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Comparative performance study of the Hall sensor based directional ground fault protection in MV mining network with ineffective earthing

Abstract. *Paper presents and discusses the investigated results of performance of ground fault protections in common use in MV (6kV and 20kV) distribution mining networks with no-effective earthing. They are compared with efficiency of operation of a newly developed Hall sensor based directional ground fault protection. On the basis of the results the appropriate conclusions regarding applicability of the Hall sensor based protection in practice in MV networks are formulated.*

Streszczenie. *W artykule omówiono wyniki badań działania powszechnie stosowanych zabezpieczeń ziemnozwarciowych sieci średniego napięcia w kopalnianych sieciach rozdzielczych 6kV i 20kV z nieskutecznie uziemionym punktem neutralnym. Porównano je z efektywnością działania, w tych samych warunkach, nowoopracowanego kierunkowego zabezpieczenia hallotronowego. Sformułowano odpowiednie wnioski i zalecenia praktyczne odnośnie do możliwości wykorzystania tego typu zabezpieczenia w praktyce. (**Badania porównawcze efektywności pracy kierunkowego, ziemnozwarciowego zabezpieczenia hallotronowego, w górniczej sieci średniego napięcia, pracującej z nieskutecznie uziemionym punktem neutralnym**).*

Keywords: Hall sensor, ground fault, directional protection, power system protection, MV cable network.
Słowa kluczowe: czujnik Halla, zwarcie doziemne, zabezpieczenie kierunkowe, Elektroenergetyczna Automatyka Zabezpieczeniowa, sieć kablowa SN.

Introduction

Problems with the detection and clearing of 1-phase ground faults in medium voltage networks with an ineffectively earthed neutral are widely known and as yet not fully overcome [1-4]. Wherever it is possible the neutral point is grounded by a properly selected resistor so that the short-circuit rms current under solid (metallic) faults is to be around 100 A. However, there are a number of limitations to the applicability of this method on safety grounds, such as electric shock, fire or explosion hazard. This is particularly a problem in the MV mine distribution networks, where it is sought to limit the 1-phase ground fault current to the lowest possible value. For this reasons they are insulated, compensated, and compensated with a forced active current component value (ACF), respectively. Regardless of the kind of the protection applied, the efficiency of a 1-phase fault detection may be insufficient, especially in cases of so-called high-resistance faults, i.e. high-values of the ground fault resistance. At this point it should be noted that for such type of faults (for example the phase conductor falling to the ground with a high resistivity) even in a network grounded through a resistor, extortion of a sufficiently high value of a short-circuit current, necessary for tripping, may prove to be impossible. Therefore, working towards of achieving the structurally simple and operationally effective ground fault protections in medium voltage networks with ineffectively earthed neutral seems the most pressing [5-7].

The paper presents and discusses the results of research on the operational efficiency of commonly used 1-phase ground fault protections in MV (6 kV and 20 kV) mining distribution networks with no effective earthing. They are compared with the performance of the newly developed Hall sensor based directional ground fault protection designed to protect the mining cable network of medium voltage. Appropriate practical conclusions are then formulated.

Hall effect directional earth fault protection

Developed directional earth fault protection using a Hall sensor as the detecting (decision-making) element is shown in Figure 1. It consists of a ferromagnetic flexible core applied (imposed) directly to the medium voltage cable in the air gap of which is situated a Hall sensor subjected to magnetic field due to ground fault current (zero sequence current $3I_0$) value and polarised at the same time by electric field intensity produced by zero sequence voltage U_0. A full description of the structure and principle of operation can be found in [8,9].

