BENEFITS OF THE MODERN ENERGY METERING SYSTEMS FOR THE DISTRIBUTION NETWORK PLANNING AND DEVELOPMENT PROCESSES WITH THE DIFFUSION OF DISTRIBUTED GENERATION.

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ABSTRACT

Load and energy flow forecasting in the distribution network is a fundamental step of the electricity grid planning process.
In this paper are illustrated the criteria and algorithms adopted by Enel Distribuzione, as developed and updated taking into account the legislative, regulatory and technical scenario.
Technological innovation of electronic measuring instruments, by which it is possible to refine the forecasts also considering the increasing presence of distributed generation on MV and LV networks, allowed a relevant progress in load forecasting.
In particular, the available measurement data allow development and implementation of a new forecasting methodology, based on separate assessment of the distributed generation contribution, just connected or expected, and of the evolution of passive loads consumption.
This methodology enables a more focused action plan on the MV network, including new HV/MV substations in order to meet the load or distributed generation power increases, or sometimes even both.

INTRODUCTION

Load forecast is one of the prerequisites for the establishment of plans for development of electricity networks.
This paper deals with the prediction of loads on MV and LV network explaining the criteria underlying the forecasts and the algorithms consequently adopted by Enel Distribuzione.
The reference scenario shows increasing complexity, given by the number of network owners, the introduction of the free energy market, more and more important by the presence of distributed generation, and finally by the continuing legislative and regulatory developments.
In this context, the methodologies developed by Enel and described in the article are based on the considerable opportunities offered by technological developments, with particular reference to instruments used by Enel Distribuzione for measuring energy and power.
These ones have made possible to refine the software "PRECAR" for the calculation of load forecasts, developed in collaboration with CESI.
Finally, the increasing of distributed generation on the electricity distribution network has required further implementations on the software, that would enable greater efficiency and reliability of the results obtained by the process of prediction of loads.

SOURCE OF MEASURED DATA

The HV grid which feed distribution network consists of a series of nodes, each one representing a HV network point (primary substations, HV users, power generating plants, points of interconnection with other DSOs) which deliver or take energy from the mains HV. Inside each node electric power metering devices are installed, identified as measurement points (PDM). A PDM can be the secondary winding of a HV/MV transformer, the point of connection of an HV user, the output of a power plant, etc.
Energy can be classified into two types:

- injected Energy: Energy flowing from Enel to other users or managers;
- absorbed Energy: Energy fed into Enel grid.

The direction of energy is defined by the direction of active energy.
The PDM measures every 15' the active and reactive energy flowing in both directions. The measuring points (and therefore nodes) involved are classified as follows:

- primary substations (PS);
- delivery points;
- HV users;
- HV power plants.

For the calculation of forecasts and the identification of critical issues, only the load data of the PS are assessed in order to make forecasts of the MV/LV network underlying any transformer which is installed in the PS itself.
All the PDM installed in the PS of Enel are bi-directional, so they can measure the energy flowing between the MV and the HV network and discriminate the current sign.
The measured parameters are:

- Active energy absorbed/injected into the Enel network;
- Inductive reactive energy absorbed/injected into the Enel network;
- Capacitive reactive energy absorbed/injected into the Enel network.

PRECAR

In 2004 Enel developed a software that, according to the load data measured every 15 minutes by the meters

installed in primary substations, make predictions and identify / report critical issues for the next decade.
PRECAR is a software which integrate components that interface with each other:

- off-line software “Forecast”: this software extracts the quarter-hour measures from the PDM, processes and loads them into a database called DB FOR; for each PDM the balance between the energy absorbed and injected is stored;
- DB FOR (historical data): database that contains energy and power measures of all meters managed by Enel Distribuzione, aggregated by node, province, region and national total, and processed on a monthly and annual basis;
- procedures to elaborate the load forecasts: based on historical measure data, the forecasts are developed for nodes (only PS), Provinces, Regions and the national total;
- DB PRECAR (provisional data): contains the results of the load forecast elaborations;
- PRECAR: intranet web site that allows viewing of historical data and forecasts, reports and graphs.

HISTORICAL DATA

On the basis of the measures, for each quarter-hour and for each PDM the active and reactive energy absorbed and injected is stored into the database.
Then, for each PDM and PS, the following parameters are calculated on a monthly and annual basis:

- active and reactive energy flown through the node;
- maximum and minimum active power and quarter-hours when they occur;
- maximum reactive power and quarter-hour when it occurs;
- maximum apparent power and quarter-hour when it occurs.

With similar process, the same parameters are calculated also for geographical entities (Regions and Provinces).
Annual energies of a give entity (PS, Province, Region) constitute the historical series for that entity. For network planning purposes, for each PS and for every year are also calculated the active powers simultaneous with the annual maximum and minimum regional power.

