Evolution of the Fault Locator on MV distribution networks: from simple stand alone device, to a sophisticated strategic component of the SMART GRID control system

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ABSTRACT

The paper describes the evolution of Fault Locator during the time, their performances and their limits and the reasons that lead to this evolution.
Describes the various versions that have taken place focusing on the latest generation of fault locator and the reasons that led to its definition.

INTRODUCTION

ENEL started using Fault Passage Indicators (FPIs) on MV networks in the '90s, when in North East part of Italy important requests of higher quality of supply came from medium-small industries in the area, as a consequence of the introduction of high technology and computer controlled apparatus and machines.
Over the years, with the increasing demands for improvement of quality of service, the FPI has evolved becoming increasingly sophisticated. Below are brief descriptions of the FPIs first, second and third generations, concluding with a more detailed discussion of the fourth generation currently being tested.

EVOLUTION OF FAULT PASSAGE INIDICATOR

<u>The First generation</u>

First FPIs where battery supplied, have to be installed on poles and were sensitive to the magnetic field; as a consequence, FPI had the capacity to detect high overcurrents (poliphase faults) and medium-low value residual current (higher than 20 A in first versions, 10 A in the more recent ones). No directional detection was possible, due to the absence of voltage signals. Discrimination between fault upstream and downstream the FPI installation point was possible due to the features of the network, i.e. the contribution to fault currents, both polyphase and single phase, has to be (and, at the time, it really was) much higher from the upstream network with respect to the one from downstream part.
Furthermore, no remote communication was present to download FPI information, only local connection was available.
In case of a permanent fault, it was possible to individuate the faulty section "following" the fault "path" along the feeder, using local signals from FPI (for instance proper lamps); to increase efficiency of preventive maintenance, instead, expecially concerning non permanent fault (giving transient interruptions) it was possible to collect information from many FPIs in a proper period and, manually, to analyze transient fault distribution on the different feeder sections, and, consequently, possible weak insulation points before a permanent fault occurs.
Evolutions of these FPI are still used from ENEL DISTRIBUZIONE, in some circumstances, but in the portable version.
Pole installed versions had been evolved too, being equipped with transmission systems of the detected events and with electric field sensor (necessary to detect voltage presence, therefore able to discriminate between self-extinguish faults and faults cleared through a CB intervention).

Figure 1: Example of first generation FPIs (modern versions, portable or pole installed, with distance data transmission)

<u>The Second generation</u>

The first generation devices worked quite well until the massive introduction of Petersen coils on ENEL DISTRIBUZIONE MV network [1]. Due to the drastic reduction of residual currents (maximum 50 A at 20 kV with 0 Ω fault resistance), it was necessary to introduce directional detection of phase to earth faults.
In addition, a survey performed on tripping residual voltage and current values recorded from MV protection devices in presence of a phase to earth fault showed that the minimum sensitivity threshold of the FPIs was too low even with insulated neutral, so that an important percentage of phase to earth faults were not detected with possible evolution in a permanent fault [2], [3].
Finally, it was decided to have the remote download of the recorded information and to use local signals from FPI for local tripping operations of motor operated switch disconnectors.
Due to this, a new version of FPI was developed, with directional detection of phase to earth faults, integrated in the SCADA system and in the MV network remote control and automation system, obviously with voltage inputs using signals coming from capacitive dividers

installed on MV switchboards, previously used for voltage presence lamps.

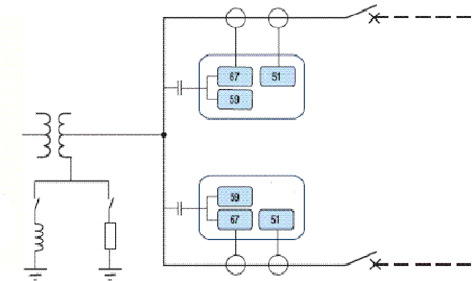

Figure 2: Example of installation with Petersen Coil

Concerning phase to earth faults, detection principles and sensitivity was exactly the same of MV feeder protection panels in HV/MV substation (faults in the range 6,5 kΩ ÷ 4 kΩ can be detected with compensated neutral, this confirmed both in laboratories and with real field tests).
About 100.000 of these devices are installed at the moment, with excellent results. In, fact, this FPI is the strategic component of MV automation system [4], [5], active on almost all the MV distribution network of ENEL DISTRIBUZIONE.

