POWER DISTRIBUTION NETWORK PLANNING IN A LARGE METROPOLITAN AREA

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INTRODUCTION

The new rules of the liberalised Italian electricity market have changed the assets of many distributors. Until 1999 the distribution of electricity in Italy was controlled by ENEL (the utility that held the virtual monopoly of power generation and transmission) and some local municipal utilities that carried out distribution activities in some cities.

In particular the city of Milan was supplied by two companies: AEM Elettricità and Enel. The EU Directive 96/92 has been implemented in Italy by Legislative Decree No. 79/1999 (the so called 'Bersani Decree'), which entered into force on 1st April 1999 and establishes that electricity distribution must be based on a single license (granted by the Italian Ministry of Industry and Commerce) in each municipality. The transfer of the ENEL’s Milan grid to AEM Elettricità was carried out in 2002.

This paper presents the main aspects of the new distribution network plan in which AEM Elettricità sets the necessary approaches in order to integrate two networks with different characteristics.

The main purpose of a network plan is to set how to develop the future plants in order to satisfy the increase of loads and at the same time to improve the continuity of supply and reduce operating costs. The new plan focuses on MV network and includes: a review of load forecast, the definition of the future network architecture and the forecast of the investments on new HV/MV substations.

Development criteria and future network architecture depend on the typical characteristics of electricity supply in a large metropolitan area. In particular, in the city of Milan, the electricity distribution is realized with cables. The realization of the new HV/MV substations and the granting of authorizations take a long time. Therefore long term forecasts for the development plans are necessary. The logic of the network development must take into account the improving of continuity of supply in order to comply with the rules stated by the Italian Authority for Electrical Energy and Gas (AEEG) and the efficient use of the existing plants in order to reduce managing costs.

This paper is structured as follows. In the first part we shall discuss about the different characteristics of the two networks and the planning criteria necessary for networks integration. The paper describes then the particular process of load forecasting. It is based on the information collected in the network data base. Load forecasts are used to set the geographical areas in which new HV/MV substations are needed. The selection of these areas depends on the geographical location of the loads and their growth but also on the possibility to find free empty spaces in the metropolitan areas and to obtain the necessary authorizations. In the third part load forecasts are used to set the scheduling of new plants.

THE TWO NETWORKS

In the following chapters we shall call network A the old AEM Elettricità network and network E the ex ENEL network. Tables 1 to 5 show the main characteristics of networks A and E.

<table>
<thead>
<tr>
<th>HV/MV</th>
<th>Net A</th>
<th>Net E</th>
</tr>
</thead>
<tbody>
<tr>
<td>N. 220/23 kV substations</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>N. 130/23 kV substations</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>N. 23 kV connections</td>
<td>10</td>
<td>70</td>
</tr>
</tbody>
</table>

TABLE 1 – Connections to HV grid and MV connections (to Enel).

<table>
<thead>
<tr>
<th>MV/LV</th>
<th>Net A</th>
<th>Net E</th>
</tr>
</thead>
<tbody>
<tr>
<td>MV [km]</td>
<td>1360</td>
<td>1350</td>
</tr>
<tr>
<td>23 kV</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>15 kV</td>
<td>760</td>
<td>0</td>
</tr>
<tr>
<td>9 kV</td>
<td>0</td>
<td>160</td>
</tr>
<tr>
<td>6 kV</td>
<td>0</td>
<td>2300</td>
</tr>
</tbody>
</table>

TABLE 2 – MV/MV substations (with possible MV/MV transformers).

There are some important differences due to different historical approaches to network development. The HV/MV substations connect the distribution network to the HV transmission grid. The managing of the HV grid in Italy is granted by GRTN, Gestore della Rete di Trasmissione Nazionale (the Italian ISO), a company formed by ENEL after the liberalization of the electricity market.

Part of the network E is connected to HV/MV substations located out of the metropolitan area. These substations have
not been transferred to AEM Elettricità. They supply power to the 70 connecting points showed in table 1. Table 3 shows that a large part of network A remains supplied at 9 kV. Table 2 shows another important difference. The number of A MV/MV substations is higher than the number of E MV/MV substations. These substations are called satellite substations. They are connected to HV/MV substations by groups of cables called transportation cables. The purpose of these cables is to transport power to strategic regions within the metropolitan area. This power is then distributed by MV distribution cables or transformed and, in turn, distributed with a lower voltage level (figure 1).

**NETWORK ARCHITECTURE**

**Generalities**

The definition of network structure is one of the most important topic of a network plan. The differences between network A and E show different historical planning criteria. In order to integrate the two networks and to set how to develop the whole network with a single standard, it is important to fix some rules. Network architecture affects the cost and the performances of the network itself as well as the continuity of supply.

