CONGESTION MANAGEMENT BY MAXIMIZING THE OVERALL SATISFACTION DEGREE OF ALL PARTICIPANTS IN THE MARKET

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Abstract - In the scope of the reregulation process of the electric sector, both competitive pool markets and contract mechanisms at the generation and commercialization levels have been emerging. At the wholesale level, and apart from Pool structures and Bilateral Contracts, there are hybrid models in which these two types of structures coexist. In any case, the dispatch coming from the Pool Market Operator, prepared according to the buying and selling offers, together with the bilateral contracted powers must be analyzed from a technical point of view by an independent entity - System Operator. The System Operator aims at checking if the scheduled injected powers do not lead to a decrease of the security standards of the system. Taking in account this concern, in this paper we describe several models to perform the technical validation of sets of electricity schedules, namely trying to minimize the financial impact of the required changes on pre-scheduled generations and loads. This objective is modelled in terms of maximizing the satisfaction degree felt by the participants in the market. The developed application uses Simulated Annealing to solve the corresponding optimization problems. In Section IV of this paper we will include results obtained from several simulations in order to illustrate and demonstrate the interest of the referred models.

I. INTRODUCTION

The restructuring process of the electric sector has been developing in the last decade in several European countries, in America, both in north and Latin American countries, and in Australia. Basically, it aims at introducing a high level of competitiveness in the generation and in the commercialization of electricity leading to a more decentralized operation of power systems and to an increase of the benefits obtained by all the agents, according to market rules. The EU Directive 96/92 that came into force in February 1999 favours the creation of an European electricity common market by considering some common, yet very general, guidelines to organize the sector in the member states. However, the electric sectors of the EU member states already displayed very different structures by the moment at which the referred Directive was approved. This turned it more difficult to adopt a common set of procedures to facilitate the implementation of the electricity common market. The discussions on the Tariffs on the Use of Networks in case of transnational power flows, organized on what is now known as the Florence Forum, is just an example of the difficulties on this process. In any case and according to the EU Directive, member states are forced to open their networks to third entities either considering published or negotiated Tariffs. More recently, recognizing the different paces adopted by member countries, it was proposed to completely liberalize the supply of electricity for all non domestic supplies till 2003 and for domestic consumers till 2005. This does not represent a major change for some countries in which the liberalization is already more developed but will correspond to a major change – that will have to be done in a short period – for several others.

Given the previous process, it is important to recognize that one needs new computational tools that must be used to guarantee the success of this restructuring process as well as the security and high reliability levels of power system operation. In fact, the presence of multiple agents using the same network, the existence of Pool organizations responsible for a purely economic dispatch [1], and the possibility of establishing Bilateral Contracts clearly leads to a more decentralized set of decisions determining power system operation. Surely, the presence of all these injections in the same period of time in the network can lead to congestion in several branches of the system or can reduce its security operational standards [2],[3]. For this reason, and completing the market mechanisms designed to organize the commercial relationship among several entities, it becomes crucial the existence of coordinating entities in charge of technical issues and of the daily operation of the systems. These entities are named Independent System Operators – ISO – and they are responsible for conducting several studies to check whether the injections communicated by the Pool operator or due to physical Bilateral Transactions are feasible in terms of several power system constraints. Congestion management is performed in different ways in different countries but it generally requires some degree of interaction between the System Operator, for one side, and Market Operators and entities responsible for bilateral trades, for the other, in order to change injections in order to alleviate congestion [4 to 8].

Given these concerns, in this paper we describe in Section II four formulations aiming at determining the most adequate procedure to alleviate congestion [9]. They basically correspond to optimization problems to perform a technical validation study of buying/selling electricity contracts. These models will be presented in terms of their increasing complexity so that the last three ones aim at maximizing the satisfaction degree felt by all participants in the market in terms if minimizing the financial impact due to changes on scheduled powers. The implemented application uses the Simulated Annealing metaheuristic to solve those problems given its reduced difficulty of implementation and its ability to escape from local optima. In Section III we present the solution algorithm and in Section IV we will detail several implementation issues and present results using a Case Study based on the IEEE 24 test system in order to illustrate the use of these models and to clarify the potential interest of the results. Finally, Section V presents some conclusions of this research.

