AUTO-ADAPTIVE FAULT PASSAGE INDICATOR WITH REMOTE COMMUNICATION IMPROVES NETWORK AVAILABILITY

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ABSTRACT

Utilities are presently strongly interested in the reduction of SAIDI and SAIFI indicators, under the pressure of regulation authorities. Moreover, in the SmartGrid context, high observability and high commandability are targeted by using more intelligent electronic devices and more communication media. This paper focuses on how installation of such IEDs as Fault Passage Indicator can be made easier and faster by avoiding configuration settings of these devices thanks to new principles making the equipment auto-adaptive to network parameters.

INTRODUCTION

Since few years, regulation authorities challenge utilities to increase network availability, estimated thanks to performance indices based on two main components which are outage duration and outage frequency. SAIDI and SAIFI are the main Key Performance Indices defined by IEEE 1366. The new paradigm of SmartGrid, where a communication architecture will be deployed, managing smart meters and Decentralized Generation (DG), with additional and enhanced sensors and actuators, allows to expect a better observability and a higher controllability of the grid. This is mainly due to the fact that more IEDs (Intelligent Electronic Devices) such as RTUs (Remote Terminal Units) and FPIs (Fault Passage Indicators) would communicate with DMS (Distribution Management System) to achieve smart feeder automation. Anyway, to work properly, these devices must be correctly set depending network parameters, such as neutral grounding system, type of cables or lines, etc. Consequently this task is not easy and requires calculations and network expertise before installation, especially for fault management. Moreover, as network is living with fluctuant load and intermittent DGs, initial settings could be inappropriate in some cases or at some periods of time.

Neutral situation	Isolated	Tuned (Petersen)	Impedant	Directly earthed
Earth fault current	Linked to stray capacitance: 2 to 200 A	Almost zero, dep. on tuning and quality factor (< 40 A)	Dep. on impedance: 100 to 2000 A	High: 2 to 25 kA, varies with the location
Damage	Low	Almost zero	Dep. on impedance	High
Voltage disturbance	None	None	Low	Significant
Restrictions	Possible overvoltages	Thermal on the coil	Thermal on the impedance	Thermal and electrodynamic
Protection against earth faults	Difficult	Complex	Easy (time discrimination)	"3-wire": easy (current discrimination)

Tab.1 fault management vs neutral grounding system

Neutral grounding system

The faults which occur on the MV network are mainly due to damaged cables or failures of MV equipment which lead to a short-circuit between the earth and one of the phases. Statistically, 70% of the faults are earth faults of which detection is very dependent on the neutral grounding system as seen in Tab 1.

Capacitive current effects

In distribution networks, when an earth fault occurs, parasitical capacitances of cables and lines produce current feedbacks as depicted below:

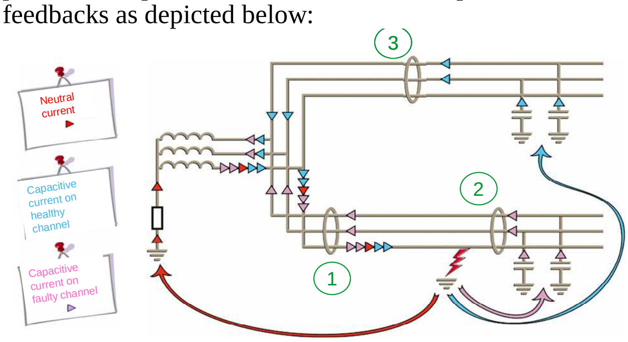

Fig.1 capacitive current effects

As illustrated, ammetric device n°1 will properly detect fault, but if capacitive currents are higher than threshold settings of devices n°2&3, those devices will wrongly indicate a fault, even on a healthy channel. Moreover, threshold has to be adapted regarding chosen neutral grounding system (see Tab1). To avoid this, directional fault detection is based on measurement of amplitudes and phases of transient currents and voltages during the fault.

