Compensation of Demand Response in Competitive Wholesale Markets vs. Retail Incentives

Ahlmahz I. Negash, *Student Member, IEEE*, Daniel S. Kirschen, *Fellow, IEEE*
Department of Electrical Engineering
University of Washington
Email: ain@uw.edu, kirschen@uw.edu

***Abstract*—In 2011 the Federal Energy Regulatory Commission (FERC) issued a landmark ruling, FERC Order 745, standardizing the compensation of demand response (DR) in competitive wholesale markets. According to this order, demand response resources participating in competitive wholesale energy markets must, like generators, be paid full locational marginal price (LMP). Many economists opposed this ruling and argued that the most efficient method is to offer dynamic prices and naturally, demand reductions are rewarded with the avoided cost of the energy not used. One of the main arguments against the order is the fact that by paying LMP for demand reductions, the market collects less in revenue than it must pay out for resources, a phenomenon known as "the billing unit effect" and must therefore, allocate the shortfall. In this paper we compare wholesale DR compensation to retail level incentives. We define demand response as a short-term added cost for the load serving entity (LSE), voluntarily paid in order to save money over the long run. Based on this view of DR, we propose a benefit sharing incentive scheme at the retail level. This scheme involves the use of a publicly broadcast grid state index implemented by the California Independent System Operator (CAISO).**

***Keywords*—optimization, demand response, incentives, pricing, dynamic pricing.**

I. Introduction

In recent years, there has been a significant spike in the interest in demand response programs in the United States. The national push towards a smarter grid necessitates the inclusion of the demand side as an active participant in energy purchases. As a result many studies have looked at quantifying the market benefits [1] [2] as well as local network benefits of DR [3]. Recognizing the need for a standardized approach to compensation as well as increased financial incentives to promote demand response enabling technology, the Federal Energy Regulatory Commission (FERC) issued Order 745, requiring demand response compensated in competitive wholesale markets be paid full locational marginal price (LMP). In other words, under this order, demand response resources sold in wholesale markets are the equivalent of generation resources. However, when a DR resource curtails, the market experiences a reduction in revenue. Since the market must pay LMP to both generators and DR providers for the resources that clear the energy market, the difference between market revenue and payouts is negative. That negative balance represents money owed to demand response resources and must be addressed through cost allocation. This highly controversial order was strongly contested by various entities, including ISOs, utilities, economists, as well as FERC commissioner, Moeller [4]. Economists argue that paying customers LMP for load reductions is essentially providing these customers a double payment because they not only enjoy bill reductions but also full LMP.

Dynamic pricing represents a more efficient alternative in that customers see and pay the time-varying cost of energy and can avoid prices they are unwilling to pay. While many utilities offer dynamic rates to their large customers, fewer opportunities are available for residential customers, who consume almost 40% of the electricity generated in the US. However, there is a growing trend in the number of residential customers being provided with (and exercising) customer choice [5]. In 2006, Illinois became the first state to require that all customers be given the option of real time pricing [6]. Texas has a thriving competitive retail market, and as a result, customers have a wide range of suppliers as well as rates to choose from. Unfortunately, customers on real time pricing are at risk of being exposed to extremely volatile and sometimes high prices. Because residential customers are in general risk averse, it is not surprising that many customers choose to remain on flat rates [7]. Incentives therefore provide a low-risk, option for voluntary demand reductions. One of the most common incentive programs offered to residential customers is direct load control (DLC), where customers are offered a fixed incentive in exchange for allowing their LSE to control a portion of the customer load. The advantage of this method is that a consumer can determine in advance whether the incentive is attractive enough and the LSE has increased certainty in DR availability. The main disadvantage for the customers, however is that they must give up control over their comfort. The disadvantage for the LSEs is that they inevitably purchase phantom DR, or load reductions that would have occurred even without incentives.

