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Directional Relay with a Hall Sensor for Mine MV Feeders with no Effective Earthing

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Introduction

Fast and selective detection and clearing of single-phase short circuits in MV feeders are of great importance at any applications due to both reliability and safety considerations. However, protections applied up to now for not extensive MV feeders (6 kV-30 kV), of a small capacitive current value, do not fulfill expectations. It is still not easy to meet the requirements particularly in strip mines where the networks operate with no effective earthing (isolated, grounded via impedance or/and via resistance, of a relatively high value). Therefore, in a case of high resistive shortings the fault current value can be very low, thus the short circuit is found to be practically impossible to detect. (Note that the relay tripping level has to be fixed relatively high due to significant errors (residual current) of zero sequent current transformers applied). Hence, a current challenge is to develop and to involve advanced solutions so that the simple structures and sensors may be used to fabricate the new reliable and sensitive ground fault protections. It can be accomplished by applying Hall sensors as measuring elements. Investigated results of a newly developed protection, where the direct Hall effect is exploited in directional relay, are presented and discussed. Results of laboratory tests are confirmed by experiments performed for the real single-phase short circuit in selected 6 kV network of a strip-mine.

Structure and principle of operation of the directional protection

A schematic diagram of this protection is shown in Fig. 1. The Hall sensor is located inside a specifically shaped air gap of the flexible magnetic core composed of two strip coils which embrace selected cable line of a protected MV feeder. Due to high flexibility of the controlled strips applied as the ferromagnetic core, it is possible to mount them easily onto the cable without any need for disconnection. Electric field intensity, affecting the Hall element, is produced by a zero sequence voltage U_o delivered from an open delta circuit of a voltage transformers set. This polarization circuit is equipped with a phase-shift system used to adjust easily the required directional characteristic of the protection, while the voltage limiter is used to protect the Hall element against overvoltages and high transient harmonics of the short-circuit faults.

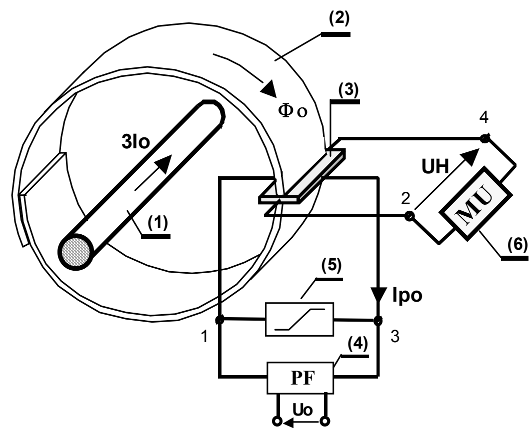

Fig. 1. Schematic diagram of the directional ground fault protection with a Hall sensor as a measuring element: 1 – protected cable line; 2 – magnetic core; 3 – Hall sensor; 4 – phase shift circuit; 5 – voltage level limiter; 6 – output detector

The output detector controls middle value of the Hall voltage U_H. In the presence of a magnetic field ϕ_o due a zero sequence current $3I_o$ an instantaneous value of the Hall voltage $U_H(t)$ can be expressed as:

$$U_H(t) = k \cdot U_o \cdot 3I_o \left[\cos(\varphi) - \cos(2\omega t + \varphi)\right] = U_{H,DC} + U_{H,AC}, \quad (1)$$

where k – constant, dependent on Hall sensor parameters; U_o, $3I_o$ – zero-sequence voltage and current amplitude respectively; φ - phase shift angle between U_o and $3I_o$.

Therefore, the output Hall voltage appears to be composed of the two components: one is DC ($U_{H,DC}$), which value depends on the phase shift angle (φ), and the AC component of a double angular frequency (2ω). For tripping of the directional protection the constant component ($U_{H,DC}$) can be applied to evaluate both value and direction of a zero-sequence power.

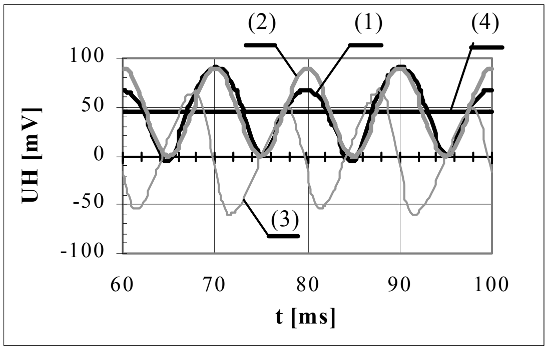

Fig. 2. Output Hall Signal, when energized by voltage (U_o=100V, 50 Hz) and current ($3I_o$=5A, 50Hz) displaced by about by about - 90°; 1 – measured value; 2 – theoretical rezults; 3 – measured for angle between input U_o and $3I_o$ reduced to a zero; 4 – measured DC component (at - 90°)

