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Optimal Price Scheduling by Augmented Lagrangian in Deregulated Power Market

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ABSTRACT

Deregulated electricity markets use a market clearing price mechanism to pay market participants for energy and service products. Lagrangianmethod is used for solving the minimization of offer cost in a deregulated electricity market. A general formulation of the market clearing price (MCP) and offer cost minimization approach is presented. The most independent system operators (ISO) determine MCP using that minimizes the offered costs. The solution algorithm for offer cost minimization has been developed based on Lagrangian methodology. Using this method is tested with 30-bus IEEE test system and numerical testing results demonstrate that the method is effective, and the resulting costs are significantly lower in pay at MCP costs when compare to actual purchase cost using MCP.

Keywords: Price,offercost,paymentcost,actualcost,market clearing price (MCP), independent system operator (ISO).

I. INTRODUCTION

Independent system operators (ISOs) generally adopt a market clearing price (MCP) mechanism to pay market participants and charge consumers for energy and ancillary service products[1]. Under this mechanism, market participants submit supply offers and demand bids for energy and ancillary services to minimize the total bid price and determine the MCPs for each product.Get paid based on the It is crucial for the ISOs to have a proper objective function and to set the MCPs correctly, since market participants are charged or MCPs. The electricity market consists of a network which is open to wholesalers,retailers and the consumers [2-4]. The pool operator is independent of the transmission owners and the consumers and hence determines the market clearing price by combining the facilities of several transmission owners into a single system and fixing it at a single lower price than the combined charges of each utility that may be located between the buyer and seller.The lagrangian approach has been tested on a 30 bus system[5].From that results offer cost are minimized.A understsnding has been made and how various market conditions have an impact on the MCP is discussed.

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. such utilities served as the only electricity provider in the region and were obliged to provide electricity to everyone in the region[6].

The utilities are vertically integrated, it was often difficult to segregate the costs incurred in generation, transmission or distribution[7-8]. 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. Genetic algorithm based market clearing was performed with minimum cost and maximize social welfare [9]. Wind power marketing scheme was developed with maximum efficiency and low under pay as bid scheme [10]. Price forecast based build hourly offer curves are discussed in [11].

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The above literatue does not deals with the Augmented lagrangian relaxation method based market price forecasting in which this work putforth to develop the optimal algorithm by considering the generation cost, fuel cost and operating cost.

II. PROBLEM FORMULATION

The objective of a power pool operator is to maximize the social welfare function which is determined as the deviation between the cumulative consumer and generator bids. Consider a system with N generators and M consumers. Let the generator bid function for the i^{th} generator be

$$C_i(Pg_i) = a_i Pg_i^2 + b_i Pg_i + C_i$$

and the consumer benefit function for the jth load be

$$Bf_j(Pd_j) = \alpha_j Pd_j^2 + \beta_j Pd_j + \gamma_j$$

Now, the objective of the pool market operator is to maximize the social welfare function

$$\sum_{j=1}^{M} Bf_j(Pd_j) - \sum_{i=1}^{N} C_i(Pg_i)$$

Subject to the power balance constraint

$$\sum_{i=1}^{N} (Pg_i) = \sum_{j=1}^{M} (Pd_j)$$

The schedules for each of the generators and the demand of each consumer that can be met is obtained as,

$$Pg_i = \lambda - b_i/2a_i$$
$$Pd_i = \lambda - \beta_j/2\alpha_j$$

Objective function,

$$\text{Minj} = \sum_{t=1}^{T} \sum_{i=1}^{I}\{ C_i(p_i(\text{t}),\text{t})\}\text{i = no of offers}$$

Demand constrain

$$P_d(t) - \sum_{i=1}^{I} p_i(t) = 0, \qquad t = 1,2,\dots\dots T$$

Pay at mcp formulation

$$J = \sum_{t=1}^{T} \sum_{i=1}^{I}\{MCP(t)p_i(t)\}$$

Pay as offer cost

$$J = \min\sum_{i=1}^{I} (Pg(i) * Ci)$$

Actual cost using MCP

$$J = \sum_{i=1}^{I}\{ MCP * p_g(i)\}$$

III. SOLUTION METHODOLOGY

Test section dealts with the solution for the problem listed in section II. Augmented lagrangian relaxation method is used to solve the listed problem. It has been formulated by considering the equality and in equality contrainsby summing the quadratic penality terms. Thus the overall convergence has been improved with fast rate. Let $\{\lambda(t)\}$be the multipliers of the relax system demand constraints, $\{\eta_i(t)\}$ be the MCP-offer inequality constraints. The augmented Lagrangian is given by,