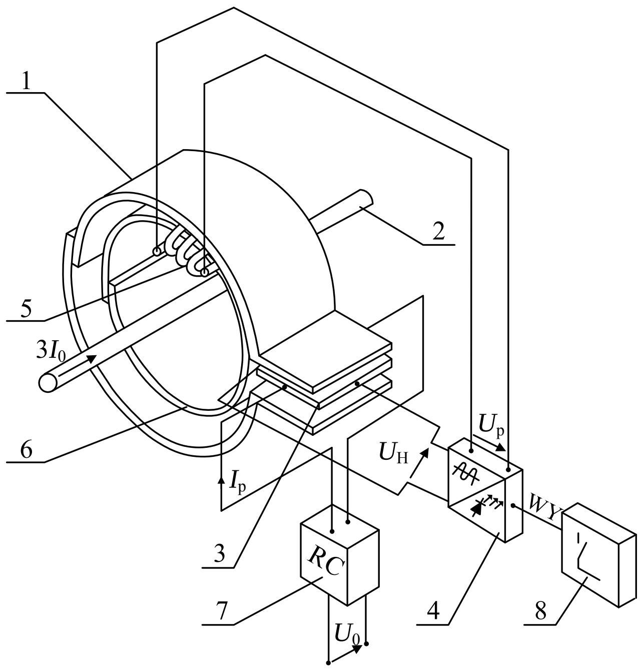

Fig. 1. Schematic diagram of a Hall effect directional earth fault protection; 1 – core balance CTs, 2 – three-phase cable, 3 – Hall sensor, 4 – measuring unit with fibre optic output, 5 – auxiliary winding (z_p), 6 – magnetic screen, 7 – phase shifter, 8 – output element

As an operational criterion an output DC voltage component of a Hall effect is employed, whose value is highest in the absence of the phase shift between $3I_0$ and U_0 as shown in Figure 2. (it is worth emphasizing that sufficient voltage value equal to around 2 V is already achieved for relatively small values of measured current and voltage signals as indicated by curve 2 in Fig. 2).

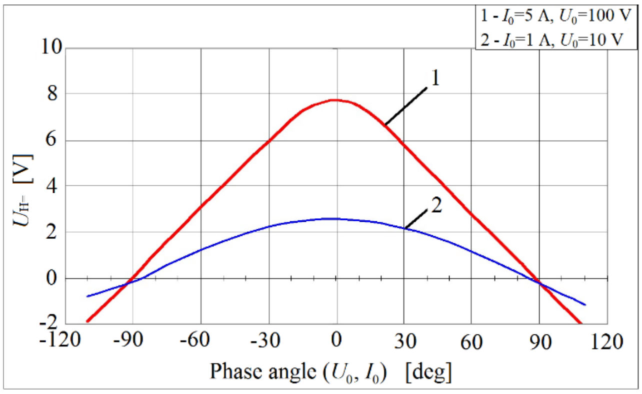

Fig. 2. The out-put dc voltage component $U_{H=}$ versus phase shift between $3I_0$ and U_0; 1) $3I_0$=5 A, U_0=100 V, 2) $3I_0$=1 A, U_0=10 V

If therefore, the protection is intended to be applied in networks where the phase shift angle is different from zero (insulated, compensated) one has to adjust a relay connection angle (RCA) by means of an electronic phase shifter included [10].

The scope and method of testing

The study was conducted for both isolated and compensated networks (of 6 kV and 20 kV) with the ACF system used to force the active rms current component (about 20 A) under solid (metallic) as well as high-resistance 1-phase faults. In isolated networks the overcurrent-time graded protections were installed whereas, in the compensated ones with the ACF function active power directional variety was used. The solid (metallic) short-circuits were performed by grounding the selected phase (line) directly to a metal line support (tower) and the high-resistance – by simulating the falling down of the phase conductor on the ground. In the compensated networks the inductor taps were changed so as to obtain the status of both over- and/or undercompensation during ground faults. The performance of protection systems powered by both residual current transformers (Holmgreen) and core balance transformers (Ferranti) was checked for comparison. During the study the network configurations were changed to obtain of both high (around 20 A - 40 A) and small (even below 0,5 A) resultant capacitive rms current values. The Hall effect directional ground fault protection was installed on the faulted cable lines and DC output Hall voltage component was primarily measured and registered while coordinating it with short-circuit current $3I_0$ and zero-sequence voltage U_0 respectively (Fig. 3).