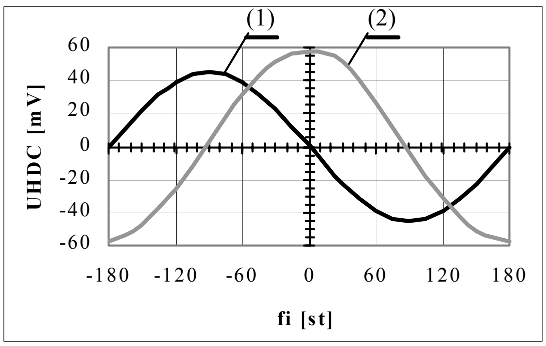

Fig. 3. DC component of Hall voltage ($U_{H,DC}$) versus displacement angle in the directional protection for MV feeder: 1 - isolated; 2 - compensated

Since its maximum is obtained for current $3I_o$ and voltage U_o being in phase ($\varphi = 0$), therefore for MV feeders operated with an isolated neutral point (where the phase shift angle value is close to about 90^o) a special phase-shift circuit has to be used (see Fig. 1) to reduce the angle φ to zero.

Laboratory test results

Performance of the protection under lab conditions when the relay is adapted for use in the MV feeders with isolated neutral point is presented in Fig. 2-5. Owing to applied phase-shift circuit the maximum DC component is found for the different angle between input voltage U_o (50 Hz) and current $3I_o$ (50 Hz) just equal to -90^o.

Its value is roughly around the amplitude of the Hall AC component of 100 Hz. Note that the AC value appears to be not symmetrical due to some structural asymmetry of the Hall element (compare curves 1 and 2 in Fig. 2). By decreasing the displacement between U_o and $3I_o$ at the input to zero we reduce the DC component to zero as well, what can be seen from curve 3 in Fig. 2.

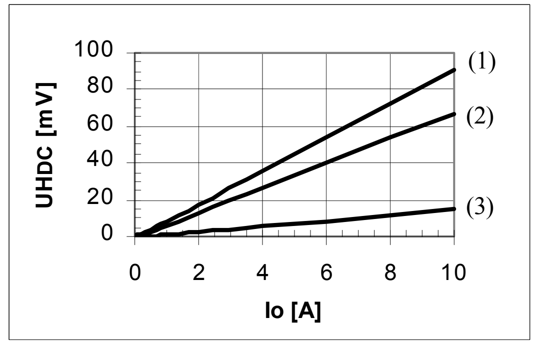

Fig. 4. Variation of the DC Hall component ($U_{H,DC}$) as a function of current ($3I_o$), for different rms value of the U_o voltage (50Hz): 1 - U_o=100V; 2 - U_o=50V; 3 - U_o=10V

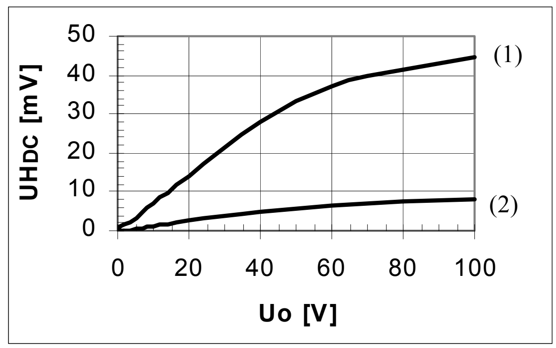

Fig. 5. DC Hall component of the Hall voltage($U_{H,DC}$) versus U_o for different short circuit rms value: 1 - $3I_o$ =5A; 2 - $3I_o$ =1A

In the presence of the voltage limiter the input U_o signal is slightly deformed, however this effect on the protection performance is almost unnoticeable [1,2]. Possibility and efficiency of adjustment of the directional characteristic made with the phase-shift circuit can be estimated from Fig. 3. It is seen that the DC value of the Hall output, therefore the protection sensitivity can be decreased depending on power consumption of the phase-shift regulation circuit.

It is desirable that the $U_{H,DC}$ value is as high as possible under short circuit conditions, therefore the influence of both zero-sequence voltage U_o and the current – sequence component were examined. It is a linear increasing function of current and voltage value up to about 10A and 30V respectively, as demonstrated in Fig 4. The nonlinear relations for the zero-sequence voltage U_o over 30V is due to contribution of the phase-shift circuit. However, it does not influence the protection performance in practice.

Investigated results under real ground fault conditions

To verify the laboratory results the directional ground fault protections with the Hall sensor as measuring element were checked under real one-phase short circuit conditions. In this context the 6kV MV feeder, operating with isolated neutral point was chosen for testing.