INSENSITIVE TO CAPACITIVE CURRENT FAULT DETECTION

Regarding previous comments, if ammetric detection is easily achievable with only current sensors, it appears inefficient in some cases such as compensated or isolated neutral grounding networks. In these cases, directional detection is necessary, but this requires voltage sensors. In a distribution network, traditional VTs are avoided because the installation is difficult and they need to be disconnected for the maintenance operations. Voltage sensors may be embedded on the bushings but they have a limited accuracy and they needs to be calibrate. Consequently, Schneider Electric developed a new earth fault detection principle to

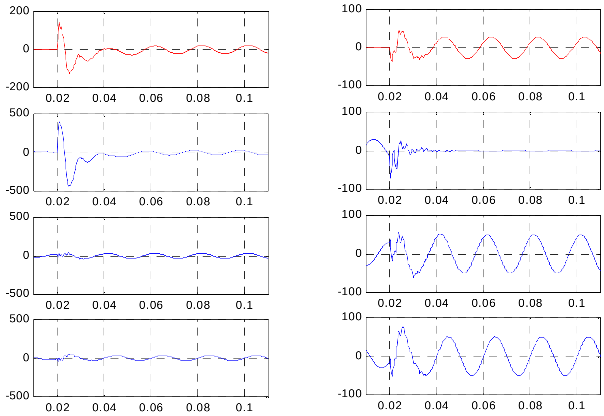

Fig.2 currents Io (in red), Ia, Ib, Ic (in blue) for a downstream earth fault and an upstream one.

avoid capacitive current effects, which does not require any voltage sensors. This algorithm called Insensitive to Capacitive Current (ICC) is explained hereafter.

Downstream phase to earth fault

In this case (Fig.2a), corresponding to device n°1 of Fig.1, during first period after fault, transient homopolar current Io is important and strongly similar in waveform to faulty phase current Ia. In opposite, healthy phase currents Ib&Ic remain more or less the same than before fault (except during transient where capacitive currents flow back): there is no common point between Io and Ib or Ic, and healthy phase currents are lower than faulty phase one, in RMS.

Upstream phase to earth fault

In this case (Fig.2b), corresponding to device n°2 of Fig.1, during first period after fault, transient homopolar current Io is only due to capacitive currents, which flow also through healthy phases b&c; in opposite, faulty phase current Ia is quasi zero as there is a short-circuit to earth upstream. Consequently, in this case, Io will be similar to Ib and Ic in waveform during first period after fault, and there will be no similitude between Io and faulty phase current Ia. Moreover, healthy phase currents appear higher than faulty phase current in RMS.

ICC algorithm

To summarize, if fault is downstream, Io is very similar to one phase current; if fault is upstream, Io is similar to two phase currents. This notion of similitude is transcribed in software thanks to correlation factors calculation. By using statistical tools, it is possible to evaluate mean μ and standard deviation σ of correlation factors: position of point (μ,σ) in the following picture gives the position (downstream or upstream) of the fault.

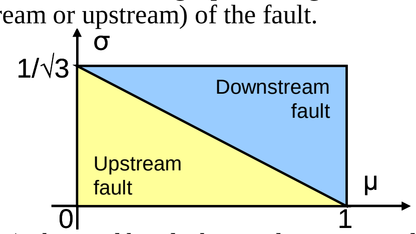

Fig.3 (μ,σ) plan and borderline to discriminate downstream and upstream earth fault.

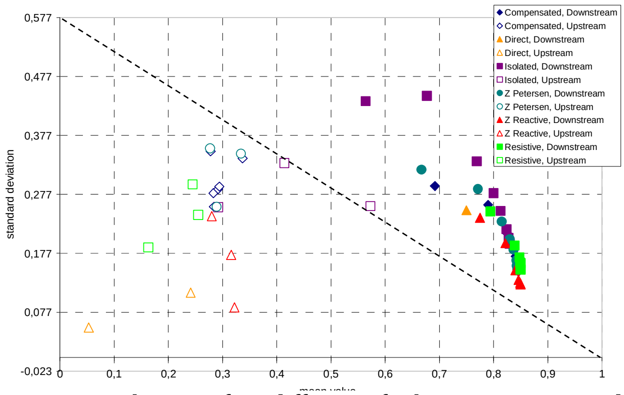

Fig.4 Simulations for different fault resistances and different neutral grounding systems.

