# INTEGRATED MODEL OF SPATIAL AND GLOBAL LOAD FORECAST FOR POWER DISTRIBUTION SYSTEMS

Claudio Marcelo BRUNORO
Sao Paulo University, Brazil
cbrunoro@uol.com.br

Fabio Sismoto EL HAGE
Daimon Engenharia e Sistemas, Brazil
fabioseh@daimon.com.br

Carlos César Barioni de OLIVEIRA
Sao Paulo University, Brazil
barioni@daimon.com.br

## *ABSTRACT*

*This paper presents the methodology and the application of a market study model based on Geographic Information System for electrical load studies. Through a proper GIS interface designed to show electrical variables in a geographical basis, the integrated forecast module enables the study of specific market variables, such as load densities, growth densities, migration vectors, gaps between capacity and energy projection and others that are essential for the strategic and tactic analysis in power distribution utilities.*

## INTRODUCTION

The proposal of this paper is to describe the methodology and the application of a market study model for spatial and global electrical load studies based on GIS (Geographic Information System), concerning energy consumption, power demand and other electric variables obtained by measurement and demand calculation.
The methodology application is directed to the consumer's market analysis in an power distribution utility, referring to planning studies for reinforcement, amplification and maintenance of the electric network and for demand and energy forecast at either levels: spatial and global. This method also allows the organization of electrical information in historic series, stored through a proper database design.
The model is based on the acquisition of external data, such as monthly measured values, daily load curves (hour-hour) in kW and power factors per supply point and distribution station, as well as geographical data such as consumption and number of consumers per class for each distribution transformer.
For the proper storage of imported data, the monthly maximum demand for each distribution station and supply point is identified together with the load curve related to that maximum demand value in a 24 hours basis. In addition, a typical monthly load curve is obtained, which represents the optimal multiple-correlated curve containing the most frequent profile observed within a month, named "strong form".
Global or spatial forecasting of a geographical or electrical entity in terms of energy consumption and maximum demand is performed by a time series build up. The used methods for consumption and maximum power forecast, concerning small areas (grid), geographic regions and substations are based on ARIMA (Box & Jenkins).
It is important to highlight that as the market forecast study is provided by a specific calculation module, designed for the forecast itself, it is not necessary to use any other statistical software.

## GENERAL PRESENTATION

The expansion planning should establish the capacity and the allocation of any future electrical components for the power distribution network. Usually, it is used the time series of the components load curves for the forecast of its demand. Another way to carry out this forecast is through the knowledge of the spatial behavior of the load which is associated with the equipment, as its probable evolution, through the models that consider the spatial load allocation [1].
Normally, it is required the use of computational tools which allow the load allocation in a geo-referenced basis. The auxiliary tools are generically named as Geographical Information Systems (GIS), which store the relevant information of each entity through different layers in a database [2].
In order to perform the spatial forecast of the energy demand, it is necessary to know three aspects of the power distribution expansion planning [3]: how the load is distributed geographically ("where"); how large is its size/magnitude ("how much"); and in which moment the load will be on this distribution with a specific magnitude ("when").
To accomplish the spatial load allocation, the utility region is divided in elementary cells (small areas), splitting the utility region in a grid with cells of 500x500 meters. These dimensions provided a suitable resolution for the forecast studies.
Generally, the model tries to support the several levels of the market forecast studies mainly. Through this model, the requirements of the regulatory and operational agencies from the Brazilian energy sector are respected, as the requirements of the utility company. These studies can be carried out in several different levels: globally (e.g.: energy marketing, tariff revision, revenue prediction); by supply point or distribution substation (e.g.: power distribution network planning) and spatially (e.g.: power distribution network planning)
The model presents a database with the geo-referenced data of the power network entities (for example: MV/LV transformer station, distribution substation, supply bus) and, consequently, the consumption and demand information

associated with these entities.

