Development of a spatial load-forecasting module for optimizing planning of electricity supply

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Abstract –In today's economy, there is a strong need to forecast and predict future load demands in order to estimate the amount of load required and to properly prepare the planning purposes. This paper presents the development of a module with the ability to calculate the spatial load forecasting in any area of study. First, the electrical distribution system must be defined with all its components. After a model of geographical and temporal prediction of this demand for electricity, which uses a Hybrid method is developed. The software Python and ARCMAP are used in order to program the module. Furthermore, the developed module considers the main requirements for a good spatial load forecasting. Land use is a key factor in this work, excluding specific areas where is not possible to have growth.

***Index Terms* – Smart planning, GIS, Spatial Load Forecasting, Python.**

I. Introduction

Nowadays, the use of Geographic Information Systems -*GIS*- in power systems is relatively moderate, since GIS are being used generally within the electric power companies in Ecuador, predominantly, for the purpose of mapping the features of the electricity network. The accurate use of Geographical Information System – GIS- technology could enhance the determination of optimal future expansion, taking into account key factors such as hydrology, roads layout and current location of customers, transformers and substations [1], and lately support a methodological approach for the Utility planning activities, considering also the best economic scenarios [2].

Spatial load forecasting in the long term predicts the magnitude of demand (how much), and its location in space (where) and time (when) [3]. Since the decade of the 50s there have been several methods for estimating electricity demand, starting from the experience of the planners, who made drawings of the population density, then mathematical algorithms were applied based on single variable models and multiple regression, which needs historical data as input parameters [4]. Technological developments and use of computers allowed working with more data and more complex models [5].

Hence, GIS manages the complexity of the methods for forecasting demand because of its ability to relate different geographical entities with alphanumeric attributes. This feature allows a spatial representation of the data, a better understanding and a variety of possible spatial analysis.

It is extremely important to obtain a good spatial model for load forecasting [6]. In order to estimate investment costs needed to install new capacity generation, considering that always the capacity and quality of power supply should meet exactly the demand of the service, otherwise unmet demand can have very high costs, not only in the investments by the Utilities, but also in the quality of service perceived by customers. Additionally, it is worth noting the long time needed for commissioning a new power plant.

Therefore, this paper proposes a methodology for performing spatial load forecasting in electrical distribution systems, a tool that runs inside ARCMAP environment and takes into account land use, the end use of energy, spatial distribution of the load and division of the forecast into small areas.

II. Spatial Load Forecasting

The diagram below shows in a simple way what mean Spatial Load Forecasting *–SLF-*. This method can be used for different time scales as short, medium and long term, from now on all that concerns to the SLF, should be understood as long-term.

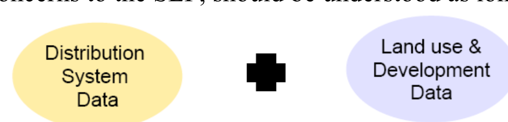

Fig. 1. Spatial Load Forecasting, [7]

A. Small Area

This is the most common technique for spatial analysis and load forecasting [8]; it is used in order to determine the load growth, the technique consists in dividing the whole area into small geographic areas, in order to achieve unification at the irregular areas. Fig. 2 illustrates the procedure; we must not forget that not all small area is actually an area of growth for forecasting. The area for forecasting is associated with geographic location. It means that each small area must have always associated their coordinates.

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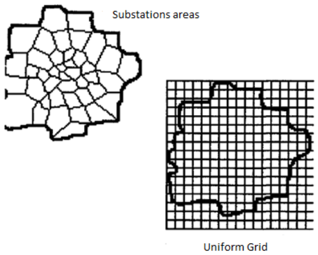

Fig. 2. Small areas for forecasting, [3]

B. Area Resolution

The table below shows the recommended resolution for spatial analysis [9], the time horizon is also recommended for load forecasting on different elements of the Utilities.

