2015

Compensation Methods for Demand Response

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COMPENSATION METHODS FOR DEMAND RESPONSE

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in Electrical Engineering
in the College of Engineering
at the University of Kentucky

By

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2015

ABSTRACT OF THESIS

COMPENSATION METHODS FOR DEMAND RESPONSE

Recently, more and more disputations about how demand response should be compensated have arisen. Moreover, the court is about to rehear the Order 745. It probably will have significant impact on the whole working system used to be built for demand response before. Nowadays, some power companies and utilities think that they will endure profits leakage while demand response resources still are compensated.

In this research, knowledge of demand response, local marginal price, Order 745 and other related concept will be explained in detail in case of misunderstanding. Associated with all these knowledge, a possible compensation method will be proposed. It combines many existing compensation methods. It mainly can be divided into three parts, i.e., high load period, off-peak period and low load period. The demand response resources will be compensated appropriately through these three periods. The compensation method endeavors to be just and reasonable.

KEYWORDS: Demand Response, Local Marginal Price, Compensation Methods, Order 745.

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ACKNOWLEDGEMENTS

First of all, I would like to thank my advisor, Dr. Liao, for giving me this interesting topic. Demand response is one important aspect of future energy systems and a deep understanding of it will help create a more effective and balanced energy market. Dr, Liao showed his patience and passion in guiding me through the research, and he taught me some important concepts and methods. Moreover, when I met some problems, my advisor provided me with relevant articles and had discussions with me. With his help, I successfully achieved the original goal of this research.

I would also like to thank Dr. Fei Zongming and Dr. Paul Dolloff for being my committee members. I would also like to thank my labmates Jie Chen, Ke Xu, Ke Chen and Zhengyuan Guan for their support.

Last but not least, my parents provided me huge love and support during my research.

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Chapter 1 Introduction

Recently, there are more and more disputations about how demand response works in the wholesale energy market and whether compensation methods of demand response are just and reasonable or not. Besides, if the full court finally makes its decision to rehear the case, it can overturn Order 745 which will be briefly introduced in the first part of this section. The other part in chapter one explains why there are so many problems about the Order being raised. The target of whole paper is to solve disputations and optimize current compensation methods through study of the Order 745 and relevant materials.

1.1 Order 745

What is the Order 745? With increasing deployment of renewable energy sources including wind, hydro and solar, together with traditional oil and coal based generation, it becomes more important to keep efficiency and stability of our wholesale energy market. The main purpose of Order No. 745 is to help wholesale energy markets to operate effectively to balance energy supply and demand. How does it work? The Order gives explanation that Demand Response (DR) plays as an alternative energy source to maintain the balance. When there is an outage and blackout, demand response programs will serve as an alternative resource to inform their customers to reduce energy consumption. Moreover, when the energy price is high enough because of high load demand, demand response will inform their customers as well. When either above condition meets, the demand response resource has to be compensated for its service at the energy market price referred as the Locational Marginal Price (LMP). In conclusion, the Order not only ensures competitiveness of demand response resources in wholesale energy markets but also removes barriers that prohibit participation of demand response resources. Moreover, the Order makes sure that the wholesale energy price preserve at just and reasonable rate with help of demand response. Last but not least, it lays down authority for demand response to sustain system reliability and satisfy resource sufficiency by quick response to balance the electricity grid. The Commission does understand that in the future, the modification of dispatch algorithms will become even more difficult so that it requires each ISO or RTO to perform the net benefits test determining a basis every month. The basis is founded mostly on historical data that cover the previous year's supply curve. It is also necessary for ISO or RTO to develop a mechanism in which the probability is analyzed when it is cost-effective to compensate demand response resources with full LMP. One more important thing of Order 745 is that each ISO or RTO still set own compensation methods even the Order spends many pages in discussing how to compensate demand response. Those discussions will be analyzed and debated in detail later.