Results

Principle was firstly tested in simulations (more than 2000) with different fault resistances, and for different neutral grounding systems, with good results, as depicted in Fig4. In some cases to the limits (such as for isolated neutral grounding system, or if point is too close to the border), this information is also completed by comparing RMS values of three phase currents during first period after fault: for downstream fault, one current is higher than two others, for upstream fault, one current is lower than two others.

FPI Flair200C

By combining these two methods (correlation factor and RMS values comparison), a robust and reliable FPI algorithm has been developed and implemented in a Flair200C, which is a MV substation remote monitoring unit. Field tests have been carried out in various European countries with successful results. The original principles have been patented [1]. Main advantage of this new FPI is that its principle is insensitive to capacitive currents, allowing to achieve same functionality than traditional directional detection without voltage sensors, with easy settings at installation on site.

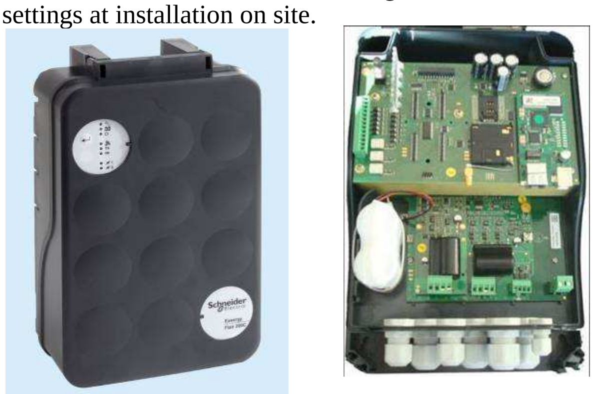

Fig.5 Easergy Flair 200C, MV substation remote monitoring control unit.

AUTO ADAPTIVE FPI

After these first promising results, Schneider Electric decided to go further in this way, attempting to use only current signals characteristics to manage all kind of faults, without referring to threshold for earth or phase faults.

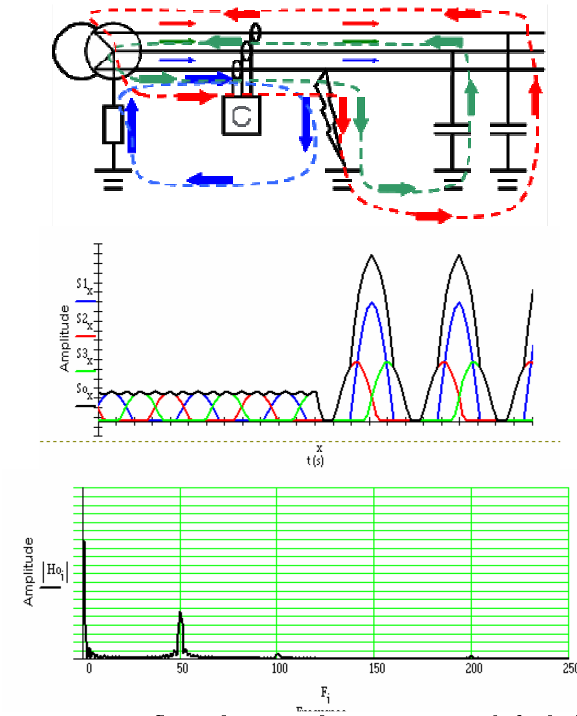

Fig.6 Current flows during a downstream earth fault, half rectified phase and zero sequence currents, and zero sequence current spectrum after fault.