TABLE I
RESOLUTION FOR DIFFERENT LEVELS

Planning purpose	***Planning Horizon (years ahead)***	***Service Area (km or km^2)***	***Forecasting resolution (meters)***
Sub-Transmission network	*5-25*	*10km*	*250*
Substation	*5-25*	*25 km^2*	*250*
Medium Voltage network	*2-20*	*3km*	*50*
Secondary substations	*1-15*	*0,5 km^2*	*50*
Low Voltage network	*1-10*	*300km*	*5*

Source : Chap 7 [3]

C. Requirements for Load Forecasting

The aim of transmission and distribution planning is to obtain reliable results without considerable mistakes; therefore, each phase of the process should aim to achieve this objective. The following requirements [3] were revised in order to obtain the prediction scenarios.

1. *Magnitude forecast - the amount of demand and energy*

It refers to the peak power of each small area for forecasting.

2. *Spatial resolution and analysis*

The second requirement is to know the location of the consumption.

3. *Time and temporary assessment*

Inclusion of time and years seasons must be defined.

4. *Time standardization for the prediction*

It is necessary to normalize the load forecast by weather, in order to assume uniform behavior.

5. Accuracy representation

It is much more important to have the ability for spatially represent the future growth.

6. *Consistency with corporate predictions*

Electrical load predictions should be aligned with Utility forecasts.

7. *Analysis of uncertainty and sensitivity*

It is worth doing several analysis scenarios to obtain different results. The sensitivity analysis pay special attention to urban culture factors.

8. *Classifying consumers*

It is necessary to classify the population according to the type of consumers by means of end-use energy.

9. *Profiles of consumers and temporary peak loads*

It defines an average annual load curve of a certain area of study; in addition, some curves in different periods are needed.

10. *Requirements of reliability*

The load predictions should be made based on how much reliability, the consumers want and how much they are willing to pay to keep it.

11. *Power factor*

Sometimes, the future use of energy is projected in order to keep the current power factor (short term) or the power factor by consumer type (long term). The following table provides an assessment of each requirement on a scale of 10 points.

TABLE II
ASSESSMENT OF THE REQUIREMENTS FOR SPATIAL LOAD FORECASTING

Rank	***Requirement***	***Importance***
1	*Forecast MW- how much*	*10*
2	*Location accuracy - where*	*10*
3	*Temporal resolution – when*	*10*
4	*Weather normalization - how*	*9*
5	*Representational accuracy – why*	*8*
6	*Consistency with corporate forecast*	*7*
7	*Analysis of uncertainty – why and how*	*7*
8	*Consumer class forecast – who*	*6*
9	*Load curve shapes*	*5*
10	*Reliability value/need*	*5*
11	*Power factor/voltage sensitivity*	*4*

Source : Chap 1 [3]

III. SPATIAL METHODS

This section presents the most successful method to perform a Spatial Load Forecasting, there are about 17 commonly used methods for load forecast, but in general, all these methods are labeled in any of the following three groups: trend, simulation, and hybrid.

A. Methods based on Trends

They are used to build a function in order to adjust the load growth patterns and estimate the future load [10]. The most common method is the multivariate regression trend that fits a polynomial function, however, this method in Spatial Load Forecasting provides a significant number of errors, but the advantage is its simplicity and effectiveness in the short term [11].

B. Simulation Based Methods

This method reproduces the historical load to identify temporal information, spatial and magnitude of load growth [12]. It is worth mentioning that this method is also known as 'similar day approach' [13] the trend coefficients obtained from the regression procedure can be used for similar days in the futures years.

C. *Hybrid Methods*

This method combines the features of the two mentioned methods, in other words, this method would be easy to use, and it does not require many interactions or advanced knowledge of the user. In theory, it would be effective in the short and long term.