In this paper, we propose a method to select the level of incentives to offer customers on flat rates for day ahead demand reductions. This incentive design is based on a benefit sharing methodology and incorporates the use of a grid condition signal proposed by the California Independent System Operator (CAISO) [8]. This CAISO grid condition signal is based on wholesale market prices and can be modified by the local utility to reflect local conditions. We then compare

This work funded in part by the NSF GRFP, and the University of Washington Clean Energy Institute (CEI).

978-1-4799-6095-8/14/$31.00 ©2014 IEEE

the customer benefits of demand reductions when compensated according to FERC order 745, and according to the proposed benefit-sharing incentive. The ultimate goal is to determine whether it is more beneficial for DR to be sold at the wholesale level or retail level.

II. FERC ORDER 745

In 2011, FERC issued its landmark Order 745 requiring that demand response be compensated at full LMP when participating in organized energy markets, provided that it is able to (a) balance supply and demand and (b) do so in a cost effective manner [4]. ISOs were required to develop a net benefits test to determine a threshold cost above which DR is cost effective. When the LMP is above this threshold, DR must be compensated according to their LMP. These tests involve using historical data to create a smoothed representative supply curve, determining the quantity for which the elasticity equals 1 on this curve, and finally determining the LMP at that quantity [9] [10] [11].

III. CAISO GRID STATE INDICATOR

The purpose of CAISO's grid state indicator is to provide end users with the necessary information to link wholesale and retail markets. This information is in the form eleven possible index values (from zero to ten) based on current wholesale market conditions, where each index value represents a range of LMP values. The underlying premise is that LMPs reflect grid states in both magnitude as well as locational price differences. The magnitude (when high) indicates potential shortages and hence, reliability risks. Locational price differences indicate congestion in the transmission level. In [8], CAISO presented a method to capture this information in a discrete index as described in Table 1. Here, the average "off-peak" price, π^{off_peak}, is determined by calculating the average price during recent (past 30 days) off-peak hours, where off-peak hours are from 7pm to 7am. Similarly, the average "on-peak" price, π^{on_peak} is determined using recent on-peak (from 7am to 7pm) prices.

TABLE I. PROPOSED STRUCTURE OF CAISO'S GSI

Grid State Index	***Lower LMP Limit ($/MWh)***	***Upper LMP Limit ($/MWh)***
0	n/a	$\leq$ -30
1	> -30	≤ 0
2	> 0	$\leq \pi^{off\_peak}$
3	$\geq \pi^{off\_peak}$	$\leq \pi^{on\_peak}$
4	$\geq \pi^{on\_peak}$	$\leq 1.1 * \pi^{on\_peak}$
5	$\geq 1.1 * \pi^{on\_peak}$	$\leq 1.33 * \pi^{on\_peak}$
6	$\geq 1.33 * \pi^{on\_peak}$	$\leq 1.67 * \pi^{on\_peak}$
7	$\geq 1.67 * \pi^{on\_peak}$	$\leq 2 * \pi^{on\_peak}$
8	$\geq 2 * \pi^{on\_peak}$	$\leq 3 * \pi^{on\_peak}$
9	$\geq 3 * \pi^{on\_peak}$	$\leq 10 * \pi^{on\_peak}$
10	$\geq 10 * \pi^{on\_peak}$	n/a

This type of index would enable price responsive customers as well as their devices. CAISO is currently implementing a process to publish this index on its website, making it available for utilities, energy service providers, application developers and consumers themselves [8]. It should be noted that CAISO envisions this type of signal to be used for voluntary load reductions only, and not for "dispatched demand response". Thus, this signal is suitable to be incorporated into residential, real time price rate designs as well as the proposed incentive method. In the following section, we describe the proposed incentive structure based on the CAISO grid state index.

