Determination of unserved load and distributed generation for power system planning purposes

José Cerda, *Student Member, IEEE*
Department of Power Systems
Ilmenau University of Technology
Gustav-Kirchhoff-St. 01, D-98693 Ilmenau.
e-mail: jose-luis.cerda-arias@tu-ilmenau.de

Dirk Westermann, *Senior Member, IEEE*
Department of Power Systems
Ilmenau University of Technology
Gustav-Kirchhoff-St. 01, D-98693 Ilmenau.
e-mail: dirk.westermann@tu-ilmenau.de

Abstract— **A fundamental step in power systems planning is the distribution of the load in the network. By the actual structure of electricity markets and the consideration of massive growth of distributed generation units, it is necessary to consider the influence of these connection points in power system planning. It has to be investigated how this effects the reduction of the active power losses and the load distribution in the network. This paper outlines a method on how the load in the network can be forecasted and the location of the distributed generation units. The proposed method is based on the spatial distribution of the load, parameter of the network and active power losses caused by each new generation facility. The model is applied to a real system showing the potential for its use.**

Keywords- *Power systems planning model, Distributed generation, Spatial load forecasting, Active power losses.*

I. Introduction

The today's structure of power systems with competitive wholesale markets for electricity encourages the introduction of new agents and products, customer partnership, new consumer behavior and the specialization of the participating stakeholders as generators, network operators and power suppliers (e.g. traders). This new structure leads to market participant seeking to maximize their utilities while minimizing the costs [1].

In this scenario it is feasible to develop systems to identify and minimize cost, particularly in the planning and operation of power systems, taking into account the massive presence of distributed generation units (*DGu*) and a new electricity consumption behavior that even might be affected by demand side management programs.

Part of the cost is allocated to the active power loss (*APL*) level in the power grid. The losses are clearly affected by the implementation of new policies which lead to a more efficient energy utilization. One scenario is that new agents will be starting businesses in medium and low voltage networks and electricity products will appear that are also incorporating the loss reduction in connection with power flows. This position directly depends on the level of the load and its distribution in the electrical system.

The current reduction of *APLs* is one aspect to be considered in the minimization of the costs of power system planning and future system operation, thus rendering voltage control, increased levels of reliability and security of supply as main technical objectives.

In the current energy scenario, it is necessary to consider influential variables in the planning models like:

- the development of new technologies which might diversify the energy matrix,
- Smart Grids with new policies that induce utilization of energy in efficiently.

Both will affect the classical *APLs* forecast models. One way to use this as a favorable effect is to determine a strategic location of these new agents in order to systematically reduce *APLs*. The location and application directly depend on the load level and its distribution in the grid.

In this context, the objective of this paper is to contribute to the development of methods for the minimization of the energy cost associated with *APLs* with respect to load distribution. They have to be estimated in a power system planning model and defined as starting point of a new model for power system planning. It has to be determined where the preferred points of new connections of consumption and *DGu* are and what their effect in the grid will be. The overall objective shall comprise considerations of their potential to support of supply in case of network failures.

The proposed method is based on the results of a temporal load forecasting method. A new forecasting methodology for the spatial distribution of the load in the electrical network will be presented. The analytic model comprises:

1. A new spatial load forecasting method which is based on a statistical model incorporating:

- the relation between the economic and demographic data of a representative area,
- the location of measurement points
- the forecast values for the load

2. An analysis of the grid which determines the maximal load to supply and loss factor of each substation based on the results of a power flow;

3. The connection of the loads distributed within the grid with a minimum geographical distance to the next substation and

4. A loss factor criterion, determining the unserved load (*UL*) areas, the location of new substation and the connection proposals for generation units.

In Section II the State of art Identification of supply points in future planning of the grid are presented. In Section III, a load distribution scheme, the identification of *UL* and possible supply points are described. Section IV presents the structure of the mathematical problem and the solution algorithm. In Section V, the scheme is applied to a real network of a metropolitan area. Finally, analysis, conclusions, and future research work in the field are presented in section VI.

II. State of the Art Identification of new Supply points

A planning model has to consider the temporary increase of the loads and their distribution in the grid [2]. This is the basis for network expansion, the location of new substations and their installed capacity. For any current or planned substation, there is a preferred place in an economic sense and another one in a technical sense – at least in the majority of the cases. The optimal location of a substation from a cost standpoint is the best compromise between all elements of the total cost.