D. Method recommended for Spatial Load Forecasting

Thus, the method to be studied in this research is a hybrid one that uses the Gompertz curve known as S curve [3] widely used in transmission and distribution, this curve is used especially to predict the load growth in small areas.
The method is labeled as hybrid because of the commercial growth is treated like a trend using data of the last years. In essence, the S Curve also is a trend. Moreover, the simulation-based part considers real data from Cuenca, in order to create a simulation scenario for the 2008, which reproduces the historical load identifying temporal information, spatial and magnitude of load (Information given by Centrosur Utility).
In order to model the load growth and its effects normally is used the S curve [14]. Two events causes that the load grows, the first is when there are new customers and the second one is the consumption growth of existing customers.
There are three parameters to control the shape of the curve S

1. Horizon year load (HYL)
2. Start time ramp load growth
3. Slope of the ramp

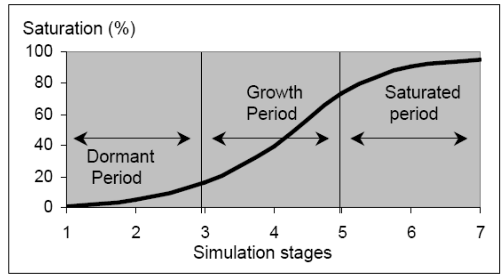

Fig. 3. S curve and its 3 stages,[7]

This paper presents a method, which uses land use. It is innovative, since it has the capability to perform load forecasts using factors such as small-area, land-use, as well as, the most accurate long-range load forecast technique available so far [15]. The method of land use with a hybrid approach was chosen, since this method offers the most accurate results [16].

Despite, this one has the higher cost of implementation, since it is needed programming several geo-process and takes into account some variables, also the quantity of information (clients, shapes) managed is considerable. The load forecast will focus at the urban core of the city of Cuenca, Ecuador, since urban core concentrates in general the majority of commercial and residential loads. Additionally, this zone is also the one with higher energy consumption. Other important factor considered is that Centrosur Utility from Cuenca City has all the information required.
In the most of cases the urban core can grow both horizontally and vertically [17]. In the long term, spatial load forecasting must answer questions such as how much, location and time of growth of the demand.

IV. Design and Implementation

The applied methodology is based on the land use method, which manages data of population, electricity demand, and commercial census as well as the classification of the study area.

1. First of all, it estimates the overall population growth in the study area by the Gompertz curve; this increase is distributed in each micro area.
2. The ability of each area to receive population is determined by a reception index, which can be calculated by considering such factors as:
   - Proximity to public transport routes
   - Proximity to downtown
   - Land Use
   - Degree of restriction to the construction
   - Land Slope

It must be noted that this index should be calculated in each micro area independently.

3. It is essential to consider the current load in each micro area; therefore, it becomes necessary to perform a linear prediction for determining the commercial growth. As was mentioned it is the trend method.
4. Since, inhabitant and commerce disaggregate the base demand, and the growth projections of population and business

are known, it is possible to calculate the future electricity demand in each micro area using the Curve S.