$$L_c(\lambda,\eta,MCP,P) \equiv \sum_{i=1}^{I}\sum_{t=1}^{T}\{MCP(t)P_i(t)+S_i(t)\}+\sum_{t=1}^{T}\{\lambda(t)\left(P_d(t)-\sum_{i=1}^{I}P_i(t)\right) + \sum_{i=1}^{I}\eta_i(t)(O_i^r(t)-MCP\,(t)+\ z_i(t)^2)\} + \frac{u}{2}\sum_{t=1}^{T}\left\{(P_d(t)-\sum_{i=1}^{I}P_i(t))^2+\ \sum_{i=1}^{I}(O_i^r(t)-MCP\,(t)+\ z_i(t)^2)^2\right\}$$

Where u is the positive penality coefficient. The augmented lagrangianfuction with minimizing $\{z_i(t)^2\}$ is given by

$$L_c(\lambda,\eta,MCP,P) \equiv \sum_{i=1}^{I}\sum_{t=1}^{T}\{MCP(t)P_i(t)+S_i(t)\}+\sum_{t=1}^{T}\{\lambda(t)\left(P_d(t)-\sum_{i=1}^{I}P_i(t)\right) + \sum_{i=1}^{I}\ \sum_{t=1}^{T}\frac{1}{2u}\ max\{O,\eta_i(t)+u(O_i^r(t)-MCP\,(t))^2-\eta_i(t)^2\} + \sum_{t=1}^{T}\frac{u}{2}\left\{(P_d(t)-\sum_{i=1}^{I}P_i(t))^2\right\}$$

IV. SIMULATION RESULTS

The pay-at-MCP is developed with argumented using MATLAB. The obtained results are presented here. Simulation has carried out for 6 unit system, the cost co-efficient and bid coefficient is in a table 1.

Table 1
Cost co-effcient and bid co-efficient

GEN.NO	*Pmin (MW)*	*Pmax (MW)*	a_i	b_i	c_i	α_i	β_i	γ_i
1	50	200	0.0038	200	0	0.0126	-1.1	22.983
2	20	80	0.0175	1.75	0	0.02	-0.1	25.313
3	15	50	0.0625	1	0	0.027	-0.01	25.505
4	10	35	0.0083	3.25	0	0.0291	-0.005	24.9
5	10	30	0.025	3	0	0.029	-0.004	24.7
6	12	40	0.025	3	0	0.0271	-0.0055	25.3

The system demand assumed as the valley pattern which is given in the table 2.

Table 2
Valley pattern

Hour	*DEMAND*	*MCP*	*Hour*	*DEMAND*	*MCP*
1	285	81.59866	13	187	67.75561
2	275	80.18611	14	192	68.46188
3	263	78.49103	15	198	69.30943
4	258	77.78476	16	210	71.00449
5	245	75.94844	17	240	75.24215
6	235	74.53587	18	247	76.23095
7	200	69.59194	19	255	77.36099
8	195	68.88565	20	260	78.06727
9	190	68.17937	21	261	78.20852
10	185	67.4731	22	270	79.47982
11	180	66.76682	23	275	80.18611
12	180	66.7668	24	283	81.31615

STEP BY STEP PROCEDURE FOR PROPOSED METHOD

Step1: MCP is determined from cost coefficient and bid coefficient as shown in Figure 1.

