ISSN 1392 – 1215

ELECTRONICS AND ELECTRICAL ENGINEERING

ELEKTRONIKA IR ELEKTROTECHNIKA

2009. No. 3(91)

T190

ELECTRICAL ENGINEERING

ELEKTROS INŽINERIJA

The Influence of Magnetic Shielding on Selectivity of a Hall Sensor based Protection

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Introduction

Problem of selective detection and fast clearing of the ground faults in MV networks is still “waiting” for right solution. It is of great importance particularly in mining MV feeders with no effective earthing due to hazard of explosion, fire and electrical shock for servicing personnel [1].

Commonly used protections employ the core balance transformers which are characterized among others by relatively high dimensions and heavy weight what usually makes their installations on a cable onerous. Besides, for the small residual current values (around 1A) they are neither not enough sensitive nor selective, particularly under the faults with interrupted arc due to the high ground resistance value (e.g. drop of a phase conductor on a ground in overhead lines). To overcome this problem a new structure of the ground fault directional protection for MV feeders has been developed using a Hall sensor as a measuring element [2,3]. Both laboratory investigations and preliminary testing under real conditions in MV mine networks of 6 and 20 kV confirmed its quality however, revealed also that the protection selectivity can be the cable load dependent (particularly under the phase current asymmetry) what is not considered as a good. We have found that satisfactory improvement of the newly developed ground fault protection can be achieved when apply selected magnetic shielding of the residual field due to cable load asymmetry. In the paper the influence of the shielding on both selectivity and sensitivity of the Hall sensor’s based protection is considered. The considerations has been carried out for the balance transformers with the magnetic screen inside. On the basis of theoretical analysis and investigations under both laboratory and real conditions of operations in the MV network the conclusions about efficiency of magnetic shielding thus about applicability of the analyzed protection are formulated.

Sensitivity problem of the protection due to cable loading

The Hall sensor, which is located inside an air gap of the core of balance transformer is affected both by magnetic field due to a zero sequent current arrising in a case of the ground faults [1] as well as by resultant field of the three phase load of the cable being protected [4]. Even for symmetrical load (when the resultant magnetic field is equal zero) the Hall sensor can be under the influence of the residual magnetic flux density. It is because of a different location of the particular phases with respect to the balance transformer’s core (different phase coupling value). Therefore, if only electrical polarization is applied (provided by a zero sequence voltage U_0) immediately at output terminals of the Hall sensor one can detect both AC and DC voltage components (see Fig. 1).

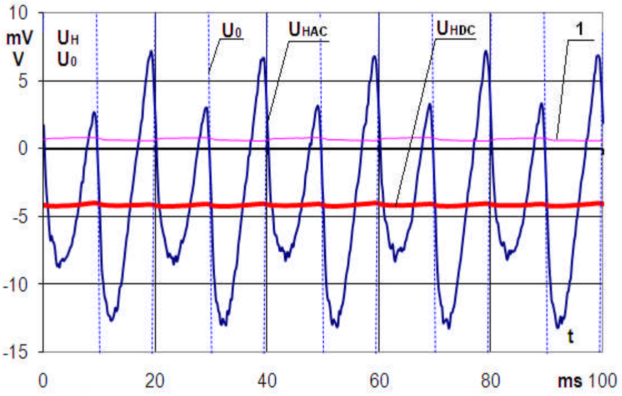

Fig. 1. Hall voltage U_H value (AC and DC components – U_{HAC}, U_{HDC}) versus time for healthy feeder under symmetrical 3-phase load (50 A) when zero sequence voltage (U_0=100V) is applied (1 – U_{HDC} for I_{load}=0)

It can result in malperformance of protections for healthy feeders at relatively low threshold of their setting.

We have found that to reduce the residual flux density affecting the Hall sensor under normal operation of the loaded 3-phase MV cable the application of a magnetic screening gives satisfactory results. This screen made of a few strips of a selected magnetic material wound directly on the protected cable inside the balance transformer, as illustrated in Fig. 2, seems to be convenient.

However, one has to take into account that the magnetic shielding reduces not only the residual field due to conductors asymmetry but also can decrease the effective field which affects the Hall sensor under the ground fault. Therefore, it must be properly selected and carefully applied.