1.2 The coming problems of Order No. 745

As mentioned before, the full court is about to votes to rehear the case which may rescind Order 745. One of the problems is that Federal Energy Regulatory Commission (FERC) keeps the authority, which was approved by Congress under the Federal Powers Act (FPA), to regulate the wholesale energy price. However the Federal Powers Act doesn't articulate what exactly should be done with demand response which means that the specific compensation method is not set. Therefore, there comes the confusion. The

Commission only rules that the compensation has to be relevant to LMP. Judging from previous experience, courts usually process the determination made by agencies like FERC who provide expertise on things which they regulated. Meanwhile the Commission made its decision mostly based on suggestions, feedback, and comments from ISO/RTO, DR companies, and DR customers. Therefore, we can infer that opinions from generator part are probably neglected. Moreover, although Order 745 successfully paved an entry for DR into the wholesale energy market without encroaching on state rights, the demand response resource is not restricted by a state's decision or law. In addition, the Order was supposed to achieve the goal that demand response should be fairly and justly treated in the energy market so that it could compete with other traditional electricity resources such as coal, natural gas, and wind power. But currently, the court has decided to "devalue demand response in wholesale energy markets and reduced the incentive for demand response providers to offer this service."[1] In a word, the court doubts former value which was by demand response resources under permission of Order 745. Moreover, in order to remove barriers that prohibit participation of demand response, the Commission greatly supports the wholesale energy market being competitive. On the other hand, Judge Janice Roger Brown, who might represent for viewpoint of the court, demonstrated that FERC removed barriers way too much instead of simply removing barriers. To keep consistent with the removing barriers rule in Order 890, the Commission further modified the Open Access Transmission Tariff allowing resources which cannot generate power themselves, especially demand response resources, to share and use most of ancillary services which were used to be built for generation resources in order 745. This could be on of reasons bringing unjust profits to demand response. Based on the feedback and comments, some people think that demand response resources can take advantages of the platform which has been built between ancillary services and generation resources.

Additionally, Judge Janice Roger Brown's continued to state, "The issue at hand was not just whether the payments were too high, but rather who has the authority to set those payments."[2] This will bring back the question that the method of setting those payments is ambiguous. Although the Commission makes the rule that compensation to demand response resource must be based on its service and the market energy price that refers to local marginal price, the approach how to lay down payment is quite different from every ISO and RTO. Each ISO or RTO still uses its own way to deal with demand response resource to reach maximum interest even the Commission makes the final call. This problem will be exaggerated and particularly discussed during the comments part. Demand response provider can achieve both reducing energy consumption and maximizing profits under current conditions. On the other hand, it probably neglects the damage to generation sources or other companies who may endure interest leakage. For the defense of Order 745, Federal Energy Regulatory Commission stated that it didn't guarantee everyone's profit. Another problem is that the demand response, modified under Order 745 somehow raised energy payments instead of decreasing them. There is another saying that only large companies, like commercial and industrial customers, could understand enough about demand response and then invest in the economic DR market to gain profits. Some power producers also raise their concerns about compensation of demand response is that the energy price is not only raised but also unfair that "those customers have already been compensated in the form of lower power bills from using less energy”. For example, some DR companies, such as EnerNoc and Viridity Energy, were already praised for the fair way to compensate customers for implementing real-time power-down technology in their buildings and factories.[3] This situation is called overcompensation. Some ISO and RTO compensate DRR with LMP which was regarded as a double payment which will be introduced in the discussion part. No matter how demand response is known as an effective way to reduce energy use, some U.S. utility trade groups and power producers begin to stand against Order 745 on demand response part.

It cannot be denied that rehearing may lead undercut or even discard one of the brightest energy future, demand response. Actually, any innovation grows with disputations. The development of demand response really needs time and patience. This thesis carries the opinion that it is unnecessary for the court to hold rehearing. Instead, certain modification can facilitate demand response to work better and contribute more in the energy market. In the following parts, advantages of demand response and re-understanding of Order 745 explain how effective an energy market will be with the operation of demand response.

Chapter 2 Chapter 2 Re-understand Order 745, Final Rule

Even though decision of rehearing the case won’t affect DR keeps playing more and more important role in energy markets, such as PJM, a setback will happen. In order to avoid such bad situation happening, this part is dedicated to deeply introduce the Order 745 and provide suggestion about optimizing DR.