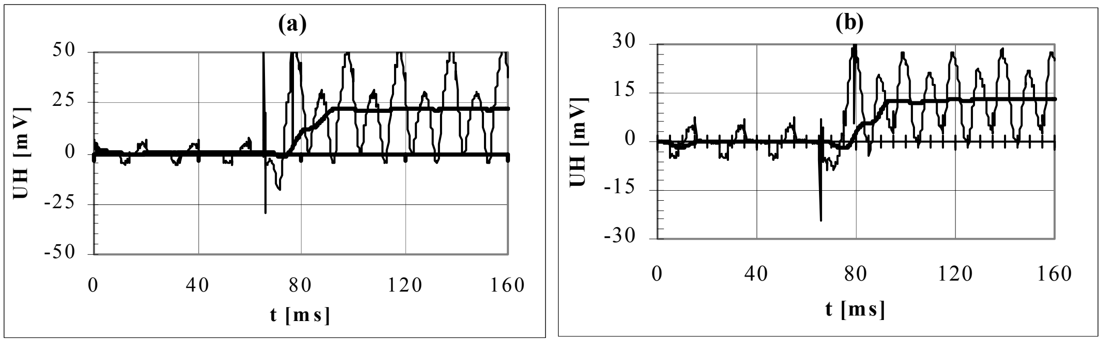

Fig. 6. Hall output voltage in a case of one phase metallic and resistive ground faults in the 6kV feeder of a strip mine operating with isolated neutral point: a) metallic short-circuit (U_o=100V, $3I_o$ =2.8A); b) metallic short-circuit (U_o=67V, $3I_o$ =1.8A)

Total capacitive current value was selected to be relatively low, around 3A RMS. From the results shown in Fig 6 it is clear that even in a case of a significantly reduced short-circuit current value (for resistive faults) the output $U_{H,DC}$ is sufficient for the reliable operation of the directional protection. Note, that the threshold steady state value of the $U_{H,DC}$ was found to appear relatively quick after about 30 ms from the moment of the short-circuit initiation. In this respect the developed directional protection with the Hall sensor as measuring device has much superior properties to the protections, which are in use today.

Conclusions

By use the Hall sensor as a measuring device the simple, it is possible to develop reliable ground fault protections. The results of laboratory tests confirmed by the experiments carried out under real one-phase short-circuit conditions in the MV feeders with no effective earthing have proved their superior properties to the protections which are in use today. Directional protections are particularly recommended, which are able to detect and to clear off the single-phase short circuits even under high resistive groundings, i.e. for significantly reduced values of both the current and voltage. However, in order for the protection to work properly under the all conditions, there is a need to check their performance in a case of faults with an intermittent electrical arc which are the most dangerous and onerous in practice.

References

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2. **Miedziński B., Okraszewski Z., Szkółka S., Szymański A..** The Influence of Hall Asymmetry on Accuracy of Measurements of the Shift Angle in Ground Fault Protections // Elektronika, 1999/40. – No 11. – P. 25–27 (in polish)

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W. Dzierżanowski, B. Miedziński, Z. Okraszewski. Kryptinė relė su Holo sensoriumi kasyklų MV maitinimo linijoms su neefektyviu įžeminimu // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2006. – No. 1(65). – P. 25–27.

Pateikti ir aptarti kryptinių relių su Holo sensoriais, kaip matavimo įtaisų, modelių tyrimų rezultatai. Laboratorinių tyrimų rezultatai palyginti su eksperimentiniais, kurie buvo atlikti realiomis sąlygomis pasirinktose šachtų konvejerių MV maitinimo linijose su įžeminimo gedimais. Il. 6, bibl. 2 (anglų kalba; santraukos lietuvių, anglų ir rusų k.).

W. Dzierżanowski, B. Miedziński, Z. Okraszewski. Directional Relay with a Hall Sensor for Mine MV Feeders with no Effective Earthing // Electronics and Electrical Engineering.– Kaunas: Technologija, 2006. – No. 1(65). – P. 25–27.

There are presented and discussed the investigated results of performance of directional relay models with Hall sensors as measuring devices. Results of laboratory tests are compared with the experiment carried out under real ground fault conditions in selected MV feeders of a strip mine. Ill. 6, bibl. 2 (in English; summaries in Lithuanian, English and Russian).

В. Дзержановски, Б. Медзински, З. Окрашевски. Направляющее реле с сенсором Холла для MV линий питания с неэффективным заземлением в шахтах // Электроника и электротехника. – Каунас: Технология, 2006. – № 1(65). – С. 25–27.

Представлены и обсуждены результаты исследований моделей направленного реле с сенсорами Холла, как устройств измерения. Результаты лабораторных исследований были сравнены с результатами исследований, проведенных в реальных условиях в отобранных MV линиях питания с дефектами заземления, находящихся в конвейерах шахт. Ил. 6, библ. 2 (на английском языке; рефераты на литовском, английском и русском яз.).