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Analysis of Magnetic Field Distribution in a Hall Sensor Based Protection

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Introduction

One of the main requirements that has to be met by any protection in general is respective sensitivity provided it is selective. If about earth fault protections it means that they must be able to indicate and to clear all types of the ground faults independently on the fault conditions and methods of earthing of system. However, in some installations like in mines and quarries earth fault current is limited to a very low level. Therefore traditional protections even using directional relays and core balance current transformers (CTs) and not able to provide some indication that an earth fault is present. Accuracy requirements are here much stringent than for other application and metering. We have found that satisfactory results both if about overcurrent as well as directional earth fault protection can be obtained when use Hall sensors as measuring devices. They can provide wide dynamic range carrying out accurate measurement at light load and operate correctly under heavy fault conditions [1,2]. However, both magnetic core parameters and the Hall sensor have to be properly selected and designed to balance high measurement accuracy against saving in cost and space.

In the paper analysis of performance of Hall sensor based ground fault protections under different load conditions of MV cable feeder has been carried out. On the basis of both calculations and investigated results conclusions about optimal structure and parameters of the magnetic core as well as the Hall sensor selection to achieve satisfactory sensitivity are formulated.

Sensitivity conditions of Hall sensor used for earth fault protections

Required high sensitivity of operation can be achieved, first of all, by use Hall samples of a small size and of as high as possible sensitivity. Small overall dimensions reduce air gap length of a core balance transformer where the Hall sensor is located, what decreases reluctance of a magnetic circuit significantly. While, the core cross section value and magnetizing path length are secondary. However, when consider the increase of the protection sensitivity one has to take into account limitations due to undevoidable noise level produced by magnetic interference of particular phase load currents of the protected cable feeder. For symmetrical 3-phase load the Hall sensor should not produce any output voltage since residual magnetic flux is negligible. However, casual location of particular conductors (phases) of the MV cable in practice regarding the air gap of the CTs with embedded Hall sensor results in considerable residual flux thus, in respective output noise voltage. In the end setting of a protection must be over the noise threshold with respective margin value for safety what can reduce sensitivity significantly. To overcome this problem we recommend application of auxiliary magnetic core served as a shield mounted over the feeder inside the core balance transformer.

Influence of magnetic shield on performance of the protection

The shield was made of a few strips of a cold-rolled magnetic sheet wound directly over a protected 3-phase feeder as illustrated in Fig. 1.

However, the shield reduces from one side residual magnetic flux generated by the phase asymmetry, but from the other affects also effective field value due to zero sequent current what is not considered as a good. Therefore, to answer a question in what way the shield influences both selectivity and sensitivity of the protection at the same time and what structural parameters are responsible for these effects the appropriate computations as well as laboratory investigations for the protection models (as demonstrated in Fig.1) were carried out.

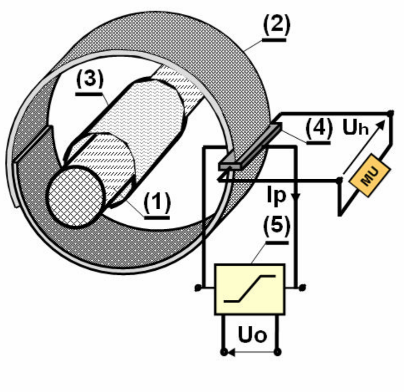


Fig.1. Sketch of a Hall sensor based directional earth fault protection with a magnetic shield applied. 1 – protected 3-phase cable feeder, 2 – magnetic core of CTs, 3 – magnetic shield, 4 – Hall sensor, 5 – signal peak limiter and phase advancer, MV – measuring and processing unit, U_0 – zero sequence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

The shield was made of the cold-rolled magnetic sheet of 0,25 mm^2 in thickness, the same as used for core of CTs, diameter of 3-phase MV cable (with gum isolation) feeder for testing was selected to be 50 mm, while this of magnetic core of CTs was varied from 90 mm and 120 mm respectively at the core cross section equal to 60 mm^2. Experimental investigations were performed for three selected shields denoted as E, F and G type (E – made of 3 strips each of 90 mm in width, F – 3 strips of 30 mm in width, G – 6 strips of 30 mm in width respectively). Error signal value without any shielding aids was found to increase directly proportional to load current and for 300 A reached value (20 mV) equivalent to 1,8 A of the ground fault what can be seen from Fig.2.

