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Operation of electromechanical and microprocessor devices of relay protection during geoinduced current effect on electrical network in the period of magnetic storm

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This paper presents investigation of operation of typical domestic electromechanical and microprocessor devices of relay protection at the geoinduced current (GIC) effect in the period of a magnetic storm. An experiment-calculated technology of the simulation of the relay protection devices operation in the electrical network was used. A 330 kV Olenegorsk-Monchegorsk signal in the current protection of the residual current realized on the basis of an electromechanical relay was the initial GIC data. The signal was recorded during the magnetic storm in the overhead power transmission line on November 24, 2001. It was shown that as opposed to an electromechanical relay, the GIC effect on the modern microprocessor device does not result in the actuation of its protection, as well as of the current protection of the residual current. The reason is the blocking of the GIC flow through the secondary measuring transformers of the device.

Keywords: magnetic storm, geoinduced current, power system, relay protection.

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Introduction

The problem of the negative impact of magnetic storms on electric power systems (EPS) is well known from a historical perspective and its relevance increases with the development of energy infrastructure, both in terms of increasing the scale and complexity of the topology of electrical networks, and in terms of technological transformation.

Magnetic storms lead to the appearance on the surface of the earth of low-frequency Geomagnetically Induced Currents (GICs) with a characteristic frequency ~ 10 mHz, which flow into electrical networks through solidly earthed neutrals of power transformers. The magnitude of the flowing into currents reaches several hundred amperes [1]. These currents can cause malfunctions in the operation of electrical power equipment [2,3] and thus can be the cause of major system accidents, which have repeatedly occurred during strong magnetic storms, mainly in high-latitude regions, for example, in 1989 and 2003 in North America and Northern Europe [4–7].

One of the reasons for such accidents is the incorrect operation of the relay protection system (RPS) when present in the electrical network GIC. Thus, false actions of the RPS initiated the development of a major system accident in the EPS Hydro–Quebec during a magnetic storm in March 1989[4]. RP devices activations under the influence of GIC were also observed in the Russian Federation, for example, in the United Energy System of the North-West in November 2001 as a result of which the 330 kV Overhead Line (OL) Olenegorsk – Monchegorsk was disconnected by the action of residual directional overcurrent protection [3].

It should be especially noted that previously all relay protection devices, including those used to protect the 330 kV Olenegorsk– Monchegorsk OL, were based on electromechanical relays. Lately, there has been an active transition in the global electric power industry to microprocessor-Microprocessor Type Protective Relays (MTPRs). These devices may have specific features of response to the effects of GIC, which determines actuality for the relevant research. This work presents the results of studies of the operation for domestic electromechanical and microprocessor-based RP devices under conditions of impact on the GIC electrical network, which recorded during a magnetic storm. Such studies are of interest when solving the problem of simulating the impact of GIC on EPS.

1. Research methodology and initial data

In the article [3] it is reported on the event (November 24, 2001, at 9 h 40 min) of a power outage during a magnetic storm of the 330 kV OL Olenegorsk–Monchegorsk in the United Power System of the North-West. The line was disconnected by the operation of the fourth stage of

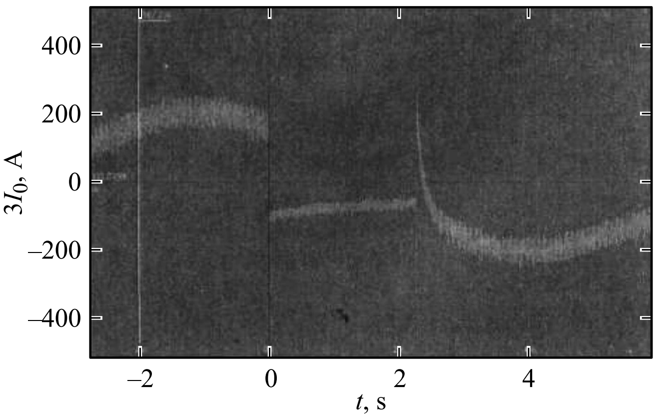

Figure 1. Oscillogram of the current in the zero-sequence protection of the Olenegorsk–Monchegorsk line from the side of the Monchegorsk substation.