2.1 Wholesale energy market

According the Final Rule, the compensation methods are introduced through organized wholesale energy market which contains two parts, Regional Transmission Organization (RTO) and Independent System Operator (ISO). What's the wholesale energy market? As we all know, electricity is normally generated by a power company. However, it won't be directly delivered to its end-use customers. Instead, it has to be purchased and re-sold for a bunch of times before reaching the end-use customers just like other commodity such as oil and stock. In summary, a wholesale energy market should consist of sale and re-sale processes. Basically, anyone can take part in the wholesale energy market under certain approvals. One condition is that power providers can become effective participants only when there is a customer or more who are willing to purchase those providers' power output. For individual trader and power marketers, they can buy and resell power through the market instead of generating energy if they want to participate in the wholesale energy market. There are many types of these participators. They include competitive independent power producers (IPPs). They do not belong to any utilities. For example, individuals purchase photovoltaic boards to generate power for individual use or sale to preferential power utilities. Participations can also be power suppliers and market traders connected to utilities. Traditional integrated utilities become participations when they begin selling extra power.[4] The competition among these participations have to be fair and just. Demand response resource doesn't produce energy at all and it is defined as a service instead of sale and resale energy marketers. Now, the brief structure of wholesale energy market will be introduced. There are two kinds of operation methods in the U.S. The most common trade which is widely applied in the wholesale energy market is multi-state interconnection. It can be regarded as interstate sales. In this operation method, the wholesale energy market is regulated across the country under ISOs and RTOs. It covers the region of Northeast, California, Mid-Atlantic, much of the Midwest, and ERCOT. But the ERCOT doesn't perform as others do. ERCOT's entire line lies only in state, Texas, and it has no connection with other states. The ISO/RTO structure guarantees the competition as well. Actually, two-thirds of the electricity is spent through ISO/RTO in the U.S. The other operation way is known as a traditional operation method. The regions including the Southeast, Southwest, Northwest, Inter-Mountain West, and vertically-integrated utilities still observe and take charge of transmission lines. More importantly, it will choose its favored generation resource instead of more effective and energy saving one to dispatch electricity during certain hours because of no competition of multi-state.

2.1.1 Day-ahead and real-time energy markets

The wholesale energy market also can be divided into day-ahead and real-time markets. The day-ahead market calculates and determines the LMPs one day before the operating day. Normally, it will inform its customers and allow them to trade wholesale electricity in order to help them avoid changeable energy price. The LMPs are based on demand bids, generation offers, transactions, and so on.[5] The advantage of this market is that payment of its customers is settled. On the other hand, the real-time market is calculating current LMPs at several minutes interval which will directly reveals actual grid operating conditions. For example, New England's ISO (NEISO) sets the interval as 5 minutes. Moreover, different from a day-ahead market, participants of the real-time energy market can trade the electricity during operating day. The advantage of real-time energy market is its flexibility. It can immediately supply the real-time demand to keep the balance of grid. Therefore, the difference between two markets can be met. Meanwhile, a separate and second financial settlement will be created by the real-time energy market as well. The real-time LMP will be predicated and then established. It is used to be a standard to charge customers or compensate electricity reduction and generation in the day-ahead energy market.[6] However, the difficulties of predicting and measuring real-time energy price are obvious.

For the convenience of their customers and themselves, most ISOs and RTOs will provide them plenty of information which they are willing to know. Customers can directly view their information online or download them for later use after they log in own accounts. The information will be illustrated through column, line, and pie charts including and tables. All of them demonstrate all kinds of energy price, management of loads, day-ahead and real-time LMP, and actual power system condition.[7] With the help of above information, the customers can read grid condition easily and make appropriate decisions.

2.2 Process of decision made

The section mainly explains that why it is unfair to revoke Order 745. First of all, every decision made in the Order has been discussed thoughtfully. For example, on March 18, 2010, the Commission, in the Notice of Proposed Rulemaking (NOPR) raised a way to eliminate current concerns that may prevent meaningful demand-side's participation. Before carrying out the final action, there are about 3,800 pages of comments being reviewed and a technical conference being held subsequently. Therefore, there are many complicated processes before the Commission makes the final decision. As mentioned in the beginning, the Commission cannot guarantee everyone's profit. In the discussion part, the Commission will tell that how difficultly and carefully it makes the final determination. Therefore, it is unfair to turn over everything about demand response in Order 745. Demand response will become more developed in management, rules, and restriction under certain modification with time.

2.3 Cost-effectiveness conditions and Net benefit test

Under definition, a demand response resource has the ability to maintain the balance between supply and demand as an alternative generation resource under RTO and ISO's structure. Meanwhile, it is important to make sure the efficiency of demand response when it serves as an alternative resource. Cost-effectiveness condition and net benefit test are two related components in Order 745 to determine when demand response has to be compensated at energy price referred to LMP. Therefore, it is reasonable to compensate demand response when it is cost-effective which is determined by the net benefits test.