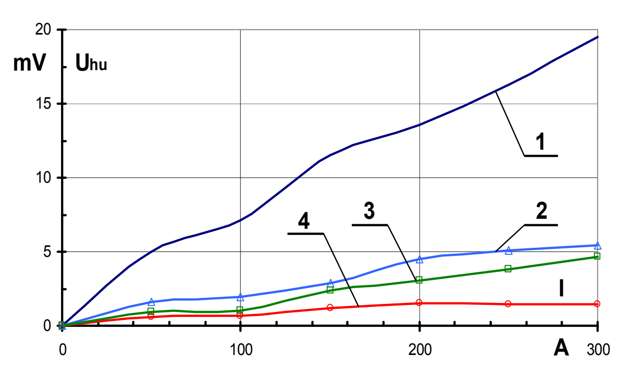


Fig. 2. Error signal U_{hu} at output of the Hall sensor as a function of load current value (symmetrical 3-phase load) for different shields investigated. 1 – without any shield, 2 – with F type shield, 3 – with G type shield, 4 – with E type shield

However, when the protection is equipped with the shield it suppresses noise significantly particularly for the shield strips much wider, with compare to this to core of CTs. For example in a case of the E type shielding the noise level is reduced by about 10 times and is almost independent on the load current value what can be compared from Fig.2 (curve 4).

As a result the protection tripping value can be set to achieve satisfactory sensitivity (much below 1 A of primary earth fault current) and sufficient selectivity. Lack of the shield makes also protection sensitive to location of grounded phase with respect to air gap with embedded Hall sensor what can be deduced from Fig.3.

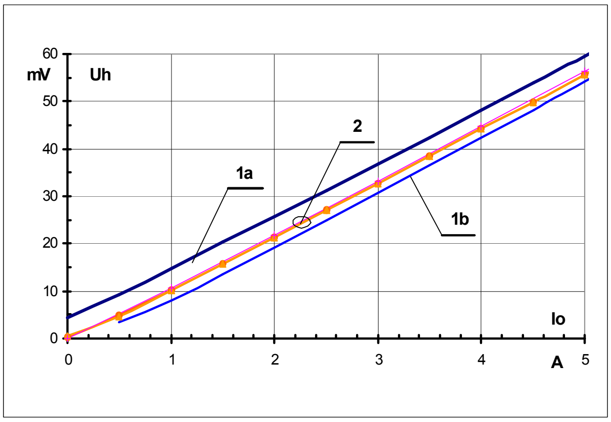


Fig. 3. Variation of the output Hall voltage value U_h with ground current I_0 – with and without the shield E type (3-phase load current equal to 50 A) – for different location of phase (L1), 1a – without shield if shorted phase L1 is located close to air gap with Hall sensor. 1b – without shield if L1 phase is moved away respectively, 2 – with shield for close and far location of L1 as well as without shield for zero load current

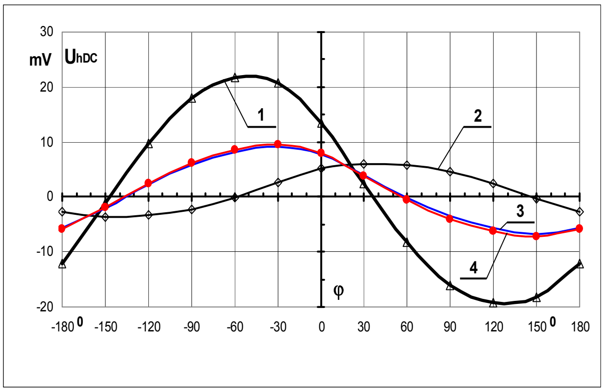


Fig. 4. DC component of the output Hall voltage U_{hdc} versus phase displacement φ between U_0 and I_0 at 300 A 3-phase load current, and primary short circuit current value I_0 = 1 A; 1 – without shielding shorted phase L1 close to air gap, 2 – without shielding, L1far from air gap, 3 – with E type shield, L1 close to air gap, 4 – with E type shield, L1 far from air gap respectively

However, it is overcame with the shielding effect. Application of the magnetic shield improves significantly also performance of the directional ground fault protection since phase error is totally independent on location of the grounded phase inside the CTs core (see Fig.4).

To design the Hall sensor based protection properly simulations using ANSYS package were performed taking as reference previously obtained experimental results.

Picture of a mesh configuration is shown in Fig.5 as an example.

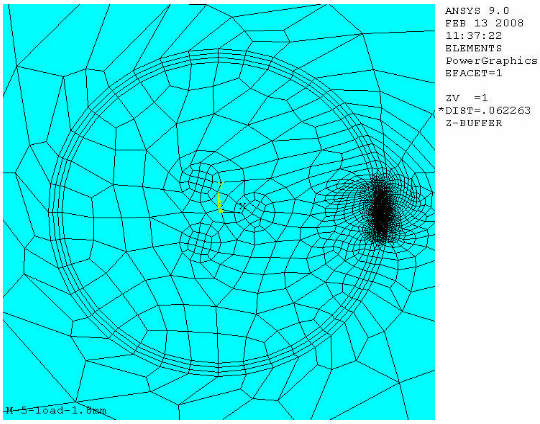


Fig. 5. Example of Mesh configuration under computation of two-dimensional distribution of a magnetic field

Results of simulations and discussion

Under simulations the influence both of CTs core dimensions, air gap length as well as ground fault current value on magnetic field distribution within air gap were considered. Computations have been performed for 2D magnetic field distribution taking into account magnetizing characteristic of CTs core material (see Fig.6) and parameters of physical model of the protection being tested.

