Stochastic Modeling to Investigate the Impacts of Wind Power on Thermal Scheduling

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ABSTRACT

This paper proposes the stochastic cost model solution technique for optimal operation of the generators in a wind-thermal scheduling considering the demand and wind power generation uncertainties. The main objective of this paper is to minimize the fuel cost and maximize the profit of generation companies (GENCO'S) with all possible constraints. The cost curve of the generating unit is linearized in a piecewise manner so that a mixed integer programming method can be used to solve the hourly load demand and wind velocity must be forecasted to prevent the errors. The generation scheduling formulations are involved the perspective of a generation company (GENCO). The stochastic model is tested on IEEE-36 unit thermal system in addition with one unit of 50MW wind power system.

Key words: Restructured power market, mixed integer programming, generation scheduling, and wind power.

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NOMENCLATURE

ASR_1	-	Additional up reserve requirement considering wind power generation.
ASR_2	-	Additional down reserve requirement considering wind power generation.
DR_i^{max}	-	Maximum ramp-down rate for thermal unit i
DS_i^{max}	-	Maximum down reserve contribution of thermal unit i.
$DS_i(t)$	-	Down reserve contribution of thermal unit i at hour t.
$F_i(.)$	-	Operation cost function of thermal unit i.
FT	-	Total operation cost over the scheduling horizon.
NT	-	Number of thermal units in the system.
NW	-	Number of wind units in the system.
P_i (t)	-	Generation of thermal unit I at hour t.
$P_i^{max}{,_T}$	-	Upper generation limit of thermal unit i.
P_i^{max} (t)	-	Maximum generation of thermal unit i at hour t.
$P_i^{min}{,_T}$	-	Lower generation limit of thermal unit i.
$P_i^{min}(t)$	-	Minimum generation of thermal unit i at hour t.

$P_L(t)$	-	System load demand at hour t.
P_{wj}^{max}	-	Upper generation limit of wind unit j.
P_{wj} (t)	-	Actual generation of wind unit j at hour t.
P^*_{wj} (t)	-	Available generation of wind unit j at hour t.
P_{WT} (t)	-	Total actual wind generation at hour t.
P^*_{WT} (t)	-	Total available wind generation at hour t.
TDR (t)	-	System ramping down capacity at hour t.
T_{OFF},i(t)	-	Time period that thermal unit i had been continuously down till period t.
T_{OFF}, i	-	Minimum down time of thermal unit i.
T_{ON}, i	-	Minimum up time of thermal unit i.
ton, i(t)	-	Time period that thermal unit i had been continuously up till period t.
TUR (t)	-	System ramping up capacity at hour t.
U_i (t)	-	Scheduled state of thermal unit i for hour t
URimax	-	Maximum ramp-up rate for thermal unit i.
US_i (t)	-	Up reserve contribution of thermal unit i at hour t.
US_i^{max}	-	Up reserve contribution of thermal unit i at hour t.
USR_B	-	System up spinning reserve requirement not considering wind power generation.

INTRODUCTION

The rise of environmental protection and the progressive exhaustion of traditional fossil energy sources have increase the interests on integrating renewable energy sources into existing power systems [1]. Since the cost of wind turbine generators has been reduced rapidly, installation of wind turbine generators as fuel savers is economically and environmentally attractive in windy regions [2]. It would be beneficial to increase the power supply capacity in the installation of power plants using wind energy sources. Therefore, it is very important to understand the wind generator capacity in production cost analysis for giving a good indicator to site new wind power plants in isolated systems. However, the intermittency and unpredictability of wind power generation creates difficulty in control of frequency and scheduling of generation [3]. It can be expected that many problems will arise in the renewable-energy-based hybrid power system, particularly in system operation and ancillary services [4].