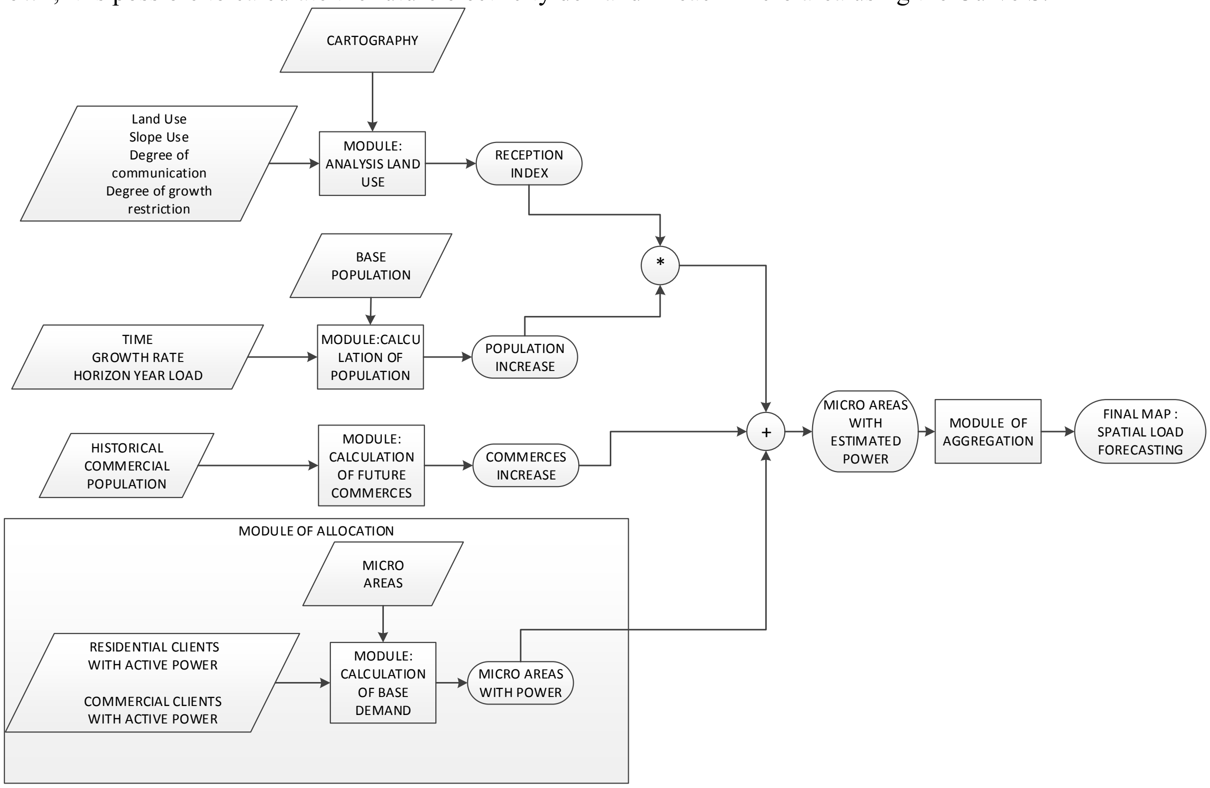

Fig. 4. Process Diagram of spatial load forecasting module.

Prior to the implementation of the module, it was necessary to obtain mapping information and census data, all the data collected and its quality is described.

1. Energy Database: This information is available from a study of end-uses energy; the database has the monthly consumption of all customers.
2. Cuenca's cartography: several layers such as streets, lots, blocks, rivers, urban parishes, additionally is provided a shapefile, which represents each client of the Centrosur Regional Electrical Company –Centrosur- located geographically.
3. Census data: The population was obtained from the "Instituto Nacional de Estadistica y Censo" –INEC-, this institute gives access to historical data.

The Fig.5 and 6. shows the resolution and the areas excluded. The first script was developed in python in order to calculate the patterns of population growth applying the curve of Gompertz.

$$y(t) = a * e^{-e^{-c(t-\Delta t)}} \qquad (1)$$

Where
a = is HYL,
c = is the growth rate,
Δt is the ramp time.

HYL is the saturation number of inhabitants in the time chosen like ramp time.

