REDUCE PEAK-TIME ENERGY USE BY DEMAND BIDDING PROGRAM IN IRAN

Hossein DELAVARIPOUR
MEEDC– Iran
Hossein.delavary@yahoo.com

Amir KHAZAEE
MEEDC– Iran
Amir.khazaee@ymail.com

Mehran GHASEMPOOR
MEEDC– Iran
Ghasempour.mehran@gmail.com

Hossein HOOSHMANDI
MEEDC– Iran
hosein.hoshmand@gmail.com

ABSTRACT

Demand bidding program (*DBP*) *is one type of demand response programs that encourages large consumers to change their energy consumption pattern and reduce their peak to increase system reliability. With implementation of advanced metering infrastructure* (*AMI*) *system in distribution network, DBP has been adopted in practice by Mashhad Electric Energy Distribution Company* (*MEEDC*) *as a system operator. MEEDC's DBP is a risk-free and internet-based bidding program that offers the candidate customers for voluntarily reducing power when a DBP event is called. This program is implemented for large consumers with a demand of* 100 *kW or greater aims to reduce peak demand of day in summer. Details of the program and the implementation issues are explored.*

INTRODUCTION

In 2009, seven sites were selected from seven cities in Iran to run large-scale, pilot projects on the smart grid and smart community. Mashhad is one of these cities in which Mashhad Electric Energy Distribution Company (MEEDC) has the responsibility to implement smart grid road map. Demand side management (DSM) technology is one of the major goals in the smart grid projects. Based on the traditional functions, the smart grid DSM has new contents including automation, demand response [1], smart consume, remote energy efficiency monitor control, energy efficiency, power generation, and so on. Future smart grid integrates demand response programs, where consumers play principle roles in optimizing energy consumption profile.

Demand bidding program (DBP) is one type of demand response programs that offers customers incentives for reducing demand when called by system operator to increase system adequacy [2,3].It is worth noting that the demand bidding is typically presented for purchase allocation problem in electric energy market [4-6]. In connection with demand response concept, demand bidding for consumers is relatively new program which involves no competition and risk-free approach to reduce energy consumption of large consumers. These two concept of demand bidding are quite different in terms of features and purposes. Demand bidding program for consumers is also useful for system operator due to improving efficiency of distribution and energy price stability. It has been recently adopted in practice by Southern California Edison (SCE) [7] and Pacific Gas and Electric Company (PG&E) [3].

One of requirements to implement DBP is AMI system [8] in distribution network. This system is implemented in Iran. A new version of the DBP is developed and implemented in practice by MEEDC as a system operator which will be discussed in details in this paper. Mashhad Electric Energy Distribution's Demand Bidding Program (MEEDC's DBP) is a risk-free and Internet-based bidding program that offers the industrial customers for voluntarily reducing power when a DBP event is called. If the candidate customer can reduce power on event day when a DBP event is activated, it will be rewarded. On the other hand, if the candidate fails to reduce the energy according to the requirement, there is no financial penalty. This risk-free feature of DBP attracts most of the large-scale customers. Mashhad is the second major city of Iran with more than 1.4 million of consumers [9,10]. As shown in Fig. 1, industrial consumers (which contained less than 1% of whole consumers in Mashhad) approximately consumed 24% of final energy consumption in 2015. Until now, more than 700 large-scale candidate customers with a demand of 100 kW or greater (during the preceding 12 months) equipped with or without emergency generation units, are participating in MEEDC's DBP.

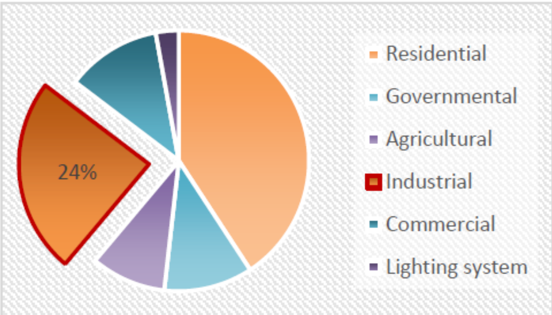

Fig. 1: Electricity consumption in each consumer groups in Mashhad

The participation days (DBP events) would be predicted previously based on load forecasting algorithms and would be notified before 14:00 PM of the event day for participating during 4 hours of the day event. The customers receive the reward if the minimum amount of their energy reduction meet 15% of their baseline. In this paper, we discuss the DBP that is currently used in practice and formulate the corresponding mathematical optimization problem. Specifically, the problem is to determine the optimal bid that maximizes the expected reward subject to requirement of the operator.

