Generation scheduling in a competitive environment

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Abstract: Electric power restructuring offers a major change to the vertically integrated monopoly. The change manifests the main part of engineers' efforts to reshape the three components of today's vertically integrated monopoly: generation, distribution and transmission. In a restructured environment, the main tasks of these three components will remain the same as before, however, to comply with FERC orders, new types of unbundling, coordination and rules are to be established to guarantee competition and non-discriminatory open access to all users.

This paper provides the generation schedule of a GENCO in a deregulated power system. It is shown that the goal of generation schedule in the new structure is different from the traditional centralized power systems. The modeling of generation scheduling problem in a competitive environment is demonstrated by taking into account the main purposes of GENCOs which are selling electricity as much as possible and making higher profit. The GENCOs of an area are introduced via a model whose objective function consists of hourly spot market price as income and different kinds of costs. The constraints are the general ones of such a problem e.g. minimum up/down time, minimum and maximum generation and ramp rate. Using one of the classical optimization methods, the hourly generation schedule of the generating units will be obtained in this competitive environment. The results of this section will be used by ISO. The ISO will finalize the schedules of GENCOs by taking into account the technical considerations like the power flow of transmission lines. The model and the optimization methods are implemented on IEEE-RTS benchmark with 24 buses and 32 generating units.

Keywords: Generation Scheduling, Competitive Environment, Miexed Integer Programming, Linear Programming.

1 Introduction

Short-term generation scheduling is one of the most important daily activities in vertically integrated utility companies. The task is to determine the commitment and generation of all schedulable power resources over a scheduling horizon to minimize the total generation cost while meeting the system demands and reserve requirements. It is mathematically formulated as a mixed-integer programming problem and schedules are represented by hourly generation levels. All individual operating constraints including hourly ramp-rate constraints have to be satisfied [1]. With the appearance of reconstruction and deregulation of modern power systems, generation scheduling in deregulated power systems has got any new characteristics and becomes quite different from that in traditional centralized power systems [2,3].

In deregulated power systems, generation scheduling will not be considered only by the system dispatching center any more but will be mainly considred by GENCOs (GENeration COmpanies). In an open market environment, GENCOs will try to schedule their units according to the operating conditions of their units, the quotations on the energy market and other economic factors. The goals of their schedule are to try to make their units have as long as possible life span and to make their power production earn as much as possible profit. Different GENCOs make their own units schedule separately [4].

This paper is demonstrated how GENCOs in a competitive environment prepare the generatoin schedule of their facilities. At first it describes the new structure of power systems. Then, a model is proposed. The model of GENCO consists of an objective function and a set of related constraints. The objective function has four components, the first one is income due to selling electricity and the others are different costs. The constraints consist of load, minimum up/down time, generation capacity and ramp rate. In the next step the model of ISO will be set up. It uses the results of GENCOs'. The criteria of objective function is the reliability of overall network. The constraints are the capacity of transmission lines. In a case study using the IEEE-RTS with 32 generating units and 38 transmission lines, the MIP (Mixed Integer Programming) and LP (Linear Programming) optimization methods are applied to obtain the best generation schedule.

2 Deregulated power system

Most of US industries have felt the heavy hand of deregulation over the past twenty years; telephones, airlines, trucking and natural gas to name a few.

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However, electric power was long felt to be too much a "natural monopoly" to face the deregulation process.

The electric power industry is undergoing major changes, both politically and technically. They are a result of the FERC's (Federal Energy Regulatory Commission) orders 888 and 889 issued in 1996. These orders essentially deregulate the transmission network, allowing producers and customers access to the network for electricity transactions.

In current and past operations, the utilities were vertically integrated. A single utility would own and operate all components necessary for providing services to their customers, from generation, through transmission, down to the distribution systems. Customers received one bill from their utility company for the entire services. Historically, a single utility would service a geographic region. The utility was responsible for providing enough generation to meet all of their customers' needs. However, after the famous New York City blackout of 1965, utilities began to interconnect.