**Planning criteria**

**MV cables planning.** Almost all the MV distribution network is made up of cables. This is one of the typical ways of supply in a metropolitan area in which there is a high density of load. In standard conditions MV cables are managed in radial configuration by sectionalizing at an intermediate MV/LV node. For this purpose two disconnecting switches are installed in every MV/LV substation. In emergency conditions, with the right relocation of the sectionalizing, it is possible to separate the faulted piece of cable from the network while the remaining MV/LV substations continue to be fed. MV cables originate at one HV/MV substation and terminate at an adjacent one. Each cable supplies several MV/LV substations as shown in figure 2. This network, which is thicker in high load density areas, covers the city.

![FIGURE 1 – Schematic diagram of network A.](image)

**Length of MV cables.** The connection between MV/LV substations must be carried out following the shortest route in order to reduce costs.

![FIGURE 2 – Schematic diagram of MV cables and MV/LV substations.](image)

Figure 2 shows a typical scheme of a MV/LV substation. The position of the sectionalizing along a MV cable is set in order to reduce the voltage drop and power losses on the cable. If the load is uniformly distributed, the position of the sectionalizing is in the middle of the cable. We shall call feeder the part of a cable between a HV/MV substation and an open disconnecting switch.

**Load of MV feeders.** MV feeders load must not cause an out of standard voltage drop. At present the extent and the load density of the metropolitan area assure the absence of voltage drop problems.
The total load of feeders should be around 50% of their capacity. This kind of feeders loading increases the cost of the network, but it improves the continuity of supply. During fault or maintenance it is in fact possible to supply a feeder from the adjacent one (see figure 4).

Moreover, in case of unavailability of a HV/MV substation, it is possible to supply the MV network connected to the faulted (or on maintenance) HV/MV substation through MV feeders which are connected to the adjacent HV/MV substations.

**Number of MV/LV substations per feeders.** Too many MV/LV substations per feeder mean, in general, a high number of customers supplied by that feeder. The number of customers per feeder must not exceed a definite value in order not to increase sharply the continuity of the supply indicator in case of fault. This indicator is set by the AEEG and consists in the total annual duration of interruptions per customer for long interruptions and for LV customers. The AEEG sets [2]:

- the targeted level of the indicator;
- the conditions for recognition of costs to the distribution companies in case of additional improvements in the continuity of supply;
- the penalty in case of negative improvements in the continuity of supply.

The choice of the number of customers per feeder should optimize the continuity of supply without causing an excessive increase in the network costs. Figure 5 shows how to improve feeder load and feeder number of customers through easy works; the MV/LV substation “a” can be easily moved to cable 2 thus reducing the load and the number of customers of cable 1.

**Cable supply.** MV/LV substations must be connected by at least two HV/MV ones. Figure 6 shows a cable supplied by one HV/MV substation. This is the typical situation of feeders that supply load around the suburbs of the city. Such situation may be improved by linking the MV cable with another HV/MV substation (see figure 6) so that the unavailability of a HV/MV substation can be supplied by the other one.

**Capacity of HV/MV substations.** The design of new HV/MV substations must consider that the HV/MV transformers must be able to supply load in case of an unavailability (during faults or maintenance) of one adjacent HV/MV substation. In such cases the transformer supplies part of the MV network that, in standard conditions, is connected to the unavailable substation.

**Network structure and MV/MV satellite substations.** Several reasons require the construction of satellite substations such as:

- the difficulties in building HV/MV substations in the centre of the metropolitan area;
- the lack of HV points of supply within the metropolitan area;
- the low cost of a satellite substation with respect to the cost of a HV/MV substation.

However the performance of satellite substations schemes is not worth in particular situations such as:

- in case of a MV bus bar fault;
- in case of a transmission cable fault when another transmission cable is not available.

The network scheme with satellite substations also involves a particular network managing during faults as well as in not standard network conditions. The possibility to connect networks A and E and the new HV/MV substations forecasted in the plan provides the chance to no longer use the MV/MV satellite substations. In the new network architecture MV cables originate at one HV/MV substation and terminate at an adjacent one. With the new structure (fig. 4) it will be possible:

- to improve the management of the MV network especially during faults;
- to make an easier coordination of the protection system of the cables;
- to improve the continuity of supply;
to reduce maintenance costs by reducing the number of
plants.

**Uniform voltage level for MV network.** The future
investments will normalize the voltage level of the network.
The new network plan sets the transfer of the 9 kV and 6 kV
loads to the 23 kV network through the transformation of the
MV/LV substations. These investments will allow to:

- reduce maintenance costs;
- improve the continuity of supply. The fault rate of the 9
  and 6 kV network is higher than the 23 kV one because
  of the obsolescence of the materials.
- To increase the efficiency of power distribution by
decreasing power losses;
- to improve the management of the store by reducing the
  number of spare parts;
- to upgrade the capacity of the distribution network in
case the transformation of MV/LV substations involves
the laying of new 23 kV cables.