Residual directional overcurrent protection (ROCP) with a time delay of 2.2 s. The protection is carried out using electromechanical relays RT-40 and RBM-178. The process accompanying the shutdown was recorded by a digital emergency event recorder (Fig. 1).

The objective of this work was a comparative study of the reaction of residual overcurrent protection of a power transformer, implemented on two types of products: an electromechanical relay RT-40/0.6 (CJSC „Cheboksary Electrical Equipment Plant") and a microprocessor device BE 2704 V041 EKRA (LLC Research and Production Enterprise „EKRA") on the impact of GIC recorded during the event described above. For this purpose, experiments were carried out to simulate such an effect on the indicated RP devices and determine their response.

The initial data for the experiments were obtained using a model of a typical section of a 500 kV power network, exposed to the influence of a GIC, implemented in the PSCAD program. The model diagram is shown in Fig. 2. The model allows, in the mode of transmission by transformers of power close to the nominal value, to calculate instantaneous current values in the windings of a group of autotransformers of the AODTSTN (i.e. single-phase three-winding power oil autotransformer with voltage regulation under load on the medium voltage side, cooling with forced circulation of oil and air with non-directional oil flow)167000/500/230/10.5 $T4.1-T4.3$ type when their core biasing with GIC. This current was set by an ideal current source J_1(Fig. 2) and corresponded to the current in the protection of the line Olenegorsk–Monchegorsk. The middle section of the current curve in Fig. 1 is modified based on the condition that the line protection did not react to the influence. Other transformers of the $T1-T3$ model played the role of galvanic separation in the mode of transferring power from the generator to the load.

The simulation was carried out for a network of a higher voltage class, since the program used does not allow us to adequately calculate the magnetic biasing of three-phase transformers installed in a 330 kV network in which the line was disconnected.

Fig. 3 shows fragments of currents in the high, medium and low voltage circuits ((HV), (MV), and (LV), respectively) of the autotransformer $T4.1$, shown to side HV. The currents obtained in this way HV, MV, LV and the residual current current are the initial data for experimental simulation.

To simulate the functioning of the studied RP devices in the structure of the electrical network, a hardware/firmware simulator developed at the Federal State Unitary Enterprise „Russian Federal Nuclear Center — All-Russian Research Institute of Experimental Physics" was used, which, using the obtained initial data, generated the following signals at the device inputs: secondary currents of current transformers (CT, SCCT) on the HV and MV sides and in the neutral of a three-phase group of autotransformers.

2. Experimental results and discussion

2.1. Experiments with relay RT-40

The main elements of the relay are a U-shaped steel core with magnet coils, a movable armature with contacts and an opposing spiral spring. When current CT passes through the coils, a magnetic force arises and the armature is attracted to the core. This force is opposing of the elastic force of the spring, which depends on the set of the operating current. When the magnetic force exceeds the elastic force, the armature moves and the normally open contacts close [8].

Using the RT-40 relay, the operation of the starting element (without a time relay and, as a result, without a time delay) of the residual overcurrent protection (ROCP) of a high-voltage line was simulated. The response setting was set similar to the setting of the 4th stage of Residual directional overcurrent protection (ROCP) of the Olenegorsk–Monchegorsk line: $3I_0 = 150$ A. Current transformer ratio is selected from the condition that the secondary current corresponds to the operating range of the relay $0.15-0.6$ A relay and is 1000/1.

Fig. 4 shows the diagram of experiments with the RT-40 relay. Residual current of CT was formed at the relay input. When the set point was reached, the relay closed, and the voltage arising across the limiting resistor was recorded on the oscilloscope, which provided visualization of the relay actuation.

Figure 5 shows the oscillogram of the generated CT current in the neutral, as well as a discrete signal displaying the start-ups of the ROCP (without time delay).

