IMPROVE YOUR SAIDI WITH ADVANCED FAULT PASSAGE INDICATION

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ABSTRACT

This paper provides some hints on how what is referred to as "Advanced Fault Passage Indication" can help electrical distribution utilities to improve their SAIDI on their electrical distribution networks.

Situation as of today

- *Customer power outages are due to various causes: on overhead Medium Voltage distribution networks, these could be animals, vegetation, wind effect, cracked insulators, salt crust deposit on isolators, lighting strikes, etc.*
- *This creates a network fault that may normally be cleared or isolated by a circuit breaker located at the primary substation.*

Distribution networks are evolving with the integration of DER.

- *In case of a fault, the fault current flows from multiple power sources: the traditional fault detection system fails and must be replaced with a directional fault detection system (ANSI 67/67N).*
- *Network devices fitted with such system indicate whether the fault is upstream or downstream, which helps to quickly reconfigure the MV network.*

Network devices providing ANSI 67N can also support ANSI 47 Broken Conductor.

- *This specific earth fault occurs when a phase conductor does not touch the ground or touches a highly resistive soil.*
- *The primary substation CB may not trip, which might lead to a highly hazardous situation as the broken conductor is still live and people, animals, vehicles or building may touch it by accident.*
- *A device fitted with ANSI 47 function may help to solve this issue.*

Expected benefits

- *Improved SAIDI through an accurate faults detection and direction indication, quick network reconfiguration and fast restoration of supply to customers*
- *Improved safety with the fast detection of broken conductor occurrences.*

Conclusion.
An advanced fault indication helps to faster restore power and make the network safer.

INTRODUCTION

For an electrical distribution utility, to improve its SAIDI means to reduce the duration of customer power outages.

Faults occurring mostly on the MV distribution network, hence this is where the effort should be put.

The first step is to automate the primary substations supplying the circuits ("feeders"). The second one is to equip the feeders themselves with sensors and devices that allow to detect and isolate the faulty network part: this paper focus on the second step.

A MV fault occurs when a phase cable or conductor connects to the ground (earth fault) or to another phase cable or conductor (short circuit or phase-to-phase fault). Such phenomena are due to various causes: on an overhead line, that could be a large bird extending its wings between phase conductors, mating squirrels jumping between phase conductors, growing vegetation or loosely hanging conductors touching during a wind storm.

In the case of a short circuit occurrence, the fault current is high and the upstream protection relay located at the primary substation trips the MV circuit breaker supplying the feeder. On an overhead line, a proper reclosing cycle can eliminate transient and non-permanent faults.

In case of earth fault occurrences, the same principle applies although with a slight difference: the CB may not be immediately tripped if the MV neutral grounding system used at the primary substation is either isolated or compensated (i.e. earthed via a Petersen coil).

As an example, while both countries have implemented Petersen coil, France immediately trips the CB while Germany leaves it on for 2 hours before tripping it, to let the possibility for the maintenance crew to locate the fault without having to cut the power to customers.

When a fault occurs, the distribution utility must locate it as soon as possible to isolate the faulty part of the MV network, and restore power to as many customers as possible. In the case of an earth fault, even if the strategy is to delay the CB tripping to reduce the outage time to customers, it is recommended to perform this location as soon as possible to avoid creating other MV faults.

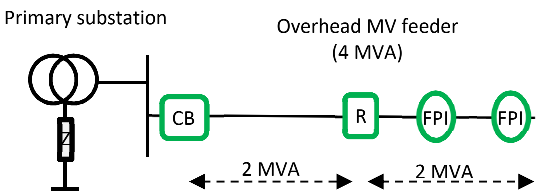
Most utilities have already put in place various strategies and equipment to reduce the SAIDI:

- For underground cable networks: open loop rings with remote controlled RMUs (ring main units) at selected points
- For overhead line networks: open loop rings and/or line reclosers at selected points to limit temporary or permanent outages only downstream, through a reclosing cycle
- Other parts of the network: MV LBS (load break switches) associated with a FRTU (feeder remote terminal unit) fitted with a fault detection algorithm and allowing a SCADA operator to remotely open/close the LBS to reconfigure the network, or simply FPIs (fault passage indicators) with a local or remote indication.

A key success of factor is to have every network device set with a proper fault detection, to help trip and/or operate the MV equipment and locate the fault.