**Remote control of MV/LV substations.** One of the most
important activities to improve the continuity of supply is the
remote control of MV/LV substations. The future plan sets
the automation of the MV network by choosing the
disconnectors of MV/LV substations that have to be remote
controlled. The remote control system shortens the time to
locate the faults on MV feeders and, in case of unavailability
of a HV/MV substation, it shortens the time necessary to
restore the supply of all the MV feeders from the adjacent
HV/MV substations. The use of a planning software [1] will
help to choose the MV/LV substations. Such substations must
be remote controlled in a feeder in order to reduce the total
duration of interruptions per customer in case of fault.

**Network supplied by ENEL.** The new plan sets the
necessary activities in order to gradually disconnect the MV
network from the HV/MV substations located out of the
metropolitan area. These substations have not been
transferred to AEM Elettricità. The objective can be reached
only with the availability of new HV/MV plants with which it
is possible to supply the 70 points of connections shown in
table 1.

### LOAD FORECAST

Load forecast is the first step to set the future network scheme
and in particular to set the location of the new HV/MV
substations [3]. Load forecast is based on the growth rate of
MV/LV substation power needs and it sets the increase rate of
loads in the metropolitan area. This process starts from the
measures of the loads of MV feeders. At network peak load
these measures are recorded in data bases. The load of each
feeder is allocated among MV/LV substations which are fed
proportionally to the power rate of MV/LV transformers and
to the contracted power available for MV customers. At the
end of this allocation a particular load is assigned to each
MV/LV substation. This load represents the substation power
need, and the sum of these loads for each MV/LV substation
corresponds to the network peak load.

It is now possible to divide the metropolitan area into regions
with a uniform load density. For this purpose the map of
Milan is divided into a grid. This grid consists of squares of 1
km per side. In network data bases each MV/LV substation is
linked to a square.

<table>
<thead>
<tr>
<th>Load density region number</th>
<th>Load density range [kW/km²]</th>
<th>Average increase rate of load [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;1000</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>&gt;=1000 &lt;4000</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>&gt;=4000 &lt;8000</td>
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<td>4</td>
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<td>4</td>
</tr>
<tr>
<td>5</td>
<td>&gt;=15000</td>
<td>4</td>
</tr>
</tbody>
</table>

**TABLE 6 – Average increase rate of load.**

The process described above is repeated. Power needs of
MV/LV substations are calculated on the network peak load
of the past years thus obtaining a different increase trend of
load for loads that belong to different load density regions
(tab. 6).

### DEVELOPMENT OF THE NETWORK

A load forecast can be obtained by increasing the present
MV/LV substations power needs with the increase rates in
table 6. Such process must also take into account particular
loads that do not follow the normal average increase. These
particular loads are due to the upgrading of old industrial
areas inside the city. They represent a discontinuity with
respect to the uniform increase rate of the load.

Figure 7 shows the metropolitan area and the regions with a
uniform load density on the 2003 peak load.

**FIGURE 7 – Load density on the 2003 peak load.**

It is possible to forecast the future network architecture by
describing the network with a simple scheme. Such scheme
originates from the above planning criteria and the results of load forecast. This scheme sets the future development of the network. It also defines the location and the transformer capacity of the new HV/MV substations, the upgrading of the existing HV/MV substations and the number of MV feeders supplied by HV/MV substations. The location of the new HV/MV substations depends on:

- the geographical location of the loads and their growth;
- the future possibility to gradually disconnect the MV network from the HV/MV substations located out of the metropolitan area;
- the possibility to find free empty spaces in the metropolitan areas and to obtain the authorizations.

**FIGURE 8 –** HV/MV substations forecasted.

Figure 8 shows the existing HV/MV substations as well as those which are forecasted for the next ten years. Moreover, the figure shows the HV/MV substations located out of the metropolitan area that have not been transferred to AEM Elettricità (“E” substations).

**SCHEDULING OF ACTIVITIES**

The comparison between load growth and the future network scheme allows us to know how many HV/MV substations have to be realized in the first part of the program. Figure 9 shows the result of the investments scheduling. The need for new HV/MV substations and the total capacity margin of the HV/MV transformers comply with the growth of power needs in the metropolitan area. The scheduling of the investments on the MV network is set in conformity with the future network architecture. The investments will follow the planning criteria described above. The main activities will regard:

- the upgrading of the obsolete plants;
- the improving of the continuity of supply;
- the development of new plants.

**FIGURE 9 –** Transformer capacity and peak load forecast.

On the basis of the investments scheduling it will be possible to define the activities which will form the three and the five-year-budgets. The activities which will form the basis of the three-year budget are particularly critical especially as regards the granting of the authorizations. The five-year budget will plan the activities that must be carried out in the short run.

**CONCLUSIONS**

The new scenario imposed by the liberalization of the electricity market has forced AEM Elettricità to set the approaches to integrate two distribution networks. The need for integration has been the chance to review some old planning criteria and to set a single standard to develop the whole network. The new network plan gives the general rules to develop the network and it sets the scheduling of the most important investments. The plan will be periodically reviewed and updated on the basis of the effective load growth and on the change of the rules imposed by the AE EEG.

**REFERENCES**

