MODELLING OF NEW TECHNOLOGIES AND VARIABLES IN COMPETITIVE MARKETS IN POWER SYSTEM PLANNING MODELS

J. Cerda-Arias and D. Westermann

Ilmenau University of Technology, Institute of Electric Power and Control Technologies - Power System Department

Gustav-Kirchhoff-Str. 1, D-98693 Ilmenau.

jose-luis.cerda-arias@tu-ilmenau.de & dirk.westermann@tu-ilmenau.de

Abstract – The new agents which are introduced in the current structure of power systems with competitive wholesale markets for electricity and the future behaviours of the customers will gradually change the electric systems' topology. Consequently, it is necessary to update the planning models and consider the relationship between the competitive markets and the power system planning and the effects of the implemented polices which lead to a more efficient energy utilization. This paper presents a planning model for the expansion of the power grids. The proposed model is based on the influence of current variables on the expansion of the power grid as, implementing new environmental and energy efficiency policies; and diversification of the energy matrix through the integration of heuristic optimization methodologies which incorporate the tariff schemes into the transmission system. The optimal expansion of the power systems considers the relation between all participants of the power systems under a security of electricity supply constraint.

Keywords: Power systems planning model, tariff transmission model, genetic algorithms, renewable energy.

1 INTRODUCTION

Today's structure of power systems with competitive wholesale markets for electricity encourages the introduction of new agents and products and the specialization of the participating stakeholders as generators, network operators and power suppliers. This will gradually affect the electric systems' topology and the manner in which it will develop in the future.

Furthermore one has to take into account the variation of the fossil fuel prices on the world market, which even anticipates the closeness of its scarcity, the instability of the fulfilment of contracts and the existence of import restrictions. Furthermore, the implementation of policies aiming to control $C0_2$ emissions, efficient use of energy and the advent of more efficient technologies have to be incorporated in new network expansion projects. They are forcing utilities and society to seek new forms of electric system expansion without affecting its economic growth. This expresses a challenge to sustain such growth and changes the vision for the power system and the security of electricity supply required.

From an economic perspective the security of electricity supply (SOS) seems incomplete to tackle the problem because the energy market is far more complex than other property and services markets. Given that energy supply planning is closely related to medium and long term decisions, this is hampering a timely adaptation of the generation and demand. This is particularly true for crisis situations (prolonged droughts, recessions, natural disasters).

SOS is usually based on internal factors to the sector under study, leaving aside the possible effects on other economic sectors. At the international level, the existing methodologies for the planning of power systems have developed with a huge amount of thermal generation and meshed transmission systems [1].

Additionally the expansion of the network topology plays an important role in the incorporation of new variables into the global analysis that describe the behaviour of the consumers and new consumption [4].

Current methodologies of transmission system development are related to classic solutions of costs minimization associated with developing a project, without considering the uncertainties related to competition in the electricity market [2].

It is necessary to find alternatives and offers (from the environmental, technical, and economic standpoint) to develop sustainable power systems with an SOS and a strategic plan for power system expansion. Currently efforts are underway to develop planning models which consider income of power generation based on renewable energy sources, the expansion of interconnected system founded on these new requirements, bearing in mind the relationship between the competitive markets and the power system planning [3].

In this paper a novel planning model for the expansion of the power grids is proposed. The model is based on the influence of current variables on the expansion of the current power grid as, implementing new environmental and energy efficiency policies and diversification of the energy matrix in a power system through the integration of heuristic optimization methodologies which incorporate variable decision as the tariff schemes into the transmission systems.

In section II the state of art about power system planning model is presented. In section III, the general formulation of methodology purposed is described. Section IV presents the modelling of the proposed methodology. In section V, the scheme is applied to a real network of a metropolitan area. Finally, analysis and conclusions are presented in section VI.

2 THE STATE OF ART: POWER SYSTEM PLANNING MODEL

Considering the current trend of electric market structures and development of new network structures, it is expected that the planning models must incorporate these signs in a gradual development. Currently planning models focus on minimized the sector cost safety standards and quality of service required without incorporating these new variables and integration required by the market.

Some of these subject are covered by a series of papers, the today's developments in the planning area considering new generation projects and transmission lines, making a network configuration in order to minimize costs and thus the system power losses, considering investment, operation and maintenance costs, and power penalty for unserved load. A summary of the extensive list of studies in this area is presented in [10-13]. They consider different types of models aimed at different targets, each with a proposed solution method according to analyze system requirements.

