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Effect of Demand Side Management on the Locational Marginal Pricing in Restructured Electricity Market

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ABSTRACT

Demand side management is an important issue in electric power systems and can be effectively applied for control, operation and management of power system as better as possible. In restructured electric power systems, the demand is very important and it can be very useful to provide the demand side management programs. Demand side management is the correction of consumers' demand for energy through various methods such as financial incentives. The purpose of demand side management is to encourage the consumers to consume less energy during peak hours, or to move the time of energy use to off-peak times. In this paper, effect of demand side management on the locational marginal pricing in restructured electricity market is investigated. A typical power system is assumed at restructured environment and the effect of demand side management on locational marginal pricing is simulated. The simulation results clearly show the effect of demand side management on power system performance and locational marginal pricing.

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INTRODUCTION

Demand side management comprises reducing electricity consumption through programs that promote electric energy efficiency or the efficient management of electrical loads. These programs may be implemented through various methods such as financial incentives or education (Chiu *et al.*, 2013). Three types of demand side management are mainly applied; (a) energy efficiency which is to Use the less power to perform the same tasks; (b) demand response which refers to a wide range of actions which can be taken at the customer side of the electricity meter in response to particular conditions within the electricity system (such as peak period network congestion or high prices); (c) dynamic demand which means advance or delay appliance operating cycles by a few seconds to increase the diversity factor of the set of loads (Arteconi *et al.*, 2012; Cooper *et al.*, 2014; Zehir and Bagriyanik, 2012; Arteconi *et al.*, 2013; Atikol, 2013; Bergaentzlé *et al.*, 2014; Finn *et al.*, 2013; Matthews and Craig, 2013; Ming *et al.*, 2013; Shipman *et al.*, 2013; Finn and Fitzpatrick, 2014; Price *et al.*, 2014).

Paper (Warren, 2014) presents a review of demand-side management policy in UK. This paper denotes that a broad definition of DSM is proposed to include current policy objectives for emissions reduction, energy security, and affordability, and encompasses energy efficiency, demand response, and on-site back-up generation and storage. This paper reviews the concept of DSM, outlines the historical impacts of DSM globally since the energy crises of the 1970s, analyses UK DSM policy, and examines the influence of EU Directives on UK DSM policy, as the country is currently deciding on how to include the demand-side in its Electricity Market Reform proposals and wider energy policy. Much of the focus of previous research has been on DSM technological trials and modeling studies rather than DSM policy and the paper contributes to filling this gap. Paper (Adika and Wang, 2014) proposes an intelligent energy management framework that can be used to implement both energy storage and appliance scheduling schemes. By adopting appliance scheduling, customers can realize cost savings by appropriately scheduling their power consumption during the low peak hours. More savings could further be achieved through smart electricity storage (Adika and Wang, 2014). Power storage allows electricity consumers to purchase power during off-peak hours when electricity prices are low and satisfy their demands when prices are high by discharging the batteries. For optimal cost savings, the customers must constantly monitor the price fluctuations in order to determine when to switch between the utility grid and the electricity storage devices. However, with a high penetration of consumer owned storage devices, the charging of the batteries must be properly coordinated and appropriately scheduled to avoid creating new peaks. Paper

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(Kinhekar *et al.*, 2014) presents a multiobjective DSM solutions based on integer genetic algorithm to benefit both utilities and consumers. The proposed algorithm provides new directions on effective implementation of DSM techniques for Indian utilities. Simulations were carried out on Indian practical distribution system with large commercial and industrial loads. Paper (Ardakani and Ardehali, 2014) investigates the effects of historical DSM data on accuracy of electrical energy consumption (EEC) modeling and long-term forecasting. To achieve the objective, optimal artificial neural network (ANN) models based on improved particle swarm optimization (IPSO) and shuffled frog-leaping (SFL) algorithms are developed for EEC forecasting. Paper (Gelazanskas and Gamage, 2013) focuses on demand side management and demand response, including drivers and benefits, shift-able load scheduling methods and peak shaving techniques. Demand side management techniques found in literature are overviewed and a novel electricity demand control technique using real-time pricing is proposed. Currently users have no means to change their power consumption to benefit the whole system. The proposed method consists of modern system identification and control that would enable user side load control.

