BUSINESS MODELS FOR DEMAND RESPONSE AGGREGATORS UNDER REGULATED POWER MARKETS

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ABSTRACT

With the boost of smart meter installations, the technical difficulties for demand response (DR) have been overcome a lot. For years, numerous DR programs have been in operation to enhance the system reliability. Meanwhile, some DR programs run on the profit of participating the power market, like arbitraging between the wholesale market and the retail market in regions with a deregulated power market. In this paper, the business model for DR aggregators under deregulated markets is revisited for comparison. The business models under regulated markets are then proposed targeting three different power dispatch modes: economic dispatch, energy-saving dispatch and open and impartial dispatch. Numerical cases are calculated to test if the utility can make profit through the proposed models. Furthermore, the influence of implementing such models on the system is analysed.

NOMENCLATURE

NG	Number of generation units
NT	Number of time periods
$p(t)$	Hourly wholesale price prediction
$B(t)$	Hourly demand bid in the wholesale market
F^D	Cost of demand response
F^U	Power purchasing cost of the utility
$\lambda_{i,t}^G$	Power purchasing cost of generation unit *i* at time *t*, in \$/MWh
$C^R()$	Real time balancing cost
$L(\tau)$	Real time load
i,t	Generation unit index, time index
$P_{i,t}$	Power generation of unit *i* at time *t*
PD_t	Base load at time *t*
DR_t	Demand curtailment at time *t*
P_i^{min}, P_i^{max}	Min/max power generation of unit *i*
DC_t^{min}, DC_t^{max}	Min/max demand curtailment at time *t*
PD_t^{max}	Max load at time *t*
P_c^{max}	Maximum energy change in the whole horizon

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INTRODUCTION

Demand side management (DSM), as was first introduced by Electric Power Research Institute (EPRI) in the 1980s has shown the potential to be a good complementary resource to generation units. Its application fields include load shaping, benefit maximization, investment delay, reliability, etc. [1] Demand response (DR) is one large group of DSM. DR users change their electrical usage pattern as a response to incentives or changes of electricity prices [2].

Previously, the main barriers of DR implementation are the technological problems. However, with the development of the smart grid, installations of advanced metering infrastructure and two-way communication have been largely spreaded. Now, shaping electricity loads has become a convenient manner for users[3].

As the hardware for DR is ready, the physical operation characteristics of DR have also been explored from different perspectives of power systems. These studies include operation of DR at the transmission grid level [4-6], distribution grid level [7] and household level [8-10].

The business model of DR is also very significant since it tells how DR could be operated efficiently and how DR could make profit for participants in the market. Researchers have studied the business models of different

stakeholders in the power market for implementing DR. These models include market efficiency enhancement [11], ancillary service provision [12], energy procurement improvement [13], price response [14], etc.

These business models are mainly discussed within a deregulated market environment. The business models under a regulated power market are seldom studied. However, even in a regulated market, as the utility has been separated from the government, the utility will lack its motivation to propel DR programs if no revenue can be made.

In this paper, we first analyse the feasibility of DR business models under regulated markets. Next, the formulation of business models under three dispatch modes in regulated power markets is given. The numerical cases are provided to test if the proposed model is profitable.

BUSINESS MODELS FOR DR AGGREGATOR

The DR aggregator acts as an entity that groups DR activities and makes it a business by offering the added value to other entities concerned. A DR aggregator can be part of different entities or a third-party entity in both deregulated and regulated markets as shown in Fig. 1. Some notations are made like that the VER aggregator means the DR aggregator as part of a generation company with variable energy resources (VER), the utility aggregator means the DR aggregator as part of a vertical integrated utility, etc.

In a deregulated power market, the vertical integrated utility was separated into several segments including the system operator (SO), the network owner, the retailer, the balancing authority, etc. The business models of DR aggregators as part of these segments have been summarized in [15]. Among these segments, the retailer aggregator may probably confront fewer market barriers since its current participation in both the wholesale market and the retail market.