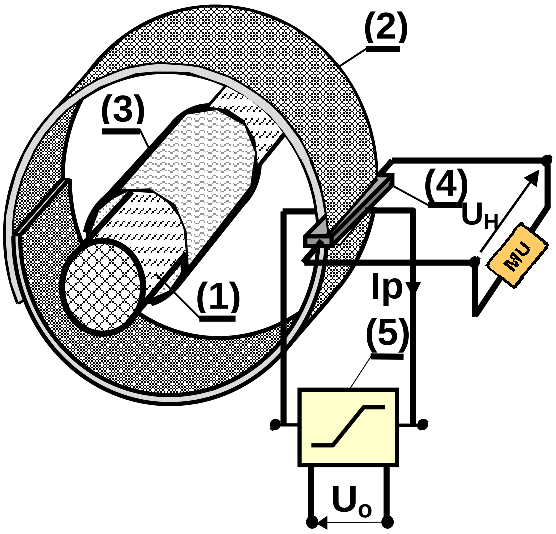

Fig. 2. Sketch of a Hall sensor based directional earth fault protection with a magnetic shield applied. 1 – protected 3-phase cable feeder, 2 – magnetic core of CTs, 3 – magnetic shield, 4 – Hall sensor, 5 – signal peak limiter and phase shifter, MV – measuring and processing unit, U_0 – zero sequence voltage, I_p – polarizing current, U_h – output Hall voltage

Analysis and investigations of the screen efficiency

The magnetic screen structure as well as its location and efficiency was selected and estimated on the basis of result of the theoretical analysis confirmed by laboratory and industrial investigations.

Theoretical approach

On the basis of FEM method using ANSYS package the 3-D field simulations were performed for the model of the Hall sensor based protection as illustrated in Fig.3 (due to symmetry of the model only a half of the structure was able to be taken under consideration).

Both the screen and the core of the balance transformer was assumed to be made of the same cold rolled magnetic sheet of the B=f(H) curve as it is seen in Fig. 4.

To confirm the assumptions, first the magnetic flux density was computed inside the air gap (where the Hall sensor is located – see Fig.2) for stimulated ground faults in selected phase conductor (e.g. L1) with current value ranged from 1 A up to about 500 A rms respectively. It was found that the flux density B tends to increase almost linearly with current up to about 200 A with following saturation for the higher values (Fig. 5).

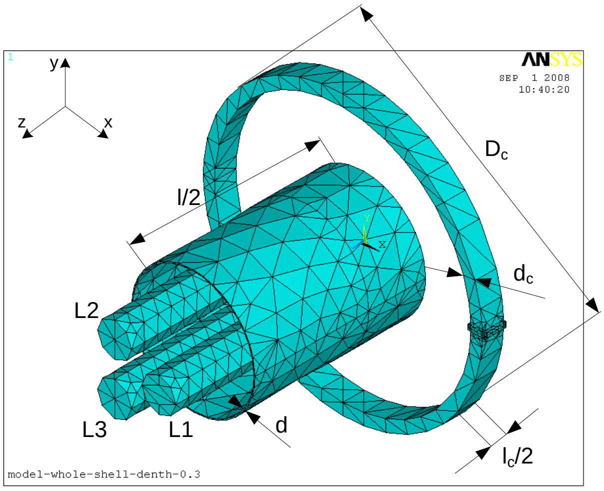

Fig. 3. Model of the protection with selected mesh for computations (l, l_c – length of the screen and transformer core; d, d_c – thickness of the screen and the core respectively; l_c=15 mm, d_c=3 mm, D_c – core diameter)

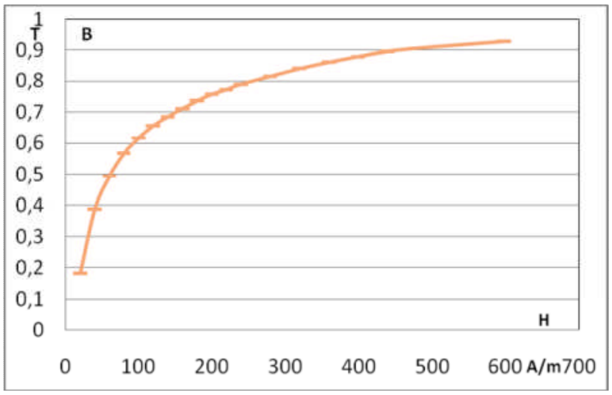

Fig. 4. Magnetization characteristic of the material applied (cold rolled magnetic sheet SURA)

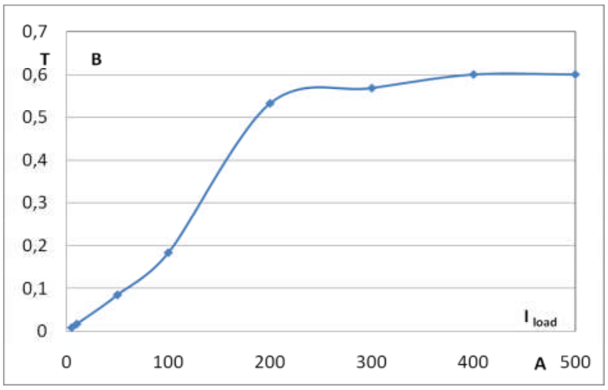

Fig. 5. Flux density inside the air gap of the balance transformer versus load current value only in one selected phase L1 (without magnetic screen)

Having confirmed that results of simulations are in satisfactory agreement with the experiment we were able to estimate the influence of the screen dimensions with respect to these of the transformer's core. It was found that to obtain high efficiency of the magnetic shielding the screen thickness selected can be relatively small however, depends on its length. For example for the shorter screen

(l/l_c=8) the increase of its relative thickness over about d/d_c≈0.6 does not make any sense while, for l/l_c=8 it can be even smaller around d/d_c≈0.2 what can be compared from Fig. 6.

