Improving HV Shunt Reactors REF Relaying

F. Uriondo[1], G. Aguirre[1], J.R. Hernández[1] and J.M. García[2]

[1] Department of Electrical Engineering
E.S.I. Bilbao, University of the Basque Country
Alameda Urquijo s/n – 48013 Bilbao (Spain)
Phone/Fax number:+0034 946 012 000, e-mail: **felipe.uriondo@ehu.es**, **gabriel.aguirre@ehu.es, joseramon.hernandez@ehu.es,**

[2] INGETEAM T&D
Pol. Ind. Artunduaga
Usasuaga 7 – 48970 Basauri (Spain)
Phone/Fax number:+0034 946 018 900, e-mail: **juanmari.garcia@ingeteam.com**

Abstract. A new Restricted Earth Fault (REF) relaying unit included in a modern Intelligent Electronic Device (IED) is presented in the paper. The new unit is designed to face the special problems that arise in the protection of shunt reactors. The unit includes a biased differential element, a current polarized directional element, a negative sequence voltage polarized element and an adaptive second harmonic blocking element along with the logic gates, timers and ancillary elements needed.

In the paper, an overall view of the problems involved with the protection of shunt reactors is given. Then, the new unit with all its refinements is presented to end with the checking of the validity of the unit via extensive EMTP simulations that cover the worst operating conditions that the unit has to face.

Key words

Shunt reactance relaying, restricted earth fault relay, ground differential relay, adaptive second harmonic blocking, adaptive biasing signal.

1. Introduction

A. Shunt reactors

Shunt reactors are used to reduce overvoltages in long overhead transmission lines and cables. The reactors are usually connected at both ends of the line since the line can be energized from both ends as shown in figure 1.

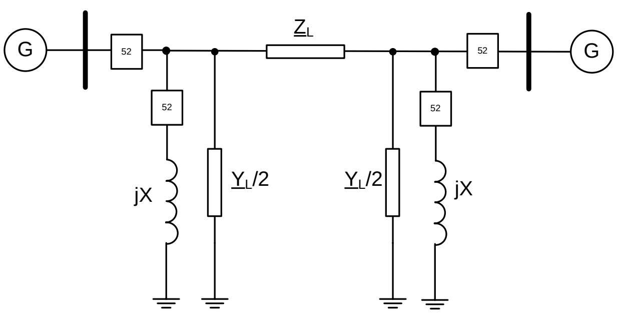

Fig. 1. One-line diagram of the line and shunt reactors.

With regard to their construction, two basic shunt reactor configurations can be found:

- Dry type reactors, connected ungrounded wye to the impedance-grounded tertiary of a power transformer, usually found at medium voltage levels.
- Oil-immersed, wye-connected, with a solidly-grounded or impedance grounded neutral, connected to the transmission line, usually found at HV and EHV levels.

B. The protection of shunt reactors

Major fault protection for dry type reactors [1] can be achieved trough overcurrent, differential, or negative-sequence relaying schemes, or by a combination of these relaying schemes. Protection for low-level turn-to-turn faults can be provided by a voltage-unbalance relay scheme connected at the neutral with compensation for inherent unbalance of system voltages and the tolerances of the reactor.

Major fault protection for oil-immersed reactors [1][4] can be achieved trough overcurrent relaying, differential relaying, or a combination of both. Protection for low-level turn-to-turn faults can be provided by impedance, negative or zero sequence overcurrent, thermal, gas-accumulator, sudden-pressure relays, or by a combination of these relays.

The REF or ground differential is used to give turn-to-ground (turn-to-core or turn-to-tank) protection in the oil-immersed type of shunt reactors. The traditional REF connections are shown in figure 2. The REF unit compares the zero sequence current calculated from the phase currents $3\underline{I}_0=\underline{I}_A+\underline{I}_B+\underline{I}_C$ with the neutral current $\underline{I}_G$ which is, by definition, of zero sequence. If the fault is external the sum of both currents (with the polarities indicated in Figure 2) is zero. When the fault is internal both currents flow from the fault-point to both ends of the reactor and, assuming that the zero sequence impedances of both ends have the same argument, both currents are in phase and their sum is not zero, it is equal to the sum of the modules of both currents. Due to its principle of operation, the REF unit is immune to overexcitation and inrush currents, so the only problem comes from the unequal saturation of the CTs.

