Price Based Unit Commitment Considering Fuzzy Uncertainty

Reza Khorramnia^{*}, Soroush Karimi Khorrami

Department of Electrical Engineering, Safashahr Branch, Islamic Azad University, Safashahr, Iran *Corresponding author: r.khorramnia@gmail.com

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Abstract In deregulated systems, bidding plays an important role for Gencos participating with the objective of maximizing profit. While making bidding strategies, factors like unit constraint and price uncertainty need to be considered as they have direct impact on the expected profit. The goal of the partnership units of solution is based on the price. By solving this problem, the generation company to determine the optimal generation schedule and unit status hourly. MCP plays an important role in the profitability of the units. In this paper, a novel approach to solving an optimal bid curve underprice uncertainty using PBUC in PAB markets is presented. Numerical results show the suitability of the method on a sample market.

Keywords: price based unit commitment, market clearing price, fuzzy uncertainty, pay as bid, Generation Company

1. Introduction

Unit commitment (UC) in electric power systems is to optimize generating resources to supply system load while satisfying prevailing constraints, such as minimum on/off time, ramping up/down, minimum/maximum generating capacity and fuel and emission limit [1,2]. In day-ahead electricity markets, generation companies offer their desirable hourly bid curves to participate in the market of the next day. Because of the significant impact of bid curve on the profit of each generation unit, proposed schedule of unit is very important.

A Genco¹ is a self-interested entity which is responsible for its own risk-based maintenance outage scheduling. Such planned outage schedules will be submitted to the independent system operator (ISO) for approval. A Gencointends to minimize potential financial risks when planning its generator maintenance outage schedules [2]. It is very crucial for a Gencoto devise a maintenance outage schedule which guarantees its potential payoffs. The main factor determining the unit is turned off or on, is the MCP² that ISO determine it.

As the market requires Gencos to bid for each unit separately or in the market with insignificant market power, the UC for each generating unit can be considered independently. Hence, for profit maximizing objective, it is profitable to operate a unit as long as the cost of producing is lower than the revenue obtained by selling that quantity produced [2].

Arroyo and Conejo [3] proposes a 0/1 mixed integer linearprogramming to maximize the unit profit from

selling bothenergy and spinning reserve in spot market. Leou and Y. N. [4] Chang proposes a PBUC³ problem considering uncertainties of energy price at the stance of GENCOs. This problem is solved by the greedy algorithm and quadratic program using the concept of decommitment. A selective enumeration technique has been proposed in [5] to solve the PBUC problem using heuristic technique in coordination with dynamic programming and non-linear programming.

Ref [6] solve the problem for thermal and combined cycle units with pump storage solution and compare it with LR^4 method. Finally It is expressed proposed method is beter.

All the proposed methods are, however, based on cost minimization objective, similar to the one used for the traditional markets. But, in deregulated markets, Gencos are usually entities owning generation resources and participating in the market with sole objective of maximizing the profits without concern of the system unless there is an incentive for it. Hence, if we consider generation planning for a period of, say 24 hours in advance, the Gencos based on the price forecast, generation unit characteristics, unit availability etc carryout profit based unit commitment (PBUC) and thereby determine the bidding strategy for each bidding period next day. In real time, they would have to meet generation as ordered by the ISO [7].

In this article, price uncertainty is considerd and suppose thas a fuzzy membership function. Also, It is assumed that the model of power market is PAB⁵. Numerical examples is presented the effectiveness of the proposed method.

^{1 -} Generation Company

^{2 -} Market Clearing Price

^{3 -} Price Based Unit Commitment

^{4 -} Lagrangian Relaxation

^{5 -} Pay As Bid

2. Price Based Unit Commitment without Considering Uncertainty

Primitive and definitive solution to simplify the problem by assuming that market price is certain.

In most power markets, a company must be produced for each unit independently owned their proposed schedule to provide that in this case, the problem of PBUC for each unit is solved independently [5].

2.1. Description of Problem

Since the schedule of Genco is determined by ISO, problem significance especially in terms of price uncertainty is clearer. The goal of the price-based unit commitment is to maximize the profit (i.e., revenue minus cost) of GENCOs subject to all constraints. This new price-based UC problem is different from traditional costminimization UC.

