A GAUSSIAN MASK MODEL FOR SPATIAL LOAD GROWTH

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ABSTRACT

The main objective of this paper is to present the results of a new model aimed at the load forecast of a region divided by grids, using a methodology based on Gaussian filter and image dilation algorithms, which provides the load growth of each cell in the studied area, separated by their consumer classes. For that matter, the history of each grid's energy and power and the global growing rate for each substation are available.

INTRODUCTION

The load forecasting, based on a study of the consumer market, has a significant relevance to the strategic planning of expansion of distribution, as it synthesizes the information which will be important for the interventions needed in the power distribution network.

The knowledge of the future market of energy is important to attend several purposes. Among them, can be highlighted as the most relevant:

- Expansion of the system distribution network.
- Provision of the information requested by the planning sector.
- Tariff studies and service cost.
- Contracts of energy supply.
- Income prediction.
- Evaluation of the marginal cost of expansion.
- Dimensioning the number of employees.

In addition, the acquisition of historical data and information is necessary to better understand of the consumers' behavior. This information can be obtained inside the company, as they are distributed in some of its departments, or externally, by searching the public and private databases, or, in some instances, through surveys of specific customers.

To assure the proper operation of the electrical system, the Brazilian regulatory agency ANEEL requested, through PRODIST standards[1], the short, medium and long term planning, which requisite the load forecast of the system. For that matter, it is requested from utilities relevant information from the analysis of its consumer market.

In this article a new spatial load growth prediction model is presented, which is based on Gaussian filter and image dilation algorithms that provide the load growth of each cell in the studied area, detached by their classes. Such method was developed over a spatial database of the utility working area (divided as a grid), considering arbitrary definitions of consumer category (by class) and land occupation.

The typical load curves of each customer category from the Brazilian power distribution companies are periodically measured during their tariff cycle. The representative curves for each customer category present in their concession area are obtained through a process based on suitable clustering techniques, namely load characterization. Using these representative curves and the monthly consumption information from each customer, it is possible to determine curves per end use (disaggregated in residential, commercial, industrial and others) for each grid.

The presented algorithm initially estimates a growth value for each cell based on a linear regression model of the load values already in the history files. As there's the cell saturation problem, it is considered that those that present a very low growth rate and a noticeable load value (that is, not grids that do not grow for lack of interest in their occupation) are saturated grids.

It is then executed a cell scoring process, in order to spread each grid's influence considering that the influence decays following a 2-dimensional Gaussian function. For that effect, growth and load parameters are used, in order to generate the morphological masks. After all those scores have been generated for every grid, a pondering factor in each element is calculated, based in a similarity measurement, taking the saturated grids as reference.

Finally, the scoring matrix is normalized in such a way that the grids are ordered by the substation they belong to, and these values are utilized as a weighting factor to determine the energy growth parcel that each cell will be awarded out of the total amount of energy to be distributed to each substation, calculated from their growth rate.

METHODOLOGY

This methodology gives the load geographic behavior considering the grid cells information, global market space, end use classifications and voltage levels.

Be $q_{i,j}$ the cell in the position (i,j) of the map, its energy $d_{i,j}$, and its growth rate $t_{i,j}$. The matrix M, r x s, can be generated, whose elements $m_{i,j}$ are given by

$$m_{i,j} = \sum_{\substack{0\le i+p\le r \\ -k\le p\le k \\ 0\le j+q\le s \\ -k\le q\le k}} (1+t_{i+p,j+q}) d_{i+p,j+q} a_{-p,-q}$$

And $a_{i,j}$ are the elements (i,j) of the A matrix given by

$$a_{i,j} = e^{\frac{i^2+j^2}{2\sigma^2}}$$

The A matrix is a discrete Gaussian Mask $2k+1$ x $2k+1$, whose center element is (0,0).

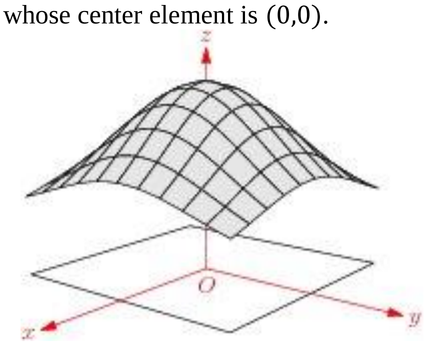

Figure 1 – An Example of a Gaussian Mask Applied to a Surface

That M matrix is the reference of how the energy growth will be distributed. However, the saturated grid cells haven't been taken into account yet. For that matter, is considered that one cell is saturated when $d_{i,j} > d_0$ and $t_{i,j} < t_0$, where d_0 and t_0 are the upper energy and growth rate thresholds, respectively. Be Q_s the set of saturated grid cells and Q the set of all grid cells, the level of saturation of one cell is given by

$$n_{i,j} = \frac{\min_{q_{p,q}\in Q_s} \left(d_{p,q}-d_{i,j}\right)^2 + \left(h_{p,q}-h_{i,j}\right)^2}{n_{max}}$$

$$n_{max} = \max_{\substack{q_{p,q}\in Q_s \\ q_{r,s}\in Q}} \left(d_{p,q}-d_{r,s}\right)^2 + \left(h_{p,q}-h_{r,s}\right)^2$$

Where $h_{i,j}$ is the quantity of consumers in the cell $q_{i,j}$. Should be noted that $n_{i,j}$ is 0 if the cell is identical to a saturated one and 1 if it is the most distant from the saturated set.

