INNOVATIVE PROTECTION SYSTEM ON DISTRIBUTION NETWORK

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ABSTRACT

The paper describes an innovative method to implement the protection system of a distribution network foreseeing a closed-ring operation plant based on a Smart Grid architecture.

A closed-ring operation scheme requires an entirely new protection system in terms of fault detector devices, components, data communication infrastructure and central control system.

The installation remote terminal units in particular MV/LV substations, fault detector devices and circuit breakers enable to select rapidly a restricted part of network where the fault occurred.

INTRODUCTION

In conventional planning and design, Distribution networks are regarded as passive elements connecting the transmission system to final customers. Networks are operated radially in order to ensure unidirectional power flows, allowing simple protection schemes and devices. Generally MV networks are designed like an "open-ring" to ensure reverse supply in case of single fault.

The increasing amount of distributed generation connected to the distribution network has determined the change of planning, design and operation rules foreseeing closed-ring operation schemes for distribution networks. The adoption of "meshed" configuration and operation of network allows to obtain a better management in terms of voltage profile, power losses and continuity of supply.

Closed ring configuration allows a better management because each part of line has the same importance in terms of interruption; in fact for each kind of fault it will be possible to interrupt a restricted part of feeder avoiding the total amount of customers disconnection; for all customers the same risk of interruption will be ensured, improving SAIDI and SAIFI indexes.

This new structure and operation method of distribution network determines the need to develop and install a different protection system, which must be able to select rapidly electric faults starting breakers installed along the ring feeder.

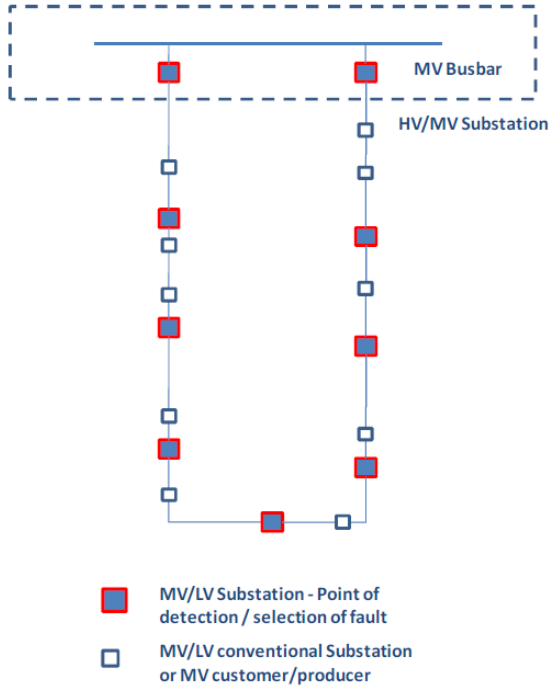

Fig 1: Scheme of closed-ring network configuration.

PILOT CLOSED-RING NETWORK

Enel Distribuzione is carrying out a project to realize an experimental closed-ring distribution network. Development and Planning network specialists identified a geographical area in Liguria, a region located in the north-western part of Italy, like described on the paper 571 session 5. In particular, the area where the meshed ring will be realized is a semi-rural and rural area with low density of customers. Distribution networks are, mainly, long overhead lines.
The feeders will be equipped with optical fibre to transmit the signals from a node to the other.

PERMISSIVE OVERREACH FUNCTION

In order to manage effectively a closed-ring network and to ensure a rapid selection of faults, avoiding interruption of a large number of customers, it was decided to adopt an innovative protection system based on typical HV techniques: Permissive Overreach (PO). During an electrical fault interesting a section of ring, fault detectors installed on each secondary substation equipped with PO

automation, will trip. In particular, referring at the following figure, if an electrical fault occurring between the nodes 5 and 6, protection tripped will be: 1, 3, 5, 6, 10, 12 and 14.

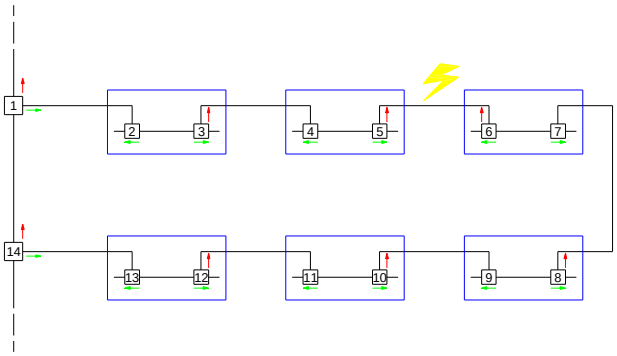

Fig 2: Fault selection by means of PO automation.