2.2. Problem Formulation

In the deregulated environment, market prices are unknown when GENCOs propose their bids. Therefore, this new algorithm should consider uncertainties exiting in price and the objective function is to maximize. Besides, the new UC problem doesn't consider satisfying load demand as its necessary constraint. The objective function and constraints of this model are described below. The objective function of this model is first depicted as follow:

$$\max F = \left\{ \sum_{t=1}^{T} Revenue(t) - Cost(t) \right\}$$
(1)

$$\max F = \left\{ \sum_{t=1}^{T} \left[(\rho(t) * P(t)) - C(P(t)) \right] * I(t) - ST(t) - SD \right\}$$
(2)

$\rho(t)$	Predicted Price
P(t)	Unit Generation
C(P(t))	Generation Cost
ST	Startup Cost
SD	Shutdown Cost

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3. Price Based Unit Commitment Considering Fuzzy Uncertainty



Figure 1. Unit benefit function and cost function

In actual power markets, due to the multiplicity of different Gencos and the multiplicity of bids, MCP of the market is an uncertain variable.

Unit Profit function from sales of energy and unit cost function is shown in the Figure 1. As can be seen, profit equals the difference between revenue and cost and greatest benefit may not occur in most generation.

3.1. Modeling Uncertainty with Fuzzy Price

The MCP is modeled as both, probability models [4,8,9] and the possibility [10,11]. In this paper, we use possibility model and price uncertainty is modeled as fuzzy variables and membership function for MCP uncertainty is shown as in Figure 2.



Figure 2. Fuzzy membership function of MCP

Figure 3 shows a membership function of possibility of price acceptance.



Figure 3. Fuzzy membership function of Acceptance price

We can assume that the set P is the set of all possible price cuts of alpha (α - Cut) and fuzzy set market prices settle in relationships can be defined:

$$\widetilde{A} = \left\{ \left(\rho, \mu_{\widetilde{A}} \left(\rho \right) \right) \mid \rho \in P \right\}$$
(3)

$$A_a = \left\{ \rho \in P \,\middle|\, \mu_{\widetilde{A}}(\rho) \ge a \right\} \; ; 0 < a < 1 \tag{4}$$

3.2. Formulating the Problem

Profits and optimum production have a sensitive relation with price. And other hands, the optimal operating point will be different for different prices .Price predictions have always been a period of change and uncertainty is therefore better results can be obtained by fuzzy model, as the price of uncertainty.

$$\max \widetilde{F} = \left[\sum_{t=1}^{T} \left\{ \left(\widetilde{\rho(t)} * P(t) - C(P(t)) \right) * I(t) - ST(t) - SD(t) \right]$$
(5)

 $\rho(\bar{t})$: fuzzy Price prediction for hour(t)

$$ST(t) = s_i + \delta_i * (1 - e^{\frac{-X(t)^{off}}{\tau}})$$
(6)

 s_i : Cold Startup Cost

- δ : Hot Shutdown Cost
- au : Unit Cooling Time Constant

3.3. Constraints of Problem

3.3.1 Minimum/Maximum Generation

$$P_{\min} \leq P(t) \leq P_{\max}; t \in T$$
(7)

P_{min}: Generation Lower Limit of UnitP(t): Generation of Unit *i for hour (t)*P_{max}: Generation Upper Limit of Unit

3.3.2 Up/Down Rate of Generation

$$P_{(t)} - P_{(t+1)} \le DR \quad ; t \in T \tag{8}$$

$$P_{(t+1)} - P_{(t)} \le UR \; ; \; t \in T$$
 (9)

DR: Down Rate of Generation UR: Up Rate of Generation

3.3.2 Minimum Up/Down Time of Unit

$$(X_{t+1}^{on} - T_{on}) * (I_{(t)} - I_{(t+1)}) \ge 0$$
(10)

$$(X_{t+1}^{off} - T_{off}) * (I_{(t+1)} - I_{(t)}) \ge 0$$
(11)