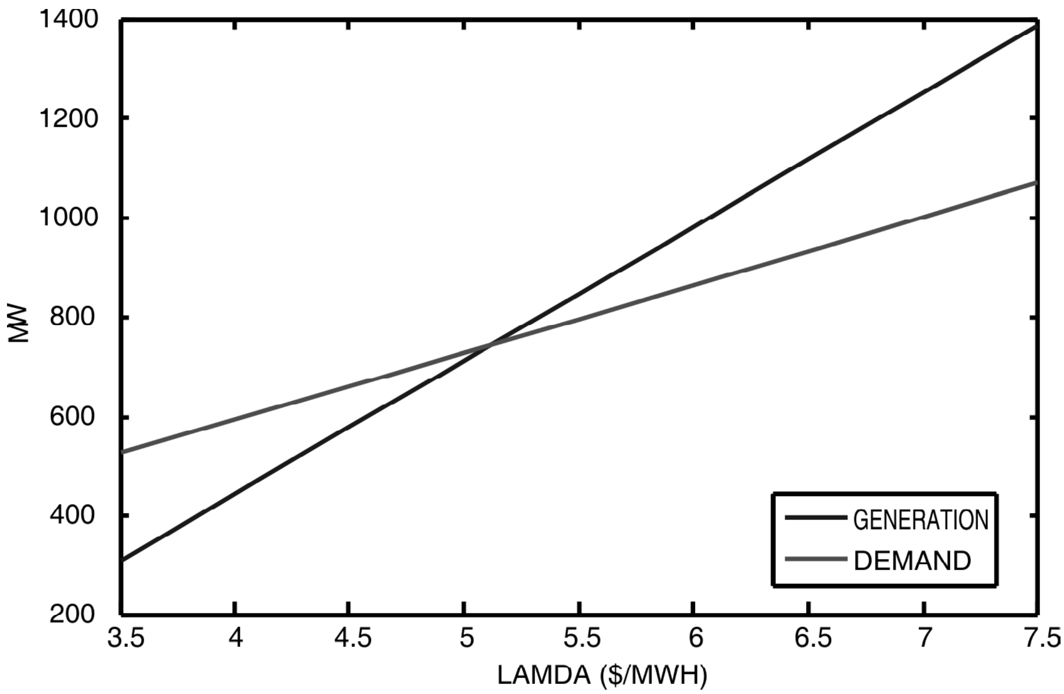

Figure 1: Bidding graph

Step2: Calculate individual offer cost and find total pay as offer cost

Hour	*Demand*	*offer1 $/MW*	*OFFER2 $/MW*	*Offer 3 $/mw*	*OFFER 4$/MW*	*OFFER5 $/MW*	*OFFER6 $/MW*
1	285	81.59866	81.59869	81.5988	82.0032	84	86.4
2	275	80.18611	80.18606	80.1861	82.0032	84	86.4
3	263	78.49103	78.49103	78.4911	82.0032	84	86.4
4	258	77.78476	77.78476	77.7849	82.0032	84	86.4

5	245	75.94844	75.94843	75.9483	82.0032	84	86.4
6	235	74.53587	74.53589	74.5359	82.0032	84	86.4
7	200	69.59194	69.5919	69.5919	82.0032	84	86.4
8	195	68.88565	68.88563	68.8857	82.0032	84	86.4
9	190	68.17937	68.17936	68.1795	82.0032	84	86.4
10	185	67.4731	67.47308	67.473	82.0032	84	86.4
11	180	66.76682	66.76681	66.7668	82.0032	84	86.4
12	180	66.7668	66.76681	66.7668	82.0032	84	86.4
13	187	67.75561	67.75558	67.7556	82.0032	84	86.4
14	192	68.46188	68.46185	68.4618	82.0032	84	86.4
15	198	69.30943	69.30941	69.3093	82.0032	84	86.4
16	210	71.00449	71.00444	71.0046	82.0032	84	86.4
17	240	75.24215	75.24216	75.2421	82.0032	84	86.4
18	247	76.23095	76.23092	76.2309	82.0032	84	86.4
19	255	77.36099	77.36098	77.361	82.0032	84	86.4
20	260	78.06727	78.06725	78.0672	82.0032	84	86.4
21	261	78.20852	78.20854	78.2085	82.0032	84	86.4
22	270	79.47982	79.47979	79.4799	82.0032	84	86.4
23	275	80.18611	80.18606	80.1861	82.0032	84	86.4
24	283	81.31615	81.31612	81.3162	82.0032	84	86.4

Step3: Find actual pay as offer cost

hour	*pay as offer cost1*	*pay as offer cost2*	*pay as offer cost3*	*pay as offer cost4*	*pay as offer cost5*	*pay as offer cost6*
1	15231.13985	3846.668	1566.664	820.032	840	1036.8
2	14338.21393	3645.226	1501.781	820.032	840	1036.8
3	13295.95629	3409.784	1425.689	820.032	840	1036.8
4	12871.11457	3313.701	1394.551	820.032	840	1036.8
5	11792.44561	3069.441	1315.128	820.032	840	1036.8
6	10988.18976	2887.013	1255.58	820.032	840	1036.8
7	8347.914601	2285.92	1057.609	820.032	840	1036.8
8	7992.898641	2204.802	1030.661	820.032	840	1036.8
9	7643.425316	2124.871	1004.045	820.032	840	1036.8
10	7299.503319	2046.128	977.7512	820.032	840	1036.8
11	6961.115121	1968.573	951.8008	820.032	840	1036.8
12	6961.106568	1968.573	951.8008	820.032	840	1036.8
13	7436.408786	2077.481	988.229	820.032	840	1036.8
14	7782.547752	2156.699	1014.645	820.032	840	1036.8
15	8205.244914	2253.332	1046.785	820.032	840	1036.8
16	9074.565023	2451.72	1112.514	820.032	840	1036.8
17	11387.54637	2977.633	1285.188	820.032	840	1036.8
18	11955.95516	3106.494	1327.203	820.032	840	1036.8
19	12618.86134	3256.619	1376.02	820.032	840	1036.8
20	13040.38834	3351.989	1406.958	820.032	840	1036.8
21	13125.35235	3371.21	1413.188	820.032	840	1036.8
22	13900.05916	3546.293	1469.846	820.032	840	1036.8
23	14338.21393	3645.226	1501.781	820.032	840	1036.8
24	15050.78107	3805.993	1553.579	820.032	840	1036.8

Step 4 : Calculate cost using payment cost minimization technique.