NATIONAL LOAD FORECASTS BASED ONLY ON HISTORICAL DATA

Load forecast calculations are mainly based on linear interpolation of the historical data (the current version of PRECAR considers the last 4 years of measures) in order to extrapolate energy and power values for the 10 years ahead.
In order to proceed with the interpolation some required conditions must be met:

- at least 3 complete years of historical data;
- energy flows in a given entity must not be constant for 2 or more consecutive year; in this case, method of interpolation is considered not applicable;
- fluctuation of energy flows over the years shall be within given thresholds; in fact in the case of transfers or acquisitions of network assets to / from other operators there may be strong variations of the energy flows such to affect the reliability of the algorithm.

If the above conditions are not met, following method ”A” will be applied.

A. Calculation methodology with historical series <3 years

If there is not a complete set of 3 years of historical data, or at least one of the criteria described above is not satisfied, the load growth rate is estimated applying a preset annual rate. This rate is generally set as the historical rate, previously calculated for the same Province, or on the basis of load evolution foreseen in the area, for example due to a new born industrial area. The same annual grow rate applies to all the PS of a certain Province.

B. Calculation methodology with historical series> 3 years

When required conditions are met, the following procedure is used.
The historical series of energy and maximum power is available for all the aggregated entities(PS, Province, Region and Enel Distribuzione network). Assuming that historical data can also be an indicator of what can happen in the future, the series may be the basis for the forecasting process. The prediction of energy values is performed by interpolation and extrapolation of the future series.
The forecast of annual active energy at different levels of aggregation is performed as follow:
1. extrapolation of future series of annual active energy, for all levels of aggregate;
2. tuning of the Province’s data extrapolations to fit the regional forecasts;
3. tuning of PS data extrapolations to fit the provincial forecasts.
Adaptations of the steps 2 and 3 shall ensure that for each year the sum of the estimates of PS energy corresponds to the prediction of the Province, and the sum of the forecasts for the province matches the predictions of the region[1].

Linear interpolation of the historical data

The typical function of linear interpolation is as follows:
$E_y = a + b \cdot y$
where:

- “a” and “b” are coefficients of the function derived from the series;
- “y” is the year for which load forecast is calculated.

The coefficients “a” and “b” are calculated using classical

1 Regions are subdivided into Provinces; location of PS is individuated through the Province where they are installed.

formulas for linear interpolation.

Evaluation of the results

A coefficient (the correlation coefficient ρ) is calculated in order to check if the interpolation represents with good approximation the measures' variability.

This coefficient can range from -1 (perfect interpolation with negative slope) to +1 (perfect interpolation with positive slope). Values near to zero indicate a poor interpolation. Acceptable values are for $\rho > 0.7$ at least.

Energy forecast for the primary substations

The algorithm for calculating PS' forecasts is similar to those shown above. The PS, however, remains critical as aggregate to the forecasting process. For this reason, a check on the results of the extrapolation and an admissibility range for the results have been introduced. A predicted value for active energy is considered acceptable if its change from previous year's value is between zero and 8%.

If any predicted value is outside this range, it is forced to the threshold.

At last, predicted values of PS energy are corrected on the assumption that the sum of the energy associated to PS of a province must be equal to the value of the energy associated to the same province for that year.

Forecasts of the Maximum Active Power

From the historical series, the annual energy and maximum active power (P_{max}) can be obtained for every past year. From these parameters it is possible to obtain the average hours of use of P_{max} (the hours of use in a year are given by the ratio of the active energy and the maximum active power of that year).

Predictions of Maximum Power for the year n + i are obtained by dividing the expected value of annual active energy E_n + i to the average hours of use, calculated above.

In the event that the hours of use of the P_{max} values have historical ups and downs, there may be cases where the elaboration provides an estimate P_{max} in the first year with a value very far from the trend of energy (opposite trend between P_{max} and energy). For these cases, a control algorithm, that will use the hours of use referred to the last historical year, was developed.

This methodology is applied at the regional, provincial and PS aggregates.

ASSESSMENT OF THE CRITICAL HV/MV SUBSTATIONS

One of the main objectives of the load forecast process is to detect and highlight the critical nodes in both present and future, anticipating the demand growth for electricity and thus the need for power available on PS.

To assess the criticality of a node the following parameters are took into consideration:

- the 98th percentile, on annual basis, of the apparent power flowing through a PS (Papp98);
- the sum of the rated power of HV/MV transformers belonging to the PS (∑PnPDM);
- the value of power resulting from the difference between ∑PnPDM and the highest rated power of the transformers installed in PS.

The 98th percentile of the apparent power has been chosen in order to eliminate, from the evaluation, non standard operating conditions of the network, for example due to faults or out of service for maintenance, during which the PS sees an additional load flow compared to its standard, with the result of having higher P_{max} measured.

The critical nodes are detected with the following criteria:

Number of HV/MV transformers in PS	Condition
1	Papp98 > Pn
2	Papp98 > 130% * min Pn (min Pn is the lowest Pn between the 2 transformers)
N	Papp98 > 130% * Σmin Pn (Σmin Pn is the sum of the lowest N-1 Pn of the transformers)

REGIONAL FORECASTS WITH FUTURE WORKS PLANNED

The national forecast is based on historical data measured by the PDM, and its aim is to identify the critical nodes. Network planning is a prerogative of the DSO who, according to the criticalities found by the software, can perform a multi-year development plan for the network.