II. TECHNICAL VALIDATION MODELS OF BUYING/SELLING POWER CONTRACTS

A. Model 1 - Minimization of the Square of the Deviations of the Initially Contracted Powers

In this first model we aim at to identifying a new set of contracted powers in such a way that the sum of the squares of the differences among its final and initial values is minimized. The formulation (1) to (7) allows us to identify the new set of contracted powers considering the DC model to translate the operation conditions of the power system.

$$\min \quad z = \sum (\Delta Pg_{ij})^2 \tag{1}$$

$$\text{subj.} \quad \sum (Pg_{ij}^{o} + \Delta Pg_{ij}) = Pl_j \tag{2}$$

$$Pg_i^{min} \le \sum (Pg_{ij}^{o} + \Delta Pg_{ij}) \le Pg_i^{max} \tag{3}$$

$$-P_k^{max} \le \sum a_{ki} (\sum Pg_{ij}^{o} - Pl_i + \sum \Delta Pg_{ij}) \le P_k^{max} \tag{4}$$

$$0 \le Pg_{ij}^{o} + \Delta Pg_{ij} \le Pl_j \tag{5}$$

$$\sum Cl(Pg_{ij}^{o} + \Delta Pg_{ij}) - Cg(\sum Pg_{ij}^{o} + \sum \Delta Pg_{ij}) \ge 0{,}0 \tag{6}$$

$$\Delta Pg_{ij} \in \Re \tag{7}$$

In this formulation:

- Pg_{ij}^{o} represents the initial contracted power between generator i and load j;
- ΔPg_{ij} represents the changes on Pg_{ij}^{o} as a result of the technical validation study;
- Pl_j represents the active load connected to node j;
- Pg_i^{min} and Pg_i^{max} are the minimum and maximum generations of generator i;
- a_{ki} is the sensibility coefficient expressing the impact of the injected power in node i in the active power flow in branch k;
- P_k^{max} represents the maximum value of the active power flow in branch k.

Constraints (2) are included to ensure that each load j is supplied by a set of contracted powers. Constraints (3) and (4) impose the min and max limits on active generations and on active branch flows. Constraints (5) impose the admissible ranges of variation to the contracted power between each generator i and each load j. Finally, constraints (6) enforce that the modified contracted powers still lead to profits. The profit of generator i is represented by the difference between:

- the sum of the amounts paid by load j with which generator i established a contract. The amount each load agreed to pay is represented by the function Cl;
- the generation cost function of generator i given by Cg.

B. Model 2 - Maximization of the Generators Satisfaction Degree Using the DC Model

Let us consider that at least a technical constraint is violated for the set of initial contracted powers. In order to eliminate that violation and as a result of the technical validation study, positive or negative deviations ΔPg_{ij} should be imposed on the initial contracted values Pg_{ij}^{o}. The objective of the technical validation study will now be to change the initial contracted powers decreasing the profits as little as possible.

In the scope of Fuzzy Sets Theory [10], it is possible to build a membership function of the profit of generator i, Prf_i, expressing the satisfaction degree felt by that generation entity regarding its profits. For this purpose, let us consider that each generating entity admits to decrease the profit associated to the initial contracted values, Prf_i^{o}, considering at the most a tolerance ε. Using these ideas, in the referred membership function profits larger than Prf_i^{o} are considered fully satisfactory - membership degree 1.0 - while profits smaller than $(1-\varepsilon).Prf_i^{o}$ are assigned a 0 membership degree. Profits between these values have a membership degree in the interval from 0 to 1.0 as it is displayed in Figure 1.

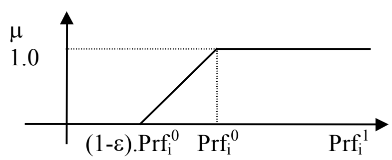

Figure 1 – Membership function of the profit of generator i.

According to this reasoning, the technical validation problem will now be formulated in terms of identifying the changes on the initial contracted powers, ΔPg_{ij}, so that the global satisfaction degree μ is maximized. This study is now formulated by (8) to (15) considering, once again, the DC model to translate the operation conditions of the power system.