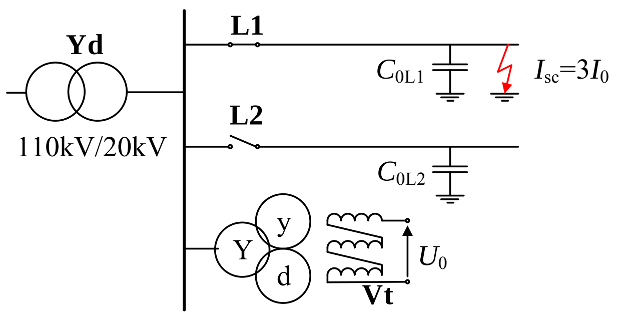

Fig. 3. Simplified diagram of an isolated network of 20 kV with a low capacitive current (I_{sc} – short circuit current to the ground, C_{0L1}, C_{0L2} – capacitance of particular line L1 and L2 to ground respectively)

Test results and discussion

An isolated network of 20 kV (selected for testing) consisted of only two overhead lines L1 and L2 of length of about 5 km each (Fig. 3). As a result, the resultant capacitive rms current did not exceed of about 4 A. The single-phase short circuits were performed in the L1 line of both at the beginning and at its end. Both overhead lines were terminated with cable connections to the switch board, which allowed to install the balance transformers (Ferranti) and the Hall sensor protection directly on the three-phase cable feeders.

During the simulated metallic ground faults at the beginning of L1 line (with disconnected L2 line) the short circuit rms current at the beginning of the fault (t=0) was about 1,5 A and decreased to around 0,3 A at the steady state, respectively, as shown in Figure 4. For such a small current value the installed over-current protection (set rms value ~1 A) was obviously failed in operation. In contrast, the measured DC component of the Hall voltage value was found to be large enough (about 10% of the maximum) to effectively detect and localise effectively in practice this type of 1-phase ground fault (Fig. 5).

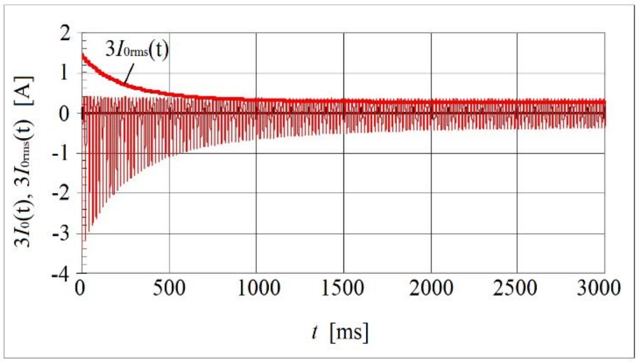

Fig. 4. The dependence of the metallic ground fault current value as a function of time

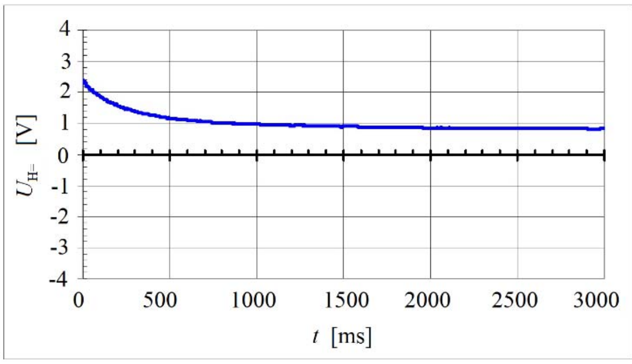

Fig. 5. Variation of the DC voltage component value versus time during metallic 1-phase short-circuit in L1 line (L2 disconnected – see Fig. 3)

During the resistive ground faults (though of a relatively low resistance equal to about 85 Ω) and the connected L2 line, the rms value of the current was increased to about 3 A in transient and decreased respectively to around 1 A in a steady state. It resulted in activation of the delay-time overcurrent protection and effective disconnection of the faulty line L1 after set-time of 1 s (Fig. 6). The DC component value measured under the same conditions was relatively higher (~35 % of the maximum), also demonstrating the usefulness of the newly developed Hall effect protection to detect and clear ground faults in the MV networks with sufficient accuracy (Fig. 7).