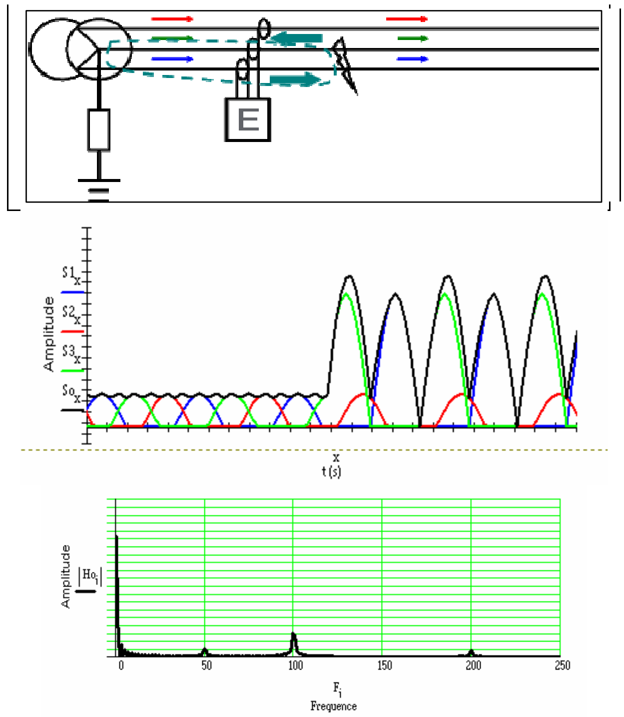

Fig.7 Current flows during a downstream biphasic isolated fault, half rectified phase and zero sequence currents, and zero sequence current spectrum after fault.

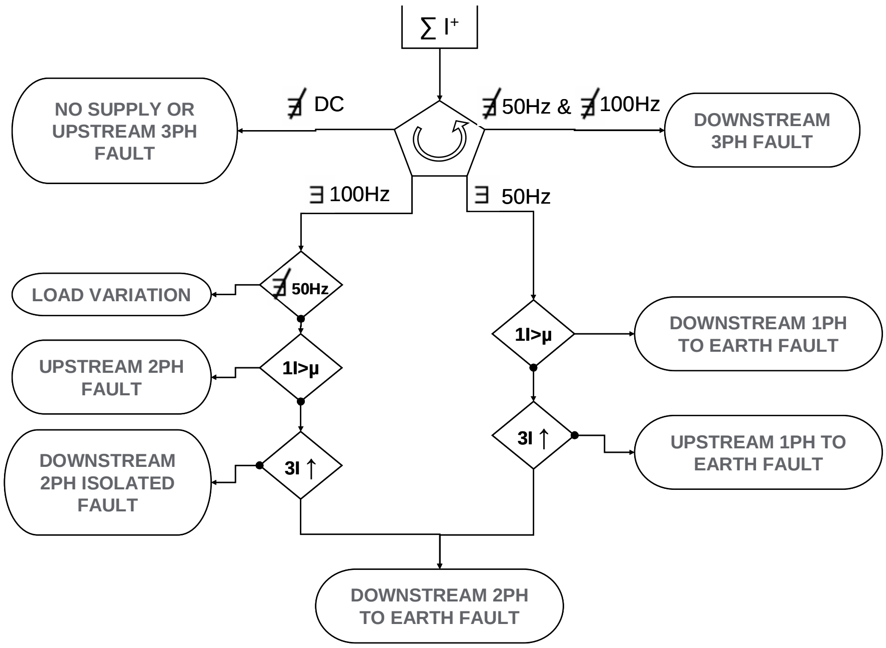

Fig.8 Auto adaptive FPI algorithm principle, working on half rectified currents, without any threshold.

Taking only into account time waveforms and frequency spectrums, a new development resulted in a global algorithm able to manage phase to earth faults and short-circuits with direction (upstream or downstream to the device) without specifying any threshold.

Half rectified currents

In previous works were used information on waveforms and magnitudes of phase and zero sequence currents. A specific analysis shows that half rectified currents include interesting elements, such as time waveforms as well as frequency spectrums. Some examples are depicted in Fig.6&7.

For example, it is visible on these figures that half rectified zero sequence current presents a significant 50Hz component for a downstream phase to earth fault, while it also presents a significant 100Hz component.

