MV HIGH IMPEDANCE FAULTS DETECTION BASED ON LV MEASUREMENTS

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ABSTRACT

Smartgrids can offer real time knowledge of the state of the LV network. The advanced metering infrastructure (AMI) which is being deployed can provide useful information for optimum grid operation in addition to billing data. With a better knowledge of the LV segment, LV/MV grid maintenance processes can be improved. Therefore, real time information of the grid enables fault management, quality of supply monitoring, and efficient handling of customer complaints.

In this context, this paper will describe an innovative and field tested solution in order to remotely detect high impedance MV faults caused by broken conductors (and any MV open phase situation).

How are these faults detected? AMI developments include monitoring elements in the low voltage output of the transformer at each Secondary Substation. These elements include LV supervision devices that measure current and voltage in the LV side of the transformer. They also monitor the quality of supply, voltage level anomalies, voltage dips, harmonics, and every significant parameter in the voltage signal. This solution is easily integrated into existing AMI deployments as no specific extra devices are required.

A series of MV line fault types have been analysed, noting that they have a direct impact in the low voltage levels of the transformers near the fault, causing voltage unbalances. In the solution described, LV supervision devices will integrate a high impedance fault detection algorithm that monitors voltage unbalances at the secondary of the MV/LV transformer. These unbalances are notified as events to the backend information systems of the Distribution Companies. These events, once they are processed, will allow the grid distribution operator to detect MV high impedance faults. In Iberdrola this implementation is achieved thanks to the connection between the metering system which receives the events and the EMS/SCADA/DMS control systems. MV/LV Transformers that have signalled this event are highlighted in the schematic diagrams, allowing an easy identification by the operator of the faulty line segment. Other functionalities, like real time querying of transformer supervisors and customer meters connectivity checking (ping) are also implemented.

The described algorithm has been successfully validated in the field. Field experiences show how this solution optimizes MV grid operation, decreasing blackout times, improving customers' perception and improving safety, as dangerous situations caused by faults in MV lines (loose conductors over resistive ground, etc.) can be identified. .

INTRODUCTION

High impedance faults (HIFs) have been a challenge for protection engineers since the creation of power systems. A HIF is produced when a primary conductor makes electrical contact with a quasi-insulated object, which can be for instance a tree branch or a high resistivity soil in the case of a broken and downed conductor. In this situation the current flowing to ground is very low, so that it may not be detected by current-based conventional relays.

The frequency of undetected HIFs in distribution systems varies from one utility to another, depending on different factors such as the type of system neutral grounding, percentage of underground lines, common type of soil, single or three phase MV loads, etc. Some utilities appraise the problem as virtually solved whereas other companies consider it as unresolved owing to the existence of a significant number of HIFs that are not detected by the protection system [1].

Anyway, in overhead networks there are several situations that are extremely hard to be detected properly in the current state-of-the-art MV feeder protection:

- Fault produced by a tree fallen over the conductor of the line.
- Conductor broken and downed on rocky or asphalt soil.
- Conductor broken on the load side.

At feeder protection level, ground sensitive over-current relays, open conductor I2/I1 protection, and high impedance (HIZ) fault detection are functionalities aimed to address these situations but that present key restrictions such as limited sensitivity, protection settings complexity and risk of incorrect trip during normal network operation in occurrence of switching operations, arcing loads, etc.

The event of a broken and downed conductor that remains energized imposes a safety hazard to people and animal life, as well as a fire ignition risk. This is why extensive research has been undertaken in the last decades in this field, but yet there is not an entirely satisfactory solution to this problem through feeder protection relays.

So it seems to be the time to look for solutions based on measurements along MV lines that benefit from the automation being deployed nowadays in MV and LV networks beyond primary substations.

ALGORITHM FOR DETECTING HIFS

Automation, supervision and control are not exclusive to HV and MV any more. Smart metering deployments offer valuable information of the LV grid that enables advanced LV supervision applications. Note that these new capabilities come with a very low cost, evolving the intelligence of those devices already installed as part of AMI (Advanced Metering Infrastructure) solution. Therefore a cost effective LV line supervision is achieved.

This is the situation of the AMI data concentrators, installed at each Secondary Substation, that are capable of monitoring the low voltage output of the transformer. These devices (whose main role is to manage Smart Meters) include monitoring elements such as the LV supervision function that measures the current and the voltage in the LV side of the transformer, monitoring the quality of supply, voltage levels anomalies, voltage dips, harmonics, and so on.