From Fig. 5 it can be seen that upon reaching the operation setting (0.15 A) at point of time $t = 1.3$ s the ROCP relay is started. According to the logic of the operation of the emergency automatics, the actuating of the ROCP and, as a consequence, the line shutdown should occur after the time delay $\Delta t = 2.2$ s at the timepoint I $t = 3.5$ s. After the line is disconnected through ~ 2 s at $t \approx 5.5$ s, the Automatic Circuit Recloser (ACR) will be launched, after

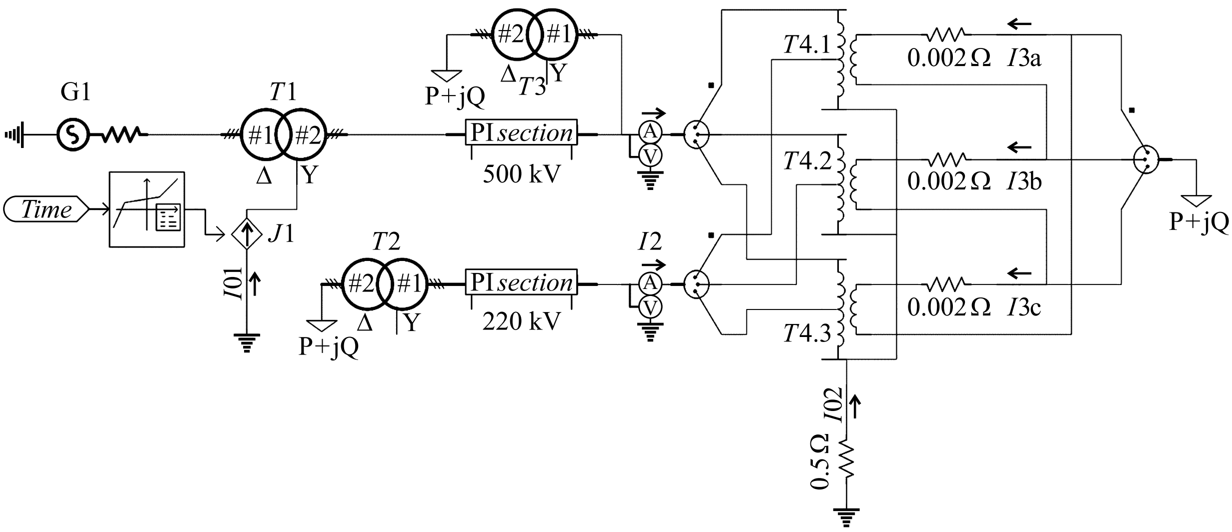

Figure 2. Model diagram in PSCAD. $T1, T2, T3$ — ideal three-phase transformers (model without taking into account core saturation);$T4.1-T4.3$ — group of single-phase autotransformers type AODTSTN (i.e. single-phase three-winding power oil autotransformer with voltage regulation under load on the medium voltage side, cooling with forced circulation of oil and air with non-directional oil flow 167000/500/230/10.5) (model taking into account core saturation); $J1$ — current source; PI Section — power line; G1 — generator.

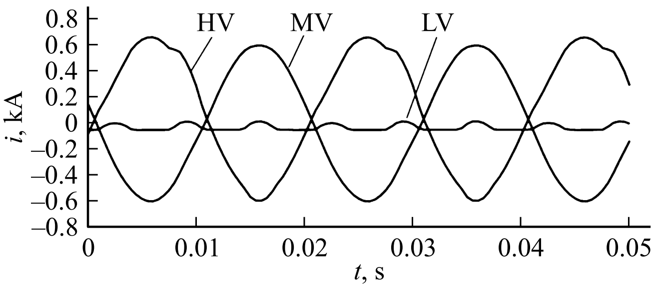

Figure 3. Currents in the circuit of high (HV), medium voltage (MV) and the tertiary delta winding (LV) of the autotransformer $T4.1$, normalized to the HV side.

