TELECONTROL AND AUTOMATION ON ENEL DISTRIBUZIONE’S NETWORK: STRATEGY AND RESULTS

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INTRODUCTION

At the end of 1998 ENEL Distribuzione launched a medium term program aimed at improving the quality of service, reducing the operating costs and updating the technology of network components.

The planned activities are going ahead according to the program, and the obtained results are better than the foreseen ones.

This above-mentioned program is based on the following main projects:

- introduction of a new grounding system in medium voltage (MV) networks;
- remote control of MV/LV substation;
- automation of fault detection, isolation and service restoration procedures on MV network.

In this paper a brief description of the projects is given and the results already achieved are reported.

ENEL DISTRIBUZIONE NETWORK

ENEL Distribution MV Network departs from the HV (High Voltage) /MV substations (Primary). The HV level is 132/150kV and the MV is 10/15/20 kV. The neutral point in the MV network is usually isolated and each MV line, departing from the MV bus bars in the primary substations, is radially operated.

The MV/LV substations (secondary) along a MV line are supplied according to an input-output connection diagram; they lower the voltage to the standard value of 230/400 V in order to supply LV customers.

Thanks to a standardization policy carried out from the early time of ENEL foundation, each component of the network is standardized so as to adopt solutions valid all over the country.

Nowadays, the network figures are the following:
- primary substation: 1.800, all remotely controlled;
- secondary substation: 347.000 (138.000 of which are pole mounted transformers); Total length of MV lines: 330.000 km;
- total length of LV lines: 700.000 km.

NEW MEDIUM VOLTAGE GROUNDING SYSTEM

In order to lower the earth currents and, at the same time, to reduce the number and the average duration of outages due to earth faults on MV networks, in some HV/MV substations the neutral conductor has been connected to the earth through a special impedance (Petersen coil + resistor) [1].

This impedance, both fixed (less expensive) and variable (more expensive and with higher operational performances) is usually connected directly by means of a breaker to the neutral output of the HV/MV transformer secondary winding. The solution with variable coil is more complex for wiring and lay-out and requires a special control device (called DAN) to tune the impedance according to the variable capacity of the network.

The system, both with fixed and with variable coils, finally, is equipped with a monitoring device (MOIM) installed in connection with the existent Remote Terminal Unit in order to monitor the intervention (positive or negative) of the grounding system in correspondence of each earth fault for each MV line.

For each bar it is possible to switch from the compensated configuration to the insulated one and vice-versa. A special control device, called GSN, manages the status of the two networks (one for each bar) in the substation and allows the remote operation.

A new generation of protections (NCI series) for MV lines has been developed to obtain the full protection against earth faults in both configurations (isolated/compensated) of the neutral, of course.

This feature is obtained by adding several programmable thresholds and angular sectors of intervention.

Figures of One Year of Experience

Data are referred to seventy-seven MV bars for a working period of 43.1 month/bar equal to an average value of 5.6 month/bar.

Principles adopted in the analysis are the following:
- each bar is compared with itself in the same period of operation of the year before;
- to remove the effect of other sources of improvement (whether conditions, telecontrol, etc) from recorded data, improvements of service quality of the traditional substations in the same area and in the same period have been taken in account (subtracted).

Improvement in the number of interruptions (net values)
- transitory (duration ≤ 1s): - 48.46%;
- short (1s < duration ≤ 3m): - 45.54%;
- long (duration>3m): - 36.19%

Improvement in long duration interruptions per voltage level:
- all levels: - 36.19%;
The time was ripe for exploiting MV telecontrol because intervention on the network. As a consequence, it is decided to extend the connection to earth of neutral point to all the 20 kV and 15 kV busbars and the mobile network covered most of the areas of the country. At the end of 2001, after about one year of experience on seventy-seven MV bus bars, we realized that results had gone beyond the expectancies. Long duration interruptions caused by localised faults, mainly on solid insulators, cable joints, terminals and MV/LV transformers, showed a big reduction in number.

