FAULT TEST IN MV NETWORK OPERATED IN "LOOP MODE". COMPARISON BETWEEN SIMULATED RESULTS (OBTAINED BY RTDS) AND SEVERAL REAL FIELD RESULTS.

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ABSTRACT

Historically in Italy MV distribution network has been normally operated in radial mode and accordingly the fault selectivity has been chronometric. Main objective of the "Smart Grid" project POI P4 of Enel Distribuzione is to test the operation of the network in loop mode with a logical selectivity during faults. The selectivity is performed using optical fiber communication via IEC-61850 standard. The paper analyzes all preliminary tests made by Enel in simulation mode using a Real-Time Digital Simulator (RTDS) in order to set the protections relays correctly and avoid unwanted protections tripping.

INTRODUCTION

This paper is focused on the "Smart Grid" project POI P4 of Enel Distribuzione. In this project MV Distribution network is operated in loop mode with a logical selectivity during faults. The experience of this project has been primary in order to implement the same technology in EXPO 2015 network (Milan).

In POI-P4 are involved five Primary Substations (PS) MV busbar, at national level, with respectively five MV network loops. These sites (Table 1) are localized in the south of Italy.

Table 1. Sites of the POI-P4 grids in Italy.

Primary Substation	Region
1. Partinico 2	Sicily
2. Ospedaletto	
3. Ponte Annibale	Campania
4. Apricena	Puglia
5. Taurianova	Calabria

In particular in this paper is analyzed Line Ground Fault (LGF) with insulated or grounded neutral with Petersen Coil.

The tests are focused on LGF due to the most frequent and hard detection. Moreover this choice allow to perform Fault Tests in the real field, without a destructive stress for the network.

The device that detect the faults along the feeders is called "RGDM". This device is able to provide high-precision measures and fault detector in the point of allocation.

The device that detect the fault through a directional relay at the head of the feeder is called "DV901".

LGF is detected monitoring zero-Sequence quantities (voltage, current and phase), using directional ground relays (67N).

When MV network is supplied in loop mode, preliminary simulation tests are fundamental to show critical parts in order to set correctly the protection relay.

Moreover simulation tests allow the analysis of all cases, with internal and external fault of the loop.

Secondly the real field tests are analyzed and a comparison between simulated fault quantities and real field quantities is provided.

LOGICAL SELECTIVITY IN ENEL POI-P4 PROJECT

Inside each Secondary Substations (SS) involved in the project are present two RGDM and each one protects directionally the downstream line.

At the head of the feeders are installed two DV901 that protect the network at the side of two feeders.

The situation of the ring is shown in Figure 1, where the tips indicate the side protected by the devices.

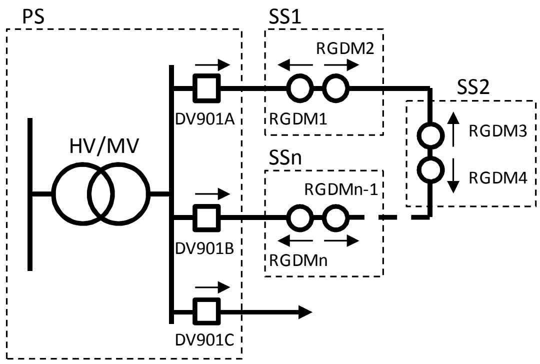

Figure 1. Loop in MV network example.

The selectivity of the protections in a loop network has to be distinguished in two different techniques.

The first is used when the fault is inside the ring and the

second when the fault is outside.
When the fault occur inside the loop both DV901 see the fault in front direction. Inside the loop some RGDM see the fault in front direction (red tips in Figure 2) and some in reverse direction (green tips in Figure 2).
All RGDMs that see the fault in front direction send to RGDM upstream a lock signal. If upstream is present a DV901 the RGDM locks the DV901. The only RGDMs that doesn't receive a lock signal must trip (Figure 2). The RGDMs that see the fault in reverse direction doesn't trip.

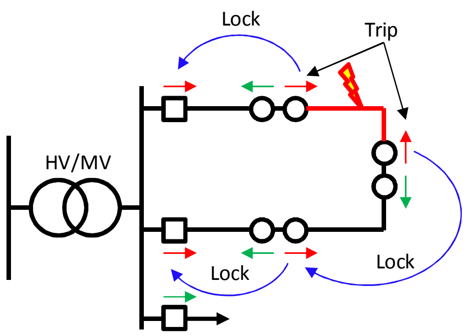

Figure 2. Fault inside the loop.