$$\max \quad z = \mu \tag{8}$$

$$\text{subj.} \quad \sum (Pg_{ij}^{o} + \Delta Pg_{ij}) = Pl_j \tag{9}$$

$$Pg_i^{min} \le \sum (Pg_{ij}^{o} + \Delta Pg_{ij}) \le Pg_i^{max} \tag{10}$$

$$-P_k^{max} \le \sum a_{ki} (\sum Pg_{ij}^{o} - Pl_i + \sum \Delta Pg_{ij}) \le P_k^{max} \tag{11}$$

$$0 \le Pg_{ij}^{o} + \Delta Pg_{ij} \le Pl_j \tag{12}$$

$$Prf_i^{l} \ge (1-\varepsilon) Prf_i^{o} + \mu\, \varepsilon\, Prf_i^{o} \tag{13}$$

$$0{,}0 \le \mu \le 1{,}0 \tag{14}$$

$$\Delta Pg_{ij} \in \Re \tag{15}$$

In this formulation Pl_j, Pg_i^{min} and Pg_i^{max}, a_{ki} and P_k^{max} have the meaning already indicated in Section II. A. Constraints (9), (10), (11) and (12) are similar to the corresponding ones already included in the model of Section II. A. Constraints (13) are included to assure that the profit of generator i is not reduced more than the value related to the referred tolerance. Since the objective function corresponds to maximize the membership degree of the profit, we are in fact trying to alleviate the violated constraints while reducing the profits as little as possible.

This formulation is similar to the model in Section II. A. except in what regards the objective function – now we are maximizing the membership degree of the profit – and constraints (13). These constraints are essentially different from the ones in the model of Section II. A. The ones in the model in Section II. A correspond in fact to impose 0.0 as the minimum limit on the profit of each generator. This means that, as results, one may obtain large changes in the profits, some ones being largely reduced while other ones being eventually very much increased. The model (8) to (15) overcomes this problem by considering a tolerance on the profit change and by maximizing the membership degree of the profit.

C. Model 3 - Maximization of the Generators Satisfaction Degree Using the AC Model and Bilateral Contracts

The previous formulation can be modified in order to integrate the AC power flow model thus leading to (16) to (28).

$$\max \quad z = \mu \tag{16}$$

$$\text{subj} \quad Pg_k - Pl_k = f_1(V, \theta) \tag{17}$$

$$Qg_k - QL_k = f_2(V, \theta) \tag{18}$$

$$-P_k^{max} \le f_3(V, \theta) \le P_k^{max} \tag{19}$$

$$V_k^{min} \le V_k \le V_k^{max} \tag{20}$$

$$Pg_i^{min} \le Pg_i^1 \le Pg_i^{max} \tag{21}$$

$$Pg_i^1 = \sum (Pg_{ij}^o + \Delta Pg_{ij}) + Ploss_i \tag{22}$$

$$\sum Ploss_i = \sum f_4(V, \theta) \tag{23}$$

$$\sum (Pg_{ij}^o + \Delta Pg_{ij}) = Pl_j \tag{24}$$

$$0{,}0 \le Pg_{ij}^o + \Delta Pg_{ij} \le Pl_j \tag{25}$$

$$Pr\, f_i^1 \ge (1-\varepsilon)\, Pr\, f_i^o + \mu\, \varepsilon\, Pr\, f_i^o \tag{26}$$

$$0{,}0 \le \mu \le 1{,}0 \tag{27}$$

$$\Delta Pg_{ij} \in \Re \tag{28}$$

In this formulation, (17) and (18) correspond to the equations of the AC power flow model considering that f1 and f2 represent the expressions of the active and reactive injected powers. Constraints (19) correspond to the limits of the active power flow in each branch, given that f3 is the expression of the active power flow in branch *k*. Constraints (20) and (21) impose the minimum and maximum values on the voltage magnitude and on each active generation. Constraints (22) correspond to the expressions of each active generation in terms of the initial contracted powers and of the changes imposed on those contracts by the technical validation study. In these expressions it is also included a term that represents the active power to generate in each generator as its contribution to compensate the active power losses. The sum of these contributions in all generators must equal the global value of the active power losses. In this sense, in constraint (23) function f4 represents the expression of the active power losses in a branch of the system. Constraints (24) to (28) have a similar meaning as already referred in section II. B.