The stochastic unit commitment problem is solved by using mixed programming approach. The aim of this optimization process is to determine unit commitment schedule common to all scenarios and to minimize the expectation of the daily operating costs over all possible set of scenarios [5]. Due to operating dynamics of power systems such as the outages of generators and transmission components and uncertainty of system demand, the security of power systems was handled traditionally by providing spinning and operating reserves considering the peak demand case or worst outage case. This is a conservative approach which could also lead to an insecure operation of power systems [6]-[7]. Deterministic unit commitment traditionally deals with the unit generation schedule in a power system. The purpose of such schedule is to minimize operating costs while satisfying prevailing constraints such as load balance, system spinning reserve, ramp rate limits, and minimum up/down time limits over a set of time periods [8].

Electric power restructuring offers a major change to the vertically integrated utility monopoly. The change manifests the main part of engineers efforts to reshape the three components of today's vertically integrated monopoly are generation, distribution and transmission. The major components of restructuring models are market power, standard costs, transmission congestion contracts and transmission pricing [9]. The electric power industry has over the years been dominated by large utilities that had an overall authority over all activities in generation, transmission and distribution of power within its domain of operation. Such utilities have often been referred to as vertically integrated utilities and centralized energy market. The utilities being vertically integrated, it was often difficult to segregate the costs incurred in generation, transmission or distribution. Therefore, the utilities often charged their customers an average tariff rate depending on their aggregated cost during a period. The price setting was done by an external regulatory agency and often involved considerations other than economics [10]. This work focuses on investigating the technical capabilities of a thermal generation system for balancing wind power [11].

An algorithm based on mixed integer programming with genetic algorithm is used for solving the generation scheduling in restructured environment [12]. After the description of the mathematical modeling in section II and the solution methodology is explained in section III, the effectiveness of the method with numerical examples is simulated in section IV. (Times New Roman, Font size:12 ,Justify aligned, paragraph :single spacing)Bacopa is a genus of 70 - 100 aquatic and palatial herbs belonging to the family plantaginaceae, distributed throughout the warmer regions of the world [1].

MATHEMATICAL MODELING

The main objective of solving the wind–thermal scheduling problem is to determine when to start up and shut down units so that the total operating cost can be minimized, while simultaneously satisfying the system and the generator constraints [3].

Objective Functions

$$Min\ F_T = \sum_{t=1}^{T}\sum_{i=1}^{NT} F_i(P_i(t)) + \sum_i (STC_{it} + SDC_{it}) \quad (1)$$

The fuel cost unit i in the time period t is usually given as the following function of $p_{it.}$

$$Fc_i(P_i) = a_i + b_i P_i + c_i P_i^{\ 2} \quad (2)$$

A. THERMAL GENERATOR UNIT CONSTRAINTS

a) Unit's maximum up/down reserve contribution constraints:

$$US_i^{\max} = d\% * P_i^{\max}, r \quad (3)$$

$$DS_i^{\max} = d\% * P_i^{\max}, r \quad (4)$$

b) Unit's up/down spinning reserve contribution constraints

$$US_i(t) = \min\{US_i^{\max}, P_i^{\max}, r - P_i(t)\} \tag{5}$$

$$DS_i(t) = \min\{DS_i^{\max}, P_i(t) - P_i^{\min}, r\} \tag{6}$$

c) Unit's ramping up/down capacity constraints:

$$UR_i(t) = \min\{UR_i^{\max}, P_i^{\max}, r - P_i(t)\} \tag{7}$$

$$DR_i(t) = \min\{DR_i^{\max}, P_i(t) - P_i^{\min}, r\} \tag{8}$$

d) Unit generation limits:

$$P_i^{\min}(t) * U_i(t) \le P_i(t) \le P_i^{\max}(t) * U_i(t) \tag{9}$$

e) Minimum up/down time constraints:

$$[t_{ON,i}(t-1) - T_{ON,i}] * [U_i(t-1) - U_i(t)] \ge 0 \tag{10}$$

$$[t_{OFF,i}(t-1) - T_{OFF,i}] * [U_i(t) - U_i(t-1)] \ge 0 \tag{11}$$

B. WIND GENERATOR UNIT CONSTRAINTS

a) Wind generation fluctuation constraints:

$$P_{wt}(t) - P_{wt}(t-1) \le TDR(t), if P_{wt}(t-1) \le P_{wt}(t) \tag{12}$$

$$P_{wt}(t-1) - P_{wt}(t) \le TUR(t), if P_{wt}(t-1) \ge P_{wt}(t) \tag{13}$$

b) Total available wind generation:

$$P_{wt}(t) = \sum_{j=1}^{n} P_{wj}(t) \tag{14}$$

c) Total actual wind generation limit:

$$0 \le P_{wt}(t) \le P_{wt}(t) \tag{15}$$

SOLUTION METHODOLOGY

In the (mixed integer programming) MIP problems, only a subset of the decision and slack variables are restricted to integer values. The procedure for solving MIP problems is similar to that of all-IP (integer programming) problems in many aspects. As in the case of an all-IP problem, the first step involved in the solution of a MIP problem. To obtain an optimal solution of the ordinary (linear programming) LP problem without considering the integer restrictions [11]-[12]. When the operating constraints are considered, such as those imposed by the unit minimum up and down time constraints, the unit ramp rate constraints, and the wind generation fluctuation constraints, etc., the conventional heuristic methods are challenged by the complicated situations [3].

A. WIND-THERMAL UNIT GENERATION SCHEDULING ALGORITHM

Incorporating wind generators into the existing utility generation scheduling problem adds further complexity to the solution methodology. In this paper, a mixed integer programming is developed to solve the wind-thermal generating units scheduling problem. In the mixed integer programming algorithm, the time horizon is divided into smaller time stages, normally of one hour each, and in every stage (or hour), corresponding states representing different combinations of commitment status (ON/OFF) for the generating units in that specific period are also specified [3]-[5].

B. DETERMINE THE MAXIMUM WIND POWER GENERATION OF A STATE

This paper, the following models have been considered relating additional Up/down spinning reserve requirements and total actual wind power generation. They are the linear model and second-order model. Several technique constraints are applied to decide the maximum wind power generation of a state. The allowable penetration level of wind power generation is determined from then wind speed and is restricted by the system maximum spinning reserve contribution, by the thermal plant lower generation limit, and by the system maximum ramping up/down capabilities of the thermal units.

C. PERFORMANCE OF RESERVE-CONSTRAINED ECONOMIC DISPATCH MODULE FOR A STATE

The optimal dispatch of generation in a wind-thermal system involves the allocation of generation among wind plants and thermal plants so as to minimize the operating costs while satisfying various constraints. This paper mainly deals with the wind generator owned by the public utility is considered and the basic requirement of this scenario is to achieve maximum fuel saving and to guarantee a reliable power supply.

D. IMPLEMENTATION OF MIP PROCEDURE

The solution procedure of the proposed wind-thermal scheduling algorithm can be stated as follows:

Step 1) Read the system data and set initial conditions.

Step 2) Initialize the MIP technique.

Step 3) Infeasibility Pick a node and solve it with the Dual Simplex Method with updated constraints.

Step 4) If the Dual Simplex is unbounded then the problem is infeasible and the node is pruned by infeasibility.

Step 5) Optimality/Bounds we now check for bounds and optimality.

Step 6) If z = cx for x, the solution to the Dual Simplex and z > z then we set z = z, and this is our new lower bound. This node is now pruned by optimality since it is currently the best solution to the MIP. If z then this is worse than our lower bound, and this node is pruned by bounds.

Step 7) Branching if x is not in integer form then we branch on the variable that is most fractional.

Step 8) Repeat Pick a new node and repeat starting on Step 1, until all nodes are pruned, at which time the node associated with the lower bound z is optimal.
Yes, go to step 9; otherwise go to step 2.