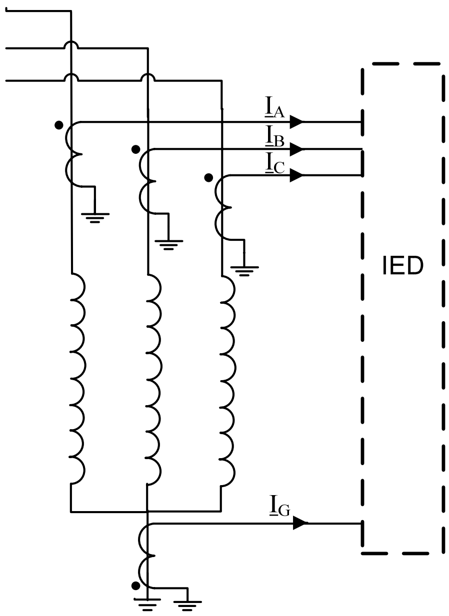

Fig. 2. CT connections of the REF relay.

C. Problems associated to REF relaying

The problems that the REF relay has to face in service can happen in the switching in, in the clearing of faults, in the disconnection of the reactor or when high currents appear in the phase CTs due to internal phase-to-phase faults.

The switching in of a reactor gives rise to inrush current. This current is nearly the same that appears in the connection of a power transformer except for two differences. The first is that the reactor core is gapped so there is no magnetic field remanence in the core. The second is that, due to the low losses in a shunt reactor, the damping of the DC component of the current is very slow. The worst condition appears when the breaker is closed at zero voltage because the flux reaches twice the value of the maximum flux in steady state operation. If the breaker is closed in at the maximum of the voltage no asymmetric current appears, this is the so called synchronized switching. Without saturation, the first peak of the current with full DC offset would be $2\sqrt{2} = 2.82$ times the rated current. The actual current peak might reach a value between 3 and 5.5 times the rated current [2]. The possibility that one or more CTs saturate in this situation is known and, when this happens, a differential current appears that can be seen by the relay as a true internal fault.

The problems during the clearing of faults appear because external faults provoke zero sequence currents that disappear when the fault is cleared. The REF unit must be secure in this situation and must not be affected by the possible inrush current due to the voltage variation or by the disappearance of the currents when the fault is cleared.