While these models comply with the proposed requirements, it is necessary to consider the new guidelines are added to the development of new power system structures, incorporating external effects to the electric power. In this line other current models developed consider the integration of energy systems, uncertainty of consumption, influence of other areas of society and current variables previously discussed, a summary of these models are:

MARKAL model [14]; *SUPER OLADE* model [15]; short-and-long optimization energy generation and optimization *(SLOEGAT)* model [16] and open market energy generation allocation *(OMEGA)* [17].

Based on these experiences, it is developed the proposed model which combined the result of these experiences analyzed, these are carried to a context of network expansion to meet the current regulatory requirements of SOS, environmental and technological.

3 GENERAL FORMULATION OF METHODOLOGY PURPOSED

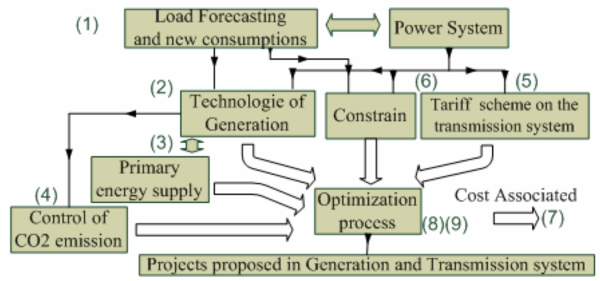

Figure 1: Scheme of the planning model proposed.

The proposed model is intended for medium and long term planning at the transmission level. The general methodology presents a differentiable objective function with nonlinear constraints, in a search space bounded by the proposed projects to assess and their combinations. Due to the nature of the optimization problem and the search for a statistical solution of location of the power generations, type of technology and the choice of branches required, under CO_2 emission control and the effect of tariff variables, a heuristic optimization methods (Genetic Algorithms, *GA*) subject to technique constraints of the power system is proposed, by its robust nature, the use if a multi-search, with probabilistic operators and easy implementation.

Fig. 1 illustrates the components undertaken by the planning model. The following is a description of each module:

(1) Load forecasting and the location of the new supply point are presented as preconditions of the result obtained in [4, 18], taking into account trimester energy blocks for the periods of winter, summer and spring-autumn. Energy blocks are considered as a function of the amount of daily energy with respect to the maximum of the peak seasonal period. In the months where changes from season to season take place the corresponding proportion are contained in the particular month.

(2) Power generation technologies. Includes: wind, solar energy, hydraulics and thermal generation (gas, biogas, coal, diesel or nuclear energy).

It is proposed that each node which do not have generation or consumption will be assessed by a set of generators belonging to each type of technology named, each one of them has a probability of use, depending on site conditions tested.

(3) Primary energy and the provision of the new generation projects. The variation of the initial cost in the short term is incorporated in the proposed model based on the probability of use of the new power generation plant, be it the distance to a network of energy, the fluctuation of prices of primary energy, breaches of contracts or the existence of an acceptable level of wind or solar radiation. This probability is incorporated in the objective function as one uncertainty cost.

(4) $C0_2$ emissions. In order to reduce $C0_2$ emissions produced, laws which encourage change in consumer behaviour have been implemented. The limits imposed by various international treaties, allow the establishing of periodic goals and in particular the transformation of existing products in electrical consumption [7], concurrently affecting the power generation which is presented as an alternative to replace some primary energies resources as is the cole or gas. The fulfilment of these goals is reflected in the cost of incorporating technology which reduces these emissions for future power generation, dimensioning the contribution of each technology by the reduction of $C0_2$ emissions.

(5) Tariff scheme. Due to the current structure of the electricity market, allowing non-discriminatory access to transmission grid, which is controlled and managed as a natural monopoly, with strong scale economies where marginal theory [6] does not cover all investment costs, operation and maintenance, owing to this difference shows that the supplementary cost called tariff [6].

The tariff scheme corresponds to the difference in the recovery of injections and retires for each section of the transmission system at marginal cost. Currently the tariff scheme is based on the implementation of *distribution factors* [6], which is explained below:

- *Generation shift distribution factor (GSDF),* factors with an application of access concepts, injection point and withdrawal point. In economic terms reflects the power injected by a generator, determining its participation on each line on the system that carries energy to an operating condition, taking a reference node that represents the system's load centre.
- *Generalized generation distribution factor (GGDF)*. These factors differ from the above factors considered total variations generation-flow and have an application of concepts access point or injection, defining a determined operating condition.
- *Generalized load distribution factor (GLDF)*. This factor is analogous to *GGDF*, but under the concept of retirement point.

In considering these variables, a decision variable is added which takes into account the use of current and new installations of the power system by means of a new power generation in order to find the best business opportunity for the transmission area, considering the estimated payment by the use of this new installation.