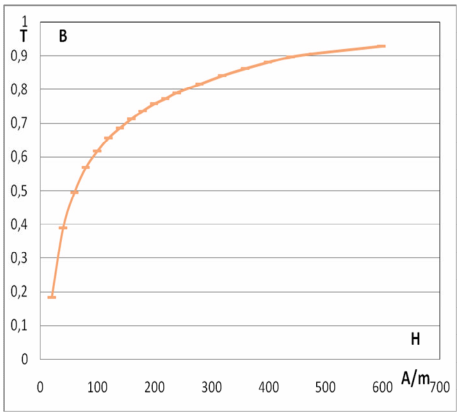
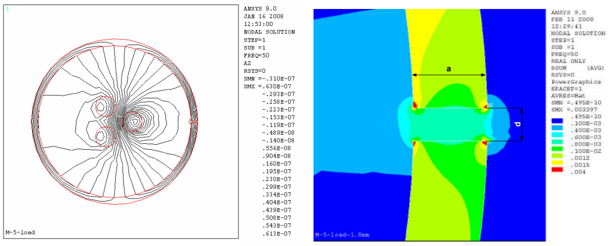


Fig. 6. Magnetization characteristic of the core material applied

Two dimensional distribution of the field for ground fault current value equal to about 50 A RMS (flowing only in grounded phase) is illustrated for example in Fig.7.



a) b)

Fig. 7. 2D distribution of a magnetic field inside the CTs core for 50 A single ground fault current. a) picture of magnetic flux, b) distribution of a magnetic flux density over the air gap (a – width of CTs core, d – length of air gap)

Variation of the flux density inside the air gap (at its geometrical centre) with the earth fault current indicates that over $I_0 \approx 12$ A the B (magnetic flux density) value increases proportionally with the current (see Fig.8). It is due to existence of the air gap and is considered as a good. Therefore, as a result, magnetic properties of the CTs core do not influence the protection performance.

It was also found that, for relatively small air gap length of the CTs core and fixed to be about 1.8 mm, the flux density does not depend on the core width (for constant remaining parameters) as it is visible from Fig.9.

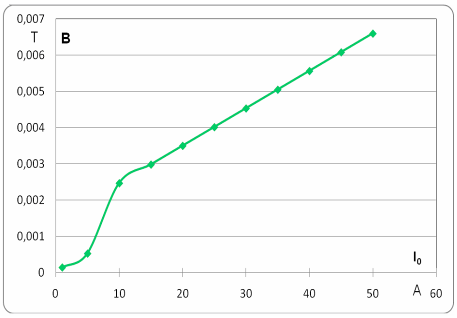


Fig. 8. Magnetic flux density inside the air gap of CTs core versus ground fault current value (RMS)

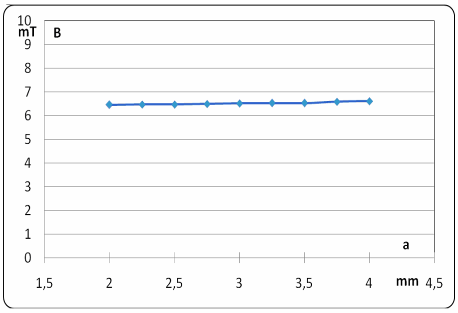


Fig. 9. Variation of magnetic flux density within air gap centre with the CTs core width for fixed gap length (equal to 1.8 mm) and ground fault current equal to I_0 = 50 A RMS

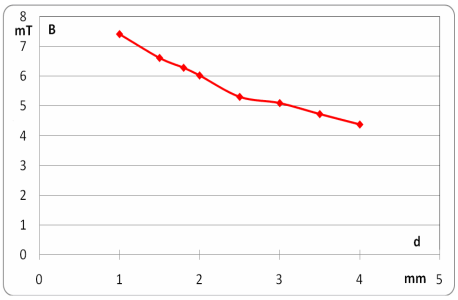


Fig. 10. Influence of the air gap length on magnetic flux density inside the air gap for fixed CTs core width a = 4 mm and earth fault current I_0 = 50 A RMS

On the contrary the field tends to decrease linearly with the gap length value (see Fig.10). Therefore, with point of view of requirements concerning sensitivity of the protection the Hall sensor should not only be highly sensitive but also of as small as possible in thickness.