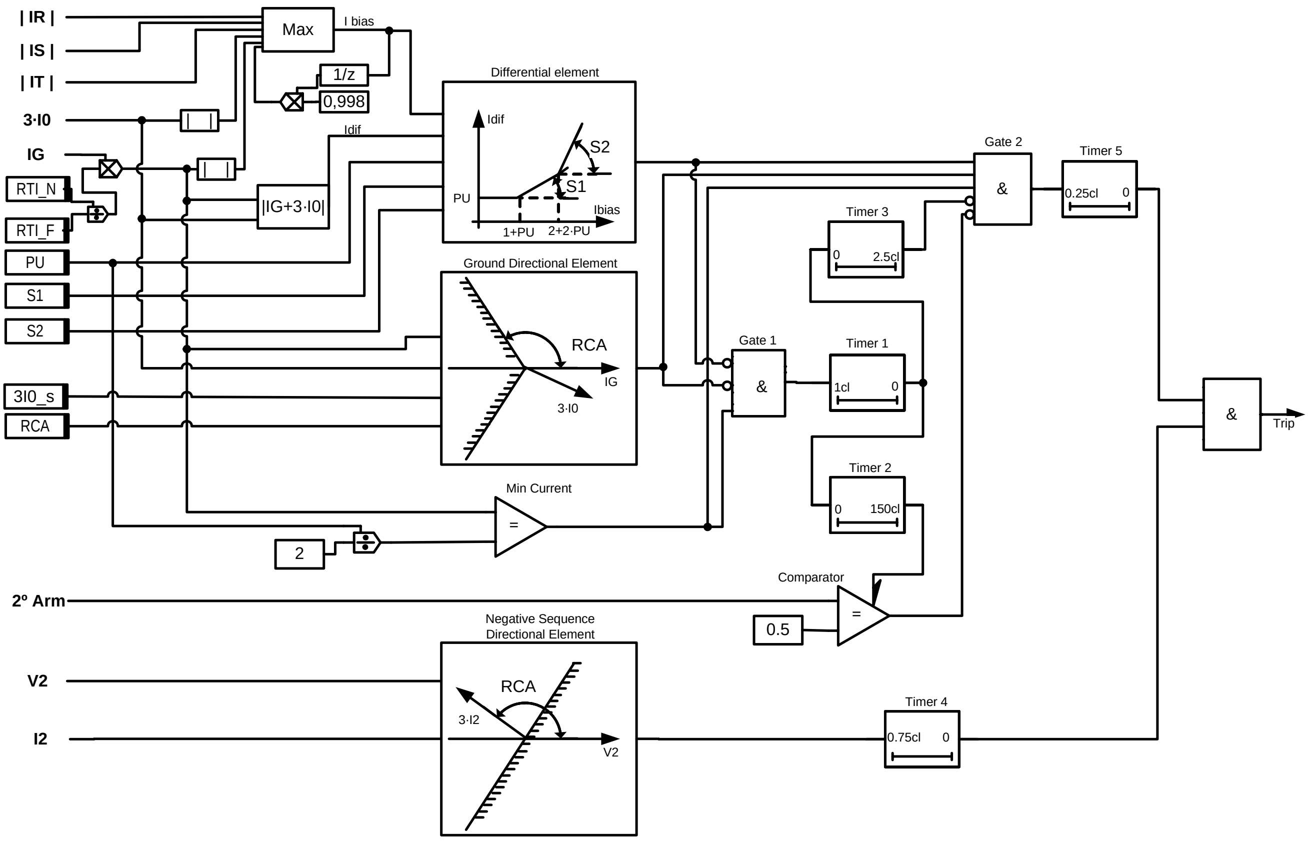

Fig. 3. Overall view of the new Restrited Earth Fault Unit

The problems involved in the disconnection of a purely reactive current are well known, i.e. they provoke switching overvoltages; however, modern surge arresters do solve the problem adequately. From the relay point of view, the only problem is the subsidence secondary current that appears in the CTs that is not a reflection of the primary current since this is zero. This current is not a problem for a REF unit that works with the fundamental components of the currents.

The internal phase-to-phase faults give rise to extremely high currents if the fault is near or in the bushings of the reactor. These high currents can saturate the phase CTs of the affected phases, and a zero-sequence differential current appears that can cause a misoperation of the REF relay. The REF unit must remain stable also in this situation.

2. The new REF unit

The core of the new unit is illustrated in Figure 3. The list of the common elements and the differences between this and pre-existing units [3] will be described in the following subsections.

A. The common elements

The common elements used in other types of REF units and the one presented in this work are the differential element (usually single sloped) and the ground directional element that calculates the angle between the ground current (I_G) and the zero sequence current calculated from the phase currents ($3 \cdot I_0$).

B. The biasing signal

The first main difference can be found in the biasing signal used in the differential element (I_{bias} in the figure). In previous designs [3] the restraining current is selected as the maximum of the phase and neutral currents. In the new design an additional current has been added to the previous currents, i.e. the previous sample restraining current multiplied by a factor of 0.998.