The identification of supply points influence the dimensions of feeders and substation. Thus, the service territory is divided into service areas of the substation. Each area of the substation is divided into subareas according to voltage levels [3]. Additionally, there is an optimal size or capacity of each substation. At which a satisfactory service/cost relationship can be achieved.

With these prerequisites, the need to build a new supply point is linked to the service area assigned to each distribution or transmission companies and their obligation to supply a new or current consumption safely.

To define the location of a new supply point and its corresponding capacity several methods are available which are used in planning systems. They are based on experiences of the planners and/or a forecast of the natural increase of the load [3].

In addition a new network component like *DGs* needs to be integrated into the planning process in a strategic way. [4,5]. Several papers analyses the system impact of *DGu* with respect to steady state and dynamic behaviour as well as stability [6, 7].

Following this line of development it is proposed to consider the *APL* reduction as another criterion (on top of *UL*) for the determination of optimal network connection points.

III. General formulation of methodology proposed

A. Spatial load forecasting model

The proposed scheme is based on the results of a temporary load forecasting model [2,4] which is governed by the statistics of demographic trends. They are represented by distribution functions comprising typical load information such as number of inhabitants and their geographical distribution, location of commercial consumption. Land use for different types of consumption and consumption patterns of industrial parks and commercial buildings will be considered as well. With this approach the load distribution per area for each type of consumption pattern is obtained a forecast index of kw/km^2 units [1].

B. Determination of factors characteristics network

A strategic distribution of the load in the power grid is based on guidelines targeting at a minimization of grid loading. Then, it is necessary to determine the maximum capacity of supply and the loss factor associated with each supply point on the network. They are defined by certain parameters. These supply points are ranked according to their consumption capacity and loss level (contribution to *APLs*) according by the utilization of the power grid.

Besides *APLs* and system state variables (generation, voltage and current levels) are obtained through a power flow [8].

When considering a static peak load scenario, for each supply point a loss factor will be computed. The loss factor is a function of the maximum capacity of each operational device which feeding the load level at the point of supply.

With these Parameters of the electricity grid is also possible to associate the spatially distributed load with the geographical distance of the electric load to the network connection point and the corresponding loss factors of each supply point.

C. Connection of loads with the electrical grid

With distribution load forecasting and the network characteristics, the connection the load to grid have to be realized with a minimum of geographic distance. Furthermore the loss factor shall be minimal and the designated substation capacity must be suitable. With this criterion the use of the lines on the low voltage level is minimized. In case of equal distance between busbars and the load it is considered that the lowest loss factor is causing least impact on loss levels of the network, and finally the capacity of busbar.

D. Unserved load and new projects on the electricity grid.

If there are *ULs* on the network size and location will be identified. *ULs* can occur in case of newly erected commercial plants of substantial increase in the consumption of the already supplied load. Considering the connection of loads with the electrical grid proposed, these *ULs* are situated in the areas farthest from the current supply points.

The possible supply points are identified assuming a load center for all *UL*s with average characteristics of the neighborhood supply points (i.e. capacity, voltage, etc.).

On other hand, the installation and operation of *DGu* will be realized based on loss factor analysis. I.e. here the capabilities of the *DGus* of reducing power flows are consider.

Considering the location of the *DGu* and the new supply points the loss factors are defined and the final distribution of the load is made. This final distribution consider *UL*s=0.

IV. Methodology proposed of the Distribution and connection of the Load To A electrical Grid

A. Spatial load forecasting model

Several factors influence in the loads behavior with respect to size and distribution.

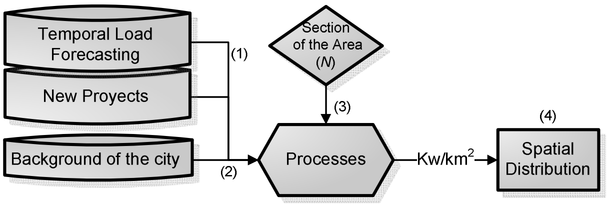

Figure 1. Spatial *LFM* module

The main objective is to obtain a value of consumption by area and its geographical location. Fig. 1 sketches the processes which could be applied to a urban consumption from a city network with the following components:

(1) *Temporal Load***.** The temporal load forecasting result associated with a expansion new project.

