Reliability-based Incentive Mechanism for Demand Response in Electric Power Market

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Abstract – DR(Demand response) is a rising issue in electricity power market by reducing load quantity instead of increasing generation for balancing demand and supply. DR resources are regarded as an extra tool of balancing supply and demand in emergency condition. DR resources usage in normal condition is also possible and used for the purpose of reliability and economic effect. For determining incentive for DR resources in PJM, fixed incentive level was used to reward the effect of market price reduction by DR program. However, since the fixed level of incentive is obtained by historical data, it cannot reflect the continuous change of market well. Furthermore, traditional method only concentrates to economic effect and it hardly concerns about the effect of preventing price variation by DR resources. In this paper, method of evaluating the market price reduction and prevention of price variation by DR is described under reliability considered situation. New mechanism for determining extra incentive is provided. From comparing the situation that DR is not implemented and the situation DR is implemented, novel mechanism can give more rewards to participants who contribute the stabilization of price and the reduction of load. Reward is exponentially increased as the DR resource stabilizes the price variation. On the other hand, reward is exponentially decreased as the DR resource increases price variation. Several cases are showed for checking effects and calculating the extra incentive.

Keywords: Demand response, Economic effect, Electricity market, Incentive mechanism, Preventing price variance

1. Introduction

Over the years, one of the most challenging problems in electric power system operation has been to effectively utilize load management. In traditional power systems, balancing supply and demand was mainly scheduled and controlled by generators. ISO(Independent System Operator) forecasted the quantity of load growth and scheduled the expansion plan of generators. However, because of the uncertainty of load forecasting, ISO hardly schedules generator expansion plan. Moreover, there are lacks of selecting construction area, constructing time and expensive cost problem in generator expansion. Because of these problems, importance of decreasing load (demand response) instead increasing generators was carried out. Early demand response programs were only used when system is under emergency condition. DR program was regarded as another tool of managing sudden increase of load. DR program participants contract with ISO before the system operating and reduce their load when event is triggered by ISO. However, since electricity power market was established, variable demand response programs which are based on market price were developed. Because of the electricity market system, price became the signal of novel DR programs.

DR participants can choose two types of program. First type of DR program is that the participant contracts with ISO or CSP(Curtailment Service Provider) for incentive payment which is paid when participant’s load is curtailed or reduced during the event period. Expectation value of benefit for participant’s response must higher than that of benefit for not being reduced of curtailed. Second, participants gather electricity price offered by ISO to analyze and maximize their profit by selecting the electricity usage. When price is high, participants reduce their electricity usage and when price is low, they increase their electricity usage for profit maximization.
Traditionally, researches and experiences of demand response program classification remark standard for dividing these two types of DR programs into incentive-based DR and price-based DR [1]-[3].

Incentive-based DR programs gather pre-contracted DR resources before load curtailment event. Price-based DR programs notify the market price or extremely high price period (Critical Peak Pricing) to lead out demand response. Fig. 1 shows current classification of DR programs [4].

![Fig. 1. Current Classification of DR programs.](image)

Nowadays, various methods of paying rewards to DR participants make the traditional standard of classifying DR program less useful. Certain incentive-based DR program uses price signal for paying incentive to participant and some price-based DR program contact with participant like incentive-based DR program.

### 2. Extra Incentive payment for DR participants

#### 2.1 Motivation of designing DR program incentive payment method

DR programs differ from each other about the quantity of incentive payment and controlling method. These components depend on the triggering point of each program. Generally, DR program which is triggered in emergency condition pays more incentive than other programs. Instead of high incentive, resources are strongly forced to curtail their quantity. Some programs even automatically curtail the participant’s load. For the case of programs which are operated in normal state condition, DR participants consider their benefit of reducing load quantity. For these DR programs, attractive incentive level is necessary for gathering resources for operating. Especially, determining the reward of incentive-based DR programs in normal condition is important since the gap of customer’s loss cost for not using electricity and incentive payment is very small. Because of this reason, most of incentive mechanism in the world is mostly based on market mechanism [5].