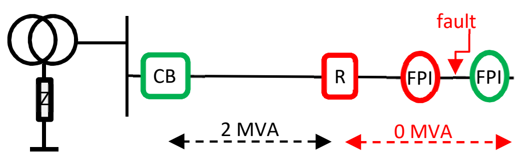
Example 1 (Fig. 1 & 2): typical and simple implementation on an overhead line feeder (note: FPI could be replaced with FRTUs).

Fig. 1



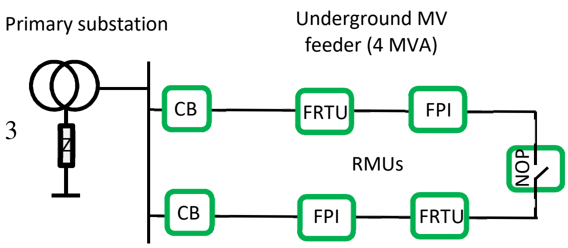
In case of fault downstream, the line recloser shall only isolate and cut power downstream. When the maintenance crew arrives on site, they will start to inspect the line from the recloser with the help of the FPI.

Fig. 2



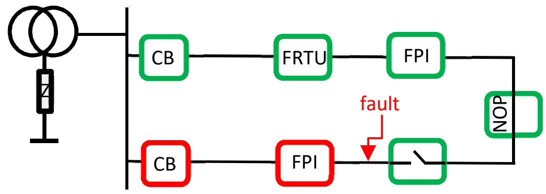
Example 2 (Fig. 3 & 4): typical implementation of an underground cable feeder set as an open loop supplied from 2 primary substation CBs, with a Normally Open Point and 5 Ring Main Units (2 in manual operation and fitted with a FPI, 3 motorized and fitted with a RTU)

Fig. 3



In case of a fault occurrence, the SCADA operator operates the remote controlled RMU to reconfigure the network and reduce the affected area. Then the maintenance crew dispatched on site utilizes the FPI to locate the fault:

Fig. 4



ADVANCED FAULT PASSAGE INDICATION

With the emergence of DER (distributed generation) on both the MV and LV networks (solar or wind farm, solar roof) and EV charging stations (electrical vehicles), new challenges are brought to existing fault protection and/or fault detection equipment.

When DER such as MV solar farms or wind farms are connected to the grid, open loop rings become closed loop rings even if on a temporary manner: earth and phase-to-phase faults become directional and require a more advanced fault detection principle.

In case of an earth fault, since DER are applied whatever the type of MV neutral grounding system (solidly grounded, resistor-earthed, isolated, Petersen coil-earthed, etc.), the earth fault direction must be determined during the transient phase which last a few hundred milliseconds. The detection uses the ANSI 67N function, which requires both V0 (voltage unbalance) and I0 (current unbalance).

And while I0 may be directly measured using a zero-sequence current transformer, V0 cannot and has to be computed from the 3 single phase voltage measurements. Hence network devices (recloser, FRTU, FPI) must be fitted with V1/ V2/ V3 measurement inputs and the capability to compute V0, and the MV measurement point (recloser, pole mounted LBS, pole, RMU) with the required single-phase voltage sensors.

Modern reclosers are normally fitted with all the necessary sensors and fault detection algorithms.

As for RMUs, they are normally equipped with either VDS (Voltage Detection System) or VPIS (Voltage Presence Indicator System). VDS as well as VPIS with voltage output can provide the 3 single phase voltage outputs. RTUs and FPIs connected to such RMUs should have 3 single phase voltage inputs and the capability to compute V0 and to execute ANSI 67N algorithm;

Like line reclosers, remote controlled LBS are fitted with 3 phase current transformers and/ or zero-sequence CT, but unlike them, they are not fitted with 3 single phase voltage sensors. Hence for the embedded FRTU to perform directional fault detection, it is required to install 3 LPVTs (low power voltage transformers) to get the 3 single phase voltages necessary for the RTU to compute V0.

Directional earth and phase-to-phase FPIs may leverage the output of VDS or VPIS installed in RMU to get the 3 single phase voltages. Pole mounted FPIs can detect directional earth fault in certain conditions, however for the detection of both directional earth and directional phase-to-phase faults on an overhead line, it is required to install 3 LVPTs like for remote controlled LBS.

Once this advanced fault indication is implemented, the duration of power outages can be significantly reduced, thus improving the SAIDI.