Directional intervention of protection produces the sending of an enabling signal from the protection tripped to the protection system directly facing. So, taking into account the example showed on the Fig 2, the protection systems that receive the enabling signal will be the numbers 5 and 6. Once received the enabling signal, automation units will control the opening the circuit breaker installed into the nodes 5 and 6.

PO system allows to select all types of electrical faults, in fact on the fault detectors will be implemented the following thresholds:

- 67N.S1 first to ground directional threshold (to select the single phase to ground fault on network grounded with impedance);
- 67N.S2 second to ground directional threshold (to select single phase to ground fault on network with insulated neutral);
- 67N.S3 third to ground directional threshold (to select the phase to phase through ground fault);
- 67.S2 second maximum directional current threshold (to select overload and short circuit with high impedance);
- 67.S3 third maximum directional current threshold (to select the short circuits with low and very low impedance);

If the nodes closer to the fault don't receive the enabling signal there will be no selection. In that case is necessary to foresee a back-up, defined: Back-up First Level (BFL), implemented into the remote control central system.
BFL function will operate just in case of failure of PO automation, sending commands to the breakers closest the fault, by means of the central control system. Coordination between functions PO and BFL will be realized with a determined delay time.

BFL function can be well represented by means of a matrix where the state of intervention of protections installed on each node of the ring is described on each column, while the threshold of protection is described on each row.

Taking into account the situation of Fig 2 and considering, for instance, a single phase to ground fault on a network grounded by impedance, there will be compiled the following BFL matrix:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
67N.S1	1	0	1	0	**1**	**1**	0	1	0	1	0	1	0	1
67N.S2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67N.S3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67.S2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67.S3	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 1 – matrix of BFL in case of single phase to ground fault.

Back-up function sends an opening command just to circuit breakers installed in the nodes 5 and 6, corresponding a couple of "1" state on the matrix (red highlight characters and masculine border of cell).

The condition to correctly identify the nodes to send the opening command, in case of failure of the local automation of protection system in PO, is to consider the cells of the BFL matrix which have been subject to a sequential change of logic status (from 0 to 1) as shown in Table 1

This allows to have a right coordination of back-up function, also when the sequence of intervention of protection system is not correct.
The following matrixes show typical cases of no right sequence of intervention:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
67N.S1	1	0	**1**	**0**	**0**	**1**	0	1	0	1	0	1	0	1
67N.S2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67N.S3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67.S2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67.S3	0	0	0	0	1	0	0	0	0	0	0	0	0	0

Table 2 – matrix of BFL in case of failure of the intervention of protection system during a single phase to ground fault.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
67N.S1	1	0	1	0	**1**	**1**	0	1	0	1	0	1	0	1
67N.S2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67N.S3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67.S2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67.S3	0	0	0	0	**1**	**1**	0	0	0	0	0	0	0	0

Table 3 – matrix of BFL in case of intervention of various thresholds of protection system during a fault.

On the Table 2 is shown the case of failure of the fault detectors closest of the fault section (between nodes 5 and 6). Central control system will command the opening of circuit breakers installed in the nodes 3 and 6, in fact for those nodes, on the BFL matrix have been respected

the condition of the passage from equal to odd of the numeration. This algorithm determines the outage of a larger number of customers (interruption of a larger portion of network), but ensures the actual selection of fault.

The Table 3 considers the case of activation of various thresholds of the protection systems installed on the secondary substations equipped of PO automation. In particular on the matrix is recorded the intervention of threshold 67.S3 and 67N.S1. These different thresholds are characterized by different time delays. In that case BFL commands the opening of the circuit breakers in nodes 5 and 6 considering the shorter time delay. BFL ensures the correct selection of the fault when the system of protection is not working correctly. In case of failure of communication data system, a further back-up, defined as Back-up Second Level (BSL), has been foreseen. The intervention of this third - and last - level of protection determines the outage of the total amount of customers supplied by the closed-ring. In fact the function BSL commands the opening of the circuit breakers installed at the starting and at the ending of ring feeder, on MV bus bar. BSL will have to be set with a delay time longer of BFL, per each threshold of protection system.

CONTINUITY OF SUPPLY IMPROVEMENT

In Italy, two standard indicators are used to evaluate the continuity of supply: average number (SAIFI + MAIDI) and average duration (SAIDI) of interruption per each LV customer.