Interconnection yielded many advantages. Reliability was improved since neighboring systems could act as buffer zones and provide additional power during fault conditions. Many power companies worked cooperatively together to avert power failures.

Additionally, utilities would buy and sell power across the interconnections or tie lines. Frequently, a utility would produce excess power and sell it at a cheaper price than a neighbor could produce it. Thus, both companies profited from this arrangement. Currently, the flow of electric power through parts of the network is closely coordinated between utilities. For many decades, it felt that if a single company owns a region's generation, transmission and distribution systems under tight regulations, was more efficient than competition [5].

As deregulation proceeds, these entities will no longer exist in close collaboration within a single utility. Indeed, it is forecasted that distinct industries may arise which specialize in only one of these areas: the GENCOs, the TRANSCOs (TRANSmission COmpanies), and the DISCOs (DIStribution COmpanies). Competition will replace cooperation. Competition, however, will spur technological growth [5]. The ISO (Independent System Operator) is independent of the above individual market participants. It is a neutral operator responsible for maintaining instantaneous of the system. The basis purpose of this entity is to ensure fair and non-discriminatory access to transmission services and ancillary services, and maintain real-time operation of the system and its grid reliability [6].

The deregulation is advancing on two levels: the wholesale level, where federal legislation is driving the changes, and the retail level, where states authorities are directing the reforms. Deregulation should, over time, bring lower electricity prices to both consumers and businesses.

The first step in deregulating electricity generation has been to create a wholesale market that allows GENCOs to compete against one another. A state-regulated system of monopoly suppliers, of course, has no need for such a market. The development of a wholesale market will lead to lower prices for businesses and consumers. Under a regulated system, power plants face little or no competitive pressure to lower production costs. The utilities charge their customers a rate that is fixed as a markup over production costs, an arrangement is devised by regulators to guarantee utilities a "reasonable" rate of return. Although the states monitor the operations of their utilities in an effort to keep costs down, the absence of competing suppliers means that the states have no standard of comparison for assessing the efficiency of a given utility's operations.

At the retail level, competition means that individual consumers are free to buy electricity from their local GENCO or from another GENCOs. Giving consumers the power to choose between competing firms helps ensure that the price savings realized at the wholesale level benefit consumers. In addition, retail competition provides firms with incentives to match their products to differences in customer preferences.

In such an environment, the GENCOs lose the guarantee of a reasonable return and must instead compete for profits. The most efficient power plants earn profits at the expense of high-cost power plants. Over time, market forces push firms to develop new technologies and better operating procedures [7]. One of the main operating procedures is generation scheduling of generating units in a GENCO's territory. In a dereglated power system, the basis of a generation plan, which is prepared by a GENCO is profit. The income is to sell the electricity according to the market price [8], and the expenses consist of operation cost and start up cost of generating units.

3 The Model description

3.1 The required data

To set up the generation scheduling model, a large extend of data is required. The information like the forecasted load of each GENCO, the total load of the network, the forecasted market price of hourly price of electricity and the technical data of network. The hourly load of each GENCO is the sum of selling electricity in power pool and through bilateral contracts. Different criteria exist for determining the spinning reserve of overall network. Reference [9] chooses the peak load for determining the reserve margin of a restructured power system. Forecasting the hourly price of electricity in the market is another important factor in solving the generation scheduling problem in a deregulated power system. For reaching to an actual data the real market price of electricity price of Norway is used [10], since there isn't any electricity price in IEEE-RTS [11]. A set of comprehensive data is required like configuration of network, the arrangement of GENCOs, the specification of GENCOs' generating units and the characteristics of transmission lines. In other words the classification of data are as follow: the single line diagram of network, the table of each GENCO's generating units, specifications (e.g. the type, min. and max. generation capacity, the coefficients of cost functions, the min. up/down time, ramp rate, start up cost), the specifications of transmission lines.

3.2 The model of GENCO

The generation scheduling problem has been tackled by many authors using a variety of objective functions. These include: maximizing the minimum reserve, levelizing the risk of generation shortage, maximizing production cost and maximizing system reliability.