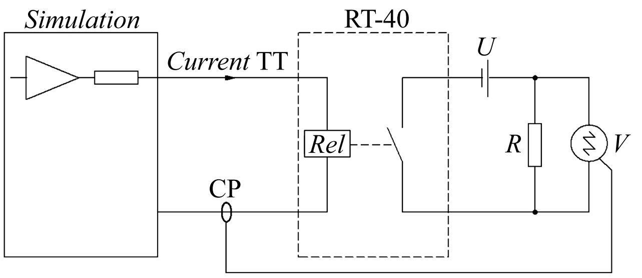

Figure 4. Experiment diagram with RT-40 relay. U — voltage source (1.5 V); R — limiting resistor (1 kΩ); V — digital oscilloscope; CP — current clamps.

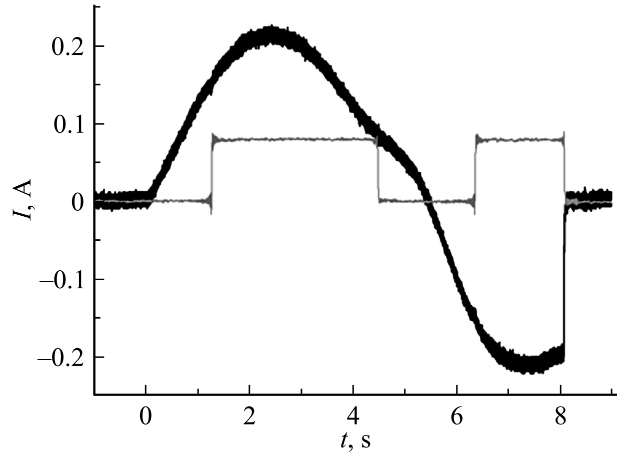

Figure 5. CT current of neutral (black curve) and relay operation signal current for RT-40 (gray curve).

which the line will be returned to operation. When the residual current subsequently decreases to the value of the return current (≈ 0.1 A), the relay opens. Thus, we can conclude that the operation of the ROCP in the experiment with the RT-40 relay is in good agreement with the effect of the ROCP on the Olenegorsk– Monchegorsk [3] line. It should be noted that in the experiments the relay is triggered again — at $t = 6.4$ s.

2.2. Experiments with MTPR BE 2704 V041

The BE 2704 V041 device has a modular design in the form of separate building blocks, i.e. Central processor boards, an analog-to-digital converter, inputs of analog (via secondary instrument transformers) and discrete signals, as well as output electromagnetic relays [9].

The MTPR BE 2704 V041 implements the following set of overcurrent protections: transformer differential protection (TDP), overcurrent protection (OCP), over-load

Trigger settings of MTPR BE 2704 V041

I_{nom} BH, A	I_{nom} CH, A	Current protection activation settings, A				
		OCP HV	OCP MV	TDP HV	TDP	CP HV
578	1258	$I_{SCCT} = 1.13$ (line) $\Delta t = 7.3\,\mathrm{s}$	$I_{SCCT} = 1.39$ (line) $\Delta t = 7\,\mathrm{s}$	$I_{SCCT} = 0.075$ $\Delta t = 2.2\,\mathrm{s}$	$I_{\mathrm{dif}}/I_{base} = 0.42$ $k_{br} = 0.5$ $I_{br}/I_{base} = 2.3$ $I_{2h}/I_{1h} = 0.15$ $\Delta t = 0$	$I_{SCCT} = 0.33$ $\Delta t = 10\,\mathrm{s}$

Note. Δt — time delay; I_{base} — base current equal to I_{nom} of HV autotransformer; I_{dif} — differential current; k_{br} — bias current; I_{br} — bias ratio; I_{1h} and I_{2h} — first and second harmonics of current, respectively.

