LOAD CRITICALITIES DETECTION ON HV/MV SUBSTATIONS IN MULTI-COUNTRY SCENARIO

Gianluca PALUMBO
Enel S.p.A. – Italy
gianluca.palumbo@enel.com

Simonetta MOREL
Enel S.p.A. – Italy
simonetta.morel@enel.com

Gregory BRUNO
Enel S.p.A. – Italy
gregory.bruno@enel.com

Francesco VIAPIANA
Enel S.p.A. – Italy
francesco.viapiana@enel.com

Carlos F. GOMEZ-ARBELAEZ
CODENSA - Enel – Colombia
carlos.gomeza@enel.com

ABSTRACT

Power load forecasting is an essential step in the network development planning process, being the base for the prediction of potential network saturation criticalities.

The goal of this paper is to show a new methodology, developed by Enel Global Infrastructure and Networks, in order to identify future saturation criticalities on HV/MV Substations, in a worldwide scenario.

Over the past few years, the Enel Group has modified its organizational structure, defining global divisions, in order to improve its cost-effectiveness in all countries where the Company operates.

This new global scenario needs a unified methodology that works in the same way in all Enel's distribution companies and that aims to detect future saturating criticalities on HV/MV Substations in standard configurations (N Condition - all elements available) and in a modified one due to one element unavailability (N-1 Condition).

The output of this methodology (detection of future criticalities) represents one of the most important inputs in the global CapEx allocation process.

INTRODUCTION

One of the main activities performed in the planning process of a Distribution grid is the identification of High Voltage (HV) network and HV/MV substations criticalities, throughout a midterm planning horizon (5 years). Thus, a reliable load forecast models is necessary in order to predict, with enough accuracy, overload network problems and Distributed Generation (DG) evolution [1].

After the identification of criticalities, the next step is to evaluate the interrelated risks and prioritize overload problems in order to identify the best works that will solve them. The proposed actions are one of the most important input elements for the CapEx allocation process.

One of Enel's Global Infrastructure and Networks challenge is to define methods and systems able to work in a multi-country scenario. The Global context, with more companies in different countries and heterogeneous conditions (environmental, technical, etc.), requires the development of a unified power load forecast methodology supported by statistical models.

A unified forecasting model, on a worldwide context, permits the use of the same planning criteria to identify network criticalities while supporting the Global CapEx allocation process.

To accomplish the HV network criticalities identification, it is necessary to forecast the future peak power load at a regional level. In the proposed methodology, three main models are used:

- Non-linear multivariable regression [2];
- Autoregressive integrate moving average (ARIMA) model;
- Linear regression model.

The best prediction has to be selected taking into account historical peak power behaviour analysis and the statistical indicator MAPE (*Mean Absolute Percentage Error*).

The forecasted peak load, at the regional level [2], is the main input to perform load flow analysis on HV network and at the same time represents an important information to validate load prediction at HV/MV level.

Furthermore, according to the proposed methodology, in order to evaluate HV/MV Substations (SS) criticalities, the following step is to foresee the maximum load of each HV/MV substation. Growth rate is calculated considering last three years peak power of a SS by a geometric average. Later, to calculate final growth, not predictable loads have to be added.

The last step is to evaluate if the forecasted load exceed the rated power of a transformer (saturation problem).

For each identified criticalities, in standard configuration (with all the elements available – N Condition) and in a modified configuration (due to one element unavailability – N-1 Condition), a risk parameter is calculated in order to prioritize the criticalities and propose works that will solve them while including them in the CapEx Allocation process.

The following picture resumes all the proposed methodology.

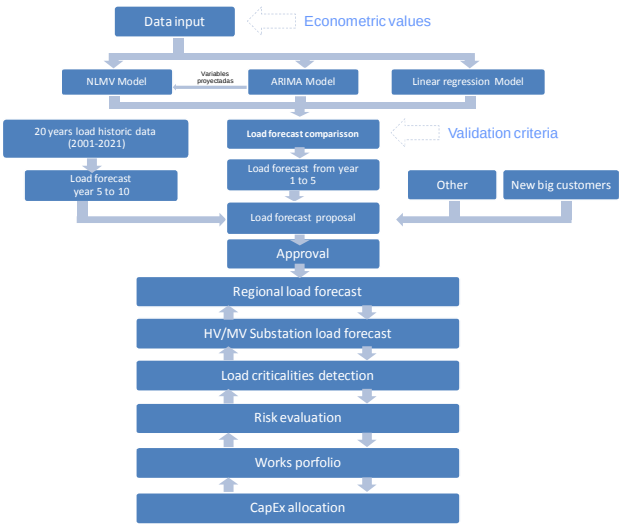

Figure 1 Multi-country criticalities detection methodology

GLOBAL LOAD FORECASTING MODELS

In order to detect future network criticalities on HV network, power flow calculation needs the future maximum peak power absorbed by a region (Italy, Romania and Spain) or from an entire Company (Argentina, Brazil, Chile, Colombia and Peru). Furthermore, as explained below, this Global power prediction represents an input for HV/MV substations criticalities detection.