Auto adaptive FPI algorithm

Such arguments as zero sequence frequency signature or magnitude or time waveforms have been deeper investigated in order to finally establish a global algorithm able to manage type and direction of faults and short-circuits, without threshold. It is summarized in figure 8.Thanks to this, in case of Fig.6, the logic is the following one:

- frequency sprectrum presents a DC component, it is not an upstream 3 phase fault,
- 100Hz component is not sufficient (regarding fundamental) to be taken into account,
- But 50Hz component is sufficient regarding fundamental, then the process considers magnitudes of phase currents: as one phase current (blue one) is higher than both others (red and green), it means than 1 current is higher than the arithmetic mean value µ of the 3 RMS values: **it is a downstream 1 phase to earth fault**.

In case of Fig.7, the logic is the following one:

- frequency sprectrum presents a DC component, it is not an upstream 3 phase fault,
- 100Hz component is sufficient (regarding fundamental) to be taken into account,
- 50Hz component is sufficient regarding 100Hz component, it is not a load variation,
- As 2 phase currents (blue and green) are higher than last one (red), that means than 1 current is not higher than the arithmetic mean value µ of the 3 RMS values: it is not an upstream 2 phases fault,
- As one current (red one) remains the same than before fault, there are no simultaneous increases of 3 currents: **it is a downstream 2 phase isolated fault.**

FPI FlairDIN V2 range

Based on these results, an auto-adaptive FPI has been developed, which is able to discriminate nature (1-phase-to-earth, 2-phases insulated short circuit, 2-phases to earth or 3-phases short-circuit) and location (upstream or downstream) of the fault without specific settings regarding the network. There is no need to set any threshold, as setting is automatically done depending on service current.
According to the patent submitted on this principle [2], a new range of FPI has been developed at DIN format, for easier installation and implementation in cubicles and substations. The 'auto-adaptive setting' advantage can be considered as a 'plug and play' functionality, validated through simulations and tests.

Fig.9 Faut Passage Indicator FlairDIN 23DV.

In case of Electrical Utility operates the network under sustained earth fault condition (such as for isolated neutral grounding system), it is possible to disable the auto setting system. If auto setting is not preferred by customer, it is always possible (but not necessary) to change manually the settings. This new range of integrated FPI combines cumulated advantages of auto-adaptive settings, self-supply and remote communication, and including output voltage relay.

IMPROVING NETWORK AVAILABILITY

Moreover, as the dedicated FPI range is directly integrated in the cubicle with a compact size, several new advantages are proposed with this device. Here is a non-exhaustive list:

- no additional box to be fitted in the substation.
- sensors are integrated in switchgear
- cost effectiveness,
- remote permanent or non permanent communication,
- Ammeter and Maximeter are included.

Another important aspect is the fact that these products have been designed to be self-supplied. In fact, by working with half rectified current signals, the zero-sequence current is never equal to zero due to DC component. This last one is sufficient to supply the device, without battery, making the product maintenance-free.

CONCLUSIONS

Future RTUs, FPIs and IEDs will certainly include new Smart Grid functions. As large deployment is expected, installation and configuration of numerous equipments must be easy and quick. Described in this article for a FPI, auto-adaptive behaviour is a solution to these needs, avoiding troubles of fixed configuration at installation. Of course, as devices will include more and more communication capabilities, uploading new configuration and new settings would appear as an alternative to auto-adaptive solution, but remote permanent communication will not be available everywhere. Moreover, auto-adaptive solution is the more flexible to network evolutions, if loads or decentralized generations present intermittent characteristics. By the way, it will also allow to avoid false alarms which can occurs in extreme conditions (such as network under-loaded or overloaded, where non ordinary currents could be misinterpreted as short-circuits or faults). All these advantages will finally make the network easier to manage, and will result in increasing its availability, for benefits of DNOs as well as of customers.

REFERENCES

[1] P. Cumunel, G. Verneau, "Détection directionnelle d'un défaut à la terre", Patent EP2169799A2, publication 2010-03-31.

[2] P. Cumunel, G. Verneau, "Identification et détection directionnelle d'un défaut dans un réseau triphasé", Patent submission n°1001847 - 2010-04-30.