DEMAND BIDDING

The Demand Bidding program is optional for customers with billed maximum demand of 100 kilowatts (kW) or greater during the past year. In one case, the candidate customer can choose the amount of energy reduction in terms of bidding value for a specific bidding event with two options. 1) Manually bid after receiving a day-ahead event alarm, in other word, customers may submit only one bid for each notification and indicate the amount of kW it will reduce for each hour of the event. 2) Standing bid which allows customers to bid at beginning of the participation period and applying it to future events. In another case, the biding value is determined by system operators or demand response aggregators. If the actual amount of energy drops to certain requirement, the customer will be rewarded. On the other hand, for the lack of joint participation in reducing the energy in the event no financial penalty is considered. This risk-free feature attracts interest of large customers.

In DBP, to calculate reward a minimum amount of energy reduction is considered which can be determined with different methods [11]. In one method, the amount of actual energy reduction must drop between certain percentages of the bid amount. In another one, a Fix amount per kW is considered as minimum bid requirement during any hours of the event. Event period is generally four hours associated with peak condition in a single day event. It should be noted that cooperation will be investigated only during this period following a call event.

An event is called in the following emergencies:

- According to forecasts by the network operator of the total demand for the day-ahead
- Prediction a rise in temperature for the day-ahead
- Lack of adequate productive resources for the day-ahead

The implementation requirements of the program are as follows:

- Network should be equipped with AMI system which allows to measure and record data in 15-minute intervals to monitor the consumption behaviour of end-user. Now all large customers in Mashhad are equipped with smart meters and consumption data in the form of reports and graphs are available for display in a Web application.
- Messaging system is required to confirm acceptance and rejection of participation in the event. Candidate customers must have access to the Internet or communication tools in order to send/receive alarm message and determine biding value. It is noteworthy, the customer is responsible for correct sending and receiving of messages. In other word, candidate customers must always check the website.
- Demand Response Providers / Aggregators (DRP/AGG): These entities are required to review the existing potentials in rewriting program, adjusting the contracts, registering customers, supporting the implementation of programs and billing.

IMPLEMENTATION OF MEEDC’S DBP

Large customers with a demand of 100 kilowatts (kW) or greater in any 3 months during the preceding 12 months are eligible to enroll and participate in DBP. Customers who are selected for participation in DBP are encouraged to reduce their energy consumption during the events that occur in summer. In this way, demand response provider (DRP) entity of MEEDC may dispatch at its discretion, to one or more customers, a day-ahead event notification by 14:00 PM. DRP will dispatch only one event per day for a minimum of two hours and a maximum of four hours during 11:00 AM to 15:00 PM. Total hours of the event, during the summer (the period of cooperation) will be less than 200 hours. Customers must reduce energy consumption more than 15% of their hourly baseline value. A valid customer specific energy baseline is calculated by averaging maximum load during two month prior to beginning participation period.

For customers who are equipped with backup generating resources such as diesel generator and CHP, MEEDC provides some benefits such fuel subsidies to make the possibility of biding optimal amount of energy reduction and so more profits. Customers can provide a part of their base load during event by using these resources. This makes better situation for customers to schedule optimal bidding value.

In addition to large industrial customers who are the best candidates for DBP implementation, hotels, city centers, entertainment centers and offices are proper customers for inserting to this program [11]. Generally these customers are equipped with emergency backup such as diesel generators, CHP and solar generators. Insertion of these resources in event hours causes reduction of energy consumption with minimal change in their consumption pattern. If the customers aren’t equipped with these resources, they can account on managing their air conditioner, lightening, heater and cooler systems for participating in DBP.

Reward or consumption credit is determined by DRP/AGG based on Rial (R) (Iran's currency) per kWh. This credit can be differently determined by DRP/AGG discretion according to customer activities, and network condition in the view of reliability and increase of generation cost. For example, in California this amount sets on 0.5 $/kWh by PG&E and SCE companies which is fixed over participation period for their load zones. In MEEDC this reward can be assigned in constant amount 2500 R/kWh which is sum of low load, mean load and full load tariffs (TOU tariffs) for day-ahead events.