Results of computations of the influence of a magnetic shield on the protection performance are found to be in a good agreement with these obtained under testing of physical model. The shield seems affect negligible the protection sensitivity what can be deduced from Fig.11. However, it improves its resistance to disturbances significantly.

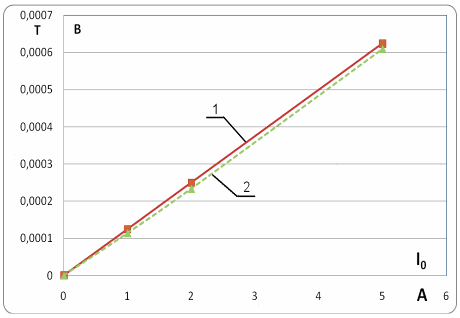


Fig. 11. Dependence of the magnetic flux density B inside the air gap of CTs core versus ground fault current (I_0) without and with magnetic shield employed over protected 3-phase cable feeder. 1 – without shield, 2 – with shield (3-phase load current equal 50 A RMS)

The obtained results of 2D simulations create a base for further three dimensional considerations to compromise sensitivity and selectivity with price and space of the protection in practice.

Conclusions

It was found that 3-phase load current value can significantly influence level of output noise voltage of the Hall sensor under operation. The noise is related also with diameter of the CTs core and location of grounded conductor (phase) with respect to air gap with embedded Hall detector. On the basis of both simulations and experimental results it was found that to obtain the reliable protection one has to employ auxiliary magnetic shield located directly on the protected cable feeder. However, to design properly both over current as well as directional protection the 3D computations are needed in further investigations.

Acknowledgment

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2. **Miedzinski B., Szymanski A., Dzierzanowski W., Wojszczyk B.** Performance of Hall Sensors when used in ground fault protections in MV networks, 39th International Universities Power Engineering Conference, UPEC 2004, Bristol UK. pp. 753-757.

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The influence of magnetic field distribution on performance of a Hall sensor based protection is presented and discussed. Noise level at output of the sensor due to asymmetry of 3-phase load as well as due to various location of the grounded phase with respect to the core CT air gap was inspected. Sensitivity of the directional ground fault protection including current and phase errors variations was considered depending on parameters of a magnetic circuit applied. To meet requirements if about selectivity an auxiliary magnetic shield located inside CT directly on the cable feeder was applied. It was found to improve the protection performance significantly. On the basis of both simulations (2D) and results of experimental investigations the conclusions about designing procedure of the effective ground fault protections as well as about further simulations of three dimensional field to make the optimization perfect and easy to handling are formulated. Il. 11, bibl. 2 (in English; summaries in English, Russian and Lithuanian).

Б. Медзински, В. Дзержановски, М. Хабрух, Х. Ванг, Л. Ху. Анализ распределения магнитного поля в датчике Гола базировал защиту // Электроника и электротехника. – Каунас: Технология, 2008. – № 4(84). – С. 35–38.

Показана влияние распределения магнитного поля на работе датчика Зала, защита представлена и обсуждена. Шумовой уровень в продукции датчика из-за асимметрии груза с 3 фазами так же как из-за различного местоположения основанной фазы относительно основного промежутка воздуха CT был осмотрен. Чувствительность направленной защиты ошибки основания, включая поток и ошибочные изменения фазы считали зависящими параметрами магнитного примененного кругооборота. Отвечать требованиям, если о селективности вспомогательный магнитный щит, расположенный в CT непосредственно на кабельном едоке был применен. Это, как находили, улучшало работу защиты значительно. И на основе (2-ых) моделирований и на основе результатов экспериментальных исследований сформулированы заключения о проектировании процедуры эффективных защит ошибки основания так же как о дальнейших моделированиях трехмерной области, чтобы сделать оптимизацию, прекрасную и легкую к обработке. Ил. 11, библ. 2 (на английском языке; рефераты на английском, русском и литовском яз.).

B. Miedzinski, W. Dzierżanowski, M. Habrych, X. Wang, Lj. Xu. Magnetinio lauko pasiskirstymo įtaka Holo jutiklio efektyvumui analizė // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 4(84). – P. 35–38.

Išnagrinėta magnetinio lauko pasiskirstymo įtaka Holo jutiklio efektyvumui. Triukšmo lygis jutiklio išėjime dėl asimetrinių 3 fazių apkrautumo toks pat kaip ir įžemintos fazės CT šerdyje. Pagrindo klaidos apsaugos jautrumas, apimdamas srovės ir fazės klaidų variacijos išanalizuotos priklausomai nuo magnetinės grandinės parametrų. Tiek modeliavimo tiek eksperimentinių tyrimų atvejais išvados yra naudingos ir tai skatina siekti tolimesnių rezultatų. Il. 11, bibl. 2 (anglų kalba; reziumė anglų kalba, rusų ir lietuvių kalba).