Improvement in long duration interruptions per category:
- 20kV: - 33.80%;
- 15kV: - 40.92%

Improvement in time duration of total amount of long interruptions:
- High density distribution area: -18.31%;
- Medium density distribution area: -26.54%;
- Low density distribution area: -14.40%;

Cost/Benefit Evaluation of Grounding of Neutral Point By Means of Reactance

Three different factors are responsible of the economical returns of the system:
- reduction of number of interruptions and, consequently, of the cumulative duration for LV customers (Σ n. int. * duration of the int.). This represent, in most situations, the major part of the economical returns, which are related to savings due to the improvement of the quality indexes established by Italian Regulator (called Authority). As a matter of fact Authority fixed penalties for values of indexes worse than the stated ones and bonuses for those better;
- reduction of periodic tests and intervention on earth plants. This factor represent the second component, in weight, of the economical return;
- reduction of use of personnel to localize the faults, due to the reduction in the number of interruptions.

At the end of 2001, after about one year of experience on seventy-seven MV bus bars, we realized that results had gone beyond the expectancies. Long duration interruptions caused by localised faults, mainly on solid insulators, cable joints, terminals and MV/LV transformers, showed a big reduction in number.

Taking into account the total cost of each installation and all possible benefits, the payback period of the investment is slightly higher than 4 years with reference to a typical substation (2 MV bars) equipped with variable coils, including the change in protection relays. As a consequence, it is decided to extend the connection to earth of neutral point to all the 20 kV and 15 kV busbars (over 2800 busbars), in the period 2002/2007.

MV NETWORK TELECONTROL

In parallel with the new grounding system in Primary substations, a bigger project started: the remote control and supervision of secondary substations [2]. This is a valid method to improve the quality of service in a relatively short time with respect to long-term structural intervention on the network. The time was ripe for exploiting MV telecontrol because the use of mobile phones has become economically viable and the mobile network covered most of the areas of the country.

The main goal of the project is to remotely control 80,000 secondary substations within the year 2004.

The main features of the System are the following:
- motorized on-load switch;
- low cost/high performance Remote Terminal Units;
- telecom modules based on GSM system;
- 29 Control Centers for all the territory.

Rtus for MV/LV Substations

There are different kinds of UP (Peripheral Unit) to operate signals, commands and, optionally, measurements. Each type can be equipped with a module to acquire and transmit 8 measures. The connection with the MV switchgears and the other devices in the substation is based on standardized cables and connectors to reduce the cost and the time of installation.

Each UP is equipped with a 24Vcc 25Ah lead acid battery (which provide also the energy for the motors) and with the battery charger. A special on-board DC/DC converter provides the power supply for the communication module (GSM mobile phone).

The application protocol is fully compliant with the IEC 870-5-101 profile except for a few modifications:
- to adapt the protocol to mobile communication system;
- to introduce spontaneous mode of connection.

Rtus are fully programmable through a PC based local configuration terminal, which can be used also for diagnostic. The application program and all the main important parameters are downloadable from the control center: that is a fundamental function to support quick and reliable software release and bug maintenance.

Telecommunication Subsystem

The key point of the project is the adoption of the existent GSM cellular network. ENEL Distribuzione developed and standardized by itself all procedures and criteria to:
- measure the Electro-magnetic field strength: well trained crews have been provided with a special tool (Windterm) based on a mobile phone, a portable PC and a special application SW;
- choose the right antenna and the right mobile provider in the area;
- monitor and maintain the efficiency of all the connections: a system based on special diagnostic messages coming from each GSM module has been set up.

GSM Module

A special integrated GSM module has been adopted in order to simplify the installation: in a plastic waterproof case a dual band cellular phone, a modem and a wafer antenna are assembled together. At the bottom of the case there are the RS232 interface, the power supply input and the connector for an external antenna. The module can be placed on the wall through a simple antenna.
basic working mode is the following: As far as the connection with the field is concerned, the authorized accesses means of a PC-Bridge, which acts as a wall against non-system LAN is connected to the company's Intranet by for the connections with RTUs. Multi-serial interface boards and ISDN modems are used been fully implemented. controlled HV/MV substations and MV/LV substations has The integration with information coming from the remote Control centers are based on powerful servers for operation and network configuration. The integration with information coming from the remote controlled HV/MV substations and MV/LV substations has been fully implemented. Multi-serial interface boards and ISDN modems are used for the connections with RTUs. To allow data export towards of f-line remote applications, the system LAN is connected to the company's Intranet by means of a PC-Bridge, which acts as a wall against non-authorized accesses. As far as the connection with the field is concerned, the basic working mode is the following:

- the control center according to a specific table of calls performs scheduled polling of peripherals weekly. Alarms are acquired by the operator and recorded in the daily electric service log;
- spontaneous calls originate directly from the peripheral when a severe alarm generates in the substation; this way of working is limited to alarms of particular gravity;
- at any moment the operator in order to acquire alarms, measurements or to send command on switches can launch a request of connection.