To satisfy different needs due to a heterogeneous scenario (environmental, technical, etc.), the proposed methodology uses three global forecasting models:

- **Non-linear multivariable regression model [2]:** the model identifies statistical correlation between historical peak load and a set of historical macroeconomic variables. The resulting equation is used to foresee global maximum power using, as input, forecasted macroeconomic variables (provided by official institutions or from ARIMA forecasts);
- **Autoregressive integrated moving average (ARIMA):** is one of the most general models for forecasting a time series. ARIMA is an autoregressive (AR), integrated (I) and moving average (MA) model.
- **Linear regression:** it is the simplest forecasting model. The model seeks, through a linear relationship of two variables, peak power load and time (year), forecasting future peak load as a function of incoming years.

New HV customers and others relevant loads

The prediction provided by statistical models is integrated by two inputs:

- Forecasted peak power of new HV customers;
- Forecasted peak power of new relevant loads (i.e. massive installation of charging point locations for electric vehicle).

The statistical models cannot directly estimate the load growth related to these two factors, due to the lack of historic data information about them. Thus, the percentage increase produced by new HV customers or others relevant loads will be separately estimated and afterwards added.

Region peak power growth rate

The region peak power growth rate ($GR_{Region_k,n}$) is calculated as follows:

$$GR_{Region_i,n} = \left(\frac{P\_max_{Region_i,n}}{P\_max_{Region_i,n-1}}\right) - 1$$

Where:
$P\_max_{Region_i,n}$ is the region i peak power load at year n;
$P\_max_{Region_i,n-1}$ is the region i peak power load at year $n-1$.

HV/MV SUBSTATIONS MAX POWER LOAD FORECASTI

The forecasted max power load ($Pmax_{k,n}$) of an HV/MV substation can be described through the following formula:

$$Pmax_{k,n} = Pmax_{k,n-1} \cdot \left(1 + GR_{k,n}\right) + P\_new_{k,n} - P\_switch_{k,n}$$

Where:
$Pmax_{k,n-1}$ is the last historical maximum power load of substation k;
$GR_{k,n}$ represents the growth rate of substation k for the forecast year n and calculated as shown in the following paragraph;
$P\_new_{k,n}$ is a not predictable load of substation k forecasted in year n;
$P\_switch_{k,n}$ is a new load assigned to substation k that comes from another HV/MV substation; this factor could be positive if the substation k receives this load, otherwise is negative.

These three factors will be described with more details in the following paragraph.

HV/MV substation Growth rate

The growth rate of each HV/MV substation is evaluated by a geometric average formula. The substation growth rate considers last 3 years of its maximum power load, last 3 years of the region peak power where the substation belongs and the region growth rate for year n. Thus, the estimation of future load is based on substation and region recent behaviour.

$$GR_{k,n} = \frac{\left(\frac{P\_max_{k,n-1}}{P\_max_{k,n-3}}\right)^{1/2}}{\left(\frac{P\_max_{Region_i,n-1}}{P\_max_{Region_i,n-3}}\right)^{1/2}} \cdot \left(1 + GR_{Region_i,n}\right) - 1$$

$GR_{k,n}$ is the geometric average growth rate considering the maximum power load for the HV/MV substation k;
$P\_max_{k,n-1}$ is the maximum power load of substation k in year $n-1$;
$P\_max_{k,n-3}$ is the maximum power load of substation k in year $n-3$;
$P\_max_{Region_i,n-1}$ is the peak power load of region i where substation k belongs in year $n-1$;
$P\_max_{Region_i,n-3}$ is the peak power load of the region i where substation k belongs in year $n-3$;

According to the proposed methodology, planner can modify the estimated growth rate if a detailed explanation is available.

Additional load allocation and load switching

As well as previously described, the growth rate is based on historic behaviour of a HV/MV substation, thus this model cannot predict future loads that haven't any connection with the past. An example of this load typology could be a massive installation of charging point locations for electric vehicle. In this case, the HV/MV substation must be selected according to where this load will be connected ($P\_new_{k,n}$).
Furthermore, a load switch between two or more adjacent substation is not included in the growth rate. For these reasons the planner has to define this changes for each substation ($P\_switch_{k,n}$). This action could be necessary when a transformer installed in a substation has a saturation criticality for a short time period. In this case it is not mandatory to upgrade the nominal capacity of the overloaded transformer but, if it is possible, move some loads to another SS without introducing overload problems. It is an effective low cost solution.

HV/MV SUBSTATION CRITICALITIES DETECTION

Network criticalities are assessed according to network development technical and network planning criteria.

The HV/MV substations are considered with the existing transformers, and with the new transformers foreseen in the latest approved investment plan for the year n.
In N condition, the HV/MV substation must be able to fulfil the entire power demand with no network element overloaded. The saturation level in N condition is calculated as follows:

$$S_{N,k,n} = \frac{Pmax_{k,n}}{\sum_{j=1}^{J} NCT_j}$$

Where $S_{N,k,n}$ is the saturation level in N condition of HV/MV substation k at year n and NCT_j is the nominal capacity power of the j-th transformer installed in the HV/MV substation k.

