode and switches position may vary, the device has a modular design. Each module is designed as a separate circuit board. Boards are combined (as in many industrial relay protection terminals) using a motherboard what makes it possible quickly to perform installation and removal of modules without the need for complete case disassembly.

The breadboard for smart relay protection of electrical networks was designed based on interaction with the electrical network model. Accordingly, the number of analog current and voltage signals brought to the breadboard is determined by the number of measuring current and voltage transformers in the model network. Six analog input boards were installed within the breadboard for processing the signals.

Model electrical network is implemented as a physical model assembled on laboratory tables. Model dimensions are 4550×1900×850 mm, it is powered by 380 V AC mains. The electrical system diagram realized is shown in Fig. 2.

The physical model includes two network sections with nominal voltages of 110 and 6 kV connected by two transformers T1 and 2. Since, the model implements the main typical electrical network elements (power lines, power transformers, electric motors, generalized load, substation bus) it allows to test all the necessary algorithms for relay protection of each element. Built-in current and voltage transformers provide galvanic isolation of the power unit from the measuring circuits and serve as an analog signal source for the smart relay protection breadboard. Switches in the model network can be operated both manually and automatically by applying a voltage to the control input; their position is monitored by special contacts which are switched together with use

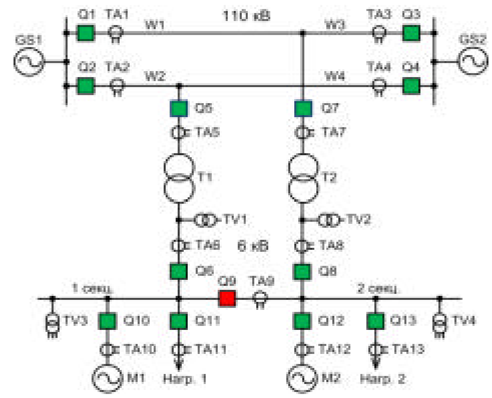

Fig. 2: Model electrical network

of the circuit breaker power contacts. The purpose of the investigation tests of a breadboard for smart relay protection of electrical networks are:

- Relay protection functional testing for all kinds of emergencies provided (short-circuit, ground fault, etc.)
- Verification of compliance with the specification requirements on relay protection response speed and FATS algorithm
- Sensitivity test of relay protection for different emergency mode parameters
- Check the selectivity of relay protection operation at emergencies in various points of the electrical network

An additional triple-pole switch which inputs are connected to phases A-C in the model at the desired point and the outputs are closed to each other and/or earthed depending on the type of damage is provided for relay protection functional testing in the physical model. Turning on this switch leads to an emergency (short-circuit or ground fault) and change the network mode parameters to that protection should respond. Connection of additional resistances makes it possible to simulate a short circuit or single phase-to-ground fault via contact resistance of a predetermined value.

At the initial stage of investigations testing of relay protection algorithms should be carried out alternately for each model network object. At the same time the protections of the object are put into operation and all others are temporarily disabled to facilitate research. Further, various emergencies should be defined in turn and the fact of protection actuation with disconnecting the switch by their command should be checked. This testing helps to ensure performance capacity of not only code but also the analog current (voltage) inputs of transmission circuits for analog and digital signals and output circuits of the relay protection breadboard.

Relay protection response speed is evaluated by the work of the algorithms that do not contain additional time delays: differential line (bus) protection, current cutoff without time delay, etc. Relay protection response time is measured from the moment of exceeding the setpoint mode parameter (e.g., for overcurrent protection the excess of phase current root-mean-square value over the operating current) to the response time of output relays that close the tripping circuit of the switch by their contacts. According to the technical project, this time should not exceed 0.03 sec. At this time, it is necessary to provide the following steps:

- Acquisition and preprocessing of the analog input signals (analog filtering, analog-to-digital conversion)
- Transfer of data from the analog input boards into discrete signals and information processing boards via serial communication channel
- Analysis of analog signals values, definition of the network mode (normal or emergency), if the network is in the emergency mode, execution of protection algorithms and sending commands to turn off the corresponding switches

Because the physical model of the electrical network does not include devices for measuring time intervals, at this stage of research there were utilized electronic stopwatches with a lower measuring limit of 0.001 sec for example, IVPR-203M. It is also possible to use stopwatches that have been completed the test device for testing protective relays of RETOM-51, RETOM-61, Neptun-3 type and others.