These data correctly processed and correlated with geographic information, can offer real time information of both LV and MV lines. How can MV supervision be extracted from LV measurements? Analysing different MV line fault types it was noted that they have a direct impact in the low voltage levels of the transformers near the fault, causing voltage unbalances [2]. This is the application of the solution described in this paper. LV supervision devices introduced above, will integrate a high impedance fault detection algorithm that monitors voltage unbalances at the secondary of the MV/LV transformer. These unbalances are notified as events to the back end information system of the Distribution System Operator (DSO). These events, once they are processed, will allow the DSO to detect MV HIFs. Main advantage of this approach is that a simple evolution on the DSO event processing engine will enable the HIFs detection. No specific additional device is required.

How can LV measurements allow MV HIFs detection? These phase-to-ground faults are not easily detected by the feeder protections. In these scenarios, voltage levels near the fault are below the normal operation parameters. The algorithm described in this section allows detecting these situations based on LV voltage unbalances.

Note that the algorithm parameters will need to be adjusted. Voltage unbalances can be caused both due to LV and MV faults. Smart Meters deployed in the LV grid provide with valuable QoS information for detecting LV faults. Therefore the algorithm described in this section should focus only on reporting those voltage unbalances caused by MV faults.

When is a LV system considered unbalanced?

An unbalance is produced when in a three-phase power system the RMS magnitude or phase angle of the line voltages are not equal. This is usually determined as a percentage of the ratio of negative sequence component to positive sequence component.

Direct, indirect and zero sequence values for voltages are calculated as follows:

$$\overrightarrow{V_d} = \frac{\overrightarrow{V_a} + \overrightarrow{V_b} * 1_{120} + \overrightarrow{V_c} * 1_{240}}{3}$$

$$\overrightarrow{V_r} = \frac{\overrightarrow{V_a} + \overrightarrow{V_b} * 1_{240} + \overrightarrow{V_c} * 1_{120}}{3}$$

$$\overrightarrow{V_0} = \frac{\overrightarrow{V_a} + \overrightarrow{V_b} + \overrightarrow{V_c}}{3}$$

Unbalance conditions required in order to report a MV high impedance fault detection event.

MV faults detection is included as a software evolution of AMI Data Concentrators installed in Secondary Substation. LV supervision will be able to generate a spontaneous event when the voltage unbalance matches certain preconfigured conditions. This algorithm requires two main configuration parameters:

- ***Ratio V_i .vs. V_d***: Indirect and direct sequences ratio for the event activation (percentage). Based on field experience, this value is set to 20% by default. This implies that both ratios, V_i/V_d(%) and V_d/V_i(%) must be greater than 20% to activate the HIF event. Also note that HIF event will not be activated if the voltage level in all phases is under 10% Un.
- ***Minimum time that the condition should be met in order to activate the event (seconds).*** This value is set to three minutes by default. Meaning that when V_i/V_d (%) and V_d/V_i (%) ratios are greater than 20% during more than 3 minutes, a spontaneous MV high impedance fault detection event will be sent to the AMI Head End System.

It should be highlighted that this algorithm will be able to cope with two possible situations to avoid false HIF events:

- Incorrect wiring of the Data Concentrators' LV supervision at the installation time (not matching RST sequence). The algorithm checks both that V_i/V_d (%) and V_d/V_i (%) ratios are over 20% to activate the event.

- Possible Data Concentrators' measurement stage failure. The algorithm will not activate the event in case the voltage of all the LV phases is under 10% Un.

DSO back end information system evolution that will enable MV HIFs detection (event processing engine).
When the voltage unbalance matches the conditions described above, a spontaneous event is sent to the back end information system. These events need to be processed in order to detect MV HIFs. A simple evolution on the DSO event processing engine is required, this evolution is described below.

When one HIF event is received at the back end information system from one Secondary Substation (SS-A), the system will confirm if any previous HIF events have been received from this same SS-A.

- If there are previous HIF events from the same location the event is joined to an existing failure.
- If it is the first HIF event a HV/MV open phase event prediction is opened.

How is a HV/MV open phase event prediction managed? Each prediction can involve several HIF events received from different LV supervisors and consequently different SS. All these events are grouped by physical connectivity (real value calculated daily in the system), associating those SS belonging to the same MV line. The information system will show a graphical representation of those lines with one or more SS that sent HIF events.

See the example below (Fig 1) where SS-A (Salduraño), SS-B (La Calera) and SS-C (La Lama), which belong to the same MV line, sent HIF events. This is the image that a system operator would see. In the closer view (Fig 2) the detailed HIF event symbol can be appreciated. The yellow square indicates an event reception from that SS. The red lightning inside the square means a HIF event. Note that in this example the failure is probably located in the branch to SS-A, SS-B, SS-C.