(2) *Background of City***.** The characteristics of the city and its inhabitants such as: City´s area; Population density (*hab/km*^{2}); distribution per household (Hab_{hause}); Density trade (*Trade/km*^{2}); Population growth and Land Use ($Land_{use}$).

(3) *Process*, according to available information the index *kw/km*^{2} is forecast, separated into sections (*N*) of the total area. The process is the following:

1. *Number of residents in each section*, with the data *hab/km*^{2} and division into sections, gives an index of habitants per section (Hab_{sec}). The number of commercial (T_{sec}), industries and farms (F_{sec}) is obtained in a similar way.
2. *Number of residents in each measurement* considers the residential measurements, Hab_{sec} and Hab_{house}. The following relation of inhabitants by measurement is obtained:

$$Hab^i_{mea} = Hab^i_{house} \cdot Hab^i_{\sec} \left[Hab / mes\right] \quad i = \sec tion \tag{1}$$

   The residential measurements also include these small trades. These are considered as the number of trade by measuring, T^i_{mea} for each section *i*.
   The rest of the commercial and industrial measures are considered as a single consumer.
3. *Consumption by residents and trade in each section*, according to the distribution of people associates with the amount of households connected to the measurements points the per capita consumption for habitant or trade is determined as follows:

$$Load^i_{hab} = \frac{P_{H0}{}^{mea} \cdot \%H_0^{mea}}{Hab^i_{mea}} \left[kw / hab\right] \quad i = \sec tion \tag{2}$$

$$Load^i_G = \frac{P_{H0}{}^{mea} \cdot \%T^{mea}}{T^i_{mea}} \left[kw / Trade\right] \quad i = \sec tion \tag{3}$$

   Where, $P_{H0}{}^{mea}$ is the measurement of active power; $\%H_0$ and $\%T,$ are the percentage of total consumption of population and trade.
4. *Load per area in each section,* according to the area ($area_{sec}$) hab_{sec} and $trade_{sec}$ are considered. Thus, the load per km^2 is calculated, considering the maximum and minimum per capita consumption.

$$Load^i_H = Load^i_{hab} \cdot \left(\frac{hab^i_{\sec}}{area^i_{\sec}}\right)\left[kw / km^2\right] \quad i = \sec tion \tag{4}$$

(4) *Spatial Distribution* considers the scenarios regarding the number of available measures. If the section (*i,j*) is considered, the maximum value V_{max} with coordinates (x_{max},y_{max}) and a minimum value V_{min} with coordinates (x_{min},y_{min}) is identified. The proposed distribution is a normal distribution *N(x,y)* with maximum magnitude V_{max}, focusing on (x_{max},y_{max}) and a variance that $N(x_{min},y_{min}) = V_{min}$. In the scenario without measurement the effect of the analysis in adjacent sections is considered.

Finally, for all these sections the maximum value is considered. These maximum values are stored in a matrix with "*kw/km*^{2} " values.

B. Factors characterising the grid

According to the criteria explained in *III.B* a simple power system is considered.

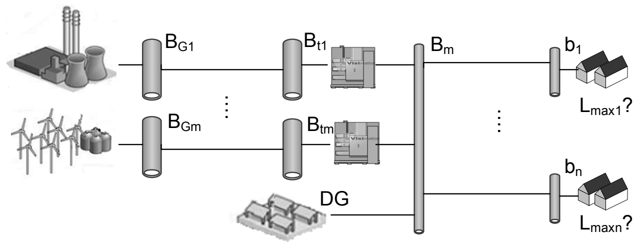

Figure 2. Maximum Load to supply

Fig. 2 shows *n* busbar consumer (b_1...b_n) supplied by an electrical system. A maximum consumption L_{maxi} connected to the busbar B_M in the medium voltage level is a function of the maximum capacities of generation and transmission facilities upstream of the busbar.

- *Maximum load*. The current capacity of the busbar is the minimum capacity of the facilities upstream of busbar of each power line, more generation directly connected to the busbar. This is expressed as follows:

$$CAP_{SIST\_M_1} = \sum_{i=1}^{m} \min\left(cap_{G_i}, cap_{g_i - t_i}, cap_{t_i - M_1}\right) + cap_{GD} \quad \left[MVar\right] \tag{5}$$

Where cap_i=corresponds to the maximum capacity of the facility *i*.