In addition to the relay protection functions and conventional system automatics, the fast automatic transfer switch algorithm has been implemented in the breadboard of smart relay protection. In the case of power failure in any of 6 kV bus sections (e.g., due to disconnection of one of the transformers T1, T2) FATS switches off without time delay corresponding input switch Q6 or Q8 and then switches on 6 kV section switch Q9, thereby providing power supply load of the de-energized section. The closing time of the section switch is no >0.02 sec. In order to ensure maintaining the motor load stability, the FATS full time should not exceed 0.03-0.04 s what implies that the time for situation analysis and giving a command to the sectional switch from the breadboard should not exceed 0.01-0.02 sec. At this time, it is necessary to perform following operations:

- Analysis of the network operation mode works for 6 kV bus sections voltage
- Issuing commands to disable the corresponding input switch (Q6 and Q8) and reception of acknowledgment on its disconnection through a discrete entry
- Issuing commands to the switching on of the section switch.

Protection response speed is checked separately for each of the algorithms which have not additional time delays. Three-phase short circuit is performed with use of the optional automatic device which point is selected on the basis of the guaranteed activation and testing of the algorithm. Output contacts of relay protection and automatics breadboard are connected to the electronic stopwatch. At the same time with switching on of an additional automatic device the stopwatch countdown starts and count termination triggers by actuation of RPA breadboard output relay. Checking is considered successful if a tripping time for all protection algorithms does not exceed the value set by the technical specifications.

Sensitivity of the relay protection is evaluated using a sensitivity coefficient which according to the electrical installation code is defined as the ratio of the calculated values (current, voltage) upon a metal short circuit within the protected area to the parameters of protection operation [9, item 3.2.20]. Upon that, the most unfavorable but a really possible network operation mode should be selected. For example, to test sensitivity of Overcurrent Protection (OP) it is necessary to choose a mode when the fault current will have the lowest value. For basic protections, response factor should be about 1.5 and for back-up protections not <1.2.

The mode parameters values for all types of damages are calculated on the basis of information on the network configuration and parameters of its elements. Based on the calculated values of currents and voltages trigger parameters (set points) and response factors are defined for all protection algorithms and then conclusion should be made about whether sensitivity is secured or not separately for each protection. For normal operation of electrical network relay protection it is required that the desired value of the sensitivity coefficient should be provided for all protection algorithms.

Experimental testing of relay protection sensitivity in existing electrical networks is not acceptable, as it is connected with the need to create multiple artificial short circuits which have a negative impact on the electrical equipment. Availability of a physical model of the electrical network offers a unique opportunity to try out all relay protection algorithms for sensitivity in the finished relay protection and automatics device without endangering the high-voltage network equipment.

As an example, let's consider sensitivity test for the overcurrent protection of connections that provide power supply of the loads 1 and 2 (Fig. 2). These protections analyze phase currents of TA11 and 13 current transformers (for loads 1 and 2, respectively) and trigger disconnection of switches Q11 and Q 13, respectively. In normal operation mode, the network has two power sources, i.e., systems GS1 and GS2 which current flows through the transmission lines W1-4 and the transformers T1 and 2. Each of the loads is supplied partly by system GS1 and partly by system GS2, accordingly. Obviously, when a short circuit occurs at load buses maximum current value analysed by protections would be in the case when both systems are in operation, that is, the network configuration has the form shown in Fig. 2. To obtain the lowest possible short-circuit current required for the experimental test of sensitivity, the following actions are performed:

- The most powerful system (i.e., having a smaller internal resistance) of the GS1, GS2 is switched off
- By switching the switches Q1-Q4 the configuration of transmission lines is set that provides maximum resistance of buses which remain in the system before the transformer T1 or T2 (depending on up to what load a study is conducted)
- Section switch Q9 is kept in the open position
- Motors M1 and M2 are disabled to exclude supply by feeding current to them

Once the above switching will be made in the circuit two-phase short circuit would be carried out on load buses (as it gives less fault current in comparison with the three-phase one) and the fact should be checked that the protection is activated under these conditions which are the most unfavorable from the point of view of relay protection.

Similarly, the sensitivity test is done for the rest of the relay protection algorithms. The key factor there is to minimize the emergency mode current what in turn is achieved by reducing the power supply capacity, increasing the network resistance from the source to the short-circuit point and selecting the type of short circuit (two-phase). The relay protection breadboard is considered to have passed the test if for all the algorithms the sensitivity is provided at the level specified in the Electrical installation code. If, however, it is not possible to ensure sensitivity under the calculated values of set points, set points adjustment is carried out to increase the sensitivity.