2.3.1 Net benefit test

Before implementing the net benefits test, both RTO and ISO are required to approximately predict that at what price level when demand response will be cost-effectively dispatching. Moreover, the price level is usually based on former supply curve and real time changing condition. Therefore, the level should be updated frequently. In conclusion, the ISO or RTO should determine the monthly threshold price that represent for the standard of net benefit test. Under following situation, dispatching demand response will have net benefit effect. As DR resource plays as an alternative generation resource, it will reduce the overall LMP because it substitutes other generation resources. Dispatching DR will be cost-effective when advantages from reduced LMP which is caused by demand response are beyond the spending of dispatching and paying LMP to demand response resources. In conclusion, the net benefit test becomes a critical condition to decide whether the dispatch of DR resources is cost-effective or not.

2.3.2 Cost-effectiveness conditions

Cost-effectiveness conditions are especially important because the Commission can apply compensation approach only when demand response resources are satisfactorily capable and cost-effective. It is widely known that customers are paying bills based on how many energy units (MWh) they consume. Additionally, change in the size of energy market will relatively vary the LMP. When the amount of the load, which is supposed to pay the electricity bill, decreases, cost per unit ($/MWh) will be unintentionally increased because of dispatching demand response resources. Furthermore, it will break the balance of wholesale load. This possible result is regarded as the billing unit effect when demand response is delivered. On the other hand, generation resources dispatching does not lead a drop of load, there won’t be the billing unit effect.

2.4 Cost allocation

In the accounting category, cost allocation is a process of providing relief to shared service organization's cost centers that provide a product or service. In turn, the associated expense is assigned to internal clients' cost centers that consume the products and services.[8] In the research, cost allocation is the process that cost will be reasonably distributed to one or more groups. Costs can be allocated only arrangement and cost allocation of the work are in the same proportion. In addition, there must be direct benefit proof related to those cost. Demand response resources are allocable if they benefit energy market from energy deduction. Furthermore, if the expense is used on multiple projects, it is necessary to determine proportion of the expense and benefits spent on each project then charge accordingly. When allocating multiple projects costs, the Principal Investigator working with the Research Administrators must ensure two things. One of them is that the costs are reasonable; the other one is that costs allocated for each one project should have appropriate documentation which reflects the Principal Investigator's judgment and indicate percentages or amounts of benefits in every project. The allocation method must be reasonable and must relate to the costs being charged. There are several points about allocation which need to be remembered. First of all, some documents such as headcount, square footage or hours directly relate to received benefit, have to be remembered. Moreover, some allocation methodologies, like budge, funding or available funds, is forbidden. Additionally, administrative expenses won't be regarded as one part of sponsored project to be charged. More importantly, allocation methodologies should be documented, auditable, and reviewed and updated periodically to ensure they are reasonable.[9]

Allocation method is generally based on effort or usage. Here is an example explaining allocation based on effort. There are two projects, A and B. A researcher spends 80% effort on A and the rest effort on B. The researcher spends total $5,000 on those projects. Since expense is directly related to the percentage of effort devoted to the project. Therefore, $4,000 (80% of $5,000) is charged to A and the rest, $1,000, is charged to B. What's going on if allocation method is based on usage? Suppose the maintenance fee of a computer lab is $10,000. The computer system is only available to class A and B. A reasonable base to allocate the expense would be computer user hours. Class A occupies the lab 150 hours in total. And class B takes advantage of the lab 50 hours. Based on usage allocation method, the cost allocated to class A is $7,500 (100/200 x $10,000). On the other hand, the cost allocated to project B would be $2,500 (50/200 x $1,000).

The allocation method for demand response will be discussed below. Now please forget about the U.S. court's opinion about vacating Order 745 at this moment, most ISO/RTO markets admit the capability of Demand Response Resource (DDR) capability. For example, MISO shows great willingness to implement DDR in its market. This Final Rule requires that each ISO and RTO to raise a method to allocate payments of demand response if their clients gain benefits from the lower LMP because of applying demand response. In accordance with Order 745, MISO worked with stakeholders to determine the best method for allocating costs for demand response. During that process, there are two keys which need be paid attention to. First of all, when Locational Marginal Price (LMP) is greater than the threshold for net benefit test, the right method to compensate demand response resource, take LMP as an example here, needs to be chosen carefully.