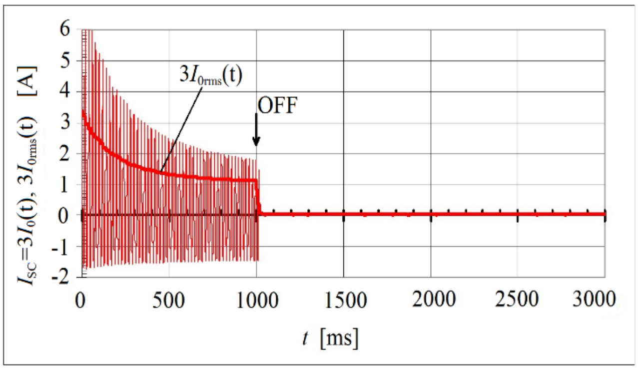

Fig. 6. Short-circuit current variation with time during 1-phase resistive ground faults (~85 Ω) in isolated networks (as in Fig. 3).

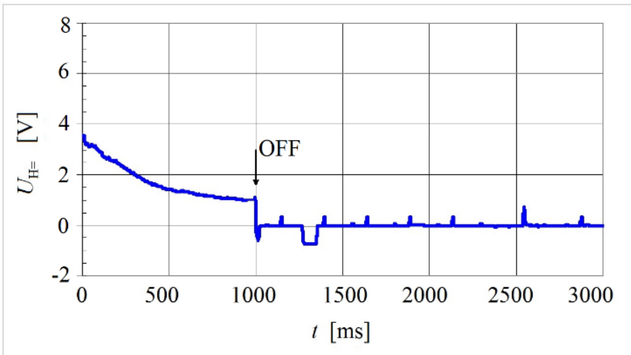

Fig. 7. The DC voltage component with time under resistive ground faults (~85 Ω) in isolated networks (as in Fig. 3)

Similar tests were performed for the network with a structure like in Figure 3, but at 6 kV rated voltage; however, the network was equipped with admittance protection (set value ~1 s). There was also no problem with the detection and the clearing of metallic 1-phase ground faults at any point of the networks, but it turned out impossible for high-resistance faults, particularly with the presence of an intermittent arc. In such cases not only did the short-circuit current indicated low rms values (below 2 A) but also there was a significant decrease in the U_0 rms value (below 10 V), as one can see for example in Figure 8 (estimated ground fault resistance equal to about 1,8 kΩ).

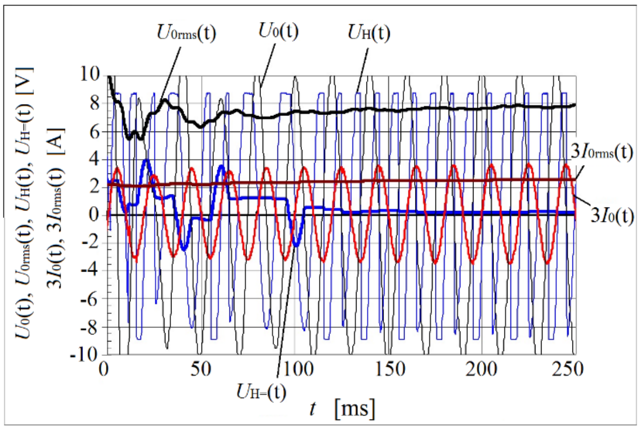

Fig. 8. Short-circuit current ($3I_0$(t) and $3I_{0rms}$(t)), voltage (U_0(t) and U_{0rms}(t)) and Hall effect voltage (U_H(t)) waveforms at the beginning of the high resistive ground fault (~1,8 kΩ) in 6 kV isolated network ($U_{H=}$(t) - DC component)

However, from the measured DC voltage component (U_{H}=) and its waveform it is evident that transient state of the initial fault duration (up to about 100 ms) can be used as a criterion for detection of the earth faults. The value of the constant component in transient seems to be sufficient for tripping. It is compromised within +1 V up to +4 V (negative values indicate the restrain area of the protection). The Hall effect protection can therefore meet satisfactory the role of a fast fault protection oriented to operation during a transient state of the earth faults which would be an advantage.

