NEW SOLUTION OF FAULT DIRECTIONAL DETECTION FOR MV FAULT PASSAGE INDICATORS

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ABSTRACT

A new solution for the phase and earth fault directional detection used in Fault Passage Indicators (FPI) is presented in this paper.
The solution is based on several low power voltage sensors using capacitor on bushing or on head cable or resistive sensors.
The principle of the phase directional detection remains on the conventional principle of protection relays (ANSI 67). The main algorithm improvement concerns the earth fault directional detection (ANSI67N), well adapted to low cost sensors and without setting depending on distribution network characteristics.

With the proposed earth fault detection algorithm, the direction of the fault, forward or backward, is determined during the first fault transient by analysing the sign of the zero sequence current and the sign of zero sequence voltage.
This method can be used with all neutral earthing systems (solid neutral earthed, impedance earthing, low impedance earthing, compensated neutral earthing, unearthed neutral) without using any parameter depending on the neutral system.
This method is adapted to radial electrical network or closed-loop network, with or without distributed generators along the feeders.

Thanks to high sensibility of the algorithm, the FPI may detect high impedance faults and transient faults, while requiring only low cost voltage sensors.

The proposed solution is now implemented in a new RTU range which has been tested on real MV grids.

INTRODUCTION

Traditional Fault Passage Indicators (FPI) was very basic devices helping the field staff to locate a fault along the feeder after a trip of the Circuit Breaker (CB) thanks to a flashing light.
These type of devices are self-supplied, with an earth-fault over current function and a flashing light located outside the MV/LV substation or on the pole of the MV line.

When a fault occurs, a crew has to be sent into the field in order to identify the location of the fault, helped by checking the position of FPI in different substations.
This is time-consuming and costly, and may lead to long outages.

Utilities today face increasing pressure to improve the reliability and efficiency of the electric grid while simultaneously enhancing power quality. They must also support a higher ratio of distributed energy resources (DER) and non-predictive loads — such as renewable energy sources, distributed storage, and electric vehicle charging stations — connected to medium voltage (MV) or low voltage (LV) distribution levels.
Innovative FPI solutions exist today to solve these challenges. This paper aims to highlight one of a major innovation to better detect all the earth faults which represent more than 80% of the faults occurring on MV feeders.

DISTRIBUTED ENERGY RESSOURCES NEEDS NEW ADVANCED DIRECTIONAL FPI

Directional Fault detection is recommended with DER. Traditional FPI operates an over-current, non-directional detection method, and consequently, don’t work properly due to energy power flow coming from the generators connected along the Medium Voltage network.

In case of a fault which occurs on a feeder with a distribution production of more than 30% forward the fault, all the FPIs will flash, and as a result, the fault is not localized.

Figure 1– example of advanced directional FPI combined with a Switch controller (Easergy SC150 – Schneider Electric)

Directional fault detection is required to have a reliable localization of the fault. For that, 2 instances of directional detection function with opposite direction are used. These instances run simultaneously with different settings.

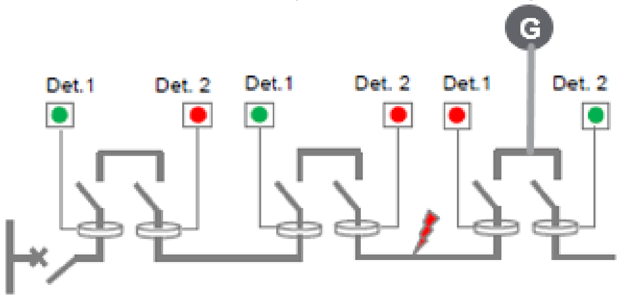

Figure 2 – example of colors used by FPIs indicating the direction of the earth-fault.

WHY FPI AND PROTECTION RELAY DIFFER ?

Nowadays the main functions required for a FPI are:

- ✓ Phase-to-phase over-current (ANSI 50/51)
- ✓ Earth fault over-current (ANSI 50N/51N)
- ✓ Broken conductor detection (ANSI 47)
- ✓ Directional phase over-current (ANSI 67)
- ✓ Directional earth over-current (ANSI 67N)
- ✓ 2 settings groups and traditional curves: Definite Time (DT), Inverse Definite Minimum Time (IDMT) with IEC & IEEE curves detection to be selective with reclosers and CB feeders protections
- ✓ Flashing light outside
- ✓ Inrush blocking based on the 2nd harmonic ratio in phase currents
- ✓ Under/over Voltage (ANSI 27/ ANSI 59) and voltage presence indicator
- ✓ Under current (ANSI 37)
- ✓ Self-powered FPI or FPI with battery system

New FPI solution uses the same approach than protection relays in terms of protection functions and protection curves in order to facilitate the coordination between relay and FPIs.

The main difference between FPI and a protection relay consists of 2 points.