These electrical data are divided into two different groups: LOAD CURVE (daily load curve with the demand and power factor values of each supply bus and substation for each hour), and CONSUMPTION (geo-referenced data for the energy consumption per customer type, geo-referenced data for the demand, and consumption for the MV and HV customers).

## METHODOLOGY

In general, the Integrated Model for the Spatial and Global Load Forecast for Power Distribution involves the processes presented in Figure 1.

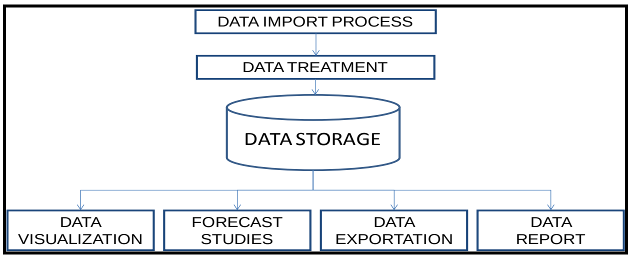


Figure 1 - Processes associated with the model

### Data import process

This process refers to the acquisition of raw data. In order to preserve the extractor efficiency, these data are provided according to the pattern determined by the protocol specification of the data import process.

For the data from the LOAD CURVE group, it is considered as relevant the values of the active demand and power factor measured for every hour and for each distribution substation and point of supply. For each one of them, the demand, power factor and time (hour, day, month and year) are imported for every single hour.

The data from the CONSUMPTION group are imported through the information that comes from the consumption monthly measurements. These measurements are taken from the MV customers and LV customers. The data are aggregated in each MV/LV distribution transformer. The data associated with the transformers are: its geographical position, distribution substation code which supplies each transformer, number of customers per type (residential, commercial, industrial, rural, others), monthly consumption (in kWh) per type of customer.

### Data treatment

After the data import process, the next step is the data treatment. So, the aim of this process is to assess the data consistency. Due to this characteristic, this process and the import module can be executed at the same time, or even depending on the user's request. The data consistency and its suitability is assessed according to pre-defined criteria

**Data treatment for the LOAD CURVE group**

Eventually, some measurements may present unexpected values or even wrong ones. So, through criteria that reflect the user's requirements, the consistency is assessed for the data of the LOAD CURVE group. This assessment is executed though two stages, where the first one is automatic and the second one manual.

On the following stage there is the extraction of the additional information. For each substation and point of supply the following data is obtained: maximum monthly demand (identification of the day and time for the maximum demand occurrence as its own value); monthly consumption (sum of the daily consumptions which were obtained through the conversion of the demand in a specific time to consumption, through the integration of the load curve area); curves – "strong forms" (load curve with the maximum statistical correlation with the most common profile observed in a month, and it is defined one "strong form" for each "type of day" i.e., week days, Saturdays and Sundays); and monthly loss in the sub-transmission system (difference between the sum of the monthly consumptions for each point of supply and for each distribution substation).

**Data treatment for the CONSUMPTION group**

After the data import process, the data from the CONSUMPTION group must the allocated spatially. So, the monthly data of the power distribution transformers are aggregated in each cell (basic geographical entity). Then, the total consumption is calculated for each cell and the load curve is determined for a typical day of the cell. The load curve for the cell is determined through a methodology that calculates load curve through the power demand. Differently from the load curve for the point of supply and for the distribution substation, this curve is not obtained through direct measurements of demand. Actually, this curve is obtained through the conversion of the measured consumptions into demands. This conversion is performed through the adjustment of the average monthly consumption into typical load curves [4].

### Data storage

For the data storage, the database presents an information hierarchy (Figure 2), which allows the analysis of these data in a spatial way, through its spatial entities, and in an electrical way.