When the fault occur outside the loop both DV901 see the fault in reverse direction, but inside the loop some RGDMs see the fault in front direction.
RGDMs that see the fault in front direction send a lock signal back and at the same time when DV901s see the fault in reverse direction send a lock signal to the firsts RGDMs in opposite direction which lock those one back (Figure 3).

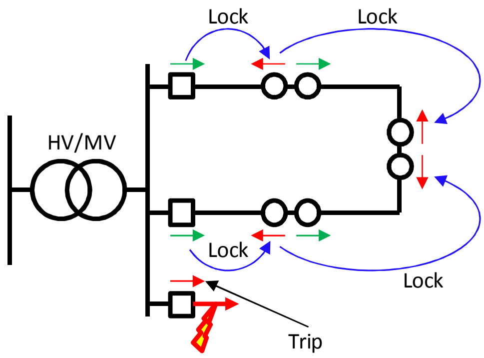

Figure 3 Fault outside the loop

This technique avoid unwanted tripping inside the loop and the only RGDM that trip is outside the ring.
Communication between devices is guaranteed by a fiber optic ring and messages are based on the IEC 61850 standard.
It is evident that how the zero-sequence current is departed inside the loop is fundamental in order to guarantee a logic selectivity.
This topic is crucial in the project and will be explained in sections below.

TEORICAL ANALYSIS

When a LGF occurs on a radially-operated MV grid, it is simple to calculate zero-sequence quantities, also if the Petersen Coil is present. Calculation is simple thanks the ratio between series and shunt zero-sequence impedances. Shunt zero-sequence impedances are normally bigger that series zero-sequence impedances, then these last can be neglected.
Also in loop mode this ratio is satisfied, but in case of loop series zero-sequence impedances play a fundamental role on zero-sequence current partition along the branches composing the loop. Moreover these impedances influence also the phase of the zero-sequence current, then fault detectors tripping sector must be reviewed.
To better understand this phenomenon, the example of Figure 4 can be analyzed. It represent the zero-sequence circuit of a very simple grid, composed by three feeders, called 1, 2 and 3. Feeders 1 and 2 are closed forming a loop, by means the boundary switch K closure. Feeder 3 is operated in radial mode.

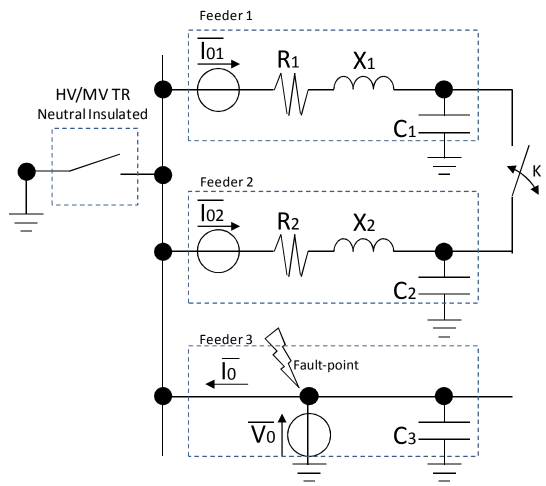

Figure 4. Zero-sequence equivalent circuit example.

On the feeder 3 a permanent fault is applied. In the zero-sequence circuit the fault is taken into account applying the voltage generator $\bar{V}_0$, which represents the zero-sequence voltage phasor.
The directional ground relays (DV901), protecting feeders 1 and 2, measure zero-sequence currents $\bar{I}_{01}$ and $\bar{I}_{02}$, and comparing it to the voltage $\bar{V}_0$. If zero-sequence currents are in the "tripping sector", relays trip.
As said before, $\bar{I}_{01}$ and $\bar{I}_{02}$ are influenced by series zero-sequence impedances of the loop branches:

$$\bar{Z}_1 = R_1 + jX_1$$
$$\bar{Z}_2 = R_2 + jX_2$$

In fact, from the circuit of Figure 4, we can write:

$$\bar{I}_{01} = \bar{I}_0 \frac{\bar{Z}_2}{\bar{Z}_1 + \bar{Z}_2}$$
$$\bar{I}_{02} = \bar{I}_0 \frac{\bar{Z}_1}{\bar{Z}_1 + \bar{Z}_2}$$

where $\bar{I}_0 = \bar{I}_{01} + \bar{I}_{02}$ is the total zero-sequence current supplied by $\bar{V}_0$.

From previous equations we can see that zero-sequence currents $\bar{I}_{01}$ and $\bar{I}_{02}$ along branches of the loop depend, in phase and magnitude, from zero-sequence branch impedances $\bar{Z}_1$ and $\bar{Z}_2$, as said before.