Resources which successfully bid in day-ahead market have obligation to reduce their load in specific period. However, the quantity of incentive payment for emergency DR program resources is decided not properly now. The reward for the effect of price reduction is determined by fixed level which is based on historical data. To provide the rational standard to DR participants in market based environment, analytic calculation method is needed. In the next session, components of extra incentives are described.

#### 2.2 Suggested Incentive Payment Method for DR Resource which replaces The Generator

Incentive payment of most DR programs is mainly consisted of two parts, energy (actual reduction) payment and capacity payment. Energy payment is based on the quantity of reduction during the event period. The DR participants are paid by market price or adjusted quantity based on energy price since resources are regarded as generator. For the case of capacity payment to the DR participants, traditional incentives of payment for incentive-based DR program were based on participant’s cost of not using electricity. For instance, BIP (Base Interruptible Program) which is operated in CAISO (California ISO) pays fixed capacity incentive for waiting emergency event by DR participants. This concept is similar to capacity payment of generators.

Contrary to generator expansion, gathering and using DR resource has additional effects to both market and system. First effect is the decrease of electricity market price. Average market price is decreased by using DR resources because the actual supply by generator is decreased. Second effect is the prevention of price variation comparing with normal condition. However, in actual, effects of DR program are hardly measured because of the scheduling and...
operation procedure already contains the aforementioned DR effects. That is, the potential of effects is not considered in calculation. Therefore, the incentive considering potential payment for normal condition DR program must be contained into total incentive. RBIP (Reliability based incentive payment) is used in this paper to present the aforementioned incentive. Total incentive can be formulated as like (1).

\[ I = EP(s) + CP + RBIP \]  

Where,

- \( I \) : Incentive for demand response
- \( EP(s) \) : Energy payment per megawatt-hour ($/MWh)
- \( CP \) : Capacity payment per megawatt-hour ($/MW)
- \( RBIP \) : Reliability based incentive payment

In the next section, RBIP is focused and the mechanism for measuring the quantity of market price reduction effect in reliability based consideration and calculating method are suggested.

### 2.3 Reliability based incentive payment

In this section, the concept of RBIP is introduced and formulated. Traditionally, the market effect caused by demand side reduction in demand response program was evaluated only in economic DR program[7]. Economical effect of DR program is valued and used for determining incentive mechanism in economic DR program. That is to say, market price reduction effect which is caused by reliability based DR program was not considered in DR incentive calculation. Emergency condition is triggered based on operating reserve rate or frequency level. Primary purpose in this situation is maintaining system reliability and market price reduction is secondary part. Some peak generators withdraw their various costs using price spike. Although the reliability based demand response program stabilizes price variation, demand response resources cannot be rewarded their proper incentive compared with economic DR programs.

Because many customers are risk-averse, they want to forecast their costs accurately for budgeting purposes. However, the retail rates can fluctuate in response to spot price(for customers on real-time pricing) or expected wholesale prices(for other customers). To the extent that demand curtailment reduces volatility in the spot market, it improves rate stability for some customers[8]-[9]. So, the effect of reducing the fluctuation of market price in emergency condition must be added to incentive payment for DR resources.

To evaluate the effect of reducing market price fluctuation, price variation at each node in two situations must be measured. First situation is dispatching without DR resources in emergency condition and second situation is dispatching with DR resources in emergency condition. Selecting the region and the quantity of DR resources can make difference in status of system and market price. In the actual implementation of DR program, specific participants in specific node reduce their contracted quantity instead of all customers reduce equal quantity. This fact can cause the differentiation of price decreasing rate of all nodes. If the quantity of some loads is decreased, direction or quantity of power flow also can be changed. Furthermore, some changes can make transmission line congestion so that LMP of specific bus can be higher than DR program is not applied in system.