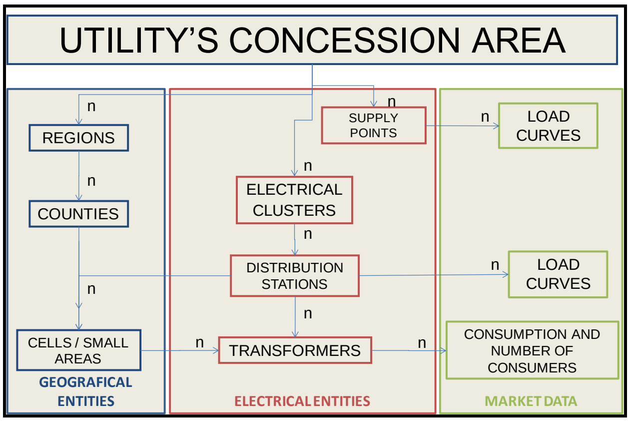

Figure 2 - Information hierarchy diagram

From the geographical point of view, the utility's concession area is divided into several regions. Considering the database structure, the concession area has several regions related to itself. It means that there is a relationship between the entities that represent the utility's concession area and the regions. This relationship is named "one-to-many" (or 1 to n). The same happens between the regions and the counties, and between counties and cells. The cells are the basic entity among the geographical entities of the power distribution company.
Considering the topology for the power network, the utility's concession area presents the following data hierarchy. It presents several point of supply through relationship "one-to-many". Besides that, this area also presents several electrical clusters through a relationship "one-to-many" which, by the way, present several distribution substations. In the same way, each substation presents several transformers, which will always be related with one substation. The transformer is the basic entity among the electrical entities of the power distribution company.
So, through this data hierarchy it is possible to execute aggregated queries for each geographical or electrical entity.

## Data visualization

Through the information store in the database it is possible to built up historical series which represent the evolution of the customer market of the utility. This series can be listed as follows:

- Monthly information: total energy consumption, consumption per customer type, load curves, global loss (difference between the sum of the consumption at the points of supply and the sum of the consumption in each cell), sub-transmission loss, comparison between the measured load curve and the one obtained through the "demand load curve calculation";
- Historical series: maximum demand per point of supply, total consumption, consumption per customer type, consumption per geographical entity and consumption per electrical entity;
- Growth rate (percent) and variations (absolute values) for the energy consumption (total and per customer type), for customer number (total and per customer type) and for maximum demand;
- Information for the forecast market studies: energy consumption prediction, maximum demand prediction, and prediction for the number of customers.

Besides that, it also possible to visualize load densities, growth densities, migration vectors, gaps between the capacities and the energy projections,
Além disso, é possível visualizar densidades de carga, densidades de crescimento, vetores de migração, lacunas entre capacidade e projeção de energia, previsões em regiões por classe de consumo e outros.

Depending on the information that is being requested for the visualization, its aggregation may be executed per geographical entity (cell, county, region, or utility's concession area), or per electrical entity (distribution substation, electrical clusters, or point of supply). This information may be visualized spatially, through thematic maps, or even through charts and tables.

## Forecast studies

For the power distribution company, the analysis of the market of energy consumption involves the consumption and demand forecasts. These forecasts should then be associated with a geographical region or even with an electrical entity. The forecasts could also be executed using different time intervals or time horizons, depending on the final purpose of the planning study, and on the requirements of each region of the utility's concession area.
The majority of the models used in demand forecast present the treatment of the historical series for the load of the consumption market (or for an electrical/geographical entity) as their starting point (single-variable model). Some of these models also consider the analysis of the time series for other data related with forecast study (multi-variable model) [5].
In a particular way, after the selection of the relevant information required by the study that will be carried out (such as the of the data that will be predicted, the period for the historical series that will be used in the forecast, the data that should be discarded during the study – e.g.: atypical behaviours, the forecast horizon, the forecast method to be used), the model described in this paper considers that the forecast generates data series according to the horizon established.
For the global forecast, it is necessary to use non-electrical data (exogenous), which present a correlation with the demands from the customer market of the utility (e.g.: temperature, revenue, industrial productivity, and population data). In this case, it is used multi-variable models ARIMA (Box & Jenkins) with co-integration, according to the recommendations of the regulatory agency of the Brazilian electrical sector. For the other forecast levels, it is used single-variable models ARIMA [6]. As

these models were considered in the Integrated Model of Spatial and Global Load Forecast, there is no need to use statistical software.