In a regulated power market, although the VER aggregator and the third-party aggregator can be profitable, the utility aggregator can directly work within the existing market framework and has fewer market barriers.

Therefore, in this section, the business model of the utility aggregator under a regulated market will be discussed and the business model of the retailer aggregator under a deregulated market will be given for comparison. In order not to influence the results and to uncover the total market potential of DR, flat retail prices are assumed for users within the two markets mentioned.

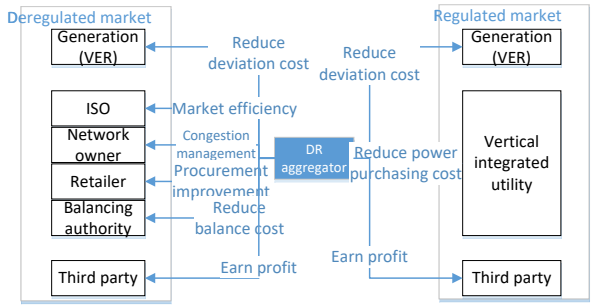

Fig. 1 Business models for DR aggregators

DR Aggregators under deregulated markets

Although business models of DR aggregators under deregulated markets can be various, the classic model is that the retailer open up the DR program for the users and arbitrage between the wholesale market and the retail market. This objective function of the retailer can be written as follow:

$$\min \sum_{t=1}^{NT} \{ p(t)B(t) + F^{D} + C^{R}(L(\tau), B(t)) \} \quad (1)$$

The first item is the bulk energy prices in day-ahead hourly bidding. The second item is the demand response cost. And the third item is the real-time upward/downward prices.

This is an ex-ante stage model for the retailer to minimize its total cost through DR. The market design of a general deregulated market is suitable for this kind of business model.

DR Aggregators under regulated markets

As has been discussed in the previous subsection, the market opportunity for DR aggregators in a deregulated power market can be noticed and applied in an easy way. However, generally in a regulated power market, people tend to think no direct arbitrage exists and demand response programs are motivated purely by incentives issued by the governors for reliability reasons.

However, this arbitrage does exist for utilities under regulated markets because in some dispatch scenarios where the DR actions may reduce power purchasing cost for utilities even if the total demand amount is not changed. In this subsection, the business models of DR aggregators under a regulated market are discussed. We want to find out whether DR aggregators in a regulated market can be profitable rather than rely on the subsidization.

A key feature of a regulated power market is no thorough competitive market exists, and the power generation is dispatched according to different rules such as policy needs, energy consumption, cost, etc. Three power dispatch models, namely economic dispatch, energy-saving dispatch and open and impartial dispatch will be

described and the corresponding business models are formulated. As the retailer is chosen as a good DR executor in deregulated markets, the role of vertical integrated utility is chosen here to study the regulated market.

Economic dispatch

The economic dispatch is usually applied where the generation side is deregulated but the retail market is still regulated. This means intuitively the most cost efficient generation unit will be dispatched first.

The objective function, as shown in (2), is to determine the amount of DR and the generation outputs such that the power purchasing cost is minimized:

$$\min F^U = \sum_{t=1}^{NT}\sum_{i=1}^{NG}\lambda_{i,t}^G P_{i,t} + \sum_{t=1}^{NT} F_t^D \quad (2)$$

The first item in the objective function (2) is the electricity purchasing cost. The second item is the cost of implementing the DR. The objective function is subject to some generation unit constraints, DR constraints as follow:

$$\sum_{i=1}^{NG} P_{i,t} = PD_t - DR_t, \forall t \quad (3)$$

$$P_i^{min} \le P_{i,t} \le P_i^{max} \quad (4)$$

$$DC_t^{min} \le DR_t \le DC_t^{max}, if\, DR_t \ge 0, \forall t \quad (5)$$

$$PD_t - DR_t \le PD_t^{max}, if\, DR_t < 0, \forall t \quad (6)$$

$$0 \le \sum_{t=1}^{NT} DR_t \le P_c^{max} \quad (7)$$

The constraint (3) is the system-wide energy balance constraint. The min/max generation limit of generation units is given in (4). The DR constraints are provided in (5)-(7). The limit on load change within time period t is provided in (5) and (6). Constraint (7) shows that the allowed load change over the whole dispatching periods is limited to P_c^{max}. Note that when $P_c^{max}=0$, the dispatched DR is deferrable. Since we assume that DR amount is relatively small, the causal effects of DR related to the appliance characteristics are not considered.