D. Model 4 – Maximization of the Generators Satisfaction Degree Using the AC Model and Bilateral Contracts and Pool Schedules

Finally, Model 3 can be enhanced including both schedules coming from Bilateral Contracts and from Pool markets. Model 4 is now given by (29) to (44).

$$\max \quad z = \mu \tag{29}$$

$$\text{subj} \quad Pgc_n^1 + Pgp_n^1 - Plc_n - Plp_n = f_{1n}(V,\theta) \quad \text{(for each node n)} \tag{30}$$

$$Qg_n - Ql_n = f_{2n}(V,\theta) \quad \text{(for each node n)} \tag{31}$$

$$-P_k^{max} \le f_{3k}(V,\theta) \le P_k^{max} \quad \text{(for each branch k)} \tag{32}$$

$$V_n^{min} \le V_n \le V_n^{max} \quad \text{(for each node n)} \tag{33}$$

$$Pgp_i^{min} \le Pgp_i^1 \le Pgp_i^{max} \quad \text{(for each d gen. i)} \tag{34}$$

$$Pgc_i^{min} \le Pgc_i^1 \le Pgc_i^{max} \quad \text{(for each c gen. i)} \tag{35}$$

$$Pgc_i^1 = \sum_j (Pgc_{ij}^o + \Delta Pgc_{ij}) + Ploss_i \quad \text{(for each c gen. i)} \tag{36}$$

$$Pgp_i^1 = Pgp_i^o + \Delta Pgp_i + Ploss_i \quad \text{(for each c gen. i)} \tag{37}$$

$$\sum_{\text{all c and d gen}} Ploss_i = \sum_k f_{4k}(V,\theta) \tag{38}$$

$$\sum_i (Pgc_{ij}^o + \Delta Pgc_{ij}) = Plc_j \quad \text{(for each load j)} \tag{39}$$

$$0 \le Pgc_{ij}^o + \Delta Pgc_{ij} \le Plc_j \quad \text{(for each i and j)} \tag{40}$$

$$\sum_i (Pgp_i^o + \Delta Pgp_i) = \sum_j Plp_j \tag{41}$$

$$Pr\, f_i^1 \ge (1-\varepsilon).Pr\, f_i^o + \mu.\varepsilon.Pr\, f_i^o \quad \text{(for each gen. i)} \tag{42}$$

$$0.0 \le \mu \le 1.0 \tag{43}$$

$$\Delta Pg_{ij} \in \Re \tag{44}$$

In this formulation active powers having an index c are related to physical Bilateral Contracts and the ones with an index p are due to schedules coming from the Pool. The variables ΔPgc_{ij} and ΔPgp_i represent the deviations coming from the technical validation study for the Bilateral Contract between the generator i and the load j and the deviation to be imposed on the scheduled of generator i coming from the Pool. All constraints are similar to the ones already present in Model 3, except constraints (41). This constraint imposes that the final values allocated to the Pool dispatched generators equal the sum of the loads initially scheduled in the Pool system. This formulation inherently accepts that branch flow or voltage magnitude violations can be addressed either within the Bilateral Contracted powers or within the Pool schedules but these two sets of schedules must remain balanced. This is expressed by constraints (39) for the Bilateral Contracts and by (41) for the Pool powers.

III. SOLUTION ALGORITHM

To solve the above described problems we used the Simulated Annealing metaheuristic [11]. This selection was due to its flexibility and easiness of implementation as well as the possibility of obtaining good results, namely given the capacity of Simulated Annealing to escape from local optima.

The algorithm departs from an initial solution corresponding to the set of initial contractual values for a given trade period. Then, it is established the neighbourhood structure of that solution from which a new solution is sampled. The acceptance of the new solution depends on the evaluation of the fitness function constituted by the objective function of the model in use and by increasing penalty terms as the constraints of the problem are more violated. A new solution is accepted if the value of its fitness function is larger/smaller – depending if we are dealing with a maximization or minimization problem - or, if the sampled solution is worse than the current, if a sampled probability is smaller than the pre-specified probability of acceptance of worse solutions. The iterative process finishes when there is no improvement of the fitness function for a number of iterations larger than a pre-specified value or when the minimum temperature of the cooling process is reached.

Figure 2 presents the simplified algorithm of the Simulated Annealing approach. w is the worse solutions counter, n is the number of iterations and T is the Temperature control parameter. In this Figure **o** designates < for a minimization problem and > for a maximization one.