The lower threshold of the score has been generated too as follows: be G the set of grid cells such as $q_{i,j} \in G$ if $d_{i,j} = 0$ and $m_{i,j} > 0$. It is defined then $l = l_o * d_{p,q}$, where $d_{p,q} \ge d_{i,j}$, $\forall q_{i,j} \in G$ and $q_{p,q} \in G$, and l_o is a percentage of the maximum that defines the threshold. Thus, the indicator function is given by

$$F_{i,j} = \begin{cases} 1 & if\ d_{i,j} > l \\ 0 & otherwise \end{cases}, \qquad \forall q_{i,j}$$

Therefore, the scores of the M matrix are pondered, generating the S matrix of the final scores, whose element $s_{i,j}$ is given by

$$s_{i,j} = \frac{F_{i,j} n_{i,j} m_{i,j}}{s_{sub(q_{i,j})}}$$

$$s_{sub(q_{i,j})} = \sum_{q_{p,q}\in Q_{sub(q_{i,j})}} F_{i,j} n_{p,q} m_{p,q}$$

Where $Q_{sub(q_{i,j})}$ is the set of grid cells that are associated with the substation $sub(q_{i,j})$, which in turn is the substation to which the cell $q_{i,j}$ is associated. Thus, to distribute the energy growth $\Delta D_{sub(q_{i,j})} = t_{sub(q_{i,j})} * D_{sub(q_{i,j})}$ of each substation, where $t_{sub(q_{i,j})}$ e $D_{sub(q_{i,j})}$ are, respectively, the growth rate and energy associated with $q_{i,j}$, the new energy $d^*_{i,j}$ can be given by

$$d^*_{i,j} = d_{i,j} + s_{i,j} \Delta D_{sub(q_{i,j})}$$

TESTS AND RESULTS

For this test scenario a middle sized city from SP, Brazil, was used, which has a power consumption of 550MVA during the first year of the study. It was applied a global growth rate of 3% per year, during four years. The area of this city is presented by the Figure 2.

The Table 1 presents the power consumption of the city over the period of five years:

Table 1 - Power Consumption of the City Used in Test Scenario

Year	MVA
2012	550,05
2013	566,55
2014	583,55
2015	601,05
2016	619,09

Figure 2 – Limits of the City Used in Test Scenario

The figures 3 and 4 present the distribution of loads in the city during the first and last years of study, respectively.

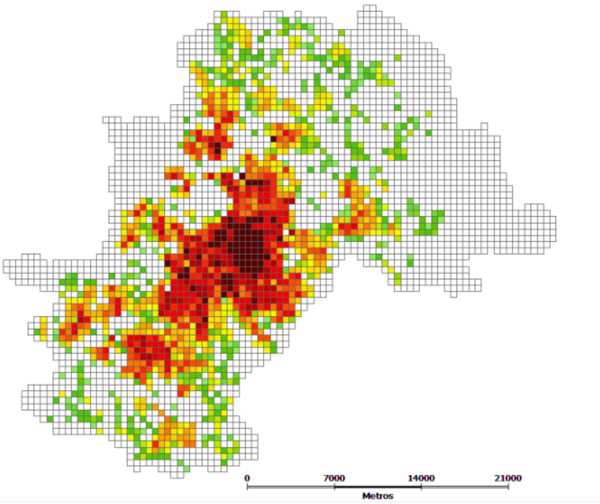

Figure 3 – Load Distribution during the First Year

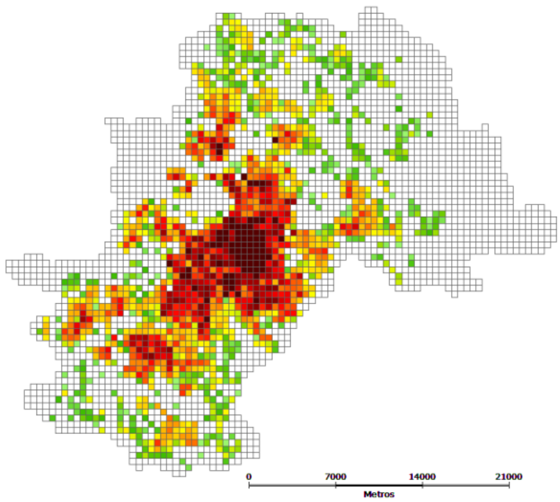

Figure 4 – Load Distribution during the Last Year

In the figures 5 and 6 a comparison is made between the central area of the city during the first and final years. It is possible to notice that, as expected, the occupied cells' growth is more concentrated near the urban pole of the city, which is the most densely occupied region (which means higher loads).