Selectivity is one of the most important characteristics of relay protection. According to Schneerson (2007), selectivity is a property of relay protection on generation of a trip command only for the damaged area or the minimum number of electrical network sections near the fault place. Protection works selectively if it disables only the damaged parts of the network and does not disconnect the equipment being intact. Otherwise, there is a non-selective protection operation. In contrast to the response speed and sensitivity, selectivity is not characterized by any numerical parameters.

As well as in the case of the sensitivity, experimental testing of relay protection selectivity in the active electrical network is not acceptable, since there is a high probability of either failure protection or vice versa, its unnecessary tripping action. The failure to protect any part of the network leads to delays in starting to operate in emergency mode, an increase in equipment damage and makes high the probability of a major system failure. False (unwanted) protection operation when it had no preconditions causes the disconnection of customers and electricity shortage resulting in a significant financial loss. In addition, short-term imbalance of power generation and consumption in the network occurs resulting in heavier network operation mode and upon disabling considerable power capacities the likelihood of system failure also raises. These negative effects can be avoided by checking the selectivity of relay protection with the physical network model for which these alarm modes are allowed.

Some relay protection algorithms have absolute selectivity that is fully protect the object under protection and do not work if failure occurs beyond it (e.g., differential protection). In this case, special selectivity check is not required because protection will be ensured upon nonfaulty circuits of input and output signals and smoothly running software. To ensure the selectivity of other algorithms the time-grading or back-current dependences are generally used. These time delays and dependences are determined on the stage of calculation and selection of relay protection set points and then an analysis of selectivity for each electrical network object is carried out. It should be noted that for branched electrical networks this analysis is complicated due to need to consider a large number of network configuration options and analysis of many factors, because of what it is necessary to use fairly complicated procedure for determining the sensitivity and selectivity (Schneerson, 2007).

For example, let's consider the experimental selectivity testing of overcurrent protection for the equipment connected to the first section of 6 kV buses (Fig. 2), namely the transformer T1, motor M1 and load 1.

First, setpoints are defined in the smart relay protection breadboard as determined by the results of emergency network modes calculation adjusted to provide sensitivity. Next, a short circuit is created in the load buses 1 and an analysis is carried out on what security algorithms were run and which ones have actuated to turn off their switches. In this case, start-up must occur for the load 1 OP and the transformer T1 OP. Also motor M1 OP can start. Only load 1 OP should trip; the remaining elements of the network should remain enabled. If so, opertion of the relay protection system is selective. Disabling the other elements (motor M1 or transformer T1) will indicate a non-selective action of relay protection as these network elements are intact; in that case it is necessary to correct the current or time actuation setpoints to ensure selectivity. Similarly, a check is carried out upon short circuit at M1 motor buses; in this situation motor M1 switch Q10 tripping is selective only.

Thereafter, the short circuit is generated directly on 6 kV buses of the first section. The RPA breadboard provides a logical bus protection based on the analysis of input OP actuation signals (trips Q6 switch) and OP of output connections of the first section (in this case the motor M1 and the load 1). If there is OP actuation of at least one output connection, bus protection is blocked and allows bay protection to operate. If the input overcurrent protection is actuated and output connections are not actuated, it means that the bus is fails; then with the minimum time delay, input overcurrent protection should actuate and disconnect the switch Q6, all other switches should remain in the previous position. Implementation of the above conditions provides the selectivity of relay protection in the case of a bus failure.

CONCLUSION

Use of a physical model of the electrical network for experimental testing of the main characteristics of the smart relay protection breadboard developed in the University “Dubna” (response speed, sensitivity and selectivity) is expedient. Availability of the main standard elements of electrical networks in the model allows testing all the relay protection algorithms for each of them. At the initial stage of investigation tests, testing of relay protection is performed for all provided kinds of emergencies. The required parameters of relay protection response speed and FATS are specified; the necessary equipment and method of response speed checking are briefly described. It is shown that the experimental testing of the sensitivity and selectivity of existing electrical networks is unacceptable and the use of the physical model makes it possible to determine these parameters without danger to the actual high-voltage network equipment. Examples of determining the sensitivity and selectivity for the segments of the model power supply are shown.

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