Of course, each alarm or command or change in open/closed status of the switches is displayed on the video diagrams and recorded in the log of the day.

**Costs/Benefits Evaluation**

Considering the total costs of the application, it is possible to disregard costs connected to control centers and to focus on costs connected to substation upgrades.
The total cost per substation is the sum of the following items:

- Motorized MV switchgears;
- RTU + battery;
- GSM module;
- Installation.

The total amount of the first version of the plan consists of 50.000 telecontrolled secondary substations corresponding to an investment close to 370 million €.

Of course, it is necessary to take into account also operational and maintenance costs per year.

Benefits have been evaluated taking into account savings coming from:

- the reduced penalty/increased bonus due to the quality of supply;
- the usual network operations that can be performed in a shorter time interval and a reduced number of crews.

The pay back period of the investment can be calculated as follows:

- with reference to the different components taking part in quality of supply (the re-supply of the healthy sections of the feeder and the number the customers connected to them), the reduction of the duration of long interruptions can be calculated as described in Fig. 1. In this drawing, different possible locations of fault are indicated. The percentages of Customers and faults on the main feeder and on the lateral branches of a typical MV ENEL feeder are derived from MEPR, which is the archive utilized for operation and planning of MV network. In the example under consideration (fault location=1), the introduction of pure telecontrol produces a reduction of cumulative interruption equal to 94,5%*LV feeder customers* 38 minutes, for a single long interruption (see TABLE I).
- with reference to the lower need of crews to operate manually on the disconnectors along the feeder, the average time needed for a single manual operation is about 40 minutes and a single crew consists of 2 men (average value).

Taking in to account the number and the localization of faults generating long interruptions, the average number of LV customers per feeder (1.000), the number of operations on the switches due to scheduled works and finally the number of remote controlled Secondary Substations, the pay back period of the investment, in the worst case, is shorter than three years (mainly due to the reduction of cumulative duration of interruptions).

**Figures at Midway and Evolution of the Plan**
Installations are in progress and at the end of October 2002 about 39,000 secondary substations are operated with telecontrol. To remote control pole mounted motorized switches the same RTU utilized for indoor applications is adopted. Of course a special waterproof case has been engineered to house electronics and batteries.

Moreover, a small number of reclosers (170) was installed, remotely operated by the same RTU engineered for pole mounted switches.

Waiting for complete reports on telecontrol applications, data already available show a real contribution to the reduction of duration in long interruptions larger then 15% with respect to the situation without any telecontrol application.

MV NETWORK AUTOMATION

Along the way of the reduction of time duration of interruptions, further improvement can be obtained by the introduction of network automation.

This word in ENEL’s jargon means the introduction of a system capable to operate fault location, isolation and service restoration automatically, without the intervention of man.

In case of large perturbation in the electric system of large areas, these techniques overcome telecontrol making possible the supply restoration on the healthy sections of the MV lines affected by faults, without any delay due to the operator's service time.

These techniques had been already adopted in the past, but, for not being supported by telecontrol, they often presented malfunctions or side effects that could not be quickly detected by the operators.

Apart from the synergy due to the overlap between automation and telecontrol, another synergy with the new grounding system adopted on MV network allows methods of automatic earth fault isolation not applicable before [4].

Fundamental Principles

Adopted automation technique is based on a group of automatons resident into the UP memory.

The actions performed by these automatons are based on the following local sensors:
- Voltage detectors;
- Fault detectors;
the timing sequences are calculated in such a way to be synchronous with the reclosing device installed in correspondence of the line circuit breaker.

The operator in the control center can program and enable these automatons for each switch disconnector along a line, activating on that the automatic procedure.

In case of a fault, the faulty section of the line is isolated and the supply is restored on the healthy sections located upstream the faulty one. The operator is alerted only at the end of this process, in order to manage the necessary repairs and to re-supply the healthy sections located downstream the faulty one.

More details on this matter can be found in [4].

REAL OPERATION RESULTS OF TELECONTROL IN LOMBARDIA

Operation results of telecontrol in Lombardia during first 10 months of 2002 confirm the theoretical analysis showing a reduction of cumulated duration higher than 20%.

The main features of MV network in Lombardia are:
- Number of MV feeders: 3,308
- Number of remote controlled secondary subs: 4,443
- Average extension of single MV feeder: 10,5km
- Cumulative duration (October 2002): 42,24 minutes.