Step 9) If feasible solution is obtained stops the iteration otherwise backtrack the output results

SIMULATION RESULTS

Table 1.Thermal Generator 36 Unit Input Data

Unit no	Pg_{min} MW	Pg_{max} MW	A_i Rs/MW^{2}hr	B_i Rs/MWhr	C_i Rs/Whr	Startup Cost Rs	Min Up time Hr	Min Down time Hr	$Hcost_i$ Rs/hr	$Ccost_i$ Rs/hr	Chour	Initial state
1	2	12	0.00	25.55	0.0253	10	1	-1	10	50	8	-1
2	4	22	117.76	37.55	0.0120	30	1	-1	30	60	5	-1
3	4	22	118.11	37.66	0.0126	30	1	-1	30	120	5	-1
4	4	22	118.91	37.96	0.0156	30	1	-1	30	60	5	-1
5	4	22	118.91	37.96	0.0019	30	1	-1	30	170	5	-1
6	4	22	118.46	37.78	0.0136	30	1	-1	30	60	5	-1
7	4	22	119.46	37.78	0.0106	30	1	-1	30	60	5	-1
8	15	76	81.14	13.35	0.0088	80	3	-2	80	250	6	3
9	15	76	81.30	13.35	0.0090	80	3	-2	80	250	5	3
10	15	76	81.36	13.41	0.0093	80	3	-2	80	250	3	3
11	15	76	81.83	13.51	0.0096	80	3	-2	80	250	5	3
12	25	100	216.78	17.28	0.0028	100	4	-2	100	200	2	-2
13	25	100	216.78	18.28	0.0059	100	4	-2	100	350	5	-3
14	25	100	217.90	18.00	0.0062	100	4	-2	100	350	5	4
15	25	100	218.34	18.10	0.0061	100	4	-2	100	350	7	4
16	25	100	218.78	18.20	0.0060	100	4	-2	100	200	5	-2
17	25	100	218.78	19.20	0.0070	100	4	-2	100	200	1	-2
18	25	100	219.78	18.60	0.0060	100	4	-2	100	350	8	4
19	54	155	143.03	10.72	0.0047	200	5	-3	200	850	2	5
20	54	155	143.32	10.74	0.0048	200	5	-3	200	850	2	5
21	54	155	143.60	10.76	0.0049	200	5	-3	200	850	3	5
22	69	197	259.13	23.00	0.0026	300	5	-4	300	1000	1	-4
23	69	197	259.65	23.10	0.0026	300	5	-4	300	1000	1	-4
24	69	197	260.08	23.04	0.0026	300	5	-4	300	1000	2	-4
25	69	197	260.18	23.20	0.0026	300	5	-4	300	1000	1	-4
26	69	197	261.18	23.50	0.0027	300	5	-4	300	1000	1	-4
27	69	197	261.58	23.40	0.0027	300	5	-4	300	1000	5	-4
28	140	350	176.06	10.84	0.0015	500	8	-5	500	1200	3	-5
29	140	350	176.06	10.86	0.0015	500	8	-5	500	1200	2	-5
30	140	350	176.06	10.66	0.0014	500	8	-5	500	1200	2	-5
31	140	350	177.96	10.96	0.0016	500	8	-5	500	1200	3	-5
32	100	400	310.00	7.49	0.0019	800	8	-5	800	2000	10	-5

33	100	400	311.91	7.50	0.0020	800	8	-5	800	2000	9	-5
34	100	400	312.91	7.51	0.0020	800	8	-5	800	2000	10	-5
35	100	400	313.91	7.612	0.0020	800	8	-5	800	2000	1	-1
36	100	400	314.91	7.532	0.0020	800	8	-5	800	2000	2	-10

Table 2. Wind Generator Unit Input Data

Time in hour	1	2	3	4	5	6	7	8	9	10	11	12
$V_{w,t}$ (m/s)	3.5	3.6	1.5	1.4	0.1	1.8	1.3	2.2	3.8	3.7	2.0	0.6
Time in hour	13	14	15	16	17	18	19	20	21	22	23	24
$V_{w,t}$ (m/s)	0.4	8.4	9.9	10.1	9.7	9.2	9.6	10	10	9.5	9.9	12.6

Table 3. Wind-Thermal Units Generation Scheduling

For the below mentioned table consider the wind-thermal units generation scheduling based on the load demand which state or unit is ON/OFF.