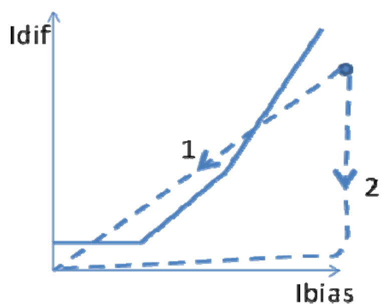

Fig. 4. Trajectories: (1) without and (2) with memory biasing .

This added signal increases the security of the unit in two different situations. The first one is simple to explain: in phase-to-phase internal faults the CTs can saturate and give rise to a differential current with a simultaneous decrease in the measured phase currents. In this situation the use of a memory restraining current keeps the I_{bias} to a high value, preventing the differential unit to trip. The second situation is that of a fault clearance. When a fault is cleared, if no memory is used, the trajectory followed by the currents is the one marked as 1 in figure 4. From the figure we can deduce that, depending on the starting point, the trajectory can cross the tripping zone. If the memory biasing is used, this is not possible since the restraining signal keeps its value, and the trajectory followed is that marked as 2 in figure 4.

C. The inrush detector

As it has been explained in previous paragraphs, one of the main problems of REF relaying is that of the connection of the shunt reactor, due to the long lasting asymmetric currents that can give rise to saturation in the phase CTs. The saturation of the CTs never happens during the first period after the switching in of the reactor. Based on this fact, an adaptive second harmonic blocking has been implemented in the unit. If during one cycle there is current in the neutral (min current high in Figure 3), there is no differential current (differential element low), and if the ground directional element is low (external fault), then a second harmonic blocking element is enabled for 150 cycles (or until the ground current disappears, whatever happens first). This adaptive blocking allows the unit to trip during the first cycle during the switching in when the fault is internal, while it blocks effectively the tripping in the case of saturation of the current transformers since second harmonic is present during the whole process of energization.

D. The change of direction detector

The Timer 3 of the unit is the third new refinement included in the REF relay. It detects changes of direction from external to internal faults. If the fault is external during one cycle, and the direction of the fault changes to internal, it prevents the unit from tripping during 1.5 cycles, that is, until the new values have settled down. With this refinement great security is achieved during the clearance of external faults.

E. The negative sequence directional element

The negative sequence directional element can be enabled or disabled by the user. It increases the overall security of the unit, but delays the trip. The negative sequence directional element is of the “boosted” type since very low negative sequence voltage values can be expected if the fault is near the neutral point of the reactor.

F. The double slope Ibias-Ioperate characteristic

The differential element itself is optimized for the errors of the current transformers as it uses a double sloped Ibias-Ioperate characteristic that provides higher sensitivity at low level currents and greater security for high level fault currents.