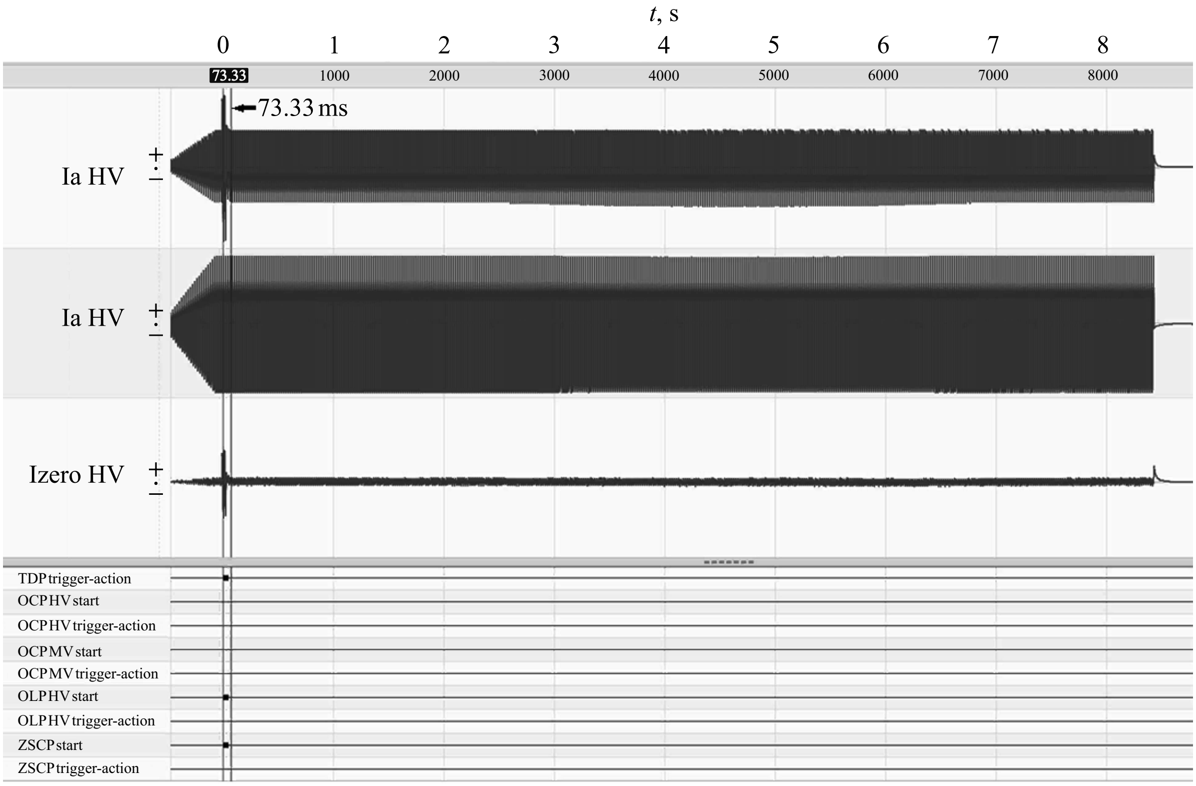

Figure 6. Currents in the phases (1st and 2nd lines), in the neutral (3rd line) of the autotransformer, logical signals for protection activation (4th to 12th lines).

protection (OLP) and ROCP. The operating values for their operation, except for ROCP, were set by analogy with the settings for current protection at an operating substation in Nizhny Novgorod region and are given in the table. Transformation coefficient of CT on the HV, MV and neutral sides is 2000/1 The ROCP settings are selected as for the 4th stage of the of the ROCP of high-voltage line Olenegorsk−Monchegorsk.

To simulate the functioning of a MTPR in an electrical network, three-phase CT currents from the HV and MV sides of the autotransformer were generated at its current inputs using a hardware and software simulator. The MTPR response was recorded using the function „emergency oscilloscope" built into the MTPR. The implementation of this possibility required the forced launch of the emergency oscilloscope. For this purpose, a section of two periods with an increased amplitude was inserted into the beginning of the signal supplied to the MTPR, which resulted in short-term starts and activation of a number of protections, which were not taken into consideration further. Fig. 6 shows the corresponding oscillograms of currents and logical signals for protection activation.