For more extensive MV networks (6 kV and 20 kV) with the capacitive current compensation and ACF system applied (R_w resistor switched on after about 3 s when the 1-phase fault is detected by the zero sequence voltage U_0 system) directional active power protections are usually used (Fig. 9).

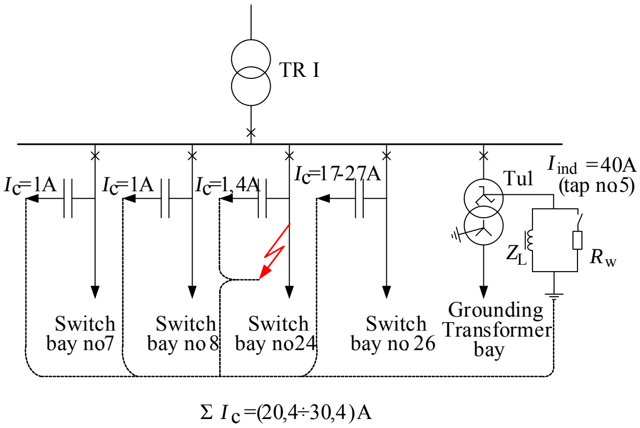

Fig. 9. Simplified network (6 kV and 20 kV) diagram with applied both compensation and ACF system (Tu-1 – grounding transformer with induction coil (Z_L) and resistor R_w to force the active component of the short-circuit current of about 20 A)

In the case of solid (metallic) short circuit the protection was reliably activated after the ACF system's operation (after 3 s). The measured DC voltage component (U_H=) of the Hall protection also indicates a satisfactory high value (around 75 % of its maximum), necessary for the selective detection of the ground fault (Fig. 10). However, one should be aware that under high-resistance faults the short-circuit current increases respectively (after activation of the ACF) but at the same time zero sequence voltage decreases (depending on the fault resistance) as shown in Figures 11 and 12, respectively.

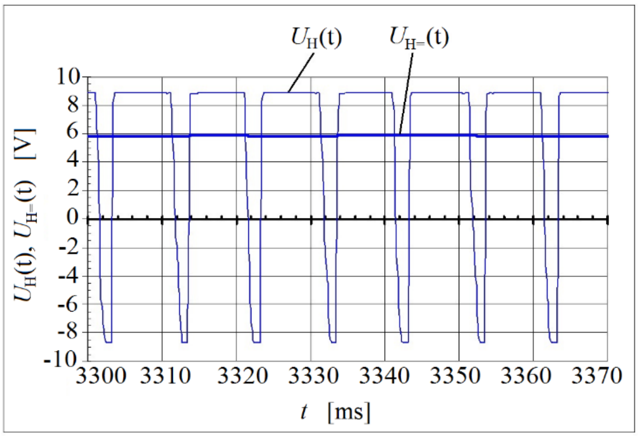

Fig. 10. Hall voltage waveform (U_H(t) and $U_{H=}$(t)) during metallic 1-phase faults in the 6 kV network (see Fig. 9) after activation of ACF system