Figure 3: Example of second generation of FL

The third generation

As no installation was possible on overhead networks, a third generation of FPIFPI was developed, with innovative integrated voltage and current sensors.

Figure 4: Detail of the voltage current sensor

Global performances are the same as the cable version, with a sensitivity up to 6,5 kΩ concerning phase to earth faults on compensated networks [6].
In addition to laboratory tests, real field tests were performed in 2008 on the global MV network automation system, including cable and overhead FPIs, both with compensated and insulated neutral, at the presence of many distribution Companies.
At present moment some thousands of these FPI are installed and in operation both in Italy and in Rumenia, on ENEL distribution networks, on MV/LV substations connected directly to overhead feeders or on pole installed switch disconnectors.

Figure 5: Example of third generation of FPI

Figure 5: installation of an outdoor FPI on a substation

Figure 6: installation of an outdoor FPI on a pole installed switch disconnector

The fourth generation

Starting from these new sensors, a fourth generation of FPI was defined, able for switchboard installation, and with a huge performance improvement.
In fact, this new device will be a strategic component of the SMART GRID control system defined by ENEL.
The new device, named RGDM (directional fault detection and measurement) is a advanced device with the following functions:

- Protection functionality;
- Automation functionality;
- Measurement and monitoring functionality;
- Distributed generation management functionality.

The device consists in a central processing unit and three electronic integrated phase voltage and current sensors.. The estimation of the zero-sequence is obtained vector sum by insertion Holmgreen of the three current and voltage sensors.
Voltage signals are obtained, on existing prototypes, through a capacitive divider, while current is derived by means of a Rogowsky coil.

Figure 7: two different prototypes of integrated voltage and current sensors

Sensors are, at least, in 0,2 accuracy class, but, through the signal conditioning performed from the electronic card, the effective overall accuracy is much higher, allowing negligible phase and module error on residual current and voltage, compatible with the very low threshold settings required from ENEL protection system (2%÷6% residual voltage setting, 1,5 A÷ 2 A residual current setting, ~ 10° maximum overall phase error, sensors and electronics, for 67N function from 1 A to 500 A phase current).
RGDM will be equipped with a optical communication port with protocol IEC 61850.

Fault detection (protection) functionality

- Directional overcurrent;
- Directional phase to earth fault;
- Cross country fault detection;
- Re-striking faults detection;
- Directional maximum active power;
- Second harmonic retention for inrush currents.

Automation functionality

- Logic selectivity (locking signal transmission and reception) for single and multi-phase faults.

Measurement and monitoring functionality

- Measurement of electrical values V, I, P, Q, power factor;
- Monitoring of the voltage harmonics in the node.

Distributed generation management functionality

- Voltage value control along the MV line by controlling static converters (for instance PV inverters);;
- Control and remote-trip of interface protection;
- Power balance in the generation node.

The integrated sensors will be directly factory installed in the switchboard housing new vacuum CBs (DY 800), which, in ENEL DISTRIBUZIONE plans, will be widely adopted at replacement of actual switch disconnectors.

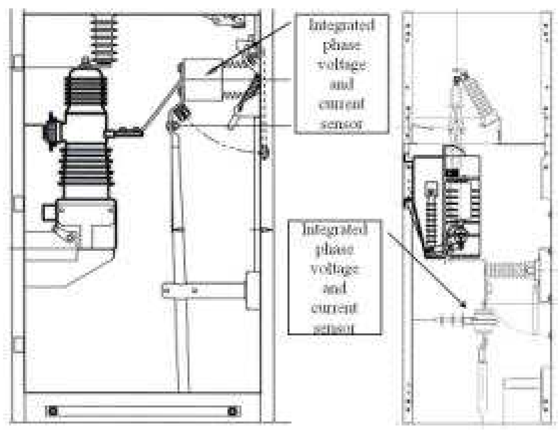

Figure 8: installation of an outdoor FPI on a pole installed switch disconnector

These CB will be installed, not only for MV network automation, but also for connection of MV Customers, both traditional (passive loads), and with internal generation (GD).