Example 3 (Fig. 5 & 6): connection of a DER through a grid connection substation (S/S)

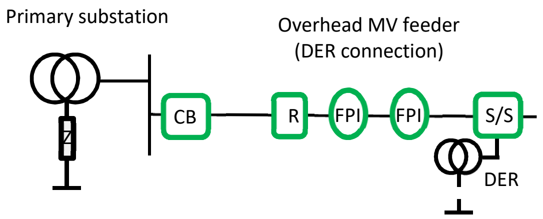


Fig. 5

With non-directional fault indication, here is what we would get:

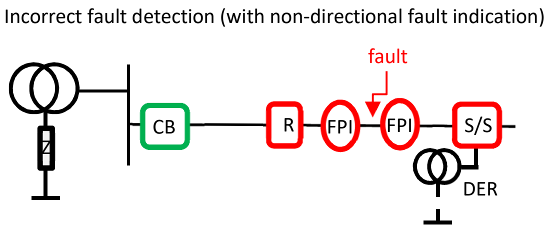


Fig. 6

With an advanced fault indication, the result would be as expected:

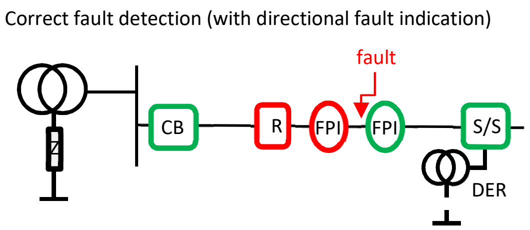
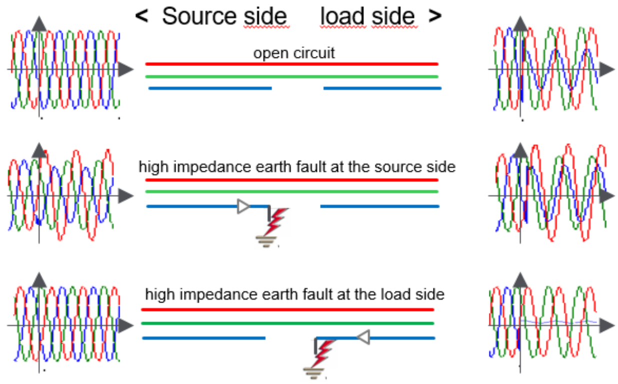


Fig. 7

SENSITIVE EARTH FAULT OR BROKEN CONDUCTOR

A "broken conductor" is a very specific type of earth fault, highly resistive, that does not directly impact the SAIDI but that is perceived as a major safety issue on an overhead distribution network. In most cases the phase conductor is hanging without touching the ground, hence the leakage current is close to nil.

One observes different types of BC, depending on where the phase conductor breaks:



Voltage profiles on the feeders, up/down the BC

From upstream feeder protection relay, this phenomenon appears as a current unbalance that may be detected by measuring the negative sequence current (ANSI 46 negative sequence/ unbalance). However, since its magnitude is extremely low, it is hard to differentiate between a normal unbalance load and this phenomenon: therefore, this detection is not accurate.

Downstream, along the line, the effect is a voltage unbalance that may be detected by measuring the negative sequence voltage (ANSI 47 negative sequence overvoltage). Devices already fitted for ANSI 67N directional earth fault detection can also perform ANSI 47 algorithm: for both it is required to measure all three single phase voltages and V0.

As a voltage unbalance is easy to detect, downstream broken conductor detection is therefore quite accurate.

<u>What are the benefits of ANSI 47 versus ANSI 46BC for the Broken Conductor detection?</u>

The algorithm of negative sequence overvoltage (protection functions [2] ANSI 47)
$\vec{Vi} = 1/3\ (\vec{V1}+a^2\vec{V2}+a\vec{V3})$ where $a = {}^{j\,2\pi/3}$ is calculated from the LV inputs.
An alarm is triggered when negative voltage $\vec{Vi}$ reaches from 2 to 30% of Vn rated within a definite time delay (from 0.5 to 60 s).

Zero-sequence phase overvoltage (ANSI 59N) is specifically designed for isolated HV/MV transformer grounding system. It is interesting to note that over/under voltage ANSI 59 or ANSI 27 cannot properly detect a Broken Conductor occurrence.