To simplify the problem and focus on the DR benefit in the regulated market environment, some of the constraints used in real operation are neglected in this formulation including power flow constraints, ramping constraints and min on/off constraints of generation units and DR.

The problem is then turned into a linear programming problem, and thus can be easily used in assessing the benefits DR can make.

Energy-saving dispatch

The energy-saving dispatch was put forward in regulated power markets like China to cut down the energy consumption in the power industry with the encouragement of integrating more energy efficient generation units.

The profit of DR under energy-saving dispatch also comes from the reduction of power purchasing cost. The cost order of generation units could be different from the energy consumption order, making this problem different from that under economic dispatch. Thus a constraint should be added to the previous problem to ensure the generation units are dispatched according to the energy consumption order:

$$(P_i^{max} - P_i^t)(P_{i+1}^t) = 0,\ i = 1, 2..., NG-1, \forall t \quad (8)$$

In this constraint, the generation units' order *i* should be reset in an increasing energy consumption order.

Open and impartial dispatch

The open and impartial dispatch has been adopted in China for a long time to guarantee the equity among different generation units in the same region. A basic point of this kind of dispatch is to ensure that the generation units have similar utilization hours.

As formulated in previous subsections, the market opportunity for DR under open and impartial dispatch depends on whether DR can reduce the power purchasing cost of the utility.

A further constraint is added to the problem (2)-(7) to reflect the feature of this dispatch:

$$\frac{\sum_{t=1}^{NT} P_{i,t}}{P_i^{max}} = \frac{\sum_{t=1}^{NT} P_{i+1,t}}{P_{i+1}^{max}},\ for\ i = 1, 2, ..., NG-1 \quad (9)$$

CASE STUDY

Numerical cases are performed on a system with 5 generation units (G1, G2, G3, G4, G5). The data profile for the generation units are shown in Table 1.

Table 1 Generation units data profile

Gen #	G1	G2	G3	G4	G5
Cost($/MWh)	14	15	30	40	50
Coal consumption (kg/MWh)	300	280	250	220	200
Min output(MW)	0	0	0	0	0
Max output(MW)	40	170	520	200	600

A real-world load profile is scaled and used as the base load here. Since this case focuses on the benefit DR could make, the DR cost is ignored here. We assume that the load change limit P_c^{max} is 0, the minimum demand curtailment DC_t^{min} is 0 and the maximum demand

curtailment/increase are both 5% of the base load.

The results under economic dispatch are shown in Fig. 2. In each time period, the generation units are dispatched based on an increasing cost order (G1, G2, G3, G4, G5). Therefore, in order to reduce the power purchasing cost, the utility would tend to shift the load from peak to valley, which is consistent with Fig. 2 (the blue line). As a result, the power purchasing cost has been reduced from $617210 to $610847.