## APPLICATION AND RESULTS

When applying it to a Brazilian utility one can see the improvement in information storage design and organization. Despite the fact that most information applied in the model has already been stored in a corporate database, they were usually used by different and not integrated applications. Figure 3, 4, 5 and 6 illustrate the results achieved through the methodology described above.

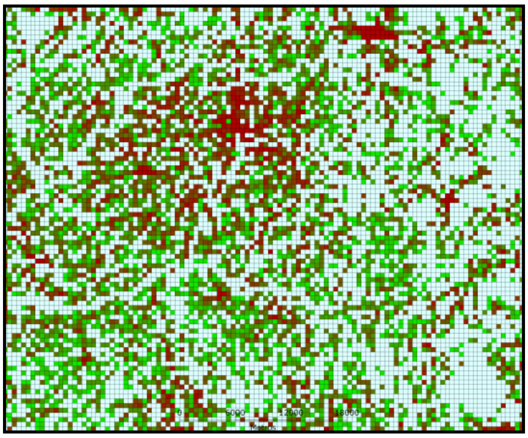

Figure 3: Geo-referenced representation of the consumption per geographical entity

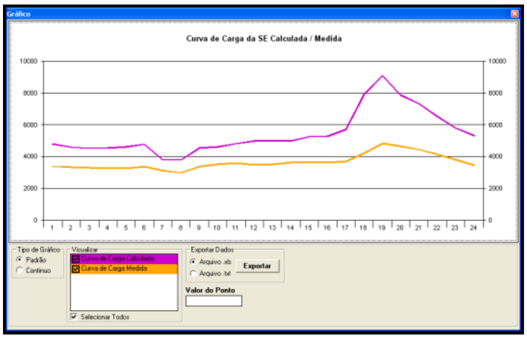


Figure 4: Historical series for the total consumption and customer type

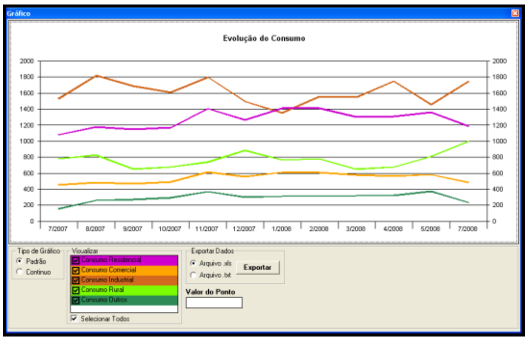


Figure 5: Load curve of a Substation

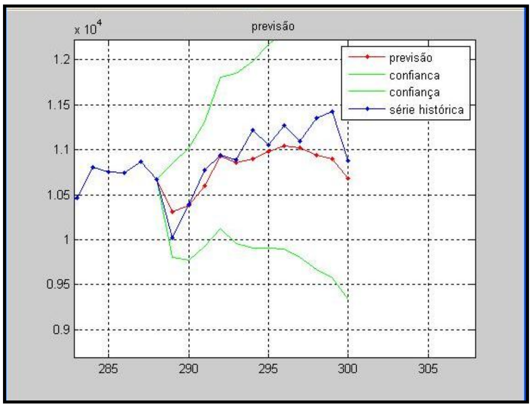


Figure 6: Result of the time series forecast

## CONCLUSIONS

Through the implementation and use of this model, the utility company owns a methodology that is capable of helping the market analysis in an effective way; aiming strategic actions of investment, such as the ones that involve invest decisions ordered by priority, necessity and economical return

Also, through a proper GIS interface designed to show electrical variables in a geographical basis, network studies and planning have became more accurate and precise. Notwithstanding, the integrated forecast module enables the study of specific market variables, such as load densities, growth densities, migration vectors, gaps between capacity and energy projection and others that are essential for the strategic and tactic analysis in energy distribution utilities.

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