IV. PROPOSED INCENTIVE SCHEME

If retail compensation is through incentive payments, then in this case, the LSE decides when short term DR payments are justified by a quantifiable long term benefit. We assume that the customer providing DR is on a flat retail rate. Here the main question is how much should the LSE or aggregator offer for DR? This incentive must be optimized according to the benefit that is gained by the LSE. Ultimately, in this type of pricing scheme, it is up to the LSE to determine what the benefit of DR is and set prices accordingly. In this paper, we define the benefit to the LSE as a reduction in economic loss when DR reduces the amount of energy the LSE sells to the consumer at a price less than the wholesale price.

When customers are on a flat retail rate, this rate represents an average cost not only across the residential class of customers but also across time. Therefore, there will be times where wholesale prices will fall below the flat rate and other times when they will rise above. The flat rate is set just high enough that the LSE can recover its approved revenue requirement. Because retail rates are regulated, and fixed for 1-3 years at a time, once the rate has been set, the LSE can increase its profit by targeting demand response specifically when wholesale prices rise above the local retail rate. Thus, the objective of the LSE is to minimize economic loss during peak priced periods.

A. Formulation of Demand Response Incentive

We define the DR incentive, Equation (1), to be an exponential function of the GSI. An exponential function is chosen in order to mimic large price spikes in the wholesale market at very high demand and therefore, provide a price signal that is more consistent with wholesale market energy price signals.

$$\begin{aligned} I &= a^{b*G-c} \\ 0 &\geq G \leq 10 \\ 0 &\geq b \leq 1 \end{aligned} \tag{1}$$

Here, a is a parameter chosen based on historical wholesale price data, b represents the portion of LSE's financial benefit due to load reductions that the LSE is willing to share with DR providers, G is the GSI, and c is a parameter that is optimized in order to ensure the incentive provided does not exceed the benefit of load reductions. Equations (2-3) give the optimization problem.

$$\min_{c} \left| \left(a^{b*G-c}\right)*D - b*R \right| \quad (2)$$

$$s.t. \quad R = \left(w^0 - r\right)D + B_l \quad (3)$$

Here, R is the LSE's total financial benefit of load reductions D; B_l is the local value of DR; r is the flat retail rate; and w^0 is the wholesale price without DR. Thus, the first term of the objective function is the incentive and the second term represents the share of the LSE's total benefit that is given to the DR provider. In other words, given an anticipated load reduction D, the LSE can predict its savings R, that result from the load reduction and the parameter c, is optimized such that the incentive does not exceed the benefit of the load reduction.

V. Comparison of Wholesale and Retail Compensation

We compare the costs and benefits of demand response compensation at the wholesale and retail levels and for various market participants. These costs and benefits are illustrated in Figures 1 and 2 and the equations are tabulated in Table 1. Here, w^0 is the wholesale price without DR, w is the wholesale price after load reductions, D is the load reduction (demand response), B_l is the local value of DR (such as reduced losses), L is the load after load reductions, r is the flat retail rate, and I is the demand response incentive. These costs and benefits are analyzed from the perspective of the load serving entity (LSE), buyers in the wholesale market (BM) including energy exporters as well as LSEs, and demand response providers (DRP).

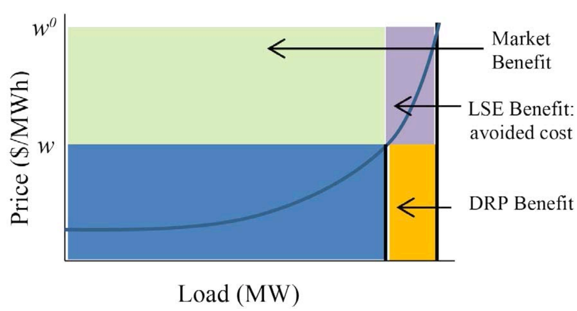

Fig. 1. Benefits and costs of demand response in the wholesale market

In Figure 1, the green shaded region represents the market benefit of load reductions enjoyed by all the buyers. The blue shaded region is the revenue that the market collects. The yellow shaded region is the payment made to DRPs. Since the revenue collected is less than the amount needed to pay LMP to both conventional generators for load, L, as well to DRPs for the reduced load, D, the payment to the DRP is a cost that must be allocated to all buyers in the market. The purple shaded region is an LSE benefit in that it represents high priced energy that it was not required to purchase;