For comparison, the average ENEL values are:
- Number of MV feeders: 22,512
- Number of telecontrolled secondary subs: 38,937
- Average extension of single MV feeder: 14,7km
- Cumulative duration (January-October 2002): 85min.

Lombardia’s MV network, therefore, has better performances with respect to the average performances of ENEL MV networks; in addition, time required for the first manual opening of a switch disconnector is about 30 minutes. As a consequence, the improvements achievable in most cases should be much more consistent.

Data from a survey, considering 2,096 long interruptions in Lombardia, show that the time needed for the first rough attempt to select a faulty line section (opening a switch-disconnector along the feeder after the definitive tripping of the line CB) without telecontrol is close to 40,9 minutes.

Since the same action by means of remote control is performed in about 8,2 minutes (average value), the improvement is more than 31 minutes for each long interruption.

The available data do not allow the calculation of the effective improvement in the cumulative duration of supply interruptions. Nevertheless taking into account:
- the average number of remote controlled SS per feeder: 1,34;
- the average number of sections per feeder (considering only the sections obtained dividing the feeder by means of remote controlled SS): 1,84;
- the average value of LV customers per section: ~ 580;
- the time reduction considering the first attempt of selection (opening of a switch in the middle of the line): ~ 33 minutes;
- the time to operate manually the first attempt: ~ 25 minutes;

the total theoretical reduction of cumulative duration obtained by telecontrol in Lombardia in 2002 should be higher than 18% (more than 9 minutes).

The real values show a reduction of cumulative duration higher than 16%, thus very close to theoretical one.

The reduction in terms of money in 2002 is slightly lower than 30% of the total investment made for telecontrol up to 2002.
Fig. 1: Diagram of a typical ENEL MV feeder

<table>
<thead>
<tr>
<th>FAULT LOCATION 1</th>
<th>OPERATING TIMES (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MANUAL (2 TEAMS)</td>
</tr>
<tr>
<td>1) Opening of CB (A)</td>
<td>0</td>
</tr>
<tr>
<td>2) First reclosure CB (A) (0,4-1 s) with negative effect</td>
<td>1</td>
</tr>
<tr>
<td>3) Second reclosure CB (A) (30 s) with negative effect</td>
<td>30</td>
</tr>
<tr>
<td>4) Opening of switch disconnector 1 in SS1</td>
<td>2400</td>
</tr>
<tr>
<td>5) Opening of switch disconnector 2 in SS1</td>
<td>2700</td>
</tr>
<tr>
<td>7) Closing of CB (A)</td>
<td>2410</td>
</tr>
<tr>
<td>8) Closing of switch disconnector 1 in SS1</td>
<td>2820</td>
</tr>
<tr>
<td>9) Closing of switch disconnector 2 in SS1</td>
<td>2940</td>
</tr>
<tr>
<td>11) Opening of CB (A)</td>
<td>2940</td>
</tr>
<tr>
<td>12) (Definitive) opening of switch disconnector 2 in SS1</td>
<td>2950</td>
</tr>
<tr>
<td>13) Closing of CB (A)</td>
<td>2970</td>
</tr>
</tbody>
</table>

Differences [min] 38,33 6,67

With manual operation (traditional) 94,5% of customers are supplied in 50 minutes
With simple telecontrol operation 94,5% of customers are supplied in 11 minutes
With automatised operation 94,5% of customers are supplied in 6 minutes

TABLE I: “Comparison of times for the selection of a faulty section”
(Manual selection, selection by remote commands, automatic selection)

In addition to this percentage, another 2% of total investment returns from the savings coming from switching operations due to scheduled works on the
As matter of fact, thanks to telecontrol, many of these activities can be performed without sending any crew on the field. Therefore the pay-back period is confirmed to be shorter than 3 years.

CONCLUSIONS

ENEL Distribuzione has planned important investments to improve the quality of service according to decisions made by the Italian regulator. Results coming from the last year are compliant with the expectancies, so the outlooks for the end of the program are promising. If the final balance will be as expected, the quality of service will be improved significantly towards the target of 115 minutes in the year 2003. That will confirm the correctness of the strategy, offering an important well proved experience to replicate wherever it is necessary.

11. REFERENCES


[2] Sergio Rogai - “Le scelte dell’ENEL Distribuzione per il telecontrollo e l’automazione della rete”, ANIE’s Meeting, Cagliari, September 1999