As referred before, demand side management has a great effect on different sections of power systems. In this paper, effect of demand side management on the locational marginal pricing in restructured electricity market is investigated. Therefore, the locational marginal pricing is reviewed in following, Paper (Sood *et al.*, 2007) presents a generalized optimal model that dispatches the pool in combination with privately negotiated bilateral and multilateral contracts while maximizing social benefit has been proposed. This model determines the locational marginal pricing (LMP) based on marginal cost theory. It also determines the size of non-firm transactions as well as pool demand and generations. Paper (Rosenberg *et al.*, 2014) follows up his earlier critique of locational marginal pricing by offering an alternative approach to LMP for congestion management involving compensation payments for constrained up and constrained down generation and an allocation algorithm of those payments to constrained interfaces and ultimately to the users of the transmission system. This alternative compensation/charge method provides greater incentives for the development of new generation than does LMP. Paper (García-Bertrand, 2006) provides a tool to determine the near-equilibrium of an electric energy market. This market works under locational marginal pricing, i.e., generating units and demand loads are paid and pay, respectively, the locational marginal prices corresponding to the nodes they are connected to. The near-equilibrium is defined as the energy transaction levels for which generating companies maximize their respective profits and consumption companies maximize their respective utilities. An independent system operator clears the market maximizing the social welfare. Conditions that ensure minimum profit for generating units can be included. However, these conditions may render a generating unit uncompetitive and expel it from the market. Demands are taken to be non-constant and values are determined as part of the solution (García-Bertrand, 2006). The near-equilibrium is obtained through the solution of a mixed-integer quadratic problem equivalent to a mixed linear complementarity problem that includes the minimum profit conditions (García-Bertrand, 2006).

This paper addresses the effect of demand side management on the locational marginal pricing in deregulated environment. A restructured power system is considered as test case and the effect of demand side management on locational marginal pricing is simulated. The simulation results demonstrate the major effect of demand side management on locational marginal pricing (Chiu *et al.*, 2013; Sood *et al.*, 2007).

Locational Marginal Pricing:

The system price in the day-ahead market is determined by matching offers from generators to bids from consumers at each node to develop a classic supply and demand equilibrium price, usually on an hourly interval, and is calculated separately for sub-regions in which the system operator's load flow model indicates that constraints will bind transmission imports. The theoretical prices of electricity at each node on the network is a calculated "shadow price", in which it is assumed that one additional kilowatt-hour is demanded at the node in question, and the hypothetical incremental cost to the system that would result from the optimized re-dispatch of available units establishes the hypothetical production cost of the hypothetical kilowatt-hour. This is known as locational marginal pricing (LMP) or nodal pricing and is used in some deregulated markets in the USA and New Zealand. In practice, the LMP algorithm described above is run, incorporating a security-constrained, least-cost dispatch calculation with supply based on the generators that submitted offers in the day-ahead market, and demand based on bids from load-serving entities draining supplies at the nodes in question.

Illustrative Test System:

In order to assess the effects of demand side management on locational marginal pricing, a six-bus test system is considered as case study and this system is depicted in Figure 1. The proposed system has six buses and five loads on buses 1 to 5. Bus 1 is swing bus, buses 3 and 6 are PV and buses 2, 4 and 5 are PQ type. The system data for power flow studies are provided at Tables 1-2 and the market data are listed in Table 3. Two demand side management programs are also considered and listed in Table 4.

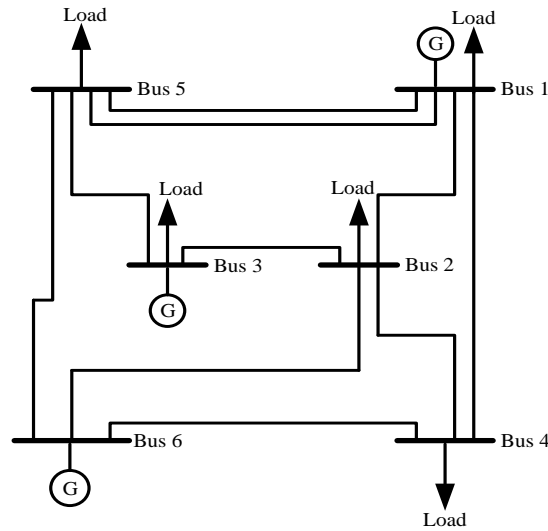


Fig. 1: Six bus test system.