Indeed, in radial mode, we can write:

$$\bar{I}_{01} = \bar{V}_0/\left(\bar{Z}_1 + \frac{1}{j\omega C_1}\right) \cong \bar{V}_0/\left(\frac{1}{j\omega C_1}\right)$$

$$\bar{I}_{02} = \bar{V}_0/\left(\bar{Z}_2 + \frac{1}{j\omega C_2}\right) \cong \bar{V}_0/\left(\frac{1}{j\omega C_2}\right)$$

because, in the zero-sequence circuit, series impedances can be neglected if compared to shunt impedances. Then, in radial mode, series parameters don't play any role on the zero-sequence current.

Previous treatment has been derived for a fault outside the loop. However this theory can be easily extended in case of fault inside the loop.

SIMULATION AND REAL FIELD TESTS

In order to study phenomena related to the permanent loop operation, Enel imported in its Real-Time Digital Simulator (RTDS), installed at the Smart Grids Test Centre of Milano (Italy), all grids of the POI-P4 project. In this section simulation results for Partinico 2 grid will be presented and discussed in comparison to real fault test performed on the same grid, in the real field.

Using "START", the automatic importer developed by Enel Distribuzione, a grid can be automatically importer in the RTDS reading topology, electrical characteristics, load data, etc., from corporate databases.

This procedure ensure the fidelity between the simulated grid and the real field. This procedure has been performed for the Partinico 2 grid, in order to have the network available in the RTDS. After this the "Runtime" page has been built in order to put faults along feeders and to read output data. Figure 5 shows the RTDS Runtime page, where the Partinico 2 grid is visible. RTDS simulation results are presented in Figure 6.

Real field tests have been performed making a LGF with 1000 ohm fault resistance (the LGF fault current in case of 0 ohm resistance is 140 A).

Making a comparison between RTDS simulation data and real field data, an error less than 8% has been detected.

CONCLUSION

This work allowed to deeply study the permanent loop operation on MV grid, deriving from it new LGF protection settings. Moreover the work avoided non-intentional trips during real field tests and confirmed the