(6) Constraints. The model must satisfy certain constraints in the network, namely respecting the voltage and current level. The constraints proposed are:

- Supplying of peak demand and maxima energy per period to analyzed.
- Maximum power and energy transmission,
- Power and energy balance in the system,
- Limit of power generation

(7) Associated costs. The costs associated with evaluating projects make up the cost function for minimize:

- Cost which includes the investment's unit price, the period in which the investment is made, equipment life, a fixed operating cost and discount rate (C_{inv}).
- $C0_2$ emissions cost depending on the technology being evaluated [7] (C_{emis}).
- Variable costs: operation and maintenance costs, cost of primary energy and the efficiency update ($C_{op\&mant}$). This cost is a function of the structure of the power system witch is mayoralty wind generation or hydro generation.
- Costs or payments for applying a tariff scheme on the transmission system of a node weighted for the use percentage of the line and the transmitted power variable. The percentage is a function of the distribution factors and the values of the reactance matrix (C_{Tar}).
- Penalty cost of unserved load (P_{UL}).

(8) Projects analyzed. The proposed projects are based on the experience of their feasibility.

- Generation and type of technology
- Branch of the new node connection in transmission,
- Extensions of current and new branches.

The new connections are proposed on the busbars which have only transfer's energy without consumption or power generation.

(9) Methodology. According to the requirements of the model, the optimization heuristics method is used for searching an optimal solution: GAs are advantageous because they are stochastic and multiple searching [8].

4 MODELLING OF THE METHODOLOGY PROPOSED

The purposed planning model described in Section III can be formulated for each time period as a mathematical optimization problem.

4.1 General structure

The general structure of the proposed model is represented for the following equations:

$$\begin{aligned} &Min \quad Z = f(\vec{x}) \\ \text{s.t}\ & g(\vec{x}) = 0 \\ & h(\vec{x}) \leq 0 \\ & \vec{x}_{\min} \leq \vec{x} \leq \vec{x}_{\max} \end{aligned} \qquad (1)$$

In this section we describe the elements of Eq. 1 and the solution method.

4.2 Objective function and Optimization Variables

As general objective function it has considered the total cost of each project and the effect of tariff scheme and unserved active power.

$$f(\vec{x}) = \sum (C_{inv} + C_{emis} + C_{op\&mant} + C_{Tar} + P_{UL}) \qquad (2)$$

C_{inv}, C_{emis}, $C_{op\&mant}$,C_{Tar} and P_{UL} were defined in III-(7).

The detailed objective function has the following structure:

$$\begin{aligned} f(\vec{x})_n = &\sum_{i=1}^{N_{NP}} CI_{in} \cdot X_{P\_in} + \sum_{i=1}^{N_{NP}} CE_{in} \cdot X_{P\_in} + \\ &+ \sum_{m=1}^{N_{PS}} \sum_{i=1}^{N_{NP}+N_{CF}} \sum_{k=1}^{N_S} CV_{inkm} \cdot \mathrm{P}_{mn} \cdot X_{E\_inkm} \pm \\ &\pm \sum_{m=1}^{N_{PS}} \sum_{i=1}^{N_{NP}} \sum_{k=1}^{N_S} \sum_{q=1}^{N_B} CSP_{qn} \cdot Per_{qin} \cdot X_{E\_inkm} + PUL_n \cdot UL_n \end{aligned} \qquad (3)$$

Where, OF_n= Objective function of period *n*,
N_{NP} = number of new project.
N_{CG} = number of current facilities
N_{PS} =number of probability scenery of wind
N_S = number of energy period (season)
N_B = number of branch
CI_{in} = C_{inv} (*$/MW*) of generator *i* in period *n,*
CE_{in} = $C0_2$ emission costs generator *i* in *n,* (*$/MW*)
CV_{inkm} = $C_{op\&mant}$ of generator or branch *i* in the period *n*, season *k* and probability of scenery *m,* (*$/MWH*).
P_m = probability of scenery *m* in the period *n,*
CSP_{in} = initial or final node's spot price of branch *i* in period *n*, depending of the *distribution factors*.
Per_{ij} = percentage of participation in a branch *i* of the generator or consumption *j* in the period *n,* depending of the distribution factors (*see VI.2*),
PUL_{in} = cost of unserved load penalty in consumption *i* on period *n*, P_{UL} (*$/MW*).
UL_n = unserved load penalty in period *n*,
X_{P_in} = installed capacity at generator, new branch or expansion of the facility *i* in period *n* and
X_{E_inkm} =energy generated by generator or transported by new branch or expansion of the facility *i* in period *n*, season *k* and probability of scenery *m.*

The access to primary energy required for each new generation plant reflects the increase in investment and operation costs, but the objective is considered an access factor to these networks and guided the power system expansion. Then this term is reflected in the division of CI_{in} and CE_{in} by a factor ε (0,1], incorporating the access to primary energy networks.