DATA MINING

As is mentioned previously, one of the requirements for proper implementation of demand side management is AMI system and data mining. In this regard, MEEDC designs a website-based real-time monitoring system to observe participations of customers carefully. Meanwhile, it is possible that customers can follow their operations and acquired rewards. Some important duties of the web service are as follow:

- Notification of participants: based on participation contract, the participants must be notified to the participants before 14:00 o'clock of the day before the event day. There were 3 types of notification: email, SMS and web service.
- Load data of participants: consumption and demand of electricity data for each participant was monitored in order to find out the level of participation.
- Participant portal: each participant had a password secured portal and participants are able to get their hourly load and consummation data. This opportunity enables the participant for cost saving planning.
- Real-time price management: this web service is also has the ability of real-time calculation of incentives and it is accessible for both participants and operators.

Fig. 2 shows mining tools for observing customer performance. In this figure, the columns present the amount of demand in event hours of one day. Red colour illustrates the lack of the customer cooperation in specific hour. For instance, Fig. 3 shows the pattern of daily consumption of a customer and its response to requirement during a specific event. In this case, customer has pledged to reduce its consumption to less than the appointed requirement. As previously mentioned, customers who equipped with emergency power generation system (mostly diesel) are able to enter them during event time and receive rewards. Fig. 4 shows load profile of a hotel that can reduce its energy consumption to less than requirement with starting its

210.592	196.6	192.256	192.272	37.62	9157598299	9155054831	[illegible]	039430012869	5025306	285
78.328	14.184	81.48	92.712	89.45	9153119737	9153104246	[illegible]	039430012871	5001617	286
154.128	12.112	130.28	164.672	171.906			[illegible]	039430012872	5001619	287
0.612	17.548	16.332	5.004	6.244			[illegible]	039430012873	5001616	288
3.21	1	9.03	9.38	8.468	9155179532	9151152121	[illegible]	039430012874	5002280	289
49.7	62.31	64.84	59.75	57.527	9141901654	9153108219	[illegible]	039430012880	5041801	290
31.83	24.268	42.25	28.428	39.334	9153300825	9155072467	[illegible]	039430012882	5013560	291
138.096	141.9	138.504	117.732	140.641	9150569650	9151153139	[illegible]	039430012884	5024385	292
68.106	63.264	52.152	80.616	88.063	9155205184	9155156451	[illegible]	039430012885	5021385	293
126.936	139.32	147.24	129.576	144.888	9151151147	9153255146	[illegible]	039430012886	5012203	294
98.496	85.728	91.16	81.496	94.428	9155213356	9151157475	[illegible]	039430012888	5002498	295
19.94	46.77	50.08	45.78	54.765	9153208296	9157660395	[illegible]	039430012892	5002510	296
59.424	61.204	61.648	64.308	60.57			[illegible]	039430012893	5017062	297
33.126	30.684	28.716	36.126	29.79	9155232050	9155148144	[illegible]	039430012894	5026606	298
83.72	74.51	88.32	112.56	132.883	9133614965	9153104616	[illegible]	039430012895	5014902	299
66.9	90.644	96.152	76.964	79.216	9151102456	9151155540	[illegible]	039430012901	5013281	300

Fig. 2: mining tools for observing customer performance

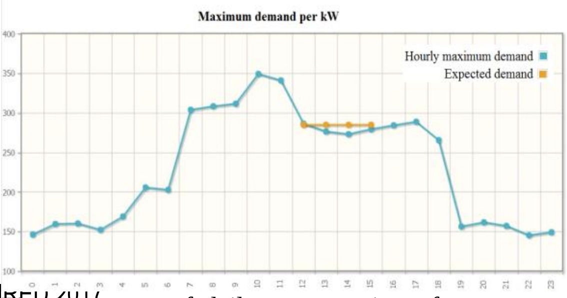

Fig. 3: pattern of daily consumption of a customer and its response to requirement during a specific event day

diesel generator. In this participation, hotel could auction approximately 350 kW from its consumption.

DEMAND BIDDING FORMULATION

In another study, this paper addresses a computational approach to help the customers in reaching maximal

Fig. 4: load profile of a hotel with starting its diesel generator during a specific event day

benefits subjected to DBP. This section presents an optimization problem including maximum reward as fitness function and energy reduction band as problem constraints. By solving this problem, amount of reduction (bid) will be calculated optimally which is beneficial for customers in improving expected reward. It is notable that this formulation is useful for customers who can schedule consumption devices in order to change probability distribution function. In other words, customers can have direct control on their consumption devices computationally. In this way, consumers can use their emergency generation resources which are more controllable. However, this formulation can also be used non-scheduled loading.