1- the hardware technology of FPI is less costly than a protection relay due to the fact that it doesn't need to operate a CB with a fast tripping by a coil or an actuator. FPI are connected to optimized current sensors with restrain measurement dynamic, unlike protection relays which required to be connected to Class P CTs with a high precision of the short circuit current.

2- FPI configuration is a dedicated one, simpler and easier to set than a protection relay which requires to know perfectly the protection plan of the networks and to be flexible to multiple applications (feeder, incoming, transfo, bus bar…). The FPI indicates all the faults (backward and forward) unlike the protection relay which must select and trip the CB only on forward faults.

CHARACTERISTICS OF THE NEW EARTH FAULT DIRECTIONAL DETECTION

New drivers in the context of Smart grid networks

The drivers to enhance FPI's algorithm are multiples:

- ✓ The MV electrical networks may be often reconfigured and neutral earthing system may change during the time life on each feeder. So FPIs must be automatically self-adapted to this change in real time without any setting change.
- ✓ The FPI must be robust to allow them to adapt to the different voltage sensors like LPVT (Low Power Voltage Transformer), PPACS (Plug on Voltage test point of connector), VDS (Voltage detection system - IEC 61243-5) whatever the accuracy.
- ✓ When an earth fault occurs, parasitical capacitances of cables and lines are charging and discharging, due to the modification of the voltage level on healthy and faulty phases. Some FPIs detects the faults current (red arrow for the FPI n° 1 in the Figure 3) and the capacitive current of the cables (blue/grey for the FPIs 1, 2 and 3 in the Figure 3). An FPI, able to operate whatever the neutral earthing system and without any setting modification, must not take into account the faults currents which are too dependent on the earthing system and which are seen only in some locations.

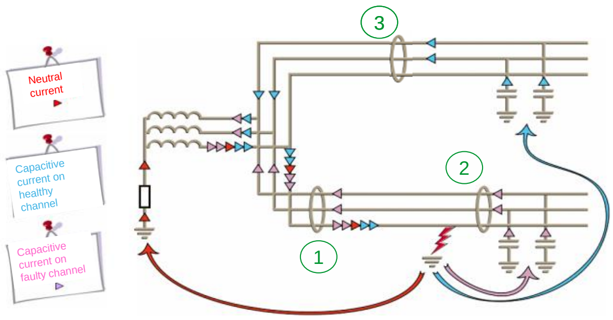

Figure 3 – circulation of fault current, and capacitive currents when a fault appears [2].

- ✓ The FPI needs to localize the faults with increasing DER along the MV feeders. For that reason, the directional phase (ANSI 67) is required and in some cases of distributed neutral earthing systems the directional earth-fault (ANSI 67N) is also recommended.

Innovative algorithm to detect directional earth-fault

Traditional way for protection relays to operate the ANSI 67N function is to use the DFTs (Discrete Fourier Transform) of the residual current and residual voltage. The two DFTs, computed at the fundamental frequency of the network, and a characteristic angle, adapted to the neutral earthing system allow to detect the fault and his direction.

This technique requires either adapting the characteristic angle to the neutral point, or implementing as many instances as there are neutral earthing system (compensated and/or isolated, as in Italy).

The new algorithm [1] keeps the main protection relay principle, while answering the new challenges listed above (Figure 4):

- It uses the DFTs (Discrete Fourier Transform) of the residual current and of the residual voltage.
- the active current is calculated according to the formula:

$$Iactif = \frac{\mathrm{Real}\left(\overrightarrow{IR} \times \overrightarrow{VR}^{*}\right)}{\|\overrightarrow{VR}\|}$$

Where $\overrightarrow{VR}$ and $\overrightarrow{IR}$ represent the residual voltage and current phasors, $\|\overrightarrow{VR}\|$ the module of the residual voltage phasor.

- It determines the direction of the fault in the transient phase, using the projection of the phasor of the residual current on the phasor of the residual voltage, by integrating the real part of the projection during the transient phase. It means that the direction will be set as forward or backward if the residuals current and voltage during the first transient period are in phase or in opposite phase. (Figure 4)

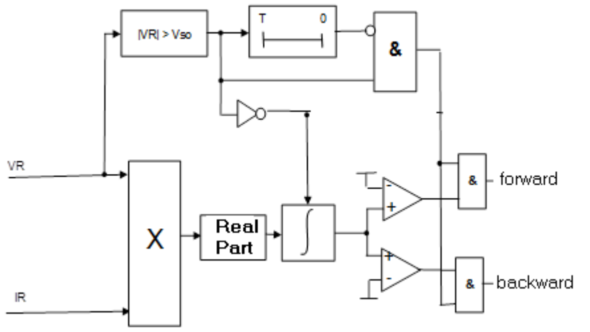

Figure 4 - Signal processing of the directional earth-fault detection

Auto-adaptive FPI

The major interest in determining the direction of the fault in the transient phase is that there is no need to adjust the characteristic angle of the projection according to the neutral point of the electrical network.