Time in hrs	**G 1**	**G 2**	**G 3**	**G 4**	**G 5**	**G 6**	**G 7**	**G 8**	**G 9**	**G 10**	**G 11**	**G 12**	**G 13**	**G 14**	**G 15**	**G 16**	**G 17**	**G 18**
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
6	1	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0
7	1	1	1	0	0	0	0	1	1	0	0	1	1	1	0	0	0	0
8	1	1	1	1	1	0	0	1	1	0	0	1	1	1	0	0	0	0
9	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0	0
10	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0	0
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
15	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	0	0
16	0	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	0
17	0	1	1	1	0	0	0	1	1	1	1	1	1	1	0	0	0	0
18	0	1	1	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0
19	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0
20	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0
21	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0
22	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0
23	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0

G 19	G 20	G 21	G 22	G 23	G 24	G 25	G 26	G 27	G 28	G 29	G 30	G 31	G 32	G 33	G 34	G 35	G 36	G 37
1	0	0	1	1	1	1	0	0	1	1	1	0	1	1	0	0	0	0
1	0	0	1	1	1	1	0	0	1	1	1	0	1	1	0	0	0	0
1	0	0	1	1	1	1	0	0	1	1	1	0	1	1	0	0	0	0
1	0	0	1	1	1	1	0	0	1	1	1	0	1	1	0	0	0	0
1	0	0	1	1	1	1	0	0	1	1	1	0	1	1	1	0	0	0
1	0	0	1	1	1	1	0	0	1	1	1	0	1	1	1	0	0	0
1	0	0	1	1	1	1	0	0	1	1	1	0	1	1	1	0	0	0
1	0	0	1	1	1	1	0	0	1	1	1	0	1	1	1	0	0	0
1	0	0	1	1	1	1	0	0	1	1	1	0	1	1	1	0	0	0
1	0	0	1	1	1	1	0	0	1	1	1	0	1	1	1	0	0	0
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1	0	0	1	1	1	1	0	0	1	1	1	0	1	1	1	0	0	0
1	1	0	1	1	1	1	0	0	1	1	1	0	1	1	1	0	0	0
1	1	0	1	1	1	1	0	0	1	1	1	0	1	1	1	0	0	1
1	1	0	1	1	1	1	0	0	1	1	1	0	1	1	1	0	0	1
1	0	0	1	1	1	1	0	0	1	1	1	0	1	1	1	0	0	1
1	0	0	1	1	1	1	0	0	1	1	1	0	1	1	1	0	0	1
1	0	0	1	1	1	1	0	0	1	1	1	0	1	1	1	0	0	1
1	0	0	1	1	1	1	0	0	1	1	1	0	1	1	1	0	0	1
1	0	0	1	1	1	1	0	0	1	1	1	0	1	1	1	0	0	1
1	0	0	1	1	1	0	0	0	1	1	1	0	1	1	1	0	0	1
1	0	0	1	1	1	0	0	0	1	1	1	0	1	1	0	0	0	1
1	0	0	1	1	1	0	0	0	1	1	1	0	1	1	0	0	0	1
1	0	0	1	1	1	0	0	0	1	1	1	0	1	1	0	0	0	1

Note: Wind-Thermal generation scheduling consider the 36 units in thermal system and 1 unit in wind energy system

RESULT ANALYSIS

For solving the generation scheduling problem, stochastic mixed integer programming method is proposed. In this work thermal and wind units are committed for 24 hours scheduling. First hour to 13th hour thermal unit alone satisfy the load demand, wind available period is 13th hour to 24th hour.