In this case, the supply to B_M-b_i feeders is equal to $CAP_{SIST\ M1}$. The capacity of each feeder B_M-b_i is a function of the capacity of the other feeders connected to M_i and the electrical parameters of the facilities with respect to infeeds at this particular busbar and infeeds at other busbars. If one considers *SF* (a scaling factor for the load), the following expression for the maximum load connecting on b_i is obtained.

$$L_{\max\_d} = SF \cdot \min\left(CAP_{SIST\_BM} \cdot \left(\frac{|Z_{BM-bi}|}{\sum_{i=1}^{n} |Z_{BM-bi}|} \right), cap_{BM-bi} \right) \quad [MVar] \tag{6}$$

Where Z_{BM-bi} equals the feeder impedance B_M-b_i, and CAP_{BM-bi} represents the maximum capacity of the feeder B_M-b_i.

This method is applied recursively to each busbar. With the maximum load from each busbar and the power flow results the *APLs* are obtained for each facility. The loss factors can be computed as well.

- *The loss factor* of a supply busbar is a function of losses in the grid devices which are loaded up to the maximum load. Due to the topology of the network (branches) one facility is feeding more than one single load. Consequently, the following criterion is necessary to derive:

The power flow result give *APLs* for each facility between the busbar *i* and *j*. They depend on the flow injected from busbar *i* to the busbar j ($Piny_{i\text{-}j}$), the direct flow to the load n ($Pl_{j\text{-}n}$) and the sum of other consumption ($Pret_j$).

Equation (7) considers the *APLs* of the facilities which directly feed the busbar with the load n plus the *APLs* from the portion of the upstream facilities in the distribution system. They are further multiplied with a factor which reflects the load n divided by the total load, minus the effect of *DGu* connected on busbar n:

$$Ls_{\rightarrow n} = \text{Apls}_{M_1-b_n} + \left(\sum_{i=1}^{m} \text{Apls}_{t_i-M_1}\right)\cdot\alpha + \left(\sum_{i=1}^{m} \text{Apls}_{g_i-t_i}\cdot\beta\right)\cdot\alpha \quad [MW] \tag{7}$$

$$\text{Apls}_{M_1-b_n} = Piny_{i-j} - \left(Pl_{j-b_n} + \text{Pr}\,et_j\right),$$

$$\alpha = \beta = Pl_{M_1-b_n}\left(1 - \frac{G_{DG}}{Pl_{M_1-b_n} + \text{Pr}\,et_{M_1}}\right) \Big/ \left(Pl_{M_1-b_n} + \text{Pr}\,et_{M_1}\right),$$

$L_{s\rightarrow n}$, depends on the structure of the system, and the number of facilities associated with the busbar n. Then the *loss factor* in n is the following:

$$Lf_n = \frac{Ls_{\rightarrow n}}{L_{\max(n)}} \tag{8}$$

Where, $L_{max(n)}$ is the maximal load at the busbar n, in *MW*.

In transmission systems the same expression is used for loss description.

C. Connection of load to the electrical grid

With the proposed grid expansion method the busbar with the lowest *Lf* will be considered first fort he connection of new loads.

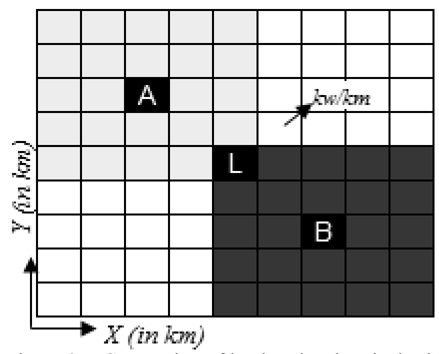

Figure 3. Connection of load to the electrical grid

Fig.3 considers the busbar A with less L_f on the area to analyze. The euclidian distance of the adyacent loads to each supply busbar is calculated and is connected.

$$d_{L_i\rightarrow bus_j} = \sqrt{\left(X_{Li} - X_{busj}\right)^2 + \left(Y_{Li} - Y_{busj}\right)^2} \tag{9}$$

Where, L_i=load i and bus_j= busbar j.

L_i is associated to busbar with the minimal geographical distance and with capacity L_{max_i}. If the sum of the L_i is greater then L_{max}, the second busbar with a minimum distance and then the minimum L_f is consider. If two busbars have the same distance, the busbar with the lowest L_f will be choosing.

D. Unserved load and new projects on the electricity grid.

After obtaining the distribution of the load on the grid, it is obtained the magnitude of *UL* and the determination of the number of busbar is a function of this magnitude and the number of sections of the area analyzed (*N*).