Hour	*Actual costs using MCP1*	*Actual costs using MCP 2*	*Actual costs using MCP 3*	*actual costs using MCP 4*	*actual costs using MCP 5*	*actual costs using MCP 6*
1	23295.07	5883.234	2396.11	1248	1248	1497.6
2	22315.7	5673.358	2337.342	1248	1248	1497.6
3	21140.45	5421.524	2266.83	1248	1248	1497.6
4	20650.77	5316.592	2237.452	1248	1248	1497.6
5	19377.58	5043.767	2161.049	1248	1248	1497.6
6	18398.2	4833.903	2102.293	1248	1248	1497.6
7	14970.41	4099.368	1896.623	1248	1248	1497.6
8	14480.72	3994.436	1867.245	1248	1248	1497.6
9	13991.03	3889.504	1837.867	1248	1248	1497.6
10	13501.35	3784.572	1808.477	1248	1248	1497.6
11	13011.66	3679.641	1779.099	1248	1248	1497.6
12	13011.65	3679.641	1779.099	1248	1248	1497.6
13	13697.22	3826.543	1820.233	1248	1248	1497.6
14	14186.9	3931.475	1849.611	1248	1248	1497.6
15	14774.54	4057.398	1884.867	1248	1248	1497.6
16	15949.78	4309.232	1955.391	1248	1248	1497.6
17	18887.89	4938.835	2131.671	1248	1248	1497.6
18	19573.46	5085.737	2172.805	1248	1248	1497.6
19	20356.95	5253.631	2219.818	1248	1248	1497.6
20	20846.64	5358.563	2249.196	1248	1248	1497.6
21	20944.57	5379.554	2255.074	1248	1248	1497.6
22	21826.01	5568.426	2307.964	1248	1248	1497.6
23	22315.7	5673.358	2337.342	1248	1248	1497.6
24	23099.19	5841.252	2384.354	1248	1248	1497.6

The comparision of pay at MCP, total pay as offer and total actual cost for each hour is lised in Table 2.

Table 2
Comparision of pay at MCP, total pay as offer and total actual cost

Hour	*Demand*	*Pay at MCP costs*	*Total pay as offer*	*Total actual cost using MCP*
1	285	23255.4	23341.3	35568
2	275	22051.2	22182.1	34320
3	263	20643.1	20828.3	32822.4
4	258	20068.3	20276.2	32198.4
5	245	18607.3	18873.8	30576
6	235	17515.7	17827.6	29328
7	200	13918.2	14388.3	24960
8	195	13432.6	13925.2	24336
9	190	12954	13469.2	23712
10	185	12297.5	13020.2	23088
11	180	12017.9	12578.3	22464
12	180	12017.9	12578.3	22464

Hour	*Demand*	*Pay at MCP costs*	*Total pay as offer*	*Total actual cost using MCP*
13	187	12670.2	13199	23337.6
14	192	13144.5	13650.7	23961.6
15	198	13723.2	14202.2	24710.4
16	210	14910.8	15335.6	26208
17	240	18058.1	18347.2	29952
18	247	18828.8	19086.5	30825.6
19	255	19726.8	19948.3	31824
20	260	20297.4	20496.2	32448
21	261	20412.3	20606.6	32572.8
22	270	21459.3	21613	33696
23	275	22051.2	22182.1	34320
24	283	23012.4	23107.2	35318.4
		$417074.045	$425063	$695011

II. CONCLUSION

The augmented Lagrangian relaxation method within an advanced has been presented for solving the pay-at-MCP problem. The MCP using the “right” Pay-at-MCP formulation, Numerical testing shows that the method and its use can lead to significant savings in the cost of purchasing power. Currently most ISO’sminimize the purchase cost under a Pay-as-Offer formulation but pay selected participants at MCP’s.It can lead to much higher overall purchase costs than the costs that can be achieved by using the Pay-at-MCP formulation. The successful and use of the Pay-at-MCP formulation produces the result in lower overall purchase costs and subsequently lower prices for consumers.

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