Each new evaluated project is represented for the optimization variable X_{P_in} and X_{E_inkm}. Then the optimization variables vector is constituted by: $\vec{x}_n = \lfloor X_{P\_in} \quad X_{E\_inkm} \rfloor$.

UL_n is constituted by the different between the total load and the generator of the new project and the current generator.

4.3 Tariff scheme

The Tariff scheme delivers to the planning model two result of the new projects' effect:

- First it is analyzed the optimal location of the new generator as a function of the minimal pay to the transmission system and
- Second it is analyzed the optimal configuration of the transmission system with the new project such as new branch or new expansion of the current branch.

For both cases it is necessary to estimate the spot price of the new supply point. This estimate is a function of the spot price of the current node that is supplying the new point and the active power losses of the branch to be analyzed (new project) [19].

a. New generator project: The component referred to the tariff scheme Per_{ij} and which spot price is used in equation 2 is a function of the distribution factors.

With *GSDF* it is necessary considered for CSP_{in} the initial node's Spot price of branch *i* and Per_{qin} has the following structure:

$$\mathrm{Per}_{\mathrm{qin}}^{\mathrm{GSDF}} = GSDF_{qin} \cdot \frac{X_{P\_in}}{\sum_{\mathrm{w=1}}^{\mathrm{N_G}} GSDF_{qwn} \cdot X_{PT\_wne}} \quad (4)$$

Where, $GSDF_{qin}$= *GSDF* of branch *q,* node *i* in *n*,
X_{P_in} = power generation in the node *i* in period *n*.
X_{PT_wne}= current and new power generation in the node *i* in period *n* and season *e.*

With *GGDF* it is necessary to consider the initial node's spot price of branch *i,* too and Per_{ij} has the following structure:

$$\mathrm{Per}_{\mathrm{qin}}^{\mathrm{GGDF}} = GGDF_{qin} \cdot \frac{X_{P\_in}}{\sum_{\mathrm{w=1}}^{\mathrm{N_G}} GGDF_{qwn} \cdot X_{PT\_wne}} \quad (5)$$

Where $GGDF_{qin}$= *GGDF* of branch *q,* node *i* in *n*.

Finally with *GLDF* it is necessary considered the consumptions node in the equation (3) replaced the variable X_{E_inkm} and by CSP_{in} the final node's Spot price of branch *i,* too and Per_{ij} has the following structure:

$$\mathrm{Per}_{\mathrm{qin}}^{\mathrm{GLDF}} = GLDF_{qin} \cdot \frac{Load_{in}}{\sum_{\mathrm{w=1}}^{\mathrm{N_L}} GLDF_{qwn} \cdot Dem_{wne}} \quad (6)$$

Where $GSDF_{qin}$= *GSDF* of branch *q,* node *i* in period *n*,
Dem_{ine} = Demand of node *i* in period *n* and season *e,*
$Load_{in}$ = load of node i in period n.

b. *New branch or expansion of current branch*. From the transmission system perspective, the effect of the distribution factor is irrelevant, because the payment by the use of the branch is in the final node. Then the marginal costs are considered in this case.

4.4 Equality Constraints

The proposed optimization model exhibits equal (E), unequal (UE) and linear (L) constraints which can be summarized as follows:

Supply of peak load (E, L). It is considered the peak load supply of each node.

$$\sum_{j=1}^{N_{NG}} X_{P\_jni} + \sum_{k=1}^{N_{NB}} \left(\left(1 - loss_{B1\_kn}\right) \cdot X_{B1\_kni} - X_{B2\_kni} \right) = Load_{in} - \sum_{j=1}^{N_G} G_{jin} \quad (7)$$

Where, N_{NG} = number of new generation
N_{NB} = number of current and new branch
N_G = number of current generation in node *i* in *n.*
X_{P_jni} = new generation *j* in node *i*, period *n.*
X_{B1_kni} = power injection of branch *k* to node *i*, period *n.*
X_{B1_kni} = power withdrawal of branch *k* in node *i*, in *n.*
$loss_{B1\_kn}$ = active power losses of branch *k*, in *n.*
G_{jin} = current generation *j* in node *i* in period *n*
(i ϵ ***I****)* and *(n* ϵ ***N****)* where ***I****={1,...,i}* is the node set, and ***N****={1,...,n}* is the period set.

New power generation technology (E, NL). In addition, only one power generation technology in each node is used:

$$\sum_{m=1,\neq j}^{N_{NG}} \sum_{j=1,\neq m}^{N_{NG}} X_{P\_mni} \cdot X_{P\_jni} = 0 \quad (8)$$

This is known as the complementary condition.