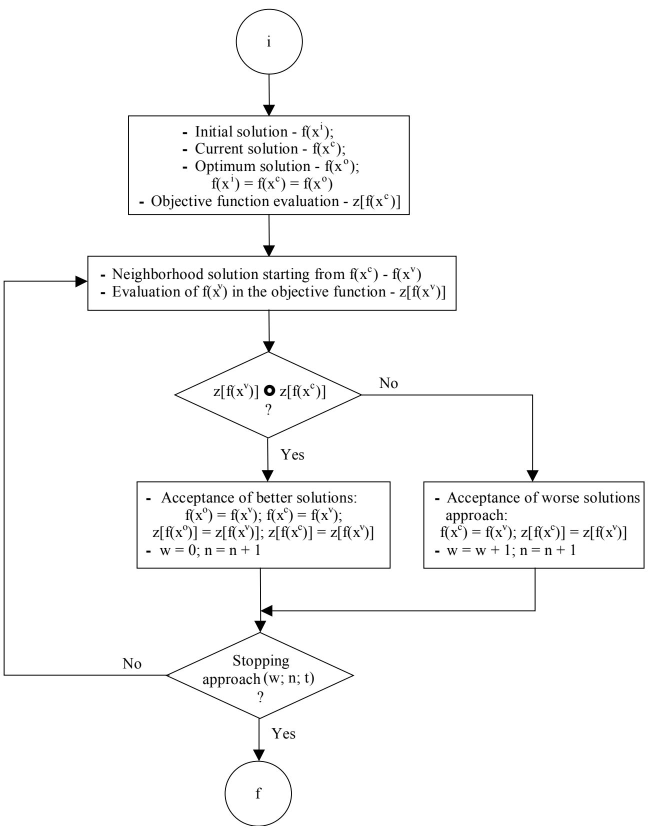

Figure 2 – Simplified solution algorithm.

IV. CASE STUDY

A. Network Test Data

The models presented in the Section II were tested using the IEEE test network of 24 bus, represented in the Figure 3. Regarding the data of this network, the loads were increased by 80% and the maximum value of the generations was doubled relatively the original values of reference [12].

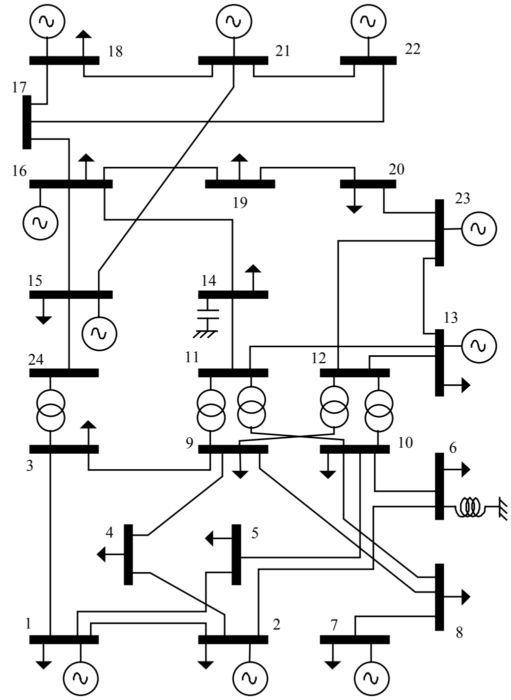

Figure 3 - IEEE Test Network of 24 bus.

The developed Models require the specification of the generator cost functions as well as the load remuneration functions. Regarding generator cost functions we used quadratic functions with parameters a and b as in (45). Regarding load remuneration functions we adopted functions as in (46). In Table I we indicate the coefficients a and b for generator cost functions and c for load remuneration functions.

$$C_g(P_g) = a.P_g + b.P_g^2 \tag{45}$$

$$C_l(P_l) = c.Pl \tag{46}$$

Table I – Data for generator cost and load remuneration functions.

Bus	a	b	c
1	4.00	0.003	13.00
2	3.50	0.004	12.50
3	-	-	11.00
4	-	-	15.00
5	-	-	15.50
6	-	-	13.50
7	5.00	0.002	13.00
8	-	-	13.00
9	-	-	12.50
10	-	-	11.80
13	6.00	0.003	10.60
14	-	-	11.00
15	2.50	0.004	10.50
16	5.50	0.003	16.00
18	9.00	0.001	12.00
19	-	-	13.40
20	-	-	13.60
21	8.00	0.001	-
22	2.00	0.004	-
23	5.75	0.003	-

B. Results Obtained with Model 1

Table II includes the generations in each bus resulting from the initially established contracts (column 2), the deviations resulting from the technical validation study (column 3) and the resulting generations in each bus (column 4). According to the initially established contracts it is immediate to conclude that there would be congestion in line 7-8 since the generation in bus 7 was 535 MW, the load in bus 7 is 225 MW and the transmission capacity of that line is 175 MW. Since node 7 is connected to the rest of the system only by line 7-8 there would be a congestion of 135 MW is this line. After running the technical validation study, the generation in bus 7 is decreased by 135 MW and this power is reallocated to other generators in a way not to lead to congestion in another branches. Finally, it can be checked that the algebraic sum of the generation deviations is zero, meaning that the global generation and the global load remain balanced.