PRECAR allows to simulate following works:

- redistribution of loads between neighboring PS;
- enhancement of existing PS increasing the power and / or the number of transformers;
- new PS, reducing the load of neighboring PS already in operation; permanent out of service of a PS in operation, thereby increasing the load in neighboring PS.

Once inserted some new works in PRECAR, it is possible to run a new load forecast process in order to verify, through a dedicated "criticalities report", if planned operations are sufficient to resolve overload issues on the network or if further actions are needed. These forecasts are the result active energy's extrapolation of PS in the last historical year available, according to the provincial rate calculated on a historical basis (or given by the user if necessary) and processed according to the planned works which affect PS already in operation.

For the new PS, the active energy is calculated according to the input of the user which reflects the predicted load conditions.

AN EXAMPLE OF FUTURE LOAD SCENARIO PERFORMED BY PRECAR

The following figures show two examples of simulation results achieved through the use of the software "PRECAR", which can be very useful in order to properly planning future works on HV/MV substations of Enel Distribuzione.

Figure 1 shows, for each region, the expected load annual average increase, expressed in percentage terms of load. Based on these results, it is possible to perform focused analysis in order to determine whether the PS, currently in operation, are able to carry, on a given time period, the expected load.

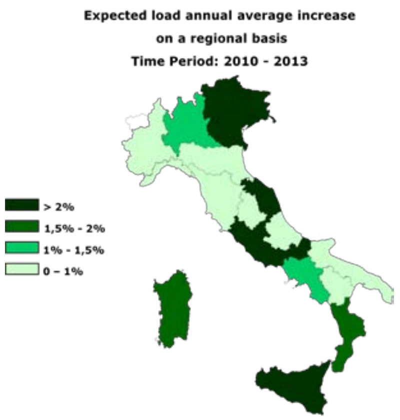

Figure 1

In this way, as Figure 2 shows, it is possible to calculate the percentage of PS that are likely to become "critical", i.e. those substations that, probably, during the specified period will be subject to a degree of transformers exploitation higher than 65%, with reference to the total rated power installed in that particular substation (for simplicity the value of 65% is referred to the case of substation with two same-size transformers)

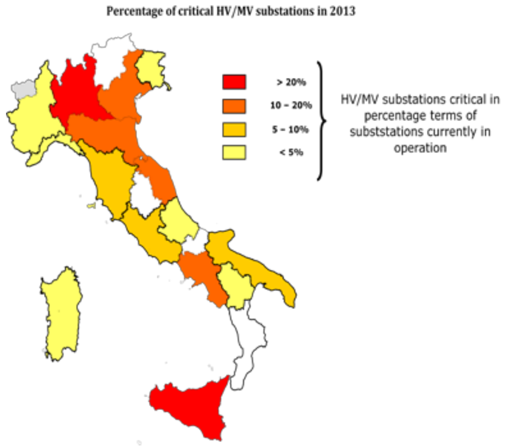

Figure 2

Once obtained the list of critical HV/MV substations, all the necessary actions can be made to solve such critical aspects: for instance, a solution can be the higher sizing of the transformers currently in operation or, if necessary, even the building of a new HV/MV substation.

FUTURE DEVELOPMENTS: THE INFLUENCE OF DISTRIBUTED GENERATION

The large increase of distributed generation (DG) on MV and LV networks in terms of generating capacity, really noticeable in some areas, is no longer negligible in order to develop new network planning criteria and, consequently, further software updates to support the process planning. For instance, in some cases, DG "helps" the network by means of feeding loads at the same voltage level to which it is connected, thus unloading lines and transformers. However, DG from renewable energy sources, for its nature, is not predictable and, nowadays, not even dispatchable: this makes power and energy flows forecasting more complex and complicated.

Moreover, as the amount of generation tends to be equal to the amount of power loads to be fed in a MV networks underlying to a PS, or even in case of energy transmission to high voltage levels, the presented load forecasting methodology reduces its validity, just because PDM is not capable of distinguish the energy produced by DG from the load energy consumption (PDM just see the energy balance).

Therefore, is under development a further application update, so that "PRECAR" will be able to properly consider just the contribution of DG energy production, in order to forecast the end users effective energy consumption.

Through the collection of DG plants data (namely rated power and identification of MV network to which they are connected) and the monthly trend of energy production (estimated from the average hours of use, depending on the specific source of generation), it will be possible to calculate the annual total amount of energy produced by all the DG underlying to a single PS.

Then, this value will be added to the total annual energy measured by the PDM, in order to obtain an estimates of the annual load historical data.

At this point, the linear extrapolation algorithm previously described can properly be applied and, therefore, load forecasting variations can be suitably calculated.

Once the described procedure is completed, the load forecast data will be integrated considering the contribution of DG, either already connected in the network or not (i.e. connection requests still in progress).

Through the methodology briefly described in this article, it will be possible to consider both the contribution of the DG (already connected or not) and the natural evolution of the load, in order to detect critical aspects and, therefore, to take the necessary countermeasures by means of planning of works to be provided on the network.