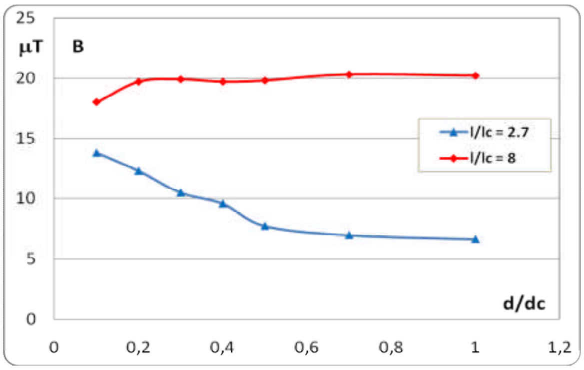

Fig. 6. Variation of the residual flux density, inside the air gap of the core due to the 10 % load asymmetry (L1= 45 A, L2=L3=50 A), with the screen thickness (d) (d_c=3 mm, l_c=15 mm)

While if use only one turn of the sheet (d=0.3 mm) the best results are visible for the relative screen length (l/l_c) of around (5÷7) as it is seen in Fig. 7.

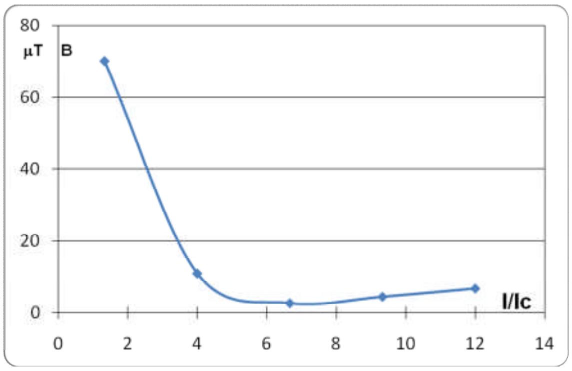

Fig. 7. Residual flux density, inside the air gap of the balance transformer with the screen length (l) under simulated 10% load asymmetry (L1= 45 A, L2=L3=50 A), (l_c=15 mm, d_c=3 mm, d/d_c=0.1)

Therefore, the slight influence of the screen thickness on the shielding efficiency makes possible to install the protection on the cable easily.

Investigated results

The investigations were carried out for a physical model of the protection with three different screens applied as follows:

- type E (l/l_c=6, S_E/S_c=1.125),
- type F (l/l_c=2, S_E/S_c=0.375),
- type G (l/l_c=2, S_E/S_c=0.75),

where S_c=60 mm^2 – cross section of the transformer's core.

The best effect was found for the screen of E type (l/l_c=6) for which, the residual voltage value U_{Hr} due to the 3-phase load current was reduced even below 6% of this without any shielding what can be compared from curves 1 and 4 in Fig. 8.

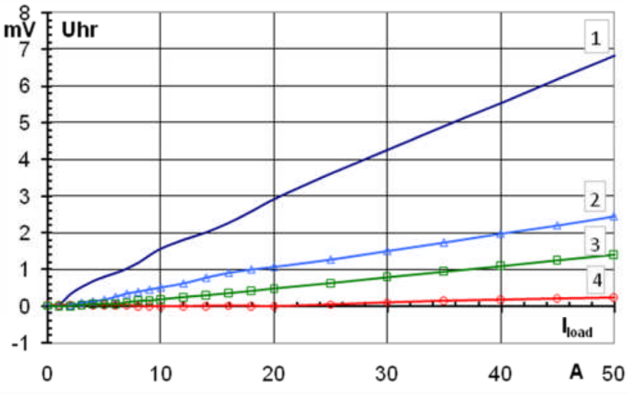

Fig. 8. Residual Hall voltage (U_{Hr}) versus 3-phase symmetrical load of the cable (1 – without the screen, 2 – screen F type, 3 – screen G type, 4 – screen E type, diameter of the core D_c=120 mm)

It depends also on the core diameter and tends to decrease for the smaller size of the balance transformer (for example the U_{Hr} value is about 2 times lower if the core diameter D_c is decreased around 25% - see Fig. 9).