The optimization problem is formulated as follow,

$$\max_{b_t}\sum_{t=1}^{T_e}\int_{\bar{E}_t-b_t.h}^{\bar{E}_t-b_t.l}(\bar{E}_t-x_t).r_t.f(x_t)dx_t \qquad (1)$$

$$l.b_t \le b_t \le h.b_t$$

where, b_t is bid amount at hour. $f(x_t)$ is probability distribution function (pdf) of total customer energy consumption x_t during hour t. $\bar{E}_t$ denotes mean energy consumption during hour t without load scheduling. r_t is pecuniary reward per unit of energy reduction. T_e is total demand bidding event hours. Respectively, l and h are minimum and maximum amount of reduction eligible to receive reward. They are defined in terms of a fraction or percentage of the bid.

In (1) the parameters, r_t, T_e, l and h are given by the MEEDC/DRP and b_t is chosen by the hotel. $\bar{E}_t$ and $f(x_t)$ are defined by the behaviour of customer energy usage.

Note that the above optimization can be applied with and without load scheduling. Without load scheduling the amount of bid may not be tuned optimally. It is notably that b_t is independent of $f(x_t)$ with load scheduling, will be the respective pdf of customer energy consumption with load scheduling.

In practical case, $f(x_t)$ is typically unknown. Therefore, an empirical distribution from measurement might be used instead. If large enough data were recorded in the past, we can estimate the required distribution of total energy consumption using a statistical method. In many cases, the energy consumption in a building can be suitably modelled by a Normal distribution according to the measurement [12]. In particular, Normal distribution provides a good fit during high load hours [12].

To simplify the optimization is done for each hour of the demand bidding event hours based on defined function (2) and using numerical derivative method [13] which allows us to determine the optimal bid.

$$\Omega(b_t) = \int_{\bar{E}_t - b_t.h}^{\bar{E}_t - b_t.l} (\bar{E}_t - x_t).f(x_t)dx_t \quad (2)$$

$$d\Omega(b_t)/db_t\big|_{b_t = b_t^*} = 0$$

With considering Normal pdf ($x \approx N(E_n, \sigma^2{}_n)$) during event hour t, the optimal bid in corresponding t is obtained by

$$b_t^* = \frac{\bar{E}_t - E_n + \sqrt{(\bar{E}_t - E_n)^2 + \frac{4(l+h)\sigma_n^2}{h-l}.ln(\frac{h}{l})}}{l+h} \quad (3)$$

where:

E_n is mean or expectation of the distribution.

σ_n is standard deviation.

σ_n^2 is variance.

The expected reward at hour t based on b_t^* is calculated as follows,

$$DB_t^* = (\frac{\bar{E}_t - E_n}{2})(erf(u) - erf(v)) + \frac{\sigma_n}{\sqrt{2\pi}}(e^{-v^2} - e^{-u^2}) \quad (4)$$

$$u = \frac{\bar{E}_t - E_n - b_t^*.h}{\sqrt{2\sigma_n^2}}, \quad v = \frac{\bar{E}_t - E_n - b_t^*.l}{\sqrt{2\sigma_n^2}}$$

$$erf(x) = (2/\sqrt{\pi})\int_0^x e^{-t^2}dt$$

Without load scheduling, $\bar{E}_t = E_n$ the optimal bid in (3) reduces to

$$b_t^* = \sqrt{\frac{4\sigma_n^2}{h^2 - l^2}.ln(\frac{h}{l})} \quad (6)$$

In this situation expected reward at hour t is found by,

$$DB_t^* = \frac{\sigma_n}{\sqrt{2\pi}}(e^{-l\sqrt{\frac{2}{h^2-l^2}ln(\frac{h}{l})}} - e^{-h\sqrt{\frac{2}{h^2-l^2}ln(\frac{h}{l})}}) \quad (7)$$

As can be seen, the reward in comparison with (4) can be assessed at a lower value without scheduling. By adjusting E_n and σ_n^2 of pdf, customer can achieve to further reward.

CONCLUSION

The demand bidding program is optional for customers with billed maximum demand of 100 kilowatts (kW) or greater during the past year who voluntarily commit to reduce their energy consumption for at least four consecutive hours during an event. In this paper, the procedure of MEEDC's DBP is presented and its impact on load profile is investigated. In addition, this paper offers a computational approach of DBP to get the maximum reward to encourage more customers. The MEEDC's DBP could have 61 MW reduction in a specific hour of an event day in summer.

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