Since the generation scheduling problem in a restructured power system becomes a multi-goal optimization problem, new model has to be sought to solve the generation schedule problem in restructured systems.

The main purpose of a GENCO is making money as much as possible. The cost function of GENCO consists of two main parts. The first part relates to selling electricity which is the income of GENCO. The second part is costs, the operation costs and start up costs of units. Maximizing the income and minimizing the costs are the main criteria. Subtracting these parts will form the objective function which is named the profit or revenue [12] [13]. In the proposed model the objective function will be maximized.

The constraints of GENCOs are similar to vertically integrated utilities. The following constraints are used in the paper:

A) The min. and max. generation of each unit,

B) Satisfying the forecasted load and spinning reserve,

C) Minimum up/down time,

D) Ramp rate constraint,

E) Emission constraint.

3.3 The model of ISO

One of the main criteria of ISO is the reliability of network and making sure that the spinning reserve is at the standard level. Minimizing the variation of spinning reserve inside the standard interval is good enough to be the main criteria in the objective function of ISO [14].

Taking into account the security of overall network, the following constraints will be introduced:

A) Satisfying the load,

B) Network capacity.

4 The simulation results

4.1 The input data

This section consists of two main parts, the first part is the schedule of GENCOs and the second is the schedule of ISO. The mentioned model is applied on IEEE-RTS of 32 generating units, 24 buses and 38 transmission lines [14]. The industrial version of LINGO software is used for simulation by computer. The 32 generating units are devided into 6 groups of GENCOs according to Table (1).

Table 1 The characteristics of GENCOs

GEN CO No.	Bus No.	Unit No.	Unit Capacity [MW]	Total Generation [MW]	Percent of Generation in Whole Area [%]
1	1	1	20	192	5.6
		2	20		
		3	76		
		4	76		
2	2	5	20	492	14.4
		6	20		
		7	76		
		8	76		
	7	9	100		
		10	100		
		11	100		
3	13	12	197	591	17.4
		13	197		
		14	197		
4	23	15	155	660	19.4
		16	155		
		17	350		
5	15	18	12	370	10.9
		19	12		
		20	12		
		21	12		
		22	12		
		23	155		
	16	24	155		
6	22	25	50	1100	32.2
		26	50		
		27	50		
		28	50		
		29	50		
		30	50		
	18	31	400		
	21	32	400		
Total Generation [MW]				3405	

Table (2) shows the forecasted price of electricity in scheduling period. For reducing the uncertainty and error of forecasting proccess the real data of electricity market price is used. It is the Norway power pool (Nordpool) hourly market prices on 18[th] of Aug. 2003 [10]. The changing coefficient is 6.9 NOK/$.

Table 2 The spot market price of Norway power pool (Nordpool)

Hour No.	Market Price [$/MWh]	Hour No.	Market Price [$/MWh]	Hour No.	Market Price [$/MWh]	Hour No.	Market Price [$/MWh]
1	36.2	7	39.9	13	46.2	19	43.1
2	34.3	8	41.1	14	46.3	20	41.8
3	33.2	9	44.4	15	45.7	21	40.6
4	32.5	10	45.9	16	44.5	22	40.7
5	31.5	11	46.3	17	43.4	23	38.6
6	34.6	12	46.3	18	43.6	24	33.2

4.2 Neration schedule of GENCO

The objective function (1) of each GENCO cosists of four parts. The income from selling electricity in the planning period ($MP_t * G_{it}$) makes the first part of objective function. MP_t is the electricity market price in time period *t*, G_{it} is the generated power of unit i in the time period *t*. a_i is the fixed cost and b_i is the variable cost of the i^{th} unit. S_{it} is the start up cost of the i^{th} unit. SUV_{it} is a binary variable which shows the start up situation of each unit from down state into up state.

$$Z = \sum_i \{ \sum_t (MP_t * G_{it}) - (a_i * X_{it}) - (b_i * G_{it}) - (S_{it} * SUV_{it}) \} \quad (1)$$