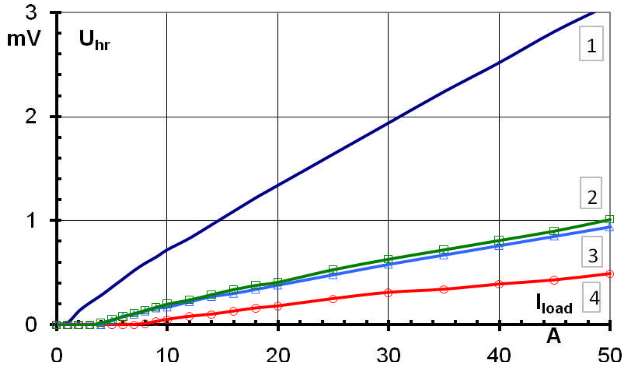

Fig. 9. Residual Hall voltage (U_{Hr}) versus 3-phase symmetrical current value (1 – without the screen, 2,3,4 – with screen F, G and E respectively, D_c=90 mm)

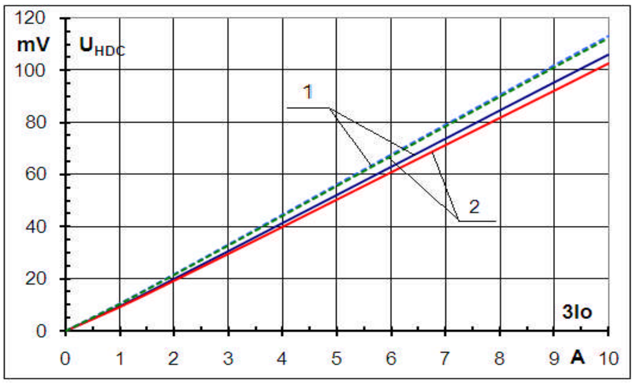

Fig. 10. DC component of the Hall sensor output versus ground fault current $3I_0$ with and without the magnetic screen of E type (1 – without the screen, 2 – with E type screen, D_c=120 mm, ---- – for D'_c/D_c=0.75)

It is worth to underline that application of the magnetic screen indicates a slight influence on the protection sensitivity. However, the sensitivity is increased for the smaller core diameter (by about 8% for $D'_c/D_c=0.75$ – see Fig. 10).

The investigated results in general was found to be in good agreement with the computations (~10%).

Conclusions

Due to asymmetry of loading of the 3-phase cable being protected as well because of different location of the particular phase conductors, with respect to the Hall sensor, a residual voltage emerges at output terminals of the protection if only electrical polarization provided by zero sequence voltage (U_0) is applied. For the high load its value can be comparable with the setting and can result in maloperation of the protection. It was found that to reduce this disturbance source the simple, specially selected magnetic screen has to be employed. It must be placed directly over the 3-phase cable being protected inside the core of the balance transformer. For the screen made of commonly used cold rolled magnetic sheet its thickness required is small provided the screen length is about 6 time longer with respect to its of the transformer. The best effect was found for both the screen and the balance transformer tightly installed on the protected 3-phase cable. It is worth to note that by use of the magnetic screen, the selectivity of the ground fault protection can be significantly improved without any visible deterioration of the sensitivity.

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Received 2009 02 10

B. Miedzinski, W. Dzierzanowski, M. Habrych, Z. Okraszewski. The Influence of Magnetic Shielding on Selectivity of a Hall Sensor based Protection // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 3(91). – P. 89–92.

A possibility of improvement of performance of the newly developed ground fault protection using a Hall sensor as measuring element is discussed. The considerations have been carried out for the new balance transformer structure with magnetic shielding on the basis of results of both analytical approach and these of investigations. Ill. 10, bibl. 4 (in English; summaries in English, Russian and Lithuanian).

Б. Миедзински, В. Дзиержановски, М. Габрих, З. Окрашевски. Влияние магнитного экранирования на селективность устройства охраны с преобразователем Холла // Электроника и электротехника. – Каунас: Технология, 2009. – № 3(91). – С. 89–92.

Обсуждается возможность повышения эффективности устройства защиты средств заземления от отказов. Для этого применяется датчик Холла как устройство измерения. На основании аналитических и экспериментальных исследований предложены рекомендации как разработать структуру балансного трансформатора с балансным экраном. Ил. 10, библ. 4 (на английском языке; рефераты на английском, русском и литовском яз.).

B. Miedzinski, W. Dzierżanowski, M. Habrych, Z. Okraszewski. Magnetinio ekranavimo įtaka Holo jutiklį naudojančios apsaugos selektyvumui // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 3(91). – P. 89–92.

Aptariama galimybė patobulinti naujai sukurto įžeminimo apsaugos nuo gedimo įtaiso efektyvumą naudojant Holo jutiklį kaip matavimo elementą. Remiantis analitinių ir eksperimentinių tyrimų duomenimis, pateiktos rekomendacijos, kaip galima sudaryti naują magnetiškai ekranuoto balansinio transformatoriaus struktūrą. Il. 10, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).