During the transient phase of the fault, the residual current is mainly provided by the capacitive currents (charge and discharge of the cables) and acts as an isolated neutral network. Using only the transient phase allows to FPIs to be insensitive to the neutral earthing systems (Figure 5).

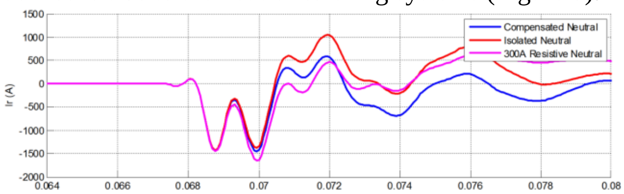

Figure 5 – residual current (Ir) after a fault occurence at 0,067s with different earthing systems.

Reliable and optimized FPI

Integrating the real part of the current projection allows to cumulate all the transient phenomena and to have a reliable detection while using non-accurate sensors.

Furthermore, this algorithm allows to reduce the computing time and then to adapt FPI with CPU based on low power consumption.

The figure 6 illustrates the interest of using the integrating real part of the current.

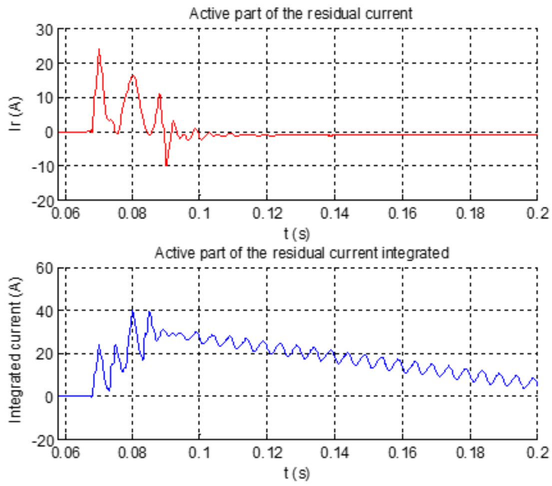

Figure 6 - real part of the residual current and real part of the residual current integrated in case of forward earth fault.

Compliance with international standards

This solution has been tested with simulation of more than 2000 scenarios covering the main characteristics of word wide networks with or without DER on each neutral earthing systems.

It has been successfully implemented on FPI and RTU like those in Figure 7 and is compliance to function ANSI 67N and to the French ERDF HN45-S-51 specifications.

Figure 7 – Easergy T300 Schneider-electric RTU using the new solution of FPI.

BENEFITS OF LOW POWER VOLTAGE SENSORS

Low power voltage transformers (LPVT) for voltage metering offer new convenient (low cost, weight, footprint, and easy to install on retrofit installation) ways to measure voltage and to calculate all associated data needed for advanced automation, such as active and reactive power, power factors, and energy and fault direction.

Figure 8 – LPVT sensors on RM6 Schneider-electric

To combine directional fault detection and Power measurement, one of the best solution is to install LPVTs resistive sensors on the cable bushing (Figure 8).

However, when power measurement isn't required, a FPI may be installed with low accurate capacitor sensors like PPACS (Figure 9) or VDS systems (voltage indicator with voltage output according to IEC 61243-5).

Figure 9 – PPACS voltage sensor on MV cable connector

Implantation of Sample value function (IEC 61850-9-2) in FPI devices help to distribute the voltage value to each feeder in the substation and to reduce the cost of voltage sensors implementation.

CONCLUSION

Due to evolutions of the MV distribution networks (closed loops, modification of the neutral earthing systems, DER), a reliable and cost effective earth-faults detection becomes a major issue for electrical Utilities. The solution proposed in this paper describes innovative solution to better detect earth-faults.

The trend is nowadays to install sophisticate connected products which associate FPI with other feeder automation functions.

Smart controllers can maximize the benefits of smart assets by hosting some local automation and by communicating with control centers or with other substations, using standard protocols, to detect the fault and to reconfigure the distribution network automatically after a fault. This also includes the capability to accurately monitor the quality of delivered energy.

Thanks to LPVT sensors, advanced FPI may provide Power measurement (according to IEC 61557-12) and Power quality (according to IEC 61000-4-30) supporting the Volt-VAR optimisation (VVO).

VVO consists of adjusting the voltage setting of Volt-VAR devices to meet certain objectives and criteria, such as to maintain voltage limits as contractually agreed upon with customers, to reduce system losses, to optimize demand reduction, or to achieve peak shaving.

These advanced FPIs are contributing also to asset management. The local fault recordings are computed by advanced FPI to enable utilities, not only reducing the number of costly field maintenance visits, but also more proactively keeping the equipment operating efficiently.

REFERENCES

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