The used constraints are in (2) to (11). i is the number of each unit in the related GENCO. t shows the time period of study and the amount of it is between 1 to 24. X_{it} is a binary variable that shows the on/off state of unit i in the time period t. G_{it} is the amount of generated power of each unit i in the time period t. $P_{i\min}$ and $P_{i\max}$ are the lower and upper limit of generation of unit i. $Load_t$ is the load of each GENCO in the time period t. r_{it} is the amount of unserved load that GENCO is permitted by ISO. RR_i shows the ramp rate of unit i. $STUV_{it}$ is a binary variable, when it takes 1 it means that the unit i was off at time period t-1 but it is on at time period t. $SHDV_{it}$ is a binary variable too, when it takes 1 it means that the unit i was on in the time period t-1, but it is off in the time period t. Constraint (2) shows the satisfaction of load. (3) is the limits of generation. (4) is the ramp rate constraint. The constraints (5) to (8) altogether represent the minmum up/down time of each unit.

$$Load_t + \sum_i r_{it} \le \sum_i G_{it} \qquad \forall t \qquad (2)$$

$$P_{i\min} * X_{it} \le G_{it} \le P_{i\max} * X_{it} \quad \forall i \ , \forall t \qquad (3)$$

$$\left| G_{it} - G_{i\,t-1} \right| \le RR_i \qquad \forall i \qquad (4)$$

$$X_{it} - X_{i\,t-1} = STUV_{it} - SHDV_{it} \quad \forall i \ , \forall t \qquad (5)$$

$$STUV_{it} + SHDV_{it} \le 1 \qquad \forall i \ , \forall t \qquad (6)$$

$$STUV_{it} + \sum_{k=t+1}^{t+MUPT_i-1} SHDV_{ik} \le 1 \quad \forall i \ , \forall t \qquad (7)$$

$$SHDV_{it} + \sum_{m=t+1}^{t+MDNT_i-1} STUV_{im} \le 1 \quad \forall i \ , \forall t \qquad (8)$$

$$\sum_i r_{it} \le \varepsilon \qquad \forall t \qquad (9)$$

$$STUV_{it} \ , SHDV_{it} \ , X_{it} = 0 \ or \ 1 \quad \forall i \ , \forall t \qquad (10)$$

$$G_{it} \ , r_{it} \ge 0 \qquad (11)$$

The simulation results by using the LINGO software which are the generation sceduling program of all GENCOs, are shown in Tables (3) through (8).

4.3 Finalizing of schedules by ISO

The ISO will confirm the generation scheduling of each GENCO. The main goal of ISO is the reliability of the overall network. After collecting the programs of all GENCOs, by taking into account the forecasted load of overall system, the maximum capacity of each transmission line and the configuration of network, it will test the proposed programs of each GENCO. If some of them violates the security of system, the ISO announces the problem to related GENCO, otherwise the ISO will confirm the generation schedule and inform the GENCO about this.

The objective function of ISO is based on reliability. So the levelization of reserve is the main criteria. The amount of reserve is 22% of peak load [9]. Minimizing the variation of reseve around the mentioned value will form the objective function.

$$Z = \sum_t DRM_t \ , \ DRM_t = \sum_b DRM_{b\,t} \qquad (12)$$

In (12) DRM_t shows the variation of reserve in the time period t and $DRM_{b\,t}$ is the variation of reserve at

Table 3 The generation schedule of GENCO1 [MW]