Supply of Energy (E, L). It is considered the energy supply of each node.

$$\sum_{j=1}^{N_{NG}} X_{E\_jniqe} + \sum_{k=1}^{N_{NB}} \left(\left(1 - loss_{B1\_knqe}\right) \cdot X_{E\_B1\_kniqe} - X_{E\_B2\_kniqe} \right) = Dem_{inqe} \quad (9)$$

Where, X_{E_jniqe} = new and current generation *j* in node *i*, period *n,* probability scenery *q* and season *e.*
$X_{E\_B1\_kniqe}$ = power injection of branch *k* to node *i*, period *n,* probability scenery *q* and season *e.*
$X_{E\_B1\_kniqe}$ = power withdrawal of branch *k* in node *i*, period *n,* probability scenery *q* and season *e.*
$loss_{B1\_knqe}$ = active power losses of branch *k*, period *n* probability scenery *q* and season *e.*
Dem_{ine} = Demand *i* in period *n* and season *e.*

Power balance in the system (UE or E, L).

$$\sum_{j=1}^{N_{NG}} X_{P\_jni} \geq \sum_{i=1}^{N_L} Load_{in} - \sum_{j=1}^{N_G} G_{jn} \quad (10)$$

Where, N_L = number of loads and $Load_{in}$= load of node *i* in period *n*.

Energy Balance in the system (UE or E, L).

$$\sum_{j=1}^{N_{NG}} X_{E\_jniqe} \geq \sum_{i=1}^{N_L} Dem_{ine} \quad (11)$$

Maximum power transmission per sections (UE, L).

$$X_{B\_kni} \leq CC_{B\_kni} + X\exp_{B\_kni} \quad (12)$$

Where, X_{B_kni}= power withdrawal of current branch *k* in node *i*, period *n.*
CC_{B_kni} = Current capacity of branch *k* in node *i*, in *n*
$Xexp_{B\_kni}$= maximal expansion estimated of the current branch *k* in node *i*, period *n.*
$Xexp_{B\_kni}$ delivers which kind of project is proposed, expansion of the reactive power, new circuits or lines.

Maximum energy transmission per sections (UE, L).

The maximum energy transmission on branch *j* is related to the maximum power transmitted.

$$X_{E\_B\_kniqe} \leq X_{B\_kni} \cdot FC_{kniqe} \quad (13)$$

Where, FC_{kniqe}= maximum load factor of transmission of branch *k* in node *i* in period *n,* probability scenery *q* and season *e.*

Limit of generation (UE, L).

$$FMIN_{jniqe} \cdot X_{P\_jni} \leq X_{E\_jniqe} \leq FMAX_{jniqe} \cdot X_{P\_jni} \quad (14)$$

Where, $FMAX_{jniqe}$ & $FMIN_{jniqe}$ = maximum and minimum plant factors *j*, period *n,* probability scenery *q* and season *e.*

Relation between periods. To relate the projects between the analyzed periods it is necessary to consider certain constraints generated by the realization of a project in an earlier period. These constraints are subject to the results of the first period analyzed (*n* = 1).

Power generation & new branch (UE, L). It is carried out the following condition:

$$\sum_{j=1}^{N_{NG}} X_{P\_j(n-1)} \leq \sum_{i=1}^{N_L} Load_{in} - \sum_{j=1}^{N_G} G_{jn}, \quad (15)$$

The next period had to carry out the limits of the new generation:

$$X_{P\_j(n-1)} \leq X_{P\_jn} \quad j = new\_project \quad (16)$$

$$X_{E\_j(n-1)iqe} \leq X_{E\_jniqe} \quad j = new\_project \quad (17)$$

If it is not carried out (16), the next period had to carry out the following constraints:

$$X_{P\_jn} = 0 \quad with\_X_{P\_jn-1} = 0 \quad j = new\_project \quad (18)$$

$$X_{E\_jniqe} = 0 \quad with\_X_{P\_jn-1} = 0 \quad j = new\_project \quad (19)$$

With these limits new generation and new branches are considered within one of the period with n-1 security as basis.

4.5 Mathematical solution method

The result of the proposed model is defined as a nonlinear optimization problem with nonlinear equality and inequality constraints. With the consideration of Eq. 8, the optimization problem requires the modelling of integer variables [20]. Fig. 2 illustrated the flow of information in the proposed model.

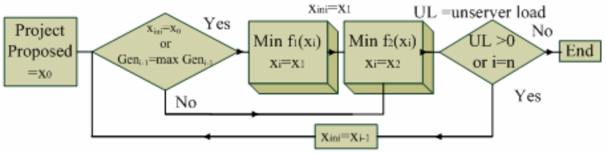

Figure 2: Flow of information in the proposed model

The algorithm begins with a set of project proposed and differentiates the cases:

- Firstly, the capacity limit of current power generation is calculated in the first module.
- In a further step reserves in power generation is analyzed.