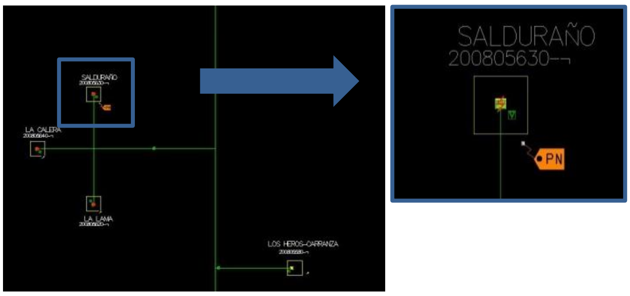

Fig1: MV HIF event prediction view at the DSO back end information system.

DETECTING HIFS IN THE FIELD

HIF feature has been activated in all those data concentrators deployed by Iberdrola with an upgradeable LV supervision meter. Since July 2016, 45.625 ZIV AMI data concentrators have this MV fault detection capability enabled and integrated into the back end information system. In the last six months, this module has reported and detected 128 real failures. Event processing engine involved in HIF management is being evolved within UPGRID H2020 European project [3], based on metropolitan Bilbao area where around 15% of the AMI data concentrators mentioned above are located.

This section compares a real field situation with the corresponding simulations to show HIF algorithm in action.

Single line diagram below (Fig 3) highlights a MV line where one failure occurred (fuse problem) in one of its phases in SLZ 530 position.

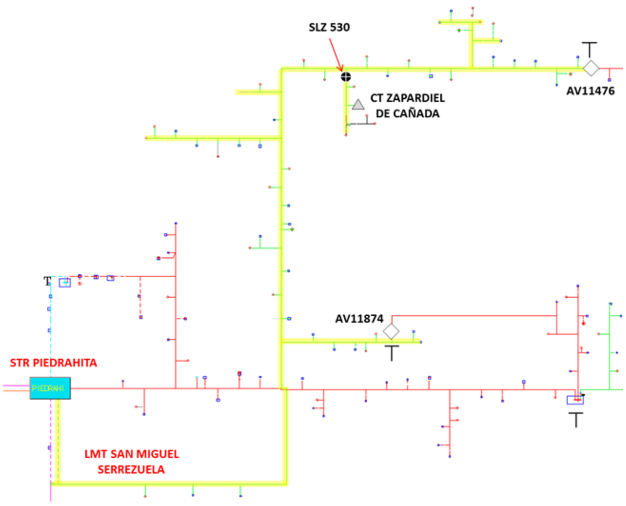

Fig3: Single line diagram – Position SLZ 530 showed a single phase failure.

In the highlighted line there are several secondary substations as shown in Table 1 below.

	Clave	0	Nombre	Propied.	Posición	Tensión	KVA	Kw	Clientes	Pot.Generación	Cli. Generación
☐	40300720	✓	PASCUALCOBO	IBD	1	BITENSION 20-...	100	---	189	0	0
☐	40300740	✓	DIEGO ALVARO	IBD	1	B2	100	---	178	0	0
☐	40300750	✓	MARTINEZ	IBD	1	B1	100	---	132	0	0
☐	40300770	✓	AREVALILLO	IBD	1	B1	75	---	155	0	0
☐	40300780	✓	NARRILLOS DEL ALAMO	IBD	1	B1	50	---	108	0	0
☐	40300790	✓	EL ALAMO	IBD	1	B1	25	---	23	0	0
☐	40300840	✓	COLLADO DEL MIRON	IBD	1	BITENSION 20-...	100	---	76	0	0
☐	40301010	✓	FC LAVADERO	IBD	1	BITENSION 20-...	250	---	16	0	0
☐	40301040	✓	CARPIO MEDIANERO	IBD	1	B1	100	---	97	0	0
☐	40301110	✓	LA IGLA-DIEGO ALVARO	IBD	1	B2	250	---	146	0	0
☐	40303350	✓	MESEGAR DE CORNEJA	IBD	1	B1	160	---	159	0	0
☐	40303440	✓	S MIGUEL SERREZUELA	IBD	1	BITENSION 20-...	160	---	155	0	0
☐	40303450	✓	ALDEALABAD MIRON	IBD	1	B1	50	---	54	0	0
☐	40303460	✓	MERCADILLO	IBD	1	B12	75	---	80	0	0
☐	40303570	✓	BECEDILLAS	IBD	1	BITENSION 20-...	400	---	133	0	0
☐	40303580	✓	CHICAPIERNA	IBD	1	B1	100	---	38	0	0
☐	41440110	✓	LOS JUNCAREJOS	IBD	1	B2(A)	50	---	7	0	0
☐	41440250	✓	CASERIO LA ZAPATA	IBD	1	B2(A)	50	---	16	0	0
☐	41440300	✓	BASCULA-MARTINEZ	IBD	1	B1	250	---	187	0	0
☐	902400802	✓	ZAPARDIEL DE CAÑADA	IBD	1	B2	250	---	230	0	0

Table 1: Secondary substations in the line under analysis.