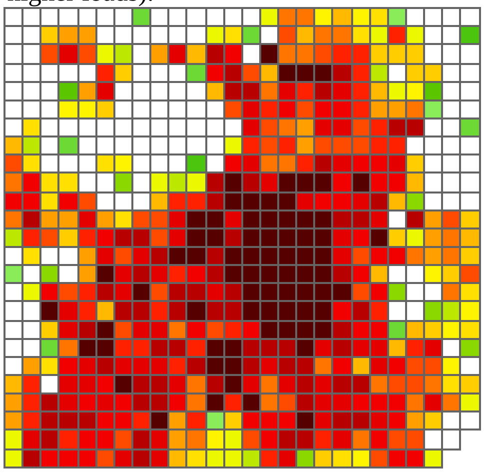

Figure 5 – Loads in the Central Area of the City during the first Year

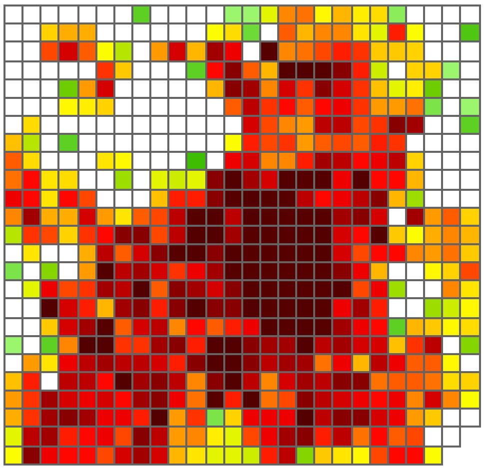

Figure 6 – Loads in the Central Area of the City during the last Year

It should be highlighted that about 60% of the global city growth occurred in this area, which represents approximately 15% of the total.

Beyond the growth of the central areas, there are cells which are initially unoccupied and develop during de study, this is shown in the figures 7 and 8.

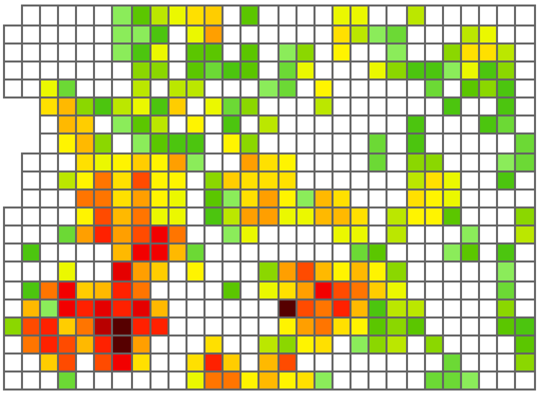

Figure 7 – Loads in the Suburb of the City during the first Year

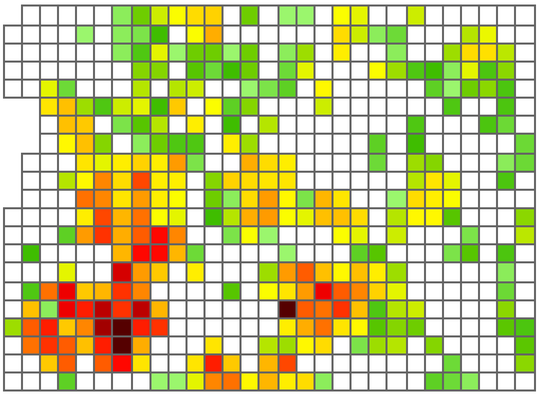

Figure 8 – Loads in the Suburb of the City during the last Year

During the study, there were 33 unoccupied cells which acquired loads. This number can be tweaked on the algorithm by changing the value of l_o, so it can reflect the quantity of new cells observed through the history of the region.

CONCLUSION

This new mathematic model has as primary results:

- The load forecast on a specific period of study, through the analysis of time series (SARIMA, Box & Jenkins and cointegrated models)
- The spatial load forecast through a grid representation of the study area and representing the loads as typical curves.
- Specific and hard treatment subjects in a long-term planning: Saturation of tiles and horizontal growth forecast.

Moreover, the proposed methodology allowed the matching between the global energy market and the load growth of the covered tiles, as well as analysis of territorial occupation and expansion of the system in areas that were initially unoccupied.

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