Unit	1	2	3	4
Hour 1	0	0	0	76
Hour 2	0	0	0	75.4
Hour 3	0	0	0	73
Hour 4	0	0	0	70.7
Hour 5	0	0	0	71.9
Hour 6	4	0	0	75
Hour 7	11.3	0	0	76
Hour 8	0	0	26.7	76
Hour 9	0	0	64.7	49.9
Hour 10	0	0	43.3	76
Hour 11	0	0	76	44.5
Hour 12	0	0	76	43.3
Hour 13	0	0	38	74.2
Hour 14	0	0	35	76
Hour 15	0	0	32.6	76
Hour 16	0	0	38	68.3
Hour 17	0	0	76	32.6
Hour 18	0	0	40.4	70.6
Hour 19	0	0	39.8	76
Hour 20	0	0	76	42.2
Hour 21	0	0	39.8	76
Hour 22	0	0	32.6	76
Hour 23	0	0	48	48.8
Hour 24	0	0	10	74.9

Table 4 The generation schedule of GENCO2 [MW]

Unit	1	2	3	4	5	6	7
Hour 1	0	0	0	0	100	94.2	0
Hour 2	0	0	0	0	91	100	0
Hour 3	0	0	0	0	85	100	0
Hour 4	0	0	0	0	100	78.9	0
Hour 5	0	0	0	0	81.9	100	0
Hour 6	0	0	0	0	100	100	0
Hour 7	0	0	0	0	100	71.5	50
Hour 8	0	0	0	0	61.3	100	100
Hour 9	0	0	0	0	100	100	91.8
Hour 10	0	4.1	0	0	100	100	100
Hour 11	7.1	0	0	0	100	100	100
Hour 12	0	4.1	0	0	100	100	100
Hour 13	0	0	0	0	85.8	100	100
Hour 14	0	0	0	0	100	82.6	100
Hour 15	0	0	0	0	100	76.6	100
Hour 16	0	0	0	0	100	70.5	100
Hour 17	0	0	0	0	76.6	100	100
Hour 18	0	0	0	0	82.6	100	100
Hour 19	0	0	0	0	100	100	94.8
Hour 20	0	0	0	0	100	100	100
Hour 21	0	0	0	0	94.8	100	100
Hour 22	0	0	0	0	100	76.6	100
Hour 23	0	0	0	0	96	50	100
Hour 24	15.5	0	0	0	100	0	100

Table 5 The generation schedule of GENCO3 [MW]

Unit	1	2	3
Hour 1	0	102.4	131.9
Hour 2	0	197	33.4
Hour 3	0	174.9	48.2
Hour 4	0	76.4	139.4
Hour 5	0	174.9	44.6
Hour 6	0	98.5	143.1
Hour 7	98.5	0	168.8
Hour 8	197	0	118.3
Hour 9	155.2	0	197
Hour 10	197	0	170
Hour 11	197	0	173.7
Hour 12	170	0	197
Hour 13	197	0	147.9
Hour 14	197	0	144.1
Hour 15	197	0	136.8
Hour 16	129.5	0	197
Hour 17	197	0	136.8
Hour 18	144.1	0	197
Hour 19	158.9	0	197
Hour 20	166.4	0	197
Hour 21	197	0	158.9
Hour 22	136.8	0	197
Hour 23	197	0	98.5
Hour 24	161.5	98.5	0

Table 6 The generation schedule of GENCO4 [MW]

Unit	1	2	3
Hour 1	0	0	261
Hour 2	0	0	256.7
Hour 3	0	0	248.6
Hour 4	0	0	240.4
Hour 5	0	0	244.5
Hour 6	0	0	269.1
Hour 7	0	0	297.8
Hour 8	0	0	350
Hour 9	0	77.5	315
Hour 10	0	155	254
Hour 11	0	77.5	335.6
Hour 12	0	59	350
Hour 13	0	136.5	247.9
Hour 14	0	155	225.1
Hour 15	0	77.5	294.5
Hour 16	0	155	208.8
Hour 17	0	155	217
Hour 18	0	77.5	302.6
Hour 19	0	155	241.6
Hour 20	0	155	249.9
Hour 21	0	77.5	319.1
Hour 22	0	77.5	294.5
Hour 23	0	0	330.8
Hour 24	0	0	289.7

bus number b in the same time period.