Closed–ring configuration will guarantee an improvement in continuity of supply, reducing significantly the number and duration of interruptions.
In this way it will be ensured a longer continuity of connection for each kind of customers (MV, LV, producers, consumers) improving their satisfaction.

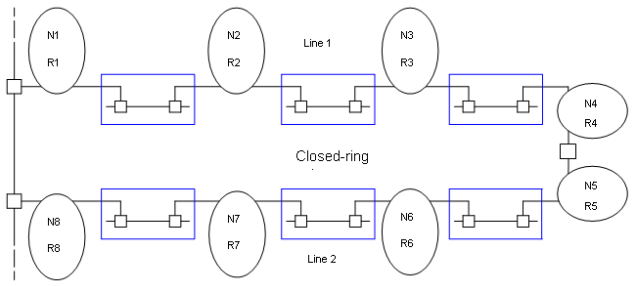

Fig 3: groups of customers between two secondary substations automated with MCD function on closed-ring network configuration

Taking into account the Fig 3, it is possible to evaluate the index of duration, and number, in case of operation in closed-ring or in conventional radial scheme. To compare correctly the continuity indexes in the two configurations, the two different radial circuits realizing the closed-ring must be considered: line 1 and line 2, each one divided into 4 electrical branches, can be connected to form a meshed configuration. In this way for every interruption it is possible to calculate the indexes of each individual line, no matter the operation scheme adopted.

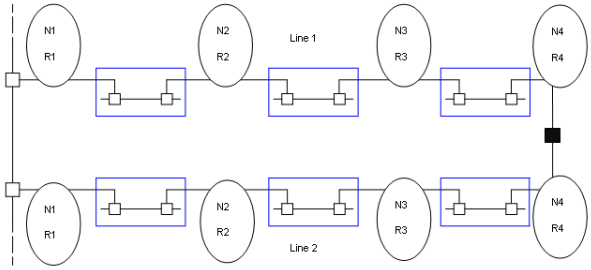

Fig 4: group of customers between two secondary substations automated with MCD function in radial configuration scheme. Separation of the network in two lines

The Index per each line (j =1 and 2) can be calculated according to the following math expressions:

$$Ind_{linej} = \frac{\sum_{k=1}^{M}(Ni \cdot Ind_{line})_k + C}{N_{linej}}$$

Eq 1: Closed-ring scheme per each single line

$$Ind_{linej} = \frac{\sum_{k=1}^{M}\left((\sum_{i=1}^{NB} Ni) \cdot Ind_{line}\right)_k + C}{N_{linej}}$$

Eq 2: Radial scheme per each single line

The advantage between the closed-ring configuration and radial scheme, taking into account the presence of the innovative protection system (PO automation), has be evaluated considering, per each interruption, the customer moment value, so:

$$\sum_{k=1}^{M}\left(Ni \cdot Ind_{linej}\right)_k < \sum_{k=1}^{M}\left((\sum_{i=1}^{NB} Ni) \cdot Ind_{linej}\right)_k$$

Eq 3: advantages of innovative protection system for closed ring operation scheme of distribution network

Through Eq 3 the potential benefit to realize a meshed network and install the innovative protection system with PO automation will be evaluated. The benefit will be compared with the development and maintenance costs.

NEW FACILITIES FOR A NEW NETWORK OPERATION

Closed ring networks, realized by means of innovative PO protection system, will guarantee several advantages for customers and for Distribution System Operators

(DSO).

Improved operation network. A closed-ring configuration increases the robustness of network, ensuring for all the time two ways of energy supply. The possibility to interrupt a restricted section of network, for fault or maintenance, allows to disconnect the producers for less time. DSO can provide a better regulation of voltage profile and finally, the structure can be used to foresee an active contribution of producers (dispersed generation) to network services.

Better quality of energy. An improving of voltage profile will increase customers' satisfaction about power quality.

Increasing of life duration of electrical components. The possibility to select the single phase to ground fault and phase to phase fault with a very low time of automation, determine a reduction of persistence of stresses and overvoltage on the electrical components of network, increasing their lifetime.

CONCLUSIONS

The comparison between traditional (radial) network scheme and proposed "meshed" configuration as described on the last chapters of this paper, highlight several advantages for customers and DSO, in terms of: customer's satisfaction and network operation. Enel Distribuzione is committed to this project as an enabling factor for the future networks (smart grids).

To fully take advantage of the described improvements of closed-ring networks a new protection system is the key.

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