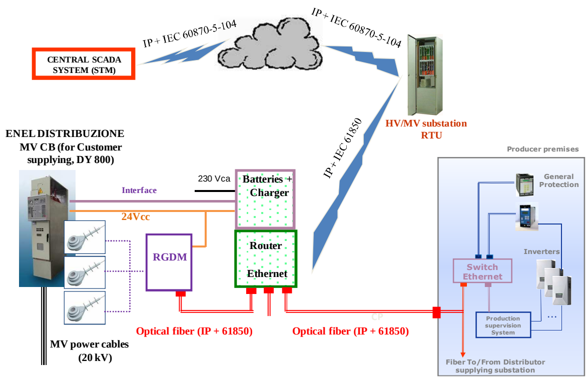

Figure 8: typical future solution for the connection of a PV plant to ENEL DISTRIBUZIONE MV network with DY 800 and RGDM

BENEFITS AND POSSIBLE DEVELOPMENTS

With the new defined solutions many benefits are available:

- the installation of combined sensors directly in the CB switchboard will allow a high accuracy of RGDM, avoiding possible problems due to a non correct installation in field;
- RGDM will be tested in factory, with possible calibration/compensation of the sensors performed from electronic card: this will eliminate, both errors consequent to adjacent phases or adjacent MV cables which can affect ROGOWSKY coils (dependent from switchboard design and realization), and/or errors of voltage sensors. This is possible thanks to the possibility to have, in factory, reference voltages and currents (in module and phase), hardly available in field;
- global cost of the CB equipped with RGDM will be lower with respect to traditional installation (FPI installed in the switchboard and only partially tested in field);
- in case of pure passive customers, it will be possible to extend the logic selectivity also to the internal plant, thanks to the customer switch connected to the MV/LV substation router through the optical fiber;
- in case of PV inverters it will be possible to control easily active and reactive power production. Settings will be transmitted to an Ethernet port on the inverters, in IEC 61850;
- in case of traditional generators a proper interface will be realized, able to communicate with voltage and frequency regulators;
- the measurements of all the electric parameters mandatory and necessary for the correct management of the distributed generation will be available, in particular active and reactive power generated/absorbed, with excellent accuracy;
- also the possibility to transmit a selective tripping signal, both to generators and to loads, will be available, therefore improving network safety and stability.

Concerning the future developments we point out that, recently, IEC TC 38 decided to create WG 46: " Current and Voltage sensors or detectors to be used for fault passage indication purposes". It's expected to have a first draft to start discussions in the second half of 2011.

Finally, it's easy to imagine an evolution of the FPI in a protection device.
This would be possible both developing the concept of an "integrated device" (a sort of "black box" assuring the whole system performances with adequate accuracy and reliability, without referring to single components, each one with its specific standards), and, with a more traditional approach, eliminating traditional CTs and VTs (and their switchboards), installing integrated phase voltage-current sensors on each CB switchboard and using protections panels able to use directly low level signals. In both cases an appreciable cost reduction would be obtained, in addition to a reduction of space.

REFERENCES

For a Conference citation:

[1] A. Cerretti, G. Di Lembo, G. Valtorta, CIRED 2005, Turin, June, 6-9, 2005, "Improvement in the continuity of supply due to a large introduction of Petersen coils in HV/MV substations",

[2] V. Biscaglia, D. Cappellieri, G. Gambelli, G. Guizzo, F. Panin, G. Rocchi, Proceedings of the Meeting "La qualita' del prodotto elettricita'. Interfacciamento Distributore-Utente", Verona, November 25-26, 1993 "Campagne di misura sulla rete elettrica: metodologia e risultati"

[3] A. Cerretti, G. Valtorta: "Rilevatore di guasto direzionale per l'automazione della rete di media tensione ", L'Energia Elettrica, Volume 78 (2001)

[4] A. Cerretti, G. Di Lembo, G. Di Primio, A. Gallerani, G. Valtorta, CIRED 2003, Barcellona, May, 12-15, 2003, "Automatic fault clearing on MV networks with neutral point connected to ground through impedance";

[5] A. Bargigia, A. Cerretti, G. Di Lembo, S. Rogai, G. Veglio, CIRED 2003, Barcellona, May, 12-15, 2003, "Telecontrol and automation on Enel Distribuzione's network: strategy and results";

[6] A. Cerretti, R. Calone, G. Di Lembo, L. Giansante, CIRED 2009, Praga, June, 8-11, 2009: "An innovative integrated current/voltage sensor for outdoor fault detectors"