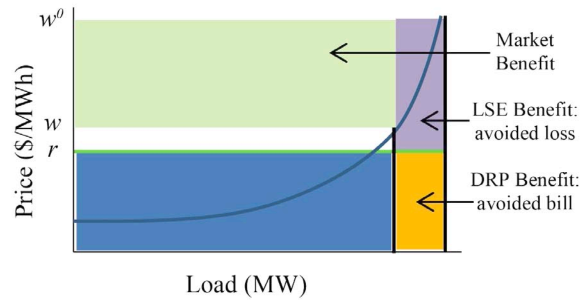

Fig. 2. Benefits and costs of demand response at the retail level

Figure 2, looks at compensation at the retail level and as such we consider the role of the retail rate, r. In the figure, the retail rate is lower than the wholesale price even after load reductions. However, if load reduction is large enough, the wholesale price will fall below r. The important distinction to make between Figure 1 and Figure 2 is that when the retail rate is considered, there is an additional LSE benefit that the wholesale compensation scheme cannot extract. The area given by $\left(w-r\right)*D$ represents avoided economic loss from the LSE when wholesale prices are still higher than retail. This benefit is contained in the LSE benefit model when a retail side DR compensation scheme is used.

Table 2 breaks down and compares each market participant's benefit and cost, if any. Note, that at the wholesale level, payments to DR resources is allocated to LSEs, where each LSE pays a fraction f, of the total cost. The market participants (BM) represent all loads, including those providing DR. That is because when DR reduces wholesale prices, everybody benefits. It is interesting to note that the economic benefit to buyers in the wholesale market is independent of whether compensation is at the wholesale or retail level. However, because wholesale markets do not consider the role of local retail rates, the benefits (and costs) for the LSE and DRP are heavily influenced by whether DR is compensated at the wholesale or retail level. Additionally, local value of demand response, B_l cannot be considered by a wholesale level compensation scheme.

TABLE II. Comparison of Benefits and Costs of Demand Response Compensation at the Wholesale and Retail Levels, and from the Perspective of Various Market Participants

	Wholesale	Retail (incentive)
	Benefits	
LSE	$\left(w^0 - w\right)\left(D\right)$	$\left(1-b\right)\left(w^0 - r\right)D + B_l$
BM	$\left(w^0 - w\right)L$	$\left(w^0 - w\right)L$
DRP	$w*D$	$I*D + r*D$
	Costs	
LSE	$\left(w*D\right)*f$	$I*D + r*D$
BM	$w*D$	---
DRP	---	---

In summary, at the wholesale level, all market participants benefit, and all market participants bear a cost. At the retail level, all market participants benefit and even the buyers in wholesale market see identical benefits as in the case of wholesale DR compensation. However, LSEs can consider their local value of DR resources and provide additional incentives to reward these resources. As a result, only the LSE bears the cost of DR compensation. Finally, because the wholesale market does not consider the role of the retail rate, the DRP avoided bill cost, $r*D$, is not reflected in either the LSE cost, nor the DRP benefit.

VI. Case Study

We analyzed the benefits and costs of DR compensation at the wholesale and retail level using load data from the PJM region for the year of 2011. Price data was simulated based on a PJM model for an averaged supply curve [9].

$$w = 2.584468^{0.000178*MW-18.14454} + 35.82109 \quad (4)$$

In (4), MW, is load, and all other constants are determined based on fitting, to this exponential curve, actual historical price/quantity pairs from generation offers. Based on this formulation, the incentive was calculated as (5):

$$I = 2.584468^{b*G-c} \quad (5)$$

The value of c, was then optimized for every selected value of benefit sharing percentage, b. The retail rate, r, was determined by calculating the average wholesale cost of supplying the original load (before load reductions) over the entire year (6).