The failure in the position SLZ530, as it was expected, was only detected in the secondary substation of Zapardiel de Cañada. The real data obtained in this failure will be compared with two different simulations, with and without a three phase motor connected.

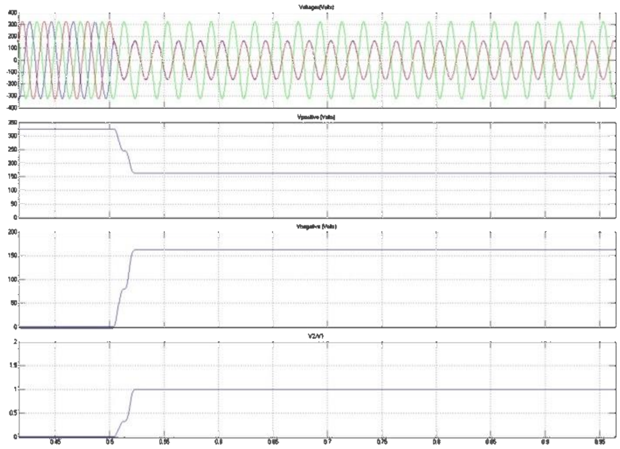

Fig 4: Simulation with computer software of a MV/LV transformer (delta-wye) of 630 kVA, fed through 2 phases in MV and a load of 100 kW; LV measurements shown.

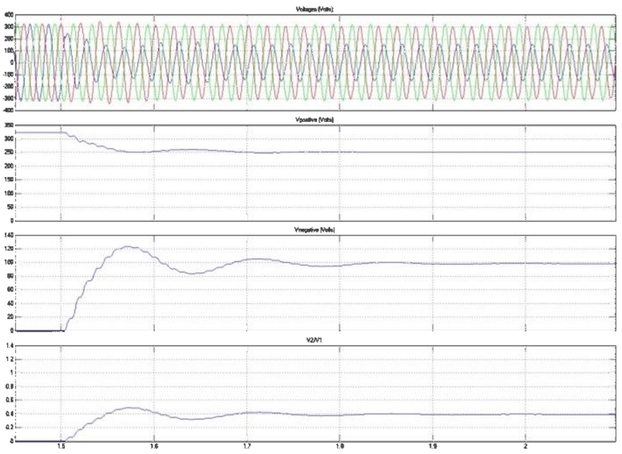

Fig 5: Simulation with computer software of a MV/LV transformer (delta-wye) of 630 kVA, fed through 2 phases in MV and a load of 100 kW and **with a motor of 40kVA**; LV measurements shown.

Figure 4 shows an ideal simulation of the failure that occurred in the field. Table 2 below compares both, the ideal simulation (theoretical) voltage levels and the in-field voltage levels (LV voltages measured in MV/LV transformers).

	Theoretical	A real case
V_r	110v	130v
V_d	110v	109v
V_a	110v, 0º	157v, 0º
V_b	110v, 0º	81v, 20º
V_c	220v, 180º	236v, 187º

Table 2: Theoretical voltage levels and in-field voltage levels comparative.

In this case, a HIF event was triggered as both ratios, V_i/V_d (119%) and V_d/V_i (83%), were greater than 20%. Note that Figure 5 shows this same simulation including a three phase motor. The presence of this element makes the simulation closer to the real scenario, with V_d/V_i (40%). The 20% threshold would be also suitable for these scenarios.

CONCLUSION

Several proposals have been published to use distributed voltage-measurements as an alternative to primary substation-based systems. The algorithm presented in this paper has some clear advantages but it also has its own drawbacks:

Advantages

- The change in voltages downstream of a downed and broken conductor is independent of the fault resistance. In fact, there is an indistinct change of voltage even in the case of a broken loop.
- MV line fuse operations can be also detected by a downstream voltage change, allowing a faster restoration started even before customer calls are received.
- Given a complete deployment of voltage measurements all over the line (as required for a complete line coverage), the result is an improved and faster fault location due to the activation of downstream indicators.

Weaknesses

- Only "serial" faults can be detected, "parallel" faults like tree contacts cannot be detected.
- The voltage measurement must be installed at all the network ends. Thus MV/LV secondary transformers seem an adequate location for the installation of voltage measurement.
- All voltage measurement locations must have a communication infrastructure. Furthermore the auxiliary DC/AC supply has to be independent of the voltage unbalance present at the moment of failure. The alarms received have to be integrated in the SCADA IT support system in order to be useful for fault management.

REFERENCES

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[2] E. BJERKAN, H.K. HØIDALEN, J.G. G. HERNES, 2007, "Reliable detection of downed and broken conductors", *CIRED 19th conference*

[3] UPGRID project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646.531