Table II – Initially contracted generations ($\sum Pg_{ij}^{o}$), deviations ($\sum \Delta Pg_{ij}$) and final generations ($\sum Pg_{ij}^{1}$).

Generator i	$\sum Pg_{ij}^{o}$ (MW)	$\sum \Delta Pg_{ij}$ (MW)	$\sum Pg_{ij}^{1}$ (MW)
1	370,000	13,000	383,000
2	366,000	19,000	385,000
7	535,000	-135,000	400,000
13	1052,000	12,000	1064,000
15	395,000	14,000	409,000
16	280,000	15,000	295,000
18	530,000	16,000	546,000
21	550,000	12,000	562,000
22	330,000	16,000	346,000
23	850,000	18,000	868,000

C. Results Obtained with Model 2

Table III presents similar values as the ones included in each column of Table II, but now considering Model 2 in which one aims at maximizing the overall satisfaction degree, considering the DC model to translate the operation of the network. It was admitted that the maximum reduction of the profit accepted by each generator, ε, was 20%. As a result, the degree of global satisfaction felt by the participants was 14%, due to the large decrease of generation allocated to generator in bus 7.

D. Results Obtained with Model 3

Table IV includes the values for the initially contracted generations (column 2), the deviations imposed by the technical validation study (column 3), the resulting contracted generations (column 4), the real generations (column 5) and the contribution of each generator to balance active transmission losses (column 6). In this case, there is a difference between the contracted generation and the real generations due to the need to contribute to balance transmission active losses. In this simulation it was admitted that ε was 20%. The profits obtained in this case lead to a level of global satisfaction felt by the participants of 35%.

The sum of the contributions of each generator to balance active transmission losses corresponds to 104,405 MW. This matches quite well the system transmission losses obtained by the addition of the losses in each branch (104,816 MW). This means that constraint (23) of Model 3 is adequately verified, so that the penalty term in the Simulated Annealing fitness function is neglectable.

Table III - Initially contracted generations ($\sum Pg_{ij}^{o}$), deviations ($\sum \Delta Pg_{ij}$) and final generations ($\sum Pg_{ij}^{1}$).

Generator i	$\sum Pg_{ij}^{o}$ (MW)	$\sum \Delta Pg_{ij}$ (MW)	$\sum Pg_{ij}^{1}$ (MW)
1	370,000	15,000	385,000
2	366,000	19,000	385,000
7	535,000	-135,000	400,000
13	1052,000	-43,000	1009,000
15	395,000	6,000	401,000
16	280,000	16,000	296,000
18	530,000	82,000	612,000
21	550,000	15,000	565,000
22	330,000	22,000	352,000
23	850,000	3,000	853,000

Table IV- Initially contracted generations ($\sum Pg_{ij}^{o}$), deviations ($\sum \Delta Pg_{ij}$), contracted generations ($\sum Pg_{ij}^{1}$), total generations (Pg_i) and active losses allocated to each generator $Ploss_i$.

Gen i	$\sum Pg_{ij}^{o}$ (MW)	$\sum \Delta Pg_{ij}$ (MW)	$\sum Pg_{ij}^{1}$ (MW)	Pg_i (MW)	$Ploss_i$ (MW)
1	370,000	-39,000	331,000	336,120	5,120
2	366,000	-13,000	353,000	360,580	7,580
7	535,000	-135,000	400,000	400,000	0,000
13	1052,000	2,000	1054,000	1095,801	41,801
15	395,000	-9,000	386,000	408,105	22,105
16	280,000	12,000	292,000	305,535	13,535
18	530,000	27,840	557,840	558,645	0,805
21	550,000	13,080	563,080	566,399	3,319
22	330,000	-27,920	302,080	308,220	6,140
23	850,000	169,000	1019,000	1023,000	4,000

E. Comparisons and Comments

The presented Model 1 is very different from the remaining ones given that we are only concerned with the minimization of the squares of the deviations to be imposed to each generation. This may lead to large variations when going from the initial profits to the final ones. On the contrary, Models 2, 3 and 4 aim at adjusting the contracted or scheduled generations so that the generators remain as satisfied as possible. In this sense, the variations of the profits will not be so large, namely because we specify a maximum reduction, ε, that can affect the final profits. To illustrate these aspects, Tables V, VI and VII include the profits associated with the generations. Tables VI and VII also include the degree of satisfaction felt by each participant in the market.