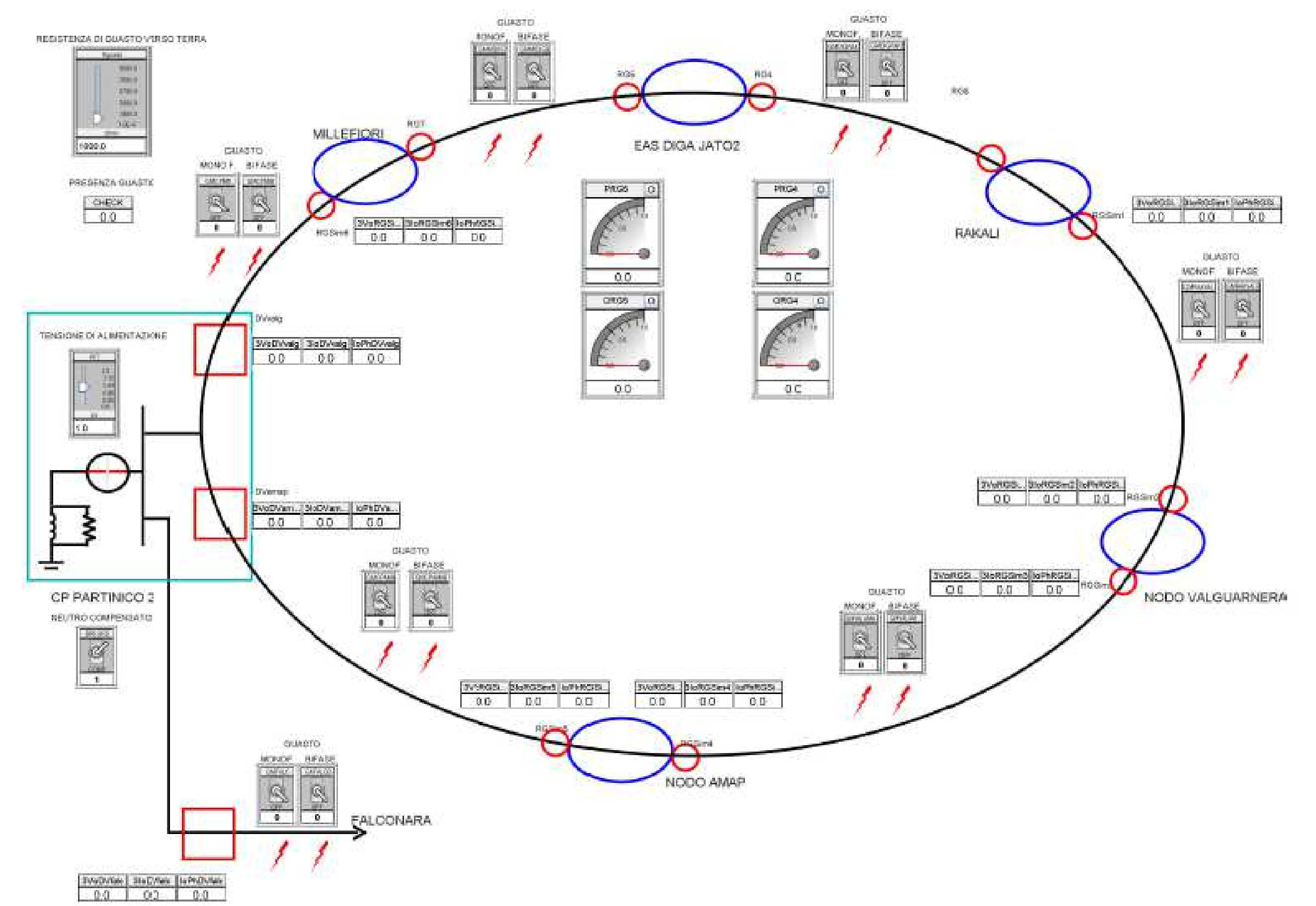

Figure 5. Partinico 2 POI-P4 grid in RTDS Runtime.

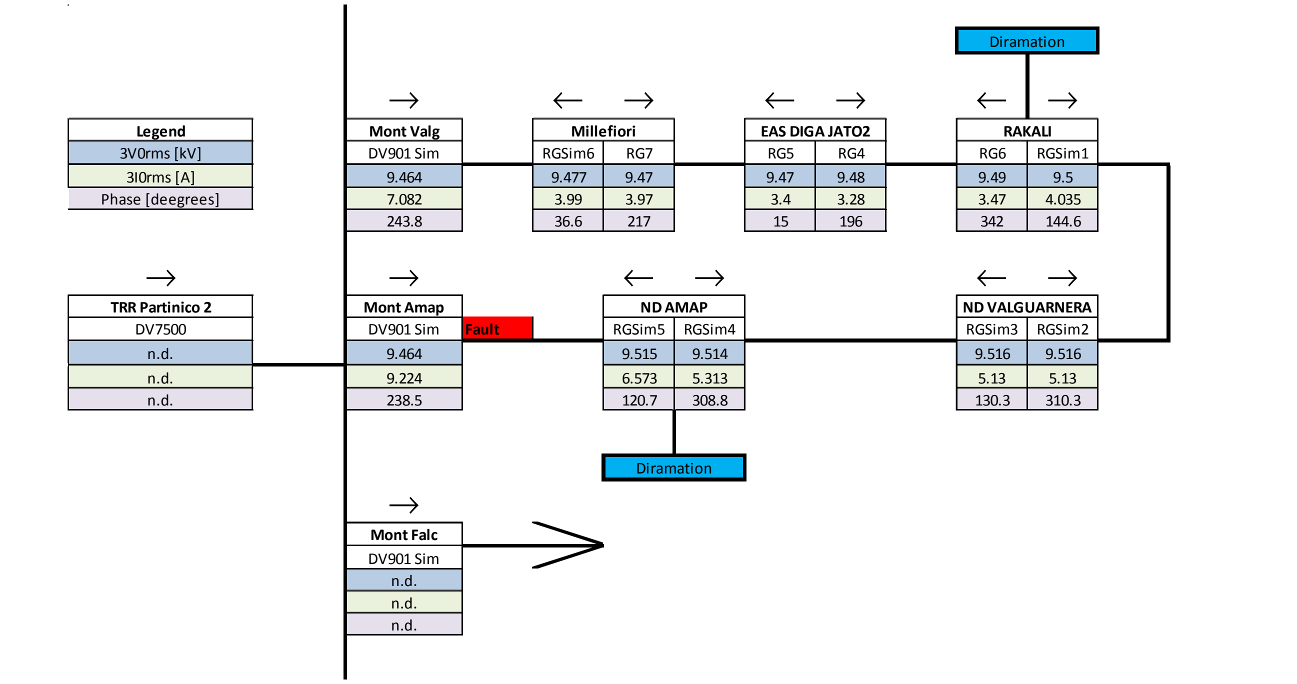

Figure 6. Partinico 2 POI-P4 RTDS simulation results.

quality of zero-sequence impedances values contained in the corporate databases. In fact these data was never used in the past thanks to the possibility to neglect it during LGF on radial grids. Thanks to the RTDS a lot of tests has been performed, in a completely safe mode.
Finally, thanks to the real field test session, a big comparison between simulation and real test results has been made and protection settings has been defined to operate the loop in permanent mode.

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