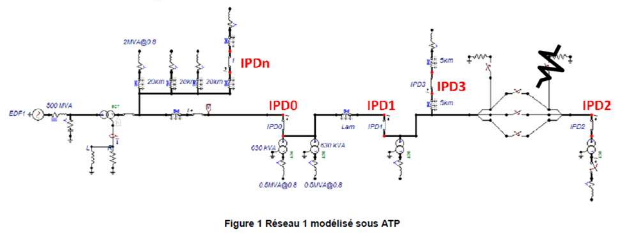
While before both functions (ANSI 47 and ANSI 46 BC) may detect the BC occurrence, ANSI 46BC is utilized in primary substation's protection relays since it monitors currents. As for ANSI 47, since it utilizes voltages it does not add much at the primary substation level as internal faults are dealt with protection relays.

For FRTUs located along the MV line, both functions may be used: however, the ANSI 46BC embedded into a FRTU would not provide more information than the one located at the primary substation, which is more accurate and can provide distant to fault information. On the contrary it makes sense to embed ANSI 47 into these FRTUs as it covers more cases not detected by the ANSI 46BC located at the primary substation protection relays.

A study has compared ANSI 46BC and ANSI47 using a negative sequence overvoltage method [4]. Over 1,200 cases of typical faults have been simulated, for 3 categories of faults. This study has considered various HV/MV transformer neutral grounding systems, network loads and fault impedances, and it has also included two DER.

Location of the detector (IPDx)	0	1	2	3	N
46BC – conductor hanging, broken jumper	12%	12%	64%	100%	100%
46BC – high impedance fault on source side	69%	80%	64%	95%	100%
46BC – high impedance fault on load side	12%	12%	64%	100%	100%
47 – all above cases	100%	100%	100%	100%	100%

***BC fault detection success rate** (%)*



Simulation of a MV network with 2 DER

The conclusion of this study is that ANSI 46BC does not detect most open circuits (broken jumpers) nor most high impedance earth faults (on the load side).
ANSI 47 has successfully detected 100% of the faults, whatever the point where voltage measurement is performed (LV or MV side of the MV/LV transformer).

Why can't the CB trip every time?

A primary substation protection relay protects a feeder by tripping the corresponding CB (circuit breaker) in case of earth and phase-to-phase faults: and while this may vary from one country or network to another, it is fair to say that 70% of faults are earth faults, for which the protection relay uses zero-sequence overcurrent function to detect. BC are a specific type of earth faults, that should be detected through the neutral current however since it may be nil, the protection relay cannot detect it. Therefore, the best way to detect a broken conductor is to measure the voltage unbalance on the load side.

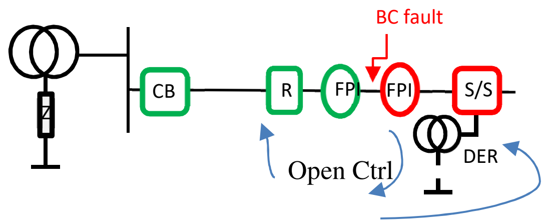
In case of a BC, the ground potential may rise and could injure someone or damage something nearby.
When the broken conductor does not touch the ground (broken jumper), the primary substation circuit breaker cannot trip but this is less critical as there is no immediate safety hazard: the RTU located down to the fault and fitted with ANSI 47 can detect the fault and send an alarm to the SCADA control center.

In priority, one should install ANSI 47 BC detection at:

- each EOL (end of line) of the MV feeders,
- each MV/LV substations connected to an overhead line (ground mounted substations, etc.) that may be the NOP (normally open point) of an open ring loop or of a meshed distribution network,
- at each pole top transformers and remote controlled LBS fitted with LPVT sensors.

The benefit of a ANSI 47 BC detection combined with connected products is to be able to automatically open the upstream recloser and activate the downstream NOP when relevant.

Fig. 8



Detection of BC with distributed automation

CONCLUSION

Due to evolution of the MV distribution network (closed loops, change of the neutral grounding system, DER, etc.), getting a reliable and cost-effective earth fault detection system becomes a major issue for electrical utilities.

The solution proposed in this paper describes an innovative solution to better detect earth-faults on compensated networks and highly resistive faults due to BC occurrence.

Nowadays the trend is to install connected products/ devices associating an advanced fault indication with other feeder automation functions.

Smart controllers can maximize the benefits of smart assets by hosting some local automation and communicating with control centers and with other *substations using standard protocols, to detect faults and automatically reconfigure the network. This may also include the capability to accurately monitor the quality of delivered energy [2].*

Such an advanced fault indication also contributes to asset management: local fault recordings may be computed to enable utilities to not only reduce the number of costly field maintenance visits, but also more proactively keep the equipment operating efficiently.

Example of advanced directional fault indicator combined with a MV switch controller (Easergy SC150 – Schneider Electric)

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