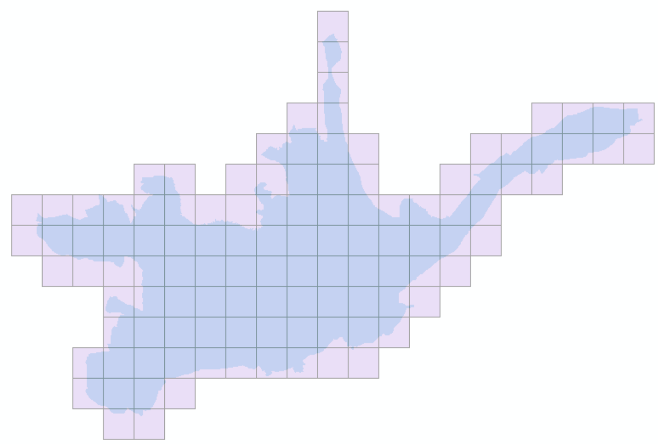

Fig. 5. Areas of 1km2

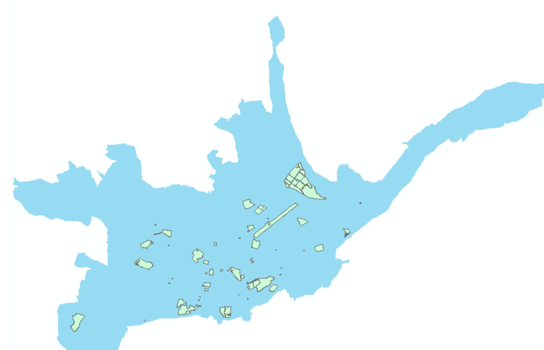

Fig. 6. Zones excluded for analysis

Additionally this script calls parameters such as growth rate of commerce, parishes' layer. After running each module, the time approximately of execution is almost 11 minutes each one. Several polygons with attributes of residential and commercial consumption of each micro area and other polygons are obtained.

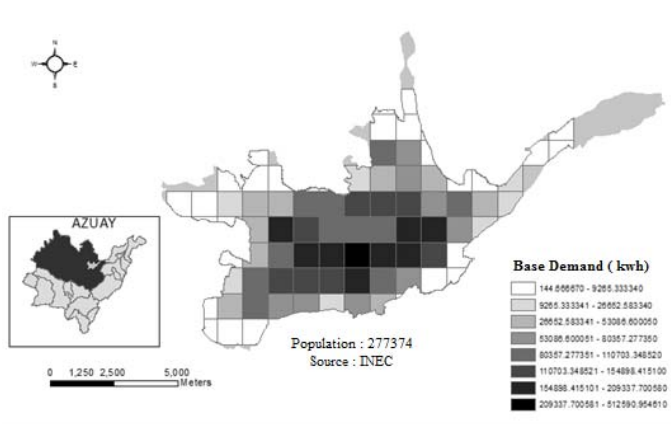

Fig. 7. Base Demand - 2008

The Fig.7 shows the calculated base demand that will be used for the calculation of the projected demand

V. Results

The reception index [18] of a micro area is the ability for receiving new inhabitants. Considering that, the population growth in a micro area *j* is directly proportional to the overall population growth of the city. Four factors for calculating it are considered:

1. Excluded Areas: these are all areas that cannot accommodate population such as stadiums, airports, universities, and others.
2. Ground Slope: it offers outstanding layer ranges from 0 to 100 degrees.
3. Degree of communication: the closeness of each micro area to the town center.
4. Restriction to growth represents the difficulty of each micro area to contain new population.

The described factors are calculated using GIS tools. The reception index in each micro area was calculated as follows

$$IA_j^{t+x} = \alpha1 * F_{1j}^{t+x} + \alpha2 * F_{2j}^{t+x} + \alpha3 * F_{3j}^{t+x} \qquad (2)$$

Where α is the weight of each factor, for this study was defined as follows:

$F_{1j}^{t+x} =$ Result of land use script that has all the excluded areas and slope land, this value is a percentage.
$F_{2j}^{t+x} =$ Degree of Communications, 12 categories, as long as closer to the center the value will be higher.
$F_{3j}^{t+x} =$ Growth restriction, are 12 categories, as long as closer to the center the value of the restriction growth will be higher.

For this research the weights were determined by simple observation, considering the land use should be at least equal to 50% because otherwise there will be no ability to receive population, and probably could not have abundant growth in each area. Additionally this factor is composed by usable areas and ground slope, the degree of communications is 10% because this do not represent a great obstacle at the time. The growth restriction is very important, for this reason, its weight is 40%. However, it is possible to change the weight of each factor and to build more scenarios.