Considering effects which are mentioned above, fixed incentive level for demand response participants is not suitable for designing the potential payment related to LMP variation part. Incentive for the market effect of DR program must be determined by the quantity of price variation which is caused by new DR program implementation. Formulation (2) and (3) are the mathematical forms which contain above effects in emergency condition.

\[
RBIP = \sum_{i=1}^{n} \left[ \frac{[\text{LMP}_i \text{after}(i)] - [\text{LMP}_i \text{before}(i)]}{\text{Q}_{\text{total}}} \right] (RBIP > 0) \\
0 \quad (RBIP \leq 0)
\]

\[
\Delta P_i = \max \left( \frac{[\text{P}\text{after}(i) - \text{P}\text{normal}(i)]}{\text{P}\text{before}(i) - \text{P}\text{after}(i)}} \right) \quad (P_{\text{before}} = P_{\text{normal}}) \\
1 \quad (P_{\text{after}} = P_{\text{normal}})
\]

Where,

- \( P_{\text{after}}(i) \) : LMP at bus \( i \) after DR implemented
- \( P_{\text{before}}(i) \) : LMP at bus \( i \) before DR implemented
\( P_{\text{normal}}(i) \): LMP at bus \( i \) at specific generator is contained

\( Q(i) \): Load quantity of bus \( i \) after DR implemented

\( Q_{\text{total}} \): Total quantity of curtailment by DR program

\( P_{\text{before}}(i) \) is the LMP of bus \( i \) calculated by DCOPF when DR resources are not applied without specific generator. \( P_{\text{after}}(i) \) is the LMP of bus \( i \) calculated by DCOPF when DR resources are implemented without specific generator. \( P_{\text{normal}}(i) \) is the LMP of bus \( i \) when specific generator is operating. \( \Delta P_r(i) \) means the factor of price variance caused by DR resources for each node.

![Diagram](Image)

**Fig. 2.** Two ways for deciding the \( \Delta P_r \).

Numerator term is determined by comparing two values, \( P_{\text{before}}(i) - P_{\text{after}}(i) \) and \( P_{\text{after}}(i) - P_{\text{normal}}(i) \). Two values mean the variation of prices between the situation that DR is implemented or not. \( P_{\text{after}}(i) - P_{\text{normal}}(i) \) is for the situation that DR resource affects the increase of price. Numerator term is depicted to A, in Fig. 2. Denominator term is determined by \( P_{\text{before}}(i) - P_{\text{normal}}(i) \). This term means the price difference between the situation of specific generator is contained or not. If denominator term is set to 0, \( \Delta P_r(i) \) is set to 1 because the price is fixed, that is to say, customer does not affected by price. Numerator term is depicted to A, in Fig. 2. \( Q(i) \) is the demand quantity of bus \( i \) after DR program is implemented. \( Q_{\text{total}} \) is the total amount of DR quantity that is used in system.

The procedure of calculating RBIP is showed in Fig 3. With generator and DR resources, two sequence of DCOPF is calculated. One is for reference LMP calculation without DR and another is for LMP with DR program implemented. Difference between two LMP data is multiplied by the quantity of load when DR is implemented. Result data is used for determining RBIP. And DR participants receive their rewards based on RBIP.

Main concept of RBIP is weighting the regional effect of DR resources and evaluate total amount of price valuation by checking the condition without DR.

In the next session, case studies show the calculation result of RBIP compared with traditional incentive calculation.

![Sequence diagram](Diagram)

**Fig. 3.** Sequence of calculating RBIP.

### 3. Case Study

Case studies based on the IEEE 30-bus system are presented in this section in order to show the quantity of reliability based incentive payment which is novel demand response incentive mechanism. Line, generator, and demand data are based on IEEE data. Fig. 4 depicts the IEEE 30-bus system [6].

To analyze the price reduction effect of demand response program, the specification of generator in bus 22 is modified. Generator in bus 22 is mostly responsible for peak load.

Four cases are showed for checking market price reduction effect.
3.1 Case A : Status result without DR program and without specific generator attending

To evaluate the effect of DR program implementation, the reference situation is necessary. In this case, generator schedule is decided without DR programs. And the generator at bus 22 is removed in scheduling. As a result, there is congestion in line 25 to 27. LMP varies from 3.95$/MWh to 4.016$/MWh (If generator is contained to the schedule, LMP is 3.901$/MWh and there is no congestion).

Fig. 4. IEEE 30 bus model.