If one considers the number of sections, the *UL* level of each section Lns_i (i=section) and the average capacities of adjacent busbars of the same section <Cap_i> are computed. Both are used to determine the amount of busbars required in each section:

$$N^\circ Busbar_{\sec c} = \left\lfloor UL_i \Big/ \langle Cap_i \rangle \right\rfloor \tag{10}$$

The value is the result of a floor function, if there is similar behavior in the adjacent sections to cover all *UL*.

The next step is to define *the center of load* at the location of a new busbar. The center of load is based on average geographical distance between the identificated *Uls*. Starting point is the load at the coordinates (x_0,y_0) adds the next adyacent *UL*,. The expression is the following:

$$x_{k,i} = \frac{\left(UL_{0,i}\cdot x_0 + \sum\limits_{j\in N^\circ Lns_i \le \langle Cap_i\rangle} UL_{j,i}\cdot x_j\right)}{\left(UL_{0,i} + \sum\limits_{j\in N^\circ Lns_i \le \langle Cap_i\rangle} UL_{j,i}\right)} \quad k = busbar \quad i = \sec tion \tag{11}$$

Where, $X_{k,j}$ represents the coordinates $x_{k,i}$ and $y_{k,i}$ in km.

E. Definition of loss factor and utilization of DGu.

With the final location of the new busbars it is possible to define their initial *Lfs,* without the effect of connected *DGu*. *Lfs* are defined as the average *Lfs* of the adjacent busbar with the same voltage considering their geographical distance to the new busbar, i.e.:

$$Lf_{k,i} = \frac{\left(\sum\limits_{j=busbar} Lf_j \cdot d_{k,j}\right)}{\left(\sum\limits_{j\in=busbar} d_{k,j}\right)} \quad k = busbar \quad i = \sec cion \tag{12}$$

Where, $d_{k,j}$ is the euclidian distance from busbar j to busbar k.

Then a new distribution of the load is possible to make. For this new distribution the same method will be applied. Here it will be considered that there are no *ULs* and new busbars without the influence of *DGu*.

However, considering the inclusion of *DGu* the distribution of load criteria needs to be modified the *Lfs* become a function of the capacities of the device ratings <Cap_i> . To model one *DGu* connected to busbar n, there impact on facility loading will be considered. As a side effect will be reduced the dependency from current facility and the supply capacity will arbitrarily increase.

Lf of the busbar n is a function of $L_{max(n)}$. If the supply to $L_{max(n)}$ is lower by the DG_n contribution , the utilization of the grid is reduced by DG_n for all associated facilities at busbar n and also *Lf* is modified.

In summary, the strategic location of *DGu*, de-congest the network, has a significant impact on the load distribution and gives a strategic direction of the growth of a grid. In order to balance the *APLs,* the location of these units in accordance with the major *Lf* is recommended.

Owing to the new busbar have not the optimal connection to the network, an approximation of *Lfs* is used for obtain the new *Lfs*, similarly to *Lfs* from adjacent busbar but the local effect *DGu*. A proposed approach is as follows:

$$Lf^{new}_{n,i} \approx Lf_{n,i}\cdot\frac{\left(L_{\max(n)} - DG_n\right)}{L_{\max(n)}} \quad n = busbar \quad i = \sec tion \tag{13}$$

The approximate effect of the introduction of *DGu* on the load distribution in the grid is analyzed with Lf^{new}.

Theoretically, the permissible level of *DGu* is two times the maximum consumption [9]. If $DG_n \leq L_{max(n)}$, a priority effect in the busbar *n* it is created. If $DG_n > L_{max(n)}$, the busbar *n* is converted in a busbar with generation $DG_n - L_{max(n)}$, $Lf^{new}=0.$, affecting the adjacent busbar.

With this new formulation the final distribution of the load is obtained.

V. VALIDATION AND APPLICATION TO A REAL NETWORK

An application of this scheme to a real distribution company (*DisCo*) is presented in this section.

A. System Description and distribution of the load.

The considered *DisCo* serves about 0.5 million people. The used measurement data comprise residential and commercial [10] customers and reflect the years 2000 to 2004.

The area of the served city is $297.6\ km^2$ and is divided into 64 sections ($N=8$). The information basis is given in [11, 12].