The constraints are shown as follow:

$$Flow_{l\,t} + G_{i\,t} \geq Load_{b\,t} + RM_{b\,t} + DRM_{b\,t} \;\; \forall\, b\,, \forall\, t \qquad (13)$$

$$\left| Flow_{l\,t} \right| \leq Flow_{l\ \max} \qquad \forall\, l\,, \quad \forall\, t \qquad (14)$$

$$DRM_{b\,t} \geq \cdot \qquad (15)$$

Constraint (13) is for satisfaction of load and reserve. $Flow_{l\,t}$ is the algebraic sum of all flows into the bus number b in the time period t. $G_{i\,t}$ is the generation of the i^{th} unit connected to bus number b in the time period t. Obviously when a unit is off this parameter will will be 0. $Load_{b\,t}$ is the forecasted load in the time t which is connected to b^{th} bus. $RM_{b\,t}$ is the amount of total reserve for b^{th} bus. (14) Shows the network flow constraint. $Flow_{l\ \max}$ is the upper limit of l^{th} line [11].

Table 7 The generation schedule of GENCO5 [MW]

Unit	1	2	3	4	5	6	7
Hour 1	0	0	0	0	0	147.4	0
Hour 2	0	0	0	0	0	145	0
Hour 3	0	0	0	0	0	140.4	0
Hour 4	0	0	0	0	0	135.9	0
Hour 5	0	0	0	0	0	138.2	0
Hour 6	0	3	0	0	0	149	0
Hour 7	0	12	0	0	0	155	0
Hour 8	0	0	0	0	0	155	43.2
Hour 9	0	0	0	0	0	100.6	120.7
Hour 10	0	0	0	0	0	75.6	155
Hour 11	0	0	0	0	0	79.8	153.1
Hour 12	0	0	0	0	0	155	75.6
Hour 13	0	0	0	0	0	77.5	139.2
Hour 14	0	0	0	0	0	59.4	155
Hour 15	0	0	0	0	0	54.76	155
Hour 16	0	0	0	0	0	50.2	155
Hour 17	0	0	0	0	0	54.8	155
Hour 18	0	0	0	0	0	77.5	136.9
Hour 19	0	0	0	0	0	155	68.6
Hour 20	0	0	0	0	0	155	73.3
Hour 21	0	0	0	0	0	132.3	91.3
Hour 22	0	0	0	0	0	54.8	155
Hour 23	0	0	0	0	0	31.7	155
Hour 24	0	0	0	8.6	0	0	155

Table 8 The generation schedule of GENCO6 [MW]

Unit	1	2	3	4	5	6	7	8
Hour 1	0	0	0	0	0	0	400.2	31.4
Hour 2	0	0	0	0	0	0	390	34.1
Hour 3	0	0	0	0	0	0	395	14.9
Hour 4	0	0	0	0	0	0	398.1	0
Hour 5	0	0	0	0	0	0	400	3.2
Hour 6	0	0	0	0	0	0	380	63.9
Hour 7	0	0	0	0	0	0	360.2	131.3
Hour 8	0	0	0	0	0	0	359	221.4
Hour 9	0	0	0	0	0	0	390.1	258.6
Hour 10	0	0	0	0	0	0	331	345
Hour 11	0	0	0	0	0	0	322.4	360.2
Hour 12	0	0	0	0	0	0	296	380
Hour 13	0	0	0	0	0	0	250	385
Hour 14	0	0	0	0	0	0	228	400
Hour 15	0	0	0	0	0	0	214.9	400
Hour 16	0	0	0	0	0	0	201	400
Hour 17	0	0	0	0	0	0	214.5	400
Hour 18	0	0	0	0	0	0	237.9	390
Hour 19	0	0	0	0	0	0	300	355.7
Hour 20	0	0	0	0	0	0	343	327
Hour 21	0	0	0	0	0	0	265.3	390.2
Hour 22	0	0	0	0	0	0	244.8	370
Hour 23	0	0	0	0	0	0	180.1	366
Hour 24	0	0	0	0	0	0	133	345

The model demonstrated in the (12) to (15) shows a LP optimization problem which will be solved through simplex method [15]. By solving the model the objective function will take the 0, which is the minimum and the best amount. It means that all generation schedules of GENCOs are feasible according to reliability target of ISO. Besides the solution shows that the reserve level will be constant during the study period and it is equal to 22% of peak load or 466.4 MW (2120 * 0.22).