 $X_{(t)}^{0}$: Time Unit *i* is in On State at time *t*

 $X_{(t)}^{off}$: Time Unit *i* is in Off State at time *t*

 T_{on} : Minimum Uo Time of Unit

 T_{off} : Minimum Down Time of Unit

3.4. Profit Calculated as a Fuzzy

Given that the price variable is a fuzzy model, fuzzy variables in the form of Figure 4 will be. Sometimes, may be the unit status is changed (on or off) for different values of the fuzzy membership function. The dependence of the unit generation at different times to each other, and the constraints on the problem, lead to the generation scheduling is difficult with solving the problem by proposed method for alpha -cutting , profit and production planning will be different. benefits of each section related to alpha [13] can be expressed:

$$\widetilde{Profit}_{\alpha} = \left\{ \left(Profit \right), \mu_{\widetilde{A}} \left(\rho \right) \middle| \rho \in A_{\alpha} \right\}$$
(12)

$$Profit_{\alpha} = \max\left(\widetilde{Profit_{\alpha}}\right)$$
 (13)

Optimal schedule of generation is calculated by equation [15]. In this regard, the combination of benefit and risk is optimized and acceptable risk level to the possible degree (n), is modeled. Parameter value of "n" in the examples and experience on the matter shall be determined by an expert.

$$Optimal \ Profit = \max\left\{ \left(Profit_{\alpha} * \mu \left(Profit_{\alpha} \right)^{n} \right) \right\} \ (14)$$

$$Optimal \ Profit = \max\left\{ \left(Profit_{\alpha} * \alpha^{n} \right) \right\}$$
(15)



Figure 4. Fuzzy membership function of profit

4. Numerical Example

In a numerical example, the PBUC problem is solved by assuming certain price. Input parameters with problem constraints are in Table 1. In this example, the market price is modeled as trapezoidal fuzzy membership function that is given in Table 2.

 Table 1. Fuzzy membership function of profit

Parameter	r Value	Parameter	Value
Initial Stat	us ON	MDT (h)	2
s (\$)	100	MUT (h)	2
δ (\$)	160	UR (MW/min)	20
τ (h)	6	DR (MW/min)	20
c (\$)	20	Pmax (MW)	120
b (\$/MW) 25	Pmin (MW)	55
a (\$/MW2	2) 0.795	pmax (\$/MWh)	110

Table 2. Trapezoidal membership function of MCP

			-r	
Hour	A1	A2	A3	A4
1	40.6	60.6	70.6	90.6
2	39.9	59.9	69.9	89.9
3	33.3	53.3	63.3	83.3
4	32.5	52.5	62.5	82.5
5	31.5	51.5	61.5	81.5
6	29.5	49.5	59.5	79.5
7	28.2	48.2	58.2	78.2
8	39.6	59.6	69.6	89.6
9	42.6	62.6	72.6	92.6
10	50	70	80	100
11	50.7	70.7	80.7	100.7
12	49.9	69.9	79.9	99.9
13	49.5	69.5	79.5	99.5
14	49.8	69.8	79.8	99.8
15	48.6	68.6	78.6	98.6
16	57.8	77.8	87.8	107.8
17	57.7	77.7	87.7	107.7
18	62.4	82.4	92.4	112.4
19	67.1	87.1	97.1	117.1
20	71.3	91.3	101.3	121.3
21	73.4	93.4	103.4	123.4
22	72.2	92.2	102.2	122.2
23	49	69	79	99
24	47.6	67.6	77.6	97.6



Figure 5. Fuzzy membership function of MCP for Sample hour

4.1. Impact of Price Uncertainty

In this section we shall assume that the market price is certain. Since the purpose of comparison between the results of different methods, is price uncertainty, it is assumed that the values chosen for the certain MCP, is A3, corresponding point of fuzzy membership function. This price is the highest possible (with membership value equal to 1) to have comparable results.

Table 3. The hourly profits without regard to price uncertainty

Hour	1	2	3	4	5	6	7	8
Profit	98	-43	-20	-20	-20	-20	-20	-145
Hour	9	10	11	12	13	14	15	16
Profit	210	614	655	609	586	606	538	1047
Hour	17	18	19	20	21	22	23	24
Profit	1040	1299	1558	1786	1905	1835	561	484
Total	15142							
Profit	15142							

4.2. Considering Uncertainty in the Fuzzy Price



Figure 6. Fuzzy membership function of profit



Figure 7. Fuzzy membership function of MCP and profit

In this numerical example, the effect of price uncertainty is represented in the final results, it is clear that the uncertainty can improve the unit profit. The hours that the unit is off, turn on/off cost (20\$),lead to negative profit at this time.