$$r = \frac{1}{8760}\sum_{h} w_h * \left(L_h + D_h\right), \qquad h = 1,2, ..8760. \quad (6)$$

A. Assumptions

For simplicity, we assume that there is only one load serving entity with many customers. When calculating the potential savings of demand response, we assume that all customers participate and reduce their loads when the GSI is higher than 4. This assumption affects the dollar value amount of LSE benefit, but is not necessary. It is likely that only a portion of the customers would participate, and it is a risk on the LSE to accurately forecast this participation such that the incentive isn't too high. In practice, small customers providing demand response must contract with a curtailment service provider, or aggregator, to offer their resources into the wholesale market. In this paper, we assume that the customer receives the entire LMP for load reductions, but in reality, the curtailment service provider takes a percentage.

VII. Results

A. Proposed Incentive Structure

Using the simulated market price data, we first converted the price data to the GSI signal. Figure 3 shows the frequency of each GSI value (from 0-10) throughout the year. The GSI of level 4 and above represent times when prices are above average peak prices. In total, these represent less than 20% of the total hours in the year.

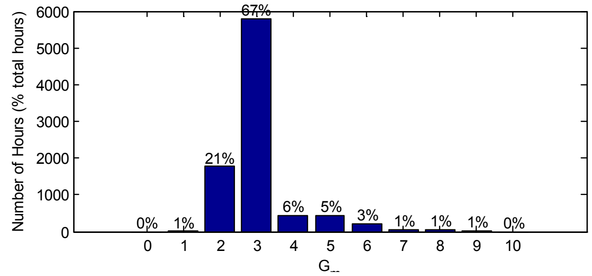

Fig. 3. Distribution of GSI index

B. Retail Level DR Incentive (function of CAISO GSI, G)

The resulting incentive (as a function of CAISO's proposed GSI), is presented in Figure 4. Because an exponential function was selected, incentives rise sharply for larger values of G. Incentives also rise more steeply for larger benefit sharing ratios, b.

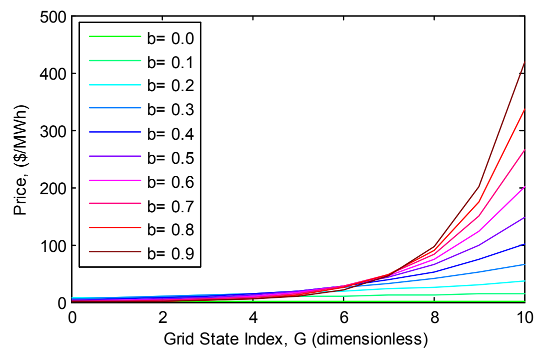

Fig. 4. Incentive for DR as a function of the GSI

C. Benefit Comparison

As shown in Table 2, the benefit of demand response for buyers in the wholesale market, in terms of market price reductions, is independent of whether DR is compensated at the wholesale or retail level. Therefore, we will concentrate our comparison on LSE and DRP benefits.

In Figure 5, we observe that for small levels of demand response ($\leq 6\%$ peak load), the LSE benefit is larger with retail DR compensation. At 1% peak load reduction, this is true for even a benefit share of 90% for the DRP.

Figure 6 shows the benefit from the DRP's point of view. Here, for large benefit share ratios, the DRP always gains a higher benefit from the retail incentive. For low benefit ratios and at low levels of load reductions (<=6%), the DRP gains more by selling in the wholesale market. However, this is largely due to our including the DRP's bill reductions due to DR in the calculation of DRP benefit. From an economic point of view, this inclusion is valid. In fact, the benefit of bill savings for the customer is the same, regardless of whether DR is sold at wholesale or retail. However, realistically, some customers might not view savings as "payment". Therefore, in order to have a more realistic comparison of wholesale vs. retail compensation from a customer point of view, we also considered the DRP benefit without including bill reductions (Figure 7). In such a case, if the load reduction is small, or if the benefit share ratio is too small, the DRP is better off selling in the wholesale market. However, for moderate load reductions (>6%), and high benefit share ratios (>60%), the DRP is better off selling at the retail level. But at moderate to high load reductions, wholesale prices fall below the retail rate, and the LSE benefit at the retail side diminishes.