Then the search for optimal solution in two stages with the following information flow will be performed:

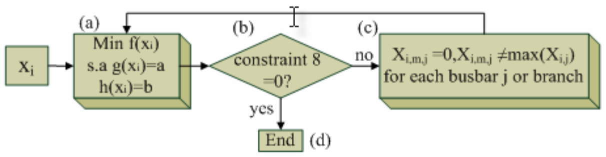

Figure 3: Flow of information in each stage

The first stage only considers the selection of technologies, the amount of power generation units and their location, merely minimizing the generation cost of each technology. This stage considers all new proposed transmission projects. It is only used in the first period or when UL>0 in other period.

The cost function uses only the relation cost with power and energy generation with the Eq. 8, (10, E), (11, E) and (14), the optimization variable are related only with power and energy generation. The optimal solution in *(a)* is evaluated in *(b),* if the Eq. 8 ≠ 0 for each node is evaluated, it is only one technology with the maximal generation at minimal cost (X_{Pmax}) is considered. For the other variable the "*Branch & Bound*" [20] method has been used. This heuristic method consists of an intervention of the optimization algorithm, forcing the variable different to the maximum generation variable to satisfy the complementary condition defined by Eq.8 (c).

$$X_{P\_mni}\Big|_{X_{P\_mni} \neq X_{P\max}} = 0 \quad (20)$$

for the technology *m*, node *i* in period *n.*

The algorithm is made with these new constraints. Then the stage delivers the optimal solution of the power and energy generation $\vec{x}_{Gn}$ for the period *n (d).*

The second stage is focused on transmission system expansion. In this stage the power generation projects elected in the previous stage or all project of the previous period are considered.

The cost function (3) is used with the all constraints, the optimal solution in *(a)* is evaluated in *(b)* (Fig. 3). If Eq. 8 ≠ 0 for each new evaluated branch, a maximum number of branches (N_{Bmax}) supplying the new consumptions are considered and the same *Branch & Bound*" method has been used.

The algorithm has been complemented with these new constraints and delivers the optimal solution of the power system $\vec{x}_n$.

The model is implemented in MATLAB [21].

5 VALIDATION AND APPLICATION TO A REAL NETWORK

The proposed method has been applied to a real distribution system (Distribution Company, *DisCo*). The results of these investigations are presented in this section.

5.1 System Description.

The considered power system comprises 600MW of power generation units, 44 nodes, 2 new nodes to supply (N1& N2), 6 types of generation technologies and 22 new lines.

Fig. 4 illustrates the marginal cost of each node in the investigated electrical system

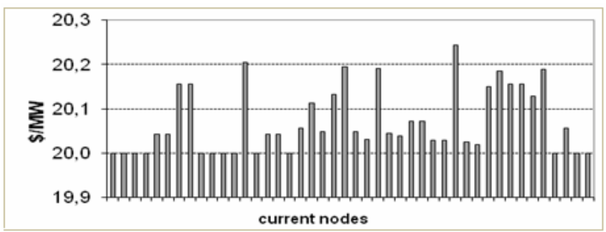

Figure 4: Spot prices of the systems

Considering the cost of the power generation projects and new branches, Fig 5 describes the component cost of each proposed technology: inversion cost per MW presented in [9], CO_2 emission produced according the cost presented in [7] and variable cost per MWh [9].

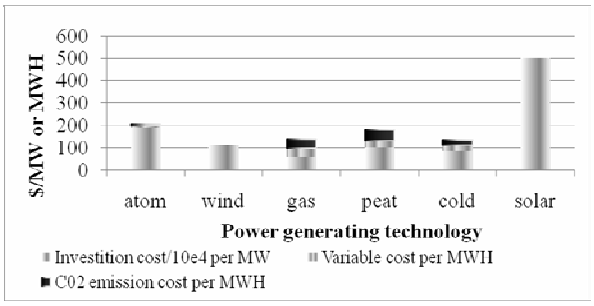

Figure 5: Cost of the new power generation project

The global load forecasting of this power system is depicted in the Fig 6. The load forecasting result and its distribution in the grid is obtained from [4] and [18].

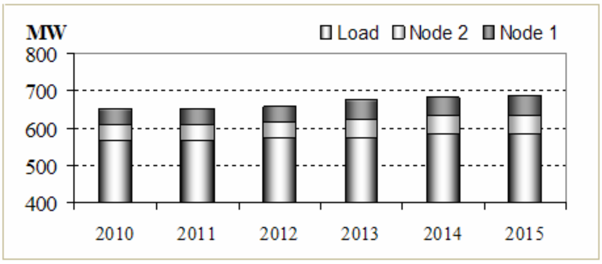

Figure 6: Load forecasting

The power generation projects consider 10 nodes for their potential connection and the new branches projects are evaluated from 11 nodes to the new nodes.