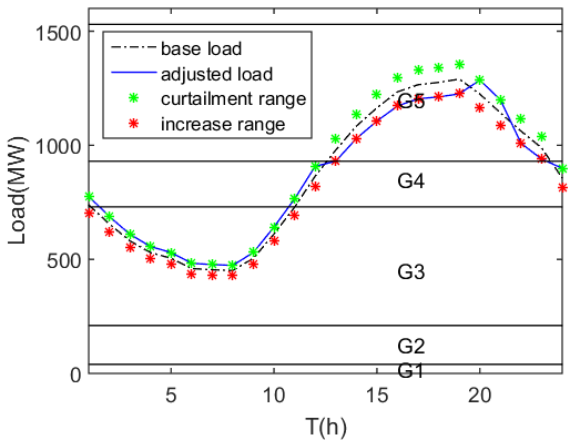

Fig. 2 Load adjustment under economic dispatch

The results under energy-saving dispatch are shown in Fig. 3. The coal consumption and the cost of generation units are not directly related (for example in our case in a reverse order). Although DR could help the utility under energy-saving dispatch to reduce energy purchasing cost, reducing energy cost in this situation may also cause other influences on the system. In this case, the low purchasing cost is met when load is relatively high in a certain time period so reducing energy cost will lead to higher peak-valley difference, as shown in Fig. 3. The power purchasing cost in this case has been reduced from $922530to $916570.

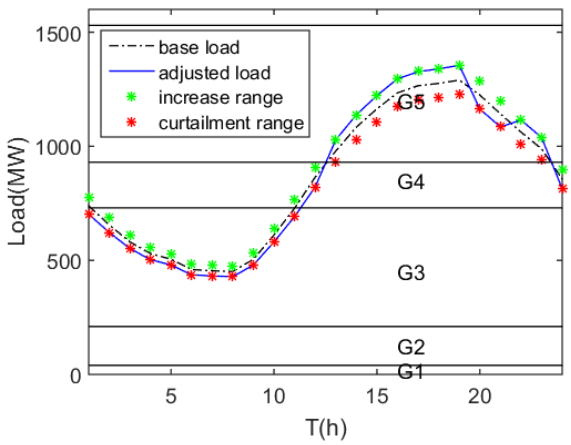

Fig. 3 Load adjustment under energy-saving dispatch

The results under open and impartial dispatch are shown in Fig. 4. According to open and impartial dispatch, the utilization hours of each generation unit should be the same during the day. The power purchasing cost is not reduced in this scenario since the generation mix in the whole day is not changed by DR. The results also prove this point. Although the load shape is changed, it is meaningless since the power purchasing cost remains $765380.

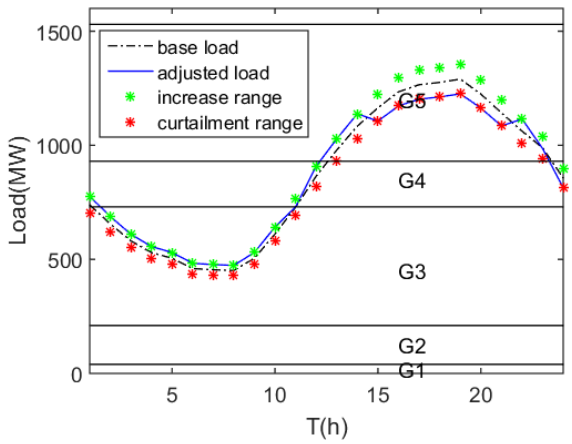

Fig. 4 Load adjustment under open and impartial dispatch

The results of DR under three dispatch modes can be summarized in Table 2. Comparatively, DR under economic dispatch could reduce the cost most and reduce the peak-valley difference. DR under open and impartial dispatch shows no influence on the cost. Under energy saving dispatch, DR is ambiguous since although the utility can reduce its cost, the peak-valley difference could be possibly raised, which is opposed to the social benefit.

Table 2 Comparison of different dispatch modes

Dispatch mode	**Economic dispatch**	**Energy-saving dispatch**	**Open and impartial dispatch**
Cost before($)	617210	922530	765380
Cost after($)	610847	916570	765380
Influence on system	Reduce peak-valley difference	Possibly increase peak-valley difference	No need for DR

CONCLUSIONS

In this paper, we propose business models for DR under three power dispatch modes in regulated power markets. From the numerical test results, it can be concluded that the utility is profitable adopting DR under economic

dispatch. Under open and impartial dispatch, DR will not affect the power purchasing cost of the utility. DR under energy-saving dispatch can reduce the cost but may possibly lead to higher peak-valley difference. Therefore, DR is profitable in regulated power markets, but its usage depends on the specific market environment.

Acknowledgments

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