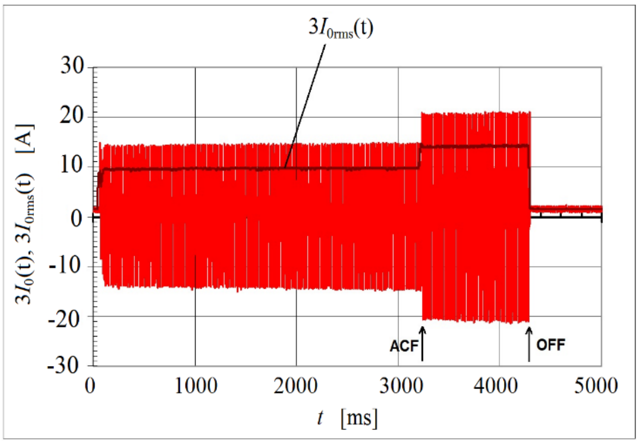

Fig. 11. Ground fault current waveform during 1-phase resistive fault (80 Ω) in 20 kV compensated network before and after activation of the ACF system

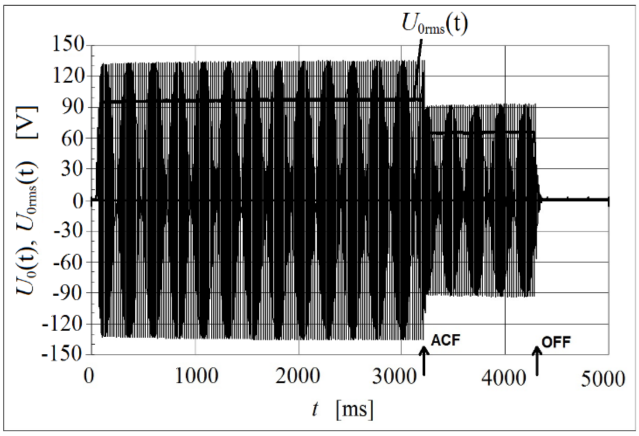

Fig. 12. Zero sequence voltage U_0 waveform (U_0(t), U_{0rms}(t)) during 1-phase resistive fault (80 Ω) in 20 kV compensated network before and after activation of the ACF system

So with considerable high fault resistance value (>1,5 kΩ) one has to face the problem of reliable operation of the commonly applied protections. On the contrary in such cases however, the value of the DC Hall voltage turns out to be sufficient for reliable operation of the newly developed directional protection (Fig. 13).

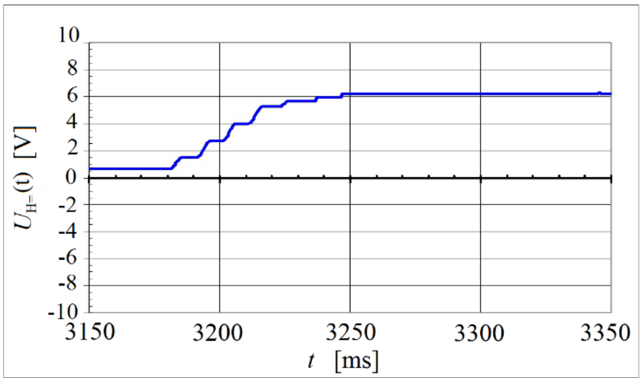

Fig. 13. Variation of the DC Hall voltage value under resistive ground fault (80 Ω) in 20 kV compensated network after activation of the ACF system

The Hall effect ground fault protection that is characterized by a simple structure and reliable operation can be therefore very useful for application in MV cable networks. It is worth emphasizing its correct operation even in difficult to detect and localize cases of 1-phase high resistance short-circuit also with evidence of an intermittent arcing.

Conclusions

The study showed, that the selective detection and clearing of 1-phase faults in MV networks (6 kV and 20 kV) with no-effective earthing may be difficult and under high-resistive faults (>1,5 kΩ) can be impossible when use available protections both time-delayed overcurrent, admittance and/or directional active – and reactive power as well. It is associated with small values of criterion quantities (both current $3I_0$ and voltage U_0) as well as the influence of errors particularly current and angular of measuring transformer systems applied.

The newly developed Hall effect directional ground fault protection for MV mining cable networks showed high reliability of operation in all cases of simulated real 1-phase short-circuits. In special cases of high resistance (>1,5 kΩ) faults even with intermittent arc the use of the DC Hall voltage in transient (<100 ms) as a criterion of the operation can be suitable.

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