5 Conclusion

It is shown that the goal of generation plan in a deregulated power system is different from the traditional centralized power system. The modeling of generation scheduling problem in a competitive environment is demonstrated that how GENCOs should make ready the schedule of their facilities. Taking into account that in the new structure, the main purposes of GENCOs are selling electricity as much as possible and making higher profit, the model of GENCOs is established. The GENCOs of an area are introduced via a model whose objective function consists of hourly spot market price as income and different kinds of costs. The constraints are minimum up/down time, min. and max. generation and ramp rate. Using one of the MIP optimization methods, the hourly generation schedule of the generating units will be obtained. The results of this section will be used by ISO. The ISO will consider either confirm or reject the schedules of GENCOs by taking into account the technical considerations like the power flow of transmission lines. The model and the optimization methods are implemented on IEEE-RTS benchmark with 24 buses and 32 generating units.

6 References

[1] X. Guan, F. Gao, A. J. Svoboda, Energy Delivery Capacity and Generation Scheduling in the Deregulated Electric Power Market, IEEE Trans. on Power Systems, Vol. 15, No. 4, pp. 1275-1280, Nov. 2000.

[2] F.F. Wu, "Coordinated multilateral trades for electric power networks," in Proc. 1996 12th Power System Computation IEEE Conf., pp. 786-790.

[3] E. Handschin, D. Kulan and D. Westermann, "Advanced energy management systems using open market structures," in Porc. 1996 International Symposium on Modern Electric Power Systems, pp. 50-59.

[4] Y. Wang and E. Handschin, "Unit maintenance scheduling in open systems using genetic algorithm," in Proc. 1999 IEEE Transmission and Distribution Conf., pp. 334-339.

[5] Mariesa L. Crow, The New Power System, December 97, January 98, IEEE Potentials.

[6] M. Shahidehpour and M. K. C. Marwali, Maintenance Scheduling in Restructed Power Systems, Norwell: Kluwer, 2000.

[7] Klitgaard, T., Reddy, R., "Lowering Electricity Prices through Deregulation", The Journal of Federal Reserve Bank of New York, Vol. 6, No. 14, Dec. 2000.

[8] Oren, S.S., Svoboda, A.J., and Johnson, R.B., "Volatility of Unit Commitment in Competitive Electricity Markets", 30th Hawaii International Conference on Systems Sciences, Maui, Hawaii , 1997, pp 594-601.

[9] Ilic M., Galiana F., Fink L., Power System Restructuring Engineering and Economics, Kluwer Academic Publishers, USA, 1998.

[10] www.Nordpool.com

[11] IEEE Reliability Test System (RTS) Task Force of the Application of Probability Methods (APM) Subcommittee, IEEE Reliability Test System, IEEE Trans. on Power Apparatus and Systems, Vol. PAS-98, No. 6, pp. 2047-2054, Nov./Dec. 1979.

[12] Valenzuela J., Mazmumdar M., Making Unit Commitment Decisions When Electericity Is Traded at Spot Market Prices, IEEE Power Engineering Society Winter Meeting, Vol. 3, pp.1509-1512, Jan.-Feb. 2001.

[13] Motto A.L., Galiana F.D., Equilibrium of Auction Markets with Unit Commitment: The Need for Augmented Pricing, IEEE Trans. on Power Systems, Vol. 17, No. 3,pp. 798-805, Aug. 2002.

[14] Kurban M., The Maintenance Schedule Optimization in an Interconnected Power System Using the Levelized Risk Method, IEEE Power Tech 99 Conference, Hungary, Aug./Sep. 1999.

[15] Taha H.A., Operations Research an Introduction, Second Edition, Macmillan Publishing Co. Inc., USA, 1976.