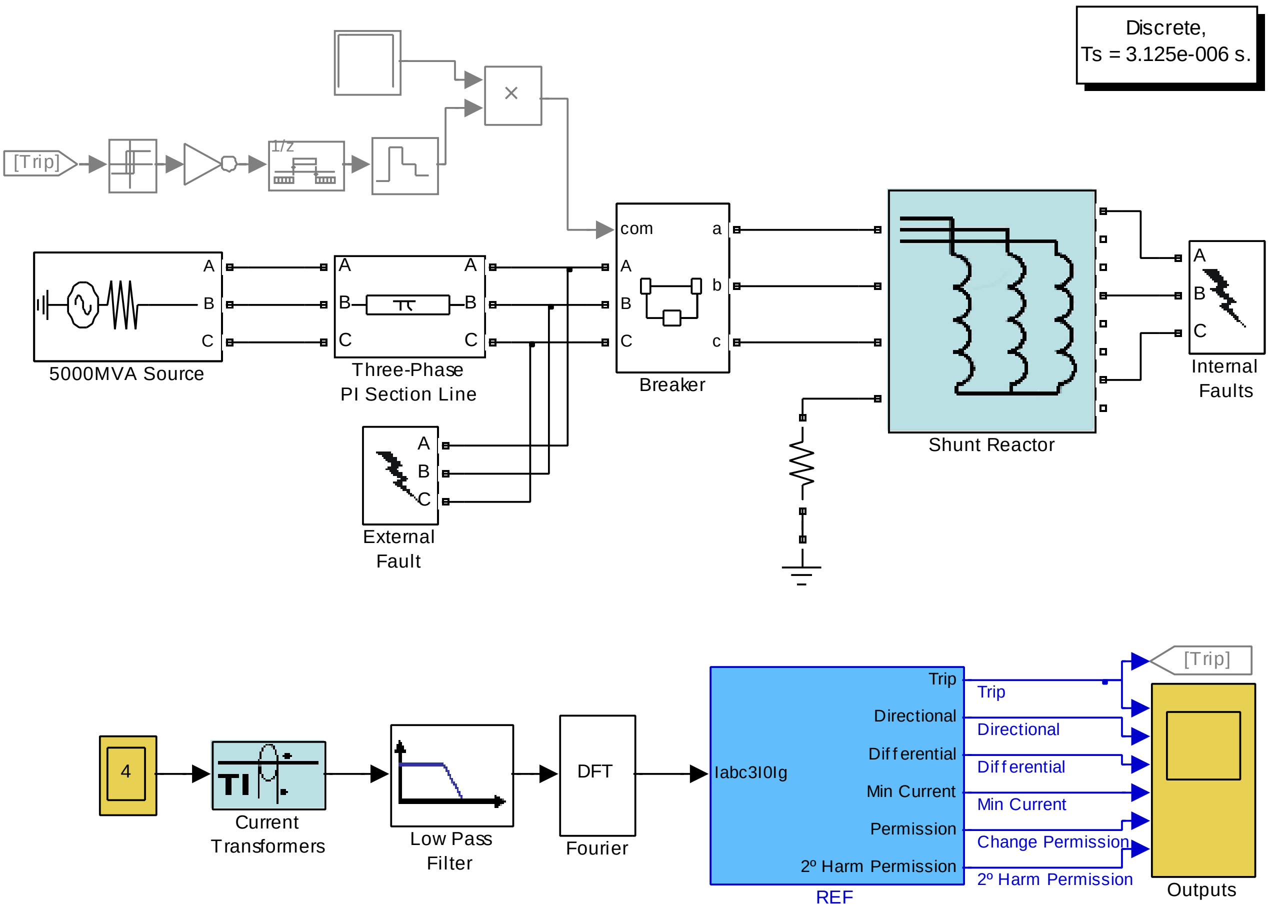

Fig. 5. One of the models used in the simulations

3. Simulations

Extensive simulations have been carried out using different models. The most representative model is shown in figure 5. The system model includes a power source feeding the shunt reactor through a transmission line with a breaker. Two fault simulators are included in the model, one for the simulation of external faults and the other for internal faults at different points of the reactor windings. The protection system model includes the modelling of the current transformers (capital in the study of this problem), the modelling of the antialising filter, the calculation of the current phasors and the REF unit itself presented in figure 3.

The simulations have been done with the purpose of checking the correct answer of the unit in the following situations:

- Stability during the switching in of the reactor.
- Stability of the unit for external faults.
- Stability of the unit for internal phase-to-phase faults.
- Sensitivity of the unit for internal faults in the switching in of the reactor.
- Sensitivity of the unit for internal faults in steady state.

Results of the simulations show that the new unit is secure and copes with all the problems associated to shunt reactors REF relaying.

4. Conclusions

A new REF unit has been presented in the paper. The particular problems that arise when protecting shunt reactors using a REF relay have been explained and a unit specially designed, with augmented security without lack of speed is presented in the paper. The unit includes different refinements that make it unique.

The unit, based on well proven principles, includes improvements to get a new REF relaying unit that can be considered almost a relaying-scheme. The unit is rather complex in design, but simulation results show that the unit is secure or fast in every situation considered.

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