α1=weighting of 50%
α2= weighting of 10%
α3= weighting of 40%
The equation to apply in each micro area would:

$$IA_j^{t+x} = \frac{0.5 * F_{1j}^{t+x} * 12 + 0.1 * F_{2j}^{t+x} + 0.40 * (12 - F_{3j}^{t+x})}{12}$$

According [18] knowing the population in the study area, It is possible to calculate the future demand and growth in each micro area.

$$P_j^{t+x} = P_j^t + (IA_j^{t+x} * \Delta P_{global}^{t+x}) \qquad (3)$$

Where:

P_j^{t+x}=future population by area
P_j^t= current population.
IA_j^{t+x}= Reception Index
ΔP_{global}^{t+x} = Global population growth (obtained of the Curve S)

The below equation is applied in order to determine the commerce growth, in the study it was chosen to enter directly the rate of population in the module. This rate was obtained of historical data externally from INEC.

$$C_j^{t+x} = A_j * x + B_j \qquad (4)$$

Finally, the future load in each area is equal to the sum of residential and commercial growth, as defined in the following equations.

$$LC_j^{t+x} = \frac{LC_j^t}{C_j^t} * C_j^{t+x} \qquad (5)$$

$$LP_j^{t+x} = \frac{LP_j^t}{P_j^t} * P_j^{t+x} \qquad (6)$$

$$L_j^{t+x} = LC_j^{t+x} + LP_j^{t+x} \qquad (7)$$

Where:

$LC_j^t =$ Base commercial demand is the current load commercial in each area, in this case in 2008.
$C_j^{t+x} =$ Future Commerce is obtained from the equation (5) using historical data of census.
$C_j^t =$ Current commerce is the number of businesses, to get this it is necessary to count the businesses of each area.
LC_j^{t+x} = Future commercial demand
$LP_j^t =$ Residential Base demand is the current residential load in each area.
$P_j^{t+x} =$ Future population is obtained of the equation (3)
$P_j^t =$Current population is the population of the each area, through the reception index the current population is distributed in each area.

LP_j^{t+x} = Future residential demand
L_j^{t+x}= Projected demand in each micro area is the sum of future commercial demand and the future residential demand.
Eq. 5 can be written as follows:

$$LC_j^{t+x} = LC_j^t * \Delta Cj \qquad (8)$$

Where:
ΔCj= commercial growth rate that is obtained from historical data.
The result after performing all the calculations is presented below.

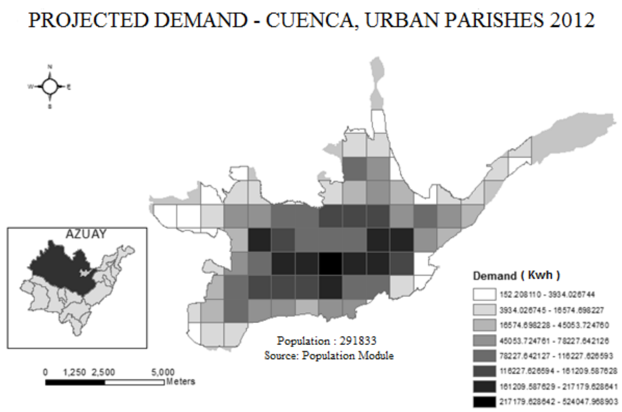

Fig. 8. Projected Demand for 2012

VI. Conclusions

The load forecast was focused at the urban core of the city of Cuenca, Ecuador, since urban core concentrates in general the majority of commercial and residential loads (almost 80%) . hence, it sample is representative. The implemented land use method with a hybrid approach predicts with high accuracy the growth of electricity demand, by modeling population growth and a calculation of the growth rate of commerce, which considers the influence of various factors: geographic (excluding areas , ground slope, proximity to downtown, degree of growth restriction) and demographic (population saturation or HYL)

Using GIS in the load forecasting represents a considerable advantage over other methods because it allows including the land use in the analysis in order to assign the projected demand at available and real places.
The total execution time, including input shapes according to the needs is approximately 2 hours; a small real time considering that manually it could take weeks, in addition, the degree of accuracy is much higher.
Results may vary widely based on the weights given to each factor; therefore it is really important to choose them properly and carefully before performing a sensitivity analysis.
It is necessary to provide to the module the capacity to deal with problems such as demand forecasting in empty areas (without initial consumption), transference between substations, it mean opening and closing of breakers into the grid. These changes in the breakers position would change the topology. The proposed method has its strengths in considering land use, the end use of energy, spatial distribution of the load and division of the forecast into small areas. The projected demand for 2012 compared with real measurements has a difference of about 3%.

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