The electrical system which supplies this area is modeled with 771 busbars in 110kV and 10kV, 600 MW of generating including 1.8 MW of distributed generation.

The temporal load forecasting result is considered in each measurement's station which is subjected to following analysis.

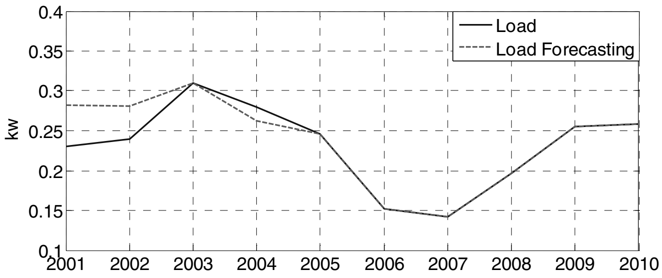

Figure 4. Load forecasting, station 394

Fig 4 shows the load profile of measurement point from downtown. One can clearly identify a fluctuation in the load over the years. . The spatial location of index kw/km^2 for each section is associated with the coordinates of the measurement points and is distributed with a normal function.

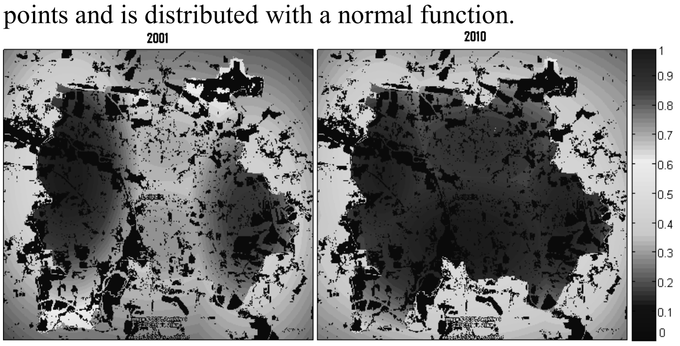

Figure 5. Spatial distribution of the load

Fig. 5 shows the load's distribution (with respect to its maximum limit for each year) for the years 2001-2010. This is a result of a statistical distribution forecast of the index kw/km^2 according to the used resolution of 64 sections. The obtained results present the move of consumption to the center town between the years analyzed.

B. Analysis of the network and connection of the load

The power flow result of the network in 2010 (with the load forecasting in real case) and its simulation with peak demand from the proposed algorithm in IV.B with two extreme case of supply, first *SF*=0.9 similar to actual security factor or supply dependencies of the current network and one extreme value with 50% of the dependencies of the current network *SF*=0.5, with this finally case it is possible seeking new supply points. The results are presented in the following table:

TABLE I. POWER FLOW RESULT

	Real case		***SF* =0.9**		***SF* =0.5**	
	MW	***MVar***	***MW***	***MVar***	***MW***	***MVar***
Gen.	590.72	231	675.86	171.13	485.4	247.9
Max Load	553	167.5	631.25	105,2	459.2	226.7
Loss	37.81(6.4%)		44.61 (6.6%)		26.21(5.4%)	

Table 1 show the variation of the maximum possible load as function of the *SF*. *SF* represents the total capacity of each facility and hence defining the limit of supply.

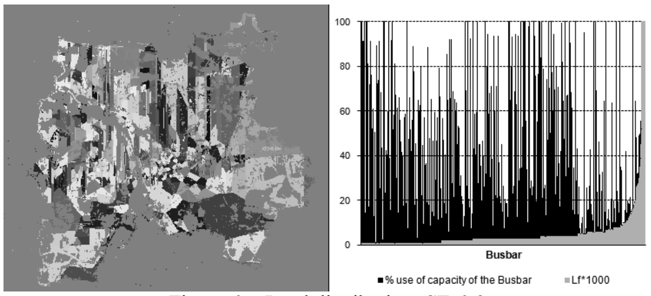

Figure 6. Load distribution, *SF*=0.9

Fig. 6 show the association of load to the network and the busbar utilization as function of the distance and *Lfs* with a *SF=0.9* in 2010. This load does not exceed the maximum allowable consumption with a *SF=0.9'*. In this case UL does not exist. The new power flow with this new load distribution is as follows.

TABLE II. NEW POWER FLOW RESULT, 2010

	Real case		***SF* =0.9**	
	MW	***MVar***	***MW***	***MVar***
Gen.	590.72	231	586.96	220.8
Load	553	167.47	553	167.47
APLs	37.81(6.4%)		34.04(5.8%)	

Table II show the reduced the *APLs* by 0.6% over the base case, which has the advantage of using this method.