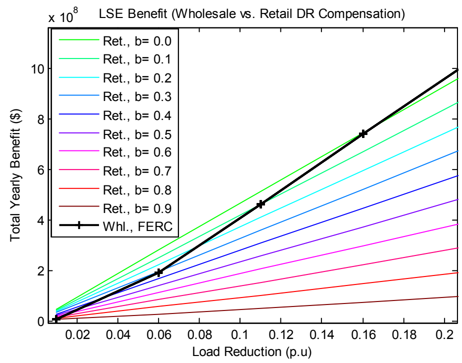

Fig. 5. Comparison of LSE benefit when demand response is compensated at wholesale vs. retail for various levels of benefit sharing ratios, b. Note, "b" is the percentage of the total LSE benefit that is shared with the DRP in the form of the proposed incentive.

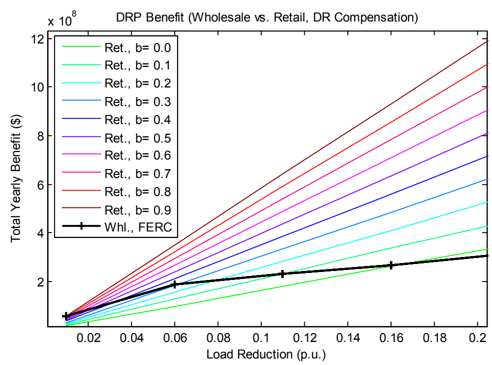

Fig. 6. Comparison of DRP benefit when demand response is compensated at wholesale vs. retail (for various levels of benefit sharing ratios, b).

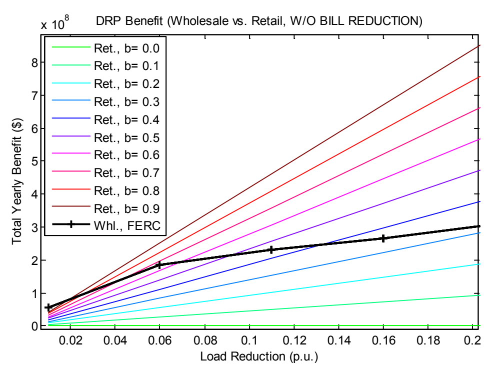

Fig. 7. Comparison of DRP benefit (not including bill savings) when DR is compensated at wholesale vs. retail (for various levels of ratios, b).

It is worth pointing out again, that we assumed no local benefits, $B_l = 0$. If local benefits, such as loss reduction, investment deferral, or other benefits, are included in the total LSE benefit due to DR, then the LSE as well as the DRP have an opportunity to both do better off on the retail side.

VIII. CONCLUSION

We presented a retail level DR compensation scheme based on the newly proposed CAISO grid state index. This index is intended to serve as a signal to customers and can be modified by load serving entities to produce dynamic rates or incentives for voluntary demand response. We compared this method to the current method of compensating DR in competitive wholesale energy markets. We find that when DR penetration is high, DRP are better off selling at the local retail level if LSEs are willing to share at least 60% of their economic benefits. At low DR penetrations (less than 15%), the wholesale market provides DRP a larger payment. The main benefit of compensating at the retail level is that a more complete picture of each participant's benefits and costs can be analyzed and modelled. Because demand response is a local resource, providing local benefits, aggregation of these resources to the wholesale level strips them of an opportunity to be compensated for local added value. Because market prices depend on load level, and are independent of whether DR is compensated at retail, all buyers in the wholesale market benefit from price reductions due to DR. Future research will quantify the minimum local benefit, B_l, that ensures both the DRP as well as the LSE are better off with retail compensation.

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