Table 4. Fuzzy profit per hour by alpha cut method

Hour	· A ₁	A _{0.75}	A _{0.5}	A _{0.25}	A_0
1	98	373	648	923	1,198.4
2	-43	232	607	882	1,157.0
3	-20	-20	249	524	798.5
4	-20	-20	203	478	752.8
5	-20	-20	149	424	698.7
6	-20	-20	37	312	587.2
7	-20	-20	-34	241	515.6
8	-145	131	596	871	1,145.9
9	210	485	760	1035	1,310.2
10	614	889	1164	1439	1,713.8
11	655	930	1205	1480	1,754.6
12	609	884	1159	1434	1,708.5
13	586	861	1136	1411	1,686.2
14	606	881	1156	1431	1,705.8
15	538	813	1088	1363	1,637.5
16	1047	1322	1597	1872	2,146.5
17	1040	1315	1590	1865	2,139.7
18	1299	1574	1849	2124	2,399.3
19	1558	1833	2108	2383	2,667.0
20	1786	2061	2336	2617	2,914.1
21	1905	2180	2456	2744	3,047.2
22	1835	2110	2385	2668	2,968.0
23	561	836	1111	1386	1,661.1
24	484	759	1034	1309	1.584.0



Figure 8. Fuzzy sets (A9, 0. 5) for fuzzy variable profits and MCP

Table 5. Optima	l selection	of generation	n schedule by	y alpha-cut
method				

AlphaCuts (α-cuts)	A_I	A _{0.75}	$A_{0.5}$	A _{0.25}	A_0
$Profit_{\alpha}$	15142	20367	26586	33214	39898
$\mu(Profit_{\alpha})or \alpha$	1	0.75	0.5	0.25	0
$Profit_{\alpha} * \alpha^{0.10}$	15142	19789	24806	28914	0
$Profit_{\alpha} * \alpha^{0.25}$	15142	18954	22356	23486	0
$Profit_{\alpha} * \alpha^{0.50}$	15142	17638	18799	16607	0
$Profit_{\alpha} * \alpha^{0.75}$	15142	16414	15808	11743	0
$Profit_{\alpha} * \alpha^{0.90}$	15142	15721	14247	9538	0
$Profit_{\alpha} * \alpha^{1.00}$	15142	15275	13293	8304	0
$Profit_{\alpha} * \alpha^{1.25}$	15142	14215	11178	5871	0
$Profit_{\alpha} * \alpha^{1.50}$	15142	13229	9400	4152	0

Hour	A_1	A _{0.75}	A _{0.5}	A _{0.25}	A ₀
2	55	55	55	55	55
3	0	0	55	55	55
4	0	0	55	55	55
5	0	0	55	55	55
6	0	0	55	55	55
7	0	0	55	55	55
8	55	55	55	55	55
9	55	55	55	55	55
10	55	55	55	55	55
11	55	55	55	55	55
12	55	55	55	55	55
13	55	55	55	55	55
14	55	55	55	55	55
15	55	55	55	55	55
16	55	55	55	55	55
17	55	55	55	55	55
18	55	55	55	55	55
19	55	55	55	55	58
20	55	55	55	58	61
21	55	55	56	59	62
22	55	55	55	58	62
23	55	55	55	55	55
24	55	55	55	55	55

Ta	ble 6. Optim	um Gene	eration of u	nit with	cons	idering]	price
une	certainty						

The hours that the unit is off or on, leads to negative profits. It is possible for the generation benefit is positive, but due to the high unit cost, total profit is negative.

With respect to the previous section, in the optimum production schedule, the profit and risk of accepting is appropriate.

Conclusion

This paper proposed a novelapproach of unit scheduling under price uncertainty using PBUC. The profit obtained using PBUC considering price (MCP) uncertainty is the membership function of Trapezoidal function. Use alphacut method to defuzzification final profit.

The method is tested with a numerical example to analyse the effect of the price uncertainty on the expected profit. Comparisons made show that the proposed method results in higher expected profits under price uncertainty. Hence, for decision makers, this method can be a tool for improving the expected profits.

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