Finally, considering the same load forecasting, but with a *SF*=0.5, there would be *UL* of 93.72*MW* by 2010.

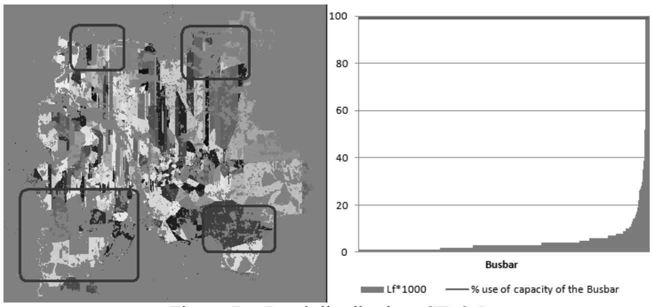

Figure 7. Load distribution, *SF*=0.5

Fig 7 shows the location of this UL, the connection of the load to the electrical grid with her busbars to 100% of their capacity (right graph).

C. Determination of unserved load and new projects associated to the grid

If it is considered the case with *SF=0.5*; there are 93.72*MW* of *UL* by 2010. In this case, it is possible to analyze the proposed new busbar.

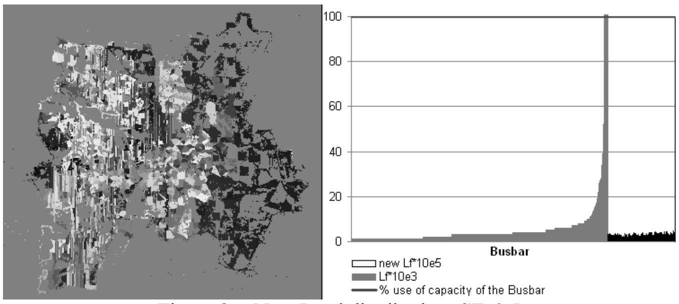

Figure 8. New Load distribution, *SF*=0.5

Fig 8 shows the new distribution proposed with 178 new busbars of 10 *kV*. In this scenario it is possible to have *UL*=0.

D. Connection of DGu as a function of Lfs value.

The busbars with major *Lfs* above average 0.02 (*see fig. 8*) and used a generation of 50*kW* are considered to analyze the location of *DGu*.

TABLE III. NEW POWER FLOW RESULT, 2010

	***SF* =0.5 without DG**		***SF* =0.5 with DG**	
	MW	***MVar***	***MW***	***MVar***
Total Gen.	583.79	227.1	583.61	224.6
Load	459.15	178.61	461.1	177.46
New *DGu*	-	-	1,9 (38 units)	0.8
New busbars	178		167	
Load in New busbars	93.76	25.473	91.82	23.54
APLs	30.88(5.29%)		30.70(5.26%)	
Average *Lfs*	0.0041		0.0031	

This new generation reduces *APLs* by 0.03%, average value of *Lfs* in 24% and the amount of new busbar is reduced

The introduction of *DGu*, provides different results with respect to its influence on the grid operation and the variation of *APLs* and *Lfs*. Then as conclusion of this approach, it is feasible to postpone transmission expansion.

VI. CONCLUSIONS

The load distribution as function of network capabilities indirectly allows for a life time extension of network components, while keeping the supply on a high of security. This also supports better the planning process with respect to cover the future load growth. The proposed methodology can be used as integral part of a net planning process in order to achieve network loss minimization by optimal load distribution.

Furthermore, it is necessary to consider the effect of distributed generation on the electrical grid with respect to new configuration which helps to increase the security of supply.

The proposed methodology of load connection to the grid is based on electrical grid parameters analysis aiming at reducing the active power losses by load distribution and active utilization of distributed generation.

According to the obtained results from a real network of a metropolitan area, the proposed scheme shows advantages. Furthermore it has been shown that it is possible to rate the load by means of the Euclidean geographical distance to each busbar. This information can be used to minimize the degree of network expansion as a whole. In addition future unserved loads can be identified as well and the strategic placing of distributed generation units for the sake of active power loss minimization will be supported as well.

In summary, the proposed scheme is presented as a complementary analysis for the planning of electrical systems under the massive presence of distributed generation units.

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