5.2 *Effect of market variables in the decision-making*

The analysis from the effect of tariff scheme for choosing the best location of a generator considers only the marginal cost without any other cost. The probability energy primary access as 1.0 of all technology and one probabilistic wind scenery are used in the base case.

Table 1 illustrates the result of the proposed planning model. The node 33 is obtained as optimal location, using *GSDF* and *GGDF* and no clear reference with *GLDF* because this factor considers the location of the load and not of the generators.

Table 1: Unitary generation cost ($/MWh)

Nodes	*GSDF*	*GGDF*	*GLDF*
2	443	381,8	0,2029
4	845	494,7	0,2029
6	4692	409,5	0,2029
10	1160	482,6	0,2029
11	786	434,1	0,2029
12	2378	464,5	0,2029
13	898	379,7	0,2029
22	217	356,0	0,2029
23	105	356,8	0,2029
33	**53**	**355,9**	0,2029

The evaluation of new branches is not affected by the *distribution factors*, because the payment by generators to the network operators is considers as cost for generators, as utilities for network operators and null for the cost function.

So the evaluation of new branches considers only the marginal costs of the initial nodes as decision variables. Table 2 presents the final result of base case.

Table 2: Finally cost of the base case.

Factor	*Total cost $*	*Gen*		*line 1*		*line 2*	
		node	*MW*	*nodes*	*MW*	*nodes*	*MW*
GSDF	1990.0	*33*	81.4	*4-N1*	40.9	*10-N2*	40.5
GGDF	2502,1	*11*	81.4	*4-N1*	40.9	*10-N2*	40.5
GLDF	877.0	*6*	81.4	*4-N1*	40.9	*23-N2*	40.5

Table 2 illustrates the result of the proposed planning model. Each distribution factor delivers a solution itself according to the payment form of the generators, the location of the load and the influence of the evaluation with the transmission system, affecting the location of the new power generation and the new lines which feed the new consumption. The result shows that *GLDF* provides a lower cost, because it depends on access to the consumption points analyzed and not of the power generation, delivers part of the responsibility of the costs to the location of the consumptions, from market variable standpoint or marginal cost payment. In conclusion of this result, the model gives us a strategic expansion of the system according to the electricity market in which it operates. Then the distributed factors and marginal cost given guidelines of how the electricity market influence in the network.

5.3 *Global solution proposed*

To consider the costs of new generation and transmission presented in Fig. 5 and in the reference [9], the load to supply presented in Fig.6, the solar and wind energy access as 1.0 of all technology and in addition, one probabilistic wind scenery P_m=0.6, m=1, is considered for all proposed nodes, because there are not measurement data of real conditions of the wind in each area of the nodes with the new power generator.

The proposed model delivers the projects plan of power generator and new branches for the next 5 years, for each distributed factor and is presented in Table 3.

The projects proposed are focused directly on supplying the proposed new points of consumption and in determine the combination of minimum cost between generation and transmission projects.

Table 3: Projects proposed in five years.

F.	*Proj.*	*Nodes*	*MW*				
			2011	*2012*	*2013*	*2014*	*2015*
GSDF	*Gen.*	*33*	84,5	2,5	2	4	1,1
	Line	*10- N1*	42,9	1,3	1	1,05	0,48
	Line	*2- N2*	42,5	1,2	0,8	1,05	0,46
GGDF	*Gen.*	*11*	84,5	2,5	2	4	1,1
	Line	*2- N1*	42,9	1,3	1	1,05	0,48
	Line	*11-N2*	42,5	1,2	0,8	1,05	0,46
GLDF	*Gen.*	*11*	84,5	2,5	2	4	1,1
	Line	*2- N1*	42,9	1,3	1	1,05	0,48
	Line	*33-N2*	42,5	1,2	0,8	1,05	0,46

Table 3 shows the result of the proposed planning model. Each distribution factor delivers a different solution with wind energy as generation's technology. The result shows that *GLDF* provides a lower cost, according with the results of the table 2. Respect to the expansion of the power generation in all factor, from 2013 the expansion of the reactive power capacity is possible used, because the increase each year is not significant for one new power generation or a new circuit.

According to the result obtained, the planning model proposed delivers a planning plan which considers SOS and the effect of the competitive market variables. These variables are a function of the nature of the electrical market analyzed and the implemented by new environmental and energy efficiency policies.