3.2 Case B : Status result with DR program for being equally assigned(same quantity) and without specific generator

In this case, the situation about neglecting regional effect is assumed. The generator at bus 22 is not contained in scheduling. DR resource quantity is equally divided and reduced by every load. In the simulation, 5.21MW of DR resources is equally divided into 20 parts of quantity 0.2605MW. As a result, there is no congestion in any lines. LMPs in buses are all same. SMP is $3.901/MWh. From the comparison of case A and case B, it is obvious that if the demand response reduction comes into system operation, it can prevent the variation of LMPs of all buses. Furthermore, it reduces LMP of each load. This result shows that DR program can replace the generator in emergency situation.

Fig. 5. RBIP of case C and LMP variation of case B and case C.

From the comparison of case B and case C, some specific combination of DR resource can cause congestion so that price fluctuation is reinforced. That is, the regional effect of specific combination is considered and implemented in calculation of extra incentive.

3.3 Case C : status with DR program for being assigned at bus 24 and 30 and without specific generator

If demand response reduction is done in specific buses, congestion problem is important because it can vary the LMP. In this case, to check the effect of specific loads reduction, bus 24 and bus 30 are selected to reduce 4MW and 1.21MW, same to total quantity which is used in case B. As a result, there is congestion in line 25 to 27. Some buses have higher LMP than that of case B.

Fig. 5 shows the comparison of LMP difference of case B and C, and RBIP/MW of case C. X-axis is the number of node and y-axis is the quantity of each component($/MWh). From Fig. 5, if the difference of LMP of case B and case C goes higher, RBIP at bus i also goes lower. Regional effect is enclosed in the mechanism of RBIP. If DR program reduces more price quantity than $P_{normal}$ at specific node, extremely high RBIP is determined for specific node. On the other hand, as price goes higher than $P_{normal}$ more and more, RBIP also goes lower exponentially. Rate of decreasing is high when difference of LMP is very high.

3.4 Case D : status result with DR program for being assigned at bus 30 only(same quantity) and without specific generator
In this section, to evaluate the effect of DR quantity combination to price variation, same amount of DR resource (5.21MW) is reduced only in bus 30. As a result, most of buses have lower LMP than the situation of DR program is not implemented, however some buses have higher LMP. LMP of bus 23 and bus 26 are higher than DR is not operated, similar to case C. The width of price variation is higher than that of case C. Some combinations of DR resource reduction strategy (case D) can make more price fluctuation, and this combination of DR program must be assessed less value than case C. Although, same quantity of DR resources is reduced and same line (from 25 to 27) is congested, DR program induces more price variation. These effects must be strictly divided and evaluated. For comparison of case C and case D, RBIP of each cases are differently calculated because of the factor, $\Delta P_v$. Fig. 6 shows the result of comparing the average prevention quantity of price variation ($P_{before} - P_{after}$) and the average RBIP for all cases. Case C and case D reduce same quantity and the same line is under congestion, however, the prevention quantity of variation at case C is much higher than case D. Therefore, the reward of case C is determined higher than case D. From the result, the prevention of price variance by DR is well implemented for extra incentive calculation.

![Fig. 6. Comparison of prevention quantity for variation and RBIP for all cases.](image)

4. Conclusion

In order to reward some effects of DR program, extra incentive must be paid to participants. From traditional payment of incentive, potential payment(RBIP) for reliability DR must be contained. New incentive payment mechanism includes market price reduction effect and prevention of price variation effect. In this paper, Method of evaluating and calculating these effects is suggested. RBIP contains two effects, market price reduction and stabilization of price variance by DR. Because the combination of DR resource quantity affects entire system, effects of all nodes are calculated and added for deciding RBIP. Also, prevention of price variance by DR is formulated by $\Delta P_v$ and applied in RBIP. As a result, regional effect which is caused by transmission line congestion is considered for determining incentive. If there is congestion, quantity of payment becomes lower than the situation that no congestion in system. Although the same quantity is decreased by DR, participants who contribute more reduction of the price variation are rewarded higher incentive payment. Rate of $\Delta P_v$ increases exponentially as the stabilization rate of the price becomes higher. On the other hand, if the stabilization rate of the price becomes lower (more fluctuation in price), penalty for this effect is increasing exponentially.

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References


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