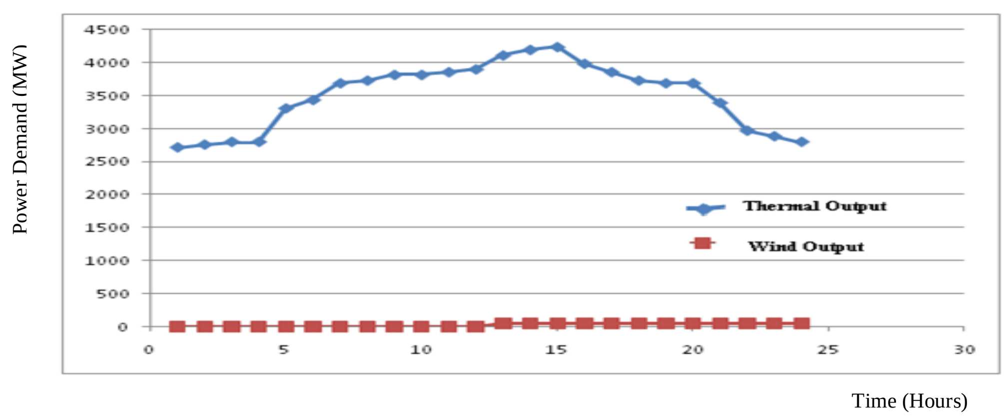

Fig.1: Total thermal and wind power output Characteristics curve

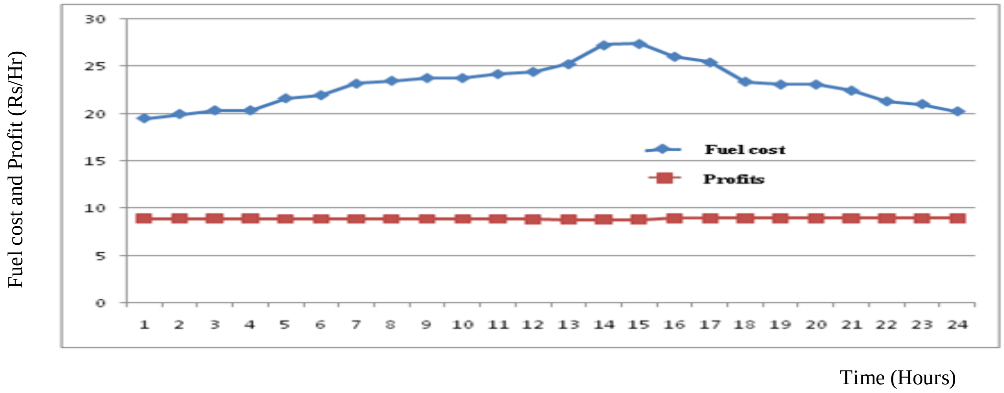

Fig.2: Fuel cost and Profit Characteristics curve

The wind unit also committed with thermal to obtain the load demand. So the fuel cost of thermal unit is reduced and profit is maximized. The hour 15 is the peak load (4242.0MW) hour for this hour the total operating cost and the fuel cost is high when comparing to other hours. But for the hour 1 the operating cost and the fuel cost is low when comparing to other hours because it is the low load (2714.9MW) hour at this hour. By including the renewable energy in generation scheduling process the total cost will be reduced and the profit maximize.

CONCLUSION

This paper proposed the mixed integer programming for solving the generation scheduling problem by considering wind and thermal unit power generation system. By adding the wind power in generation scheduling, the thermal unit fuel cost is minimized and the profit is maximized. The effectiveness of the proposed method has been evaluated for a system consisting of IEEE-36 unit thermal systems, one equivalent wind energy system. The method of generation that have very fast response to reach a optimal in generation schedule. Also, increases the efficiency of electricity production and distribution interms of characteristics and offers higher quality, secure and more reliable electricity at low prices.

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BIOGRAPHY

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