In N-1 condition, the HV/MV transformer can be overloaded, thus the maximum HV/MV transformer load in N-1 scenario is equal to the rated apparent power (NCT) increased by an overload factor s.
So, in N-1 scenario for a HV/MV substation with n transformers, the $Pmax_{k,n}$ value is equal to the maximum load that can be supplied in case of a fault on the max size transformer:

$$S_{N-1,k,n} = \frac{Pmax_{k,n}}{\sum_{j=1}^{J-1} NCT_j \cdot (1 + s_j) + RMT_{k,n}}$$

Where:
$S_{N-1,k,n}$ is saturation level in N-1 condition of HV/MV substation k at year n ;
s_j is the overload factor of the j-th transformer;
$RMT_{k,n}$ is the supply restoration level, equal to the sum of the loads that can be re-energized by the outgoing MV lines from adjacent HV/MV substations.

$S_{N,k,n}$ and $S_{N-1,k,n}$ must be less than 100%, in order to accomplish the criteria specified above. If saturation levels are greater than 100%, the HV/MV substation is overloaded and presents a risk situation (criticality). The criticalities ranking is defined as in following table:

Rank N cond.	Saturation level $S_{N,k,n}$	Rank N-1 cond.	Saturation level $S_{N-1,k,n}$
C	100% – 110%	**D**	100% – 110%
B	110% – 120%	**C**	110% – 125%
A	> 120%	**B**	125% – 140%
		A	> 140%

Table 1 Criticalities rank

To solve detected criticalities it is necessary to identify the right works to be executed. The effectiveness of the proposed solutions to solve HV/MV substations criticalities will be checked individually in year $x+5$ (where x is the commissioning year scheduled for the project under examination) the associated criticalities will have to be resolved.

Risk evaluation

At this stage, all the reliability criticalities have been identified and classified.

Criticalities rank, defined above, are just used to define the shortcomings relative importance, but there is not an exact correlation between this rank and the potential effect on load or customers. Saturation level is evaluated through the relative value of the overload with respect to the rated capacity, thus providing a rough indicator of the risk of a failure or of a reduction in the service life of the overloaded transformer. Furthermore, an N condition criticality rank

is not directly comparable to an analogous one in N-1 condition. As a matter of fact, an N condition criticality is more alarming than an N-1, because the latter depends on the probability that the failure.

The potential effect on customers has to be individually evaluated for each criticality, in the form of the failed delivery of the demanded load, using the Capacity Deficit for N condition ($DC_{N,k,n}$)

$$DC_{N,k,n} = Pmax_{k,n} - \sum_{j=1}^{J} NCT_j$$

$Pmax_{k,n}$ is the maximum forecasted load of the analysed SS;
NCT_j is the nominal capacity power of the j-th transformer;

The Substation Capacity Deficit for N-1 condition ($SDC_{N-1,k,n}$) is calculated as follows for each N-1 critical substation:

$$SDC_{N-1,k,n} = \sum_{j=1}^{J} DC_{N-1}[TR_j]$$

$$DC_{N-1,k,n}[TR_j] = max\left\{0, Pmax_{k,n} - \sum_{j=1}^{J-1} NCT_j\right\}$$

$DC_{N-1,k,n}[TR_j]$ will be zero if the fault of the j-th transformer doesn't originate a criticality.

To evaluate the associated risk to each criticality its probability of occurrence has to be estimated. As far as N condition criticalities are concerned, the event is 'certain' so $P_{N,k} = 1$. Furthermore, the probability of a N-1 condition criticality is the probability of the contingencies originating the criticality itself:

$$P_{N-1,k} = \frac{FpY \cdot AD}{8760h}$$

Where FpY is the number of faults per year, and AD is the average duration of the fault originating the contingency (hours).
The risk (R_N and R_{N-1}) associated to a saturation criticality or to a contingency will be calculated as the product of the impact on customers and the related probability.

Risk associated to N condition criticality, in MVA, will be:

$$R_{N,k,n} = P_{N,k} \cdot DC_{N,k,n} = DC_{N,k,n}$$

Risk associated to N-1 condition contingency, in MVA, will be:

$$R_{N-1,k,n} = P_{N-1,k} \cdot SDC_{N-1,k,n}$$

Saturation criticalities will be prioritized basing on the risk value. Being equivalent the risk value, N condition criticalities will override N-1 ones.

After prioritizing the saturation criticalities, planners must propose a project portfolio to the financial area in order to define the CapEx allocation associated to Load Increase category.

CONCLUSIONS

- Power load forecasting is an essential input in the planning process to take decisions, thus it represents the base to predict potential saturation problems on the network.
- Saturation criticalities will be prioritized basing on the risk value rather than the saturation level. The risk value depends on the event probability and its associated capacity deficit.
- A unified detection criticalities methodology in all countries ensures an optimization of the CapEx allocation process.

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