Table V – Profits of the generators obtained with Model 1 (Cl_i - remuneration, Cg_i - generation cost and Prf_i - profit of the generator i).

Gen i	Cl_i (\$)	Cg_i (\$)	Prf_i (\$)
1	4927.500	1972.067	2955.433
2	5037.000	1940.400	3096.600
7	4884.000	2320.000	2564.000
13	13534.900	9780.288	3754.612
15	4464.000	1691.624	2772.376
16	3661.000	1883.575	1777.425
18	7141.600	5212.116	1929.484
21	6073.000	4811.844	1261.156
22	4373.000	1170.864	3202.136
23	10387.000	7251.272	3135.728

Table VI – Profits of the generators obtained with Model 2 (Prf_i^o - initial profit, min Prf_i - minimum profit admitted for the generator *i*, Prf_i - final profit of the generator i, μ_i - satisfaction degree felt by generator i).

Gen i	Prf_i^o (\$)	min Prf_i (\$)	Prf_i (\$)	μ_i
1	2881.800	2305.440	2946.824	1
2	2987.476	2389.981	2995.500	1
7	3307.550	2646.040	2739.000	0.14
13	3749.088	2999.270	3761.558	1
15	2673.400	2138.720	2802.896	1
16	1704.800	1363.840	1707.552	1
18	1891.100	1512.880	1895.856	1
21	1222.500	978.000	1309.675	1
22	3072.400	2457.920	3224.484	1
23	3115.000	2492.000	3200.822	1

In this case, the reallocation of the contracted powers mainly affect the satisfaction degree of generator 7. This is clearly due to the bottleneck imposed by line 7-8, thus illustrating the impact that deficiencies in planning and expansion of transmission systems can impose to market activities.

Table VII – Profits of the generators obtained with Model 3 (Prf_i^o - initial profit, min Prf_i - minimum profit admitted for the generator *i*, Prf_i - final profit of the generator i, μ_i - satisfaction degree felt by generator i).

Gen i	Prf_i^o (\$)	min Prf_i (\$)	Prf_i (\$)	μ_i
1	2881.800	2305.440	2713.217	0.71
2	2987.476	2389.981	2803.264	0.69
7	3307.550	2646.040	2874.360	0.35
13	3749.088	2999.270	3570.452	0.76
15	2673.400	2138.720	2751.316	1
16	1704.800	1363.840	1543.328	0.53
18	1891.100	1512.880	1823.216	0.82
21	1222.500	978.000	1429.581	1
22	3072.400	2457.920	2782.311	0.53
23	3115.000	2492.000	3308.867	1

When compared with Model 2, Models 3 is clearly more realistic because it represents the network operation conditions using a full AC model. This more accurate representation leads to a more accurate evaluation of the satisfaction degree of the participants and to the possibility of allocating to each generator a contribution to balance transmission active losses. These contributions can be of interest if this ancillary service is remunerated. In this case, this AC application allows the ISO or any other entity to accurately evaluate these contributions and set the corresponding remunerations to the generators.

V. CONCLUSIONS

The presented models correspond to optimization tools aiming at performing technical validation studies over sets of buying/selling electricity bilateral contracts. These formulations, namely the one that integrates the AC power flow model allows us to obtain changes on the values of initially contracted powers avoiding large decreases of the profits of the generating entities. This formulation can still be completed by considering sets of injections communicated by a Pool Market Operator considering that a power system is structured in an hybrid way admitting both bilateral contracts and generation/load bids. This AC formulation presents a clear proximity with OPF type formulations with which system operators are already well acquainted. This means that the installation of this type of applications in control centers could be done with a reduced training effort. The referred optimization models lead to computer applications in which we adopted Simulated Annealing to identify good quality solutions. The adoption of this metaheuristic is justified given its facility of implementation together with the inherent possibility of escaping from local optima.

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