6 CONCLUSIONS

The proposed planning model provides an analysis of current variables which influence the power system expansion. Particularly the competitive market variables and the effect of new technologies are introduced as decision variables in the solution of the planning models. This solution has to cover all the needs of the participants and deliver a secure supply of energy.

In terms of results, the proposed planning model delivers the guidelines for the expansion of the network, one of this is based on competitive market variables, as it is shown in Table 1 and Table 2. Also the general result considers the effect of the current cost of each technology evaluated in probable scenarios which consider the wind influence and the possibility of primary energy access.

The result obtained indicated that the relation of the electrical market and planning system area is possible to consider in an optimization solution, also, of the environment and access to the primary energies standpoint, the methodology allows analyzing the different current power generation technologies with their different cost components, according of the application of environmental and energy polices.

In summary, this application complement the result obtained in other study and includes an update of the variables that influence the current and future power systems structure, determining the degree of network expansion as a whole.

REFERENCES

[1] Palma R., Moya O., Vargas L., "*Object-Oriented Simulation Software for a Competitive Environment - Application to Transmission Expansion Planning*", EPRI, Rio de Janeiro, Brazil, 28-30 Nov., 2001.

[2] Cuadros R., Palma R, „*Integrated Tariff Model and Expansion of Power Transmission Networks* ", IEEE Chile, 2003.

[3]European Commission (2000) "Towards a European strategy for energy security," Green Paper: Nov. 29, 2000

[4] Cerda, J., Westermann, D., "*Load forecasting scheme based on energy efficiency for planning the expansion of electrical systems*", PowerTech 2009, PES, July 2009, Bucharest, Romania.

[5] Karabuluta K., Yilmazb A:, *"long term energy consumption forecasting using genetic programming",* Mathematical and computational applications, vol. 13, N°2, pp. 71-80, 2008.

[6] Brokering, W., Palma, R., Vargas, L., "*Ñom Lüfke (El rayo domado) o Los Sistemas Eléctricos de Potencia*", Ed. Prentice Hall, ISBN 9789702612926.

[7] Traber, T., "*Impact of Market on Price Effects of the German Feed in Tariff under the European Emission Trading System*", German Institute for Economic Research (DIW Berlin), 2008.

[8] An A.; Hao X.; Yuan G.; Zhao C. and Su H, "*Parallel adaptive hybrid genetic optimization algorithm and its application*", PACIIA 2009. Asia Pacific Conference 2009, Page(s): 471-475.

[9] Tarjanne R., Luostarinen K. , "*Competitiveness comparison of the electricity production alternatives",* Lappeenranta University of technology, ISBN 951-764-895-2.

[10] Nirmal-Kumar Nair C., Zhanga L., "*SmartGrid: Future networks for New Zealand power systems incorporating distributed generation, Energy Policy*", Electrical & Computer Engineering, University of Auckland, Auckland 1142, New Zealand, May 2009

[11] Coll-Mayor D., Paget M., Lightner E., "*Future intelligent power grids: Analysis of the vision in the European Union and the United States Export Find Similar*" , Energy Policy, Vol. 35, No. 4. (April 2007), pp. 2453-2465.

[12] Bouffard F., Galiana F., "*Stochastic Security for Operations Planning With Significant Wind Power Generation Export Find Similar*",Power Systems, IEEE Transactions on In Power Systems, IEEE Transactions on, Vol. 23, No. 2. (2008), pp. 306-316.

[13] Kumar A., Paddison R.,"*Trust and Collaborative Planning Theory: The Case of the Scottish Planning System Export Find Similar*",International Planning Studies (June 2000), pp. 205-223.

[14] Seebregts A., Goldstein G., Smekens K., "*Energy/Environmental Modeling with the MARKAL Family of Models*", ETSAP Annex VII(199-2001), Homepage: http://www.ecn.nl/

[15] Homepage: http://www.olade.org.ec

[16] Homepage: http://www.cepba.upc.es/project/sloegat.htm

[17] OMEGA Homepage:http://dbs.cordis.lu/fep-cgi/

[18] Cerda, J., Westermann, D., "*Determination of unserved load and distributed generation for power system planning purposes*", MEPS 2010, 20 - 22 September 2010, Wroclaw, Poland.

[19] Rui B., Fangxing L., "*Probabilistic LMP forecasting considering load uncertainty*". *IEEE Trans. Power Syst*, vol. 24,N. 3, August 2009.

[20] Ravindra S., Lasdon L., "*Computational Experience with a Safeguarded Barrier Algorithm for Sparse Nonlinear Programming"*, Comp. Optimization, Kluwer Academic Publishers, Vol. N°19, Issue 1, April 2001, pp. 107 – 120, ISSN: 0926-6003.

[21] MATLAB homepage: http://www.matworks.com