From Fig. 6 it is clear that, in contrast to experiments with the RT-40 relay, there is no quasi-constant current in the neutral, no starts and, accordingly, activation of protections, including ROCP, do not occur.

It should be noted that, unlike the RT-40, analog signals enter the BE2704 V542 device through secondary instrument transformers. The measured resistance of their secondary windings is $57\,\Omega$, inductance is $5\,\mathrm{N}$, impedance

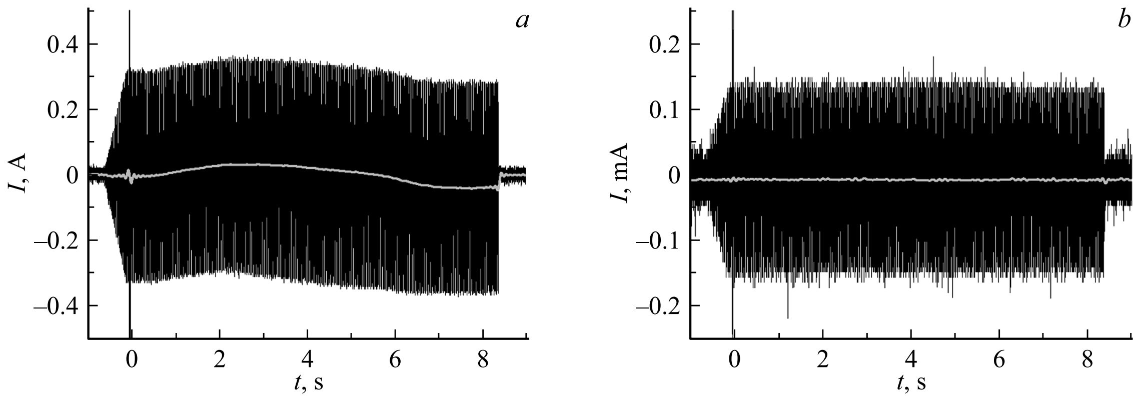

Figure 7. Current oscillograms in the primary (*a*) and secondary (*b*) circuits of the measuring transformer MTPR BE2704 V542 (black graphs — total currents; gray — low-frequency components).

at the fundamental harmonic is about 1.5 kΩ. These transformers may not pass low-frequency signals, which is the reason for the failure of the RCP.

To investigate this effect, appropriate measurements were performed. The current in the primary circuit of the transformer was recorded with current clamps, and to measure the secondary current, a shunt with a resistance of 200 Ω was connected to the open circuit. The shunt rating was selected in order to minimize current distortion caused by connecting an additional resistance to the MTPR measuring circuit and the need to obtain a measured signal with a level of at least 10 mV for its correct oscillographic recording. The CVC measurement results are presented in Fig. 7. It can be seen that the constant component presenting in the primary circuit of the transformer is absent in the secondary one.

Conclusion

1. Using computational and experimental technology for simulating the operation of relay protection devices in an electrical network, the functioning of typical domestic electromechanical and microprocessor RP devices under the influence of GIC caused by magnetic storms has been studied. As initial data, a signal was used in the current directional protection of the residual current, recorded during the magnetic storm on November 24, 2001 HV, in line 330 kV Olenegorsk–Monchegorsk, which led to its shutdown.

2. The effects of GIC have been shown

— actuation of the ROCP relay the RCP relay, similar to the event on the Power Transmission Line of 330 kV Olenegorsk–Monchegorsk, which confirms the adequacy of the simulation modeling;

— failure of the protection the protections implemented in the MTPR, including the ROCP, due to the blocking of the GIC by the secondary measuring transformers MTPRs .

3. The discovered features of the operation of electromechanical and microprocessor-based relay protection devices must be taken into account when extrapolating historical emergency events in EPS that occurred due to the impact of GIT, simulating the impact of GIT on EPS, as well as developing appropriate methods and means of protection.

Conflict of interest

The authors declare that they have no conflict of interest.

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