Table 1: The generators data of six-bus test system.

Bus	Type	P_D [MW]	Q_D [MVar]	P_G^{max} [MW]	P_G^{min} [MW]	Q_G^{max} [MW]	Q_G^{min} [MW]
1	V θ	80	16	200	0	50	-10
2	PQ	240	48	-	-	-	-
3	PV	40	8	400	0	100	-10
4	PQ	160	32	-	-	-	-
5	PQ	240	48	-	-	-	-
6	PV	0	0	600	0	180	-10

Table 2: The branches data of six-bus test system.

Bus From	Bus To	r_{ij} [p.u.]	x_{ij} [p.u.]	b_{ij}^{sh} [p.u.]	S_{ij}^{max} [MVA]
1	2	0.040	0.400	0.00	120
1	3	0.038	0.380	0.00	120
1	4	0.060	0.600	0.00	100
1	5	0.020	0.200	0.00	120
1	6	0.068	0.680	0.00	90
2	3	0.020	0.200	0.00	120
2	4	0.040	0.400	0.00	120
2	5	0.031	0.310	0.00	120
2	6	0.030	0.300	0.00	120
3	4	0.059	0.590	0.00	120
3	5	0.020	0.200	0.00	120
3	6	0.048	0.480	0.00	120
4	5	0.063	0.630	0.00	95
4	6	0.030	0.300	0.00	120
5	6	0.061	0.610	0.00	98

Table 3: The system data for market studies.

bus	MW offer	Offer Price [\$/MW]
1	200	9
3	400	20
6	600	15

Table 4: Demand side management programs.

DSM Program	Active power scheduling
1	30% decreasing of active and reactive loads at bus 2
2	20% decreasing of active and reactive loads at bus 5

Simulation results:

The proposed DSM programs are simulated at the given test system. Table 5 shows the LMPs of the system at normal condition and following DSM programs 1 and 2. It is clearly seen that the DSM programs have a great effect on the system performance and LMPs. Following DSM Program 1 and 30% decreasing the load at bus 5 as a prescheduled program, the LMP at buses 1, 2, 4 and 5 is significantly decreased and in buses 3 and 6 are marginal producers and LMP in these buses is constant. Following DSM Program 2 and 20% decreasing the load at bus 2, the LMPs are decreased, but not as much as the DSM Program 1.

Table 5: LMPs of the system at normal condition and following DSM programs 1 and 2.

Bus No.	LMPs at Normal Condition	LMPs following DSM Program	
		1	2
1	25.68	18.94	21.12
2	22.18	20.64	19.23
3	20.00	20.00	20.00
4	21.50	17.55	18.55
5	46.94	19.43	32.05
6	15.00	15.00	15

In order to more studies, the lines congestions are listed under all cases in Table 6. It is seen that the congestion is changed under different cases. The DSM programs have significant effect on transferred power through the lines. Based on the proposed results, the DSM programs are suitable choices to change the power system performance and providing different facilities for consumers and operators.

Table 6: Transferred power though the line following all cases.

From Bus	To Bus	Transferred power though the line (P.u.)		
		Normal Condition	DSM Program 1	DSM Program 2
1	4	0.064	0.077	0.040
1	2	0.115	0.190	0.033
5	1	0.516	0.508	0.578
2	4	0.041	0.159	0.0571
3	2	0.715	0.505	0.392
4	6	0.799	0.883	0.820
5	6	0.504	0.604	0.582
5	1	0.516	0.508	0.578
4	6	0.799	0.883	0.820
5	3	0.928	0.352	0.762
2	6	0.845	1.095	0.868
2	6	0.845	1.095	0.868

Conclusions:

This paper presented the effect of demand side management on the locational marginal pricing in deregulated electricity market. A restructured power system was assumed as test system and the effect of demand side management on locational marginal pricing was simulated and investigated. The simulation results demonstrated the great effect of demand side management on locational marginal pricing and line congestions. According to the proposed results, the DSM programs can be successfully applied to control of power system performance and changing system condition.

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