Secondly, cost allocation for demand response should be applied with necessarily the same proportion amount of load reduction in each location. Surcharges applied to all buyers in the real-time energy market in the applicable zone pro rata.[10]

Here is an example which ISO-NE used to test the impact of demand response cost allocation methods on basic service rates and on overall consumer costs for two compensation methods to demand response, DR providers are paid the locational marginal price less the retail generation rate and the full LMP for demand reductions.[11] LMP_t represent for LMP at hour t; L_t is the loads at hour t; D_t means demand reductions at hour t; G_t is the generator's output at hour t; RR is the retail generation rate. The superscript DA or RT is used to represent for the price or the quantity applied in the day-ahead market or the real-time market. In the first compensation method, which is paying LMP-G to demand response, three payments from generator, LSE and DR are added together. There yields a positive settlement imbalance, missing money, equal to $(LMP_t^{RT} - RR) \times D_t^{RT}$. When there is no DR's participation, the profit of LSE will become $P_0 = \sum_{t=0}^{T}(-LMP_t \times L_t + RR_0 \times L_t)$. Customer payment ($C_0$) under basic situation is $C_0 = \sum_{t=0}^{T} RR_0 \times L_t$, which obviously is the last part of former equation. When all DR costs are allocated to the LSE, then the profit of LSE is $P_1 = \sum_{t=0}^{T}(-LMP_t \times L_t + RR_1 \times L_t)$. In this equation, it implies that LSE has to make up the missing money. And $C_1 is \sum_{t=0}^{T} RR_1 \times (L_t - D_t)$When LDC is required to pay all DR costs, the profit of LSE becomes $P_2 = \sum_{t=0}^{T}[-LMP_t \times L_t + RR_2 \times L_t + (LMP_t - RR_2) \times D_t]$ where $C_2 = \sum_{t=0}^{T} RR_2 \times (L_t - D_t) + \sum_{t=0}^{T}(LMP_t - RR_2)\, D_t$. In order to compare customers' payment, all profits of LSE are set to zero. It is meaningless to analyze the condition when t is equal to zero. Then Table 2.1 shows the equation of retail rate at three different situations.

RR_0	$\sum_{t=0}^{T}(LMP_t \times L_t) / \sum_{t=0}^{T} L_t$
RR_1	$\sum_{t=0}^{T}(LMP_t \times L_t) / \sum_{t=0}^{T} L_t$
RR_2	$\sum_{t=0}^{T}[LMP_t \times (L_t - D_t)] / \sum_{t=0}^{T}(L_t - D_t)$

Table 2.1Retail rate for compensation method, LMP-G

Compare these rates and have relation $RR_2 < RR_1 = RR_0$. Substitute these three RR back to the customer's payments and process the comparison, $C_1 < C_2 < C_0$.

Similarly, when the compensation to demand response is only LMP,

$P_1' = \sum_{t=0}^{T}[-LMP_t \times L_t + RR_1' \times (L_t - D_t)]$ *and* $P_2' = \sum_{t=0}^{T}[-LMP_t \times (L_t - D_t) + RR_2' \times (L_t - D_t)]$. The customer's payment will become $C_1' = \sum_{t=0}^{T} RR_1' \times (L_t - D_t) = \sum_{t=0}^{T} LMP_t \times L_t$ *and* $C_2' = \sum_{t=0}^{T} RR_2' \times (L_t - D_t) + \sum_{t=0}^{T} LMP_t \times D_t = \sum_{t=0}^{T} LMP_t \times L_t$ The difference is that there applied a hybrid method that the cost is allocated into the LSE and the LDC each hour respectively. Then $P_3' = \sum_{t=0}^{T}[-LMP_t \times L_t + RR_3' \times L_t]$. And $C_3' = \sum_{t=0}^{T} RR_3' \times (L_t - D_t) + \sum_{t=0}^{T} RR_3' \times D_t = \sum_{t=1}^{T} LMP_t \times L_t$. Therefore, no matter how the rate changes in the second compensation method, customers' payments stay the same. There are listed three retail rates for the second compensation method when profit of LSE is set to zero. Table 2.2 reveals the above situation.

RR_1'	$\sum_{t=0}^{T}(LMP_t \times L_t) \,/ \sum_{t=0}^{T}(L_t - D_t)$
RR_2'	$\sum_{t=0}^{T}[LMP_t \times (L_t - D_t)] \,/ \sum_{t=0}^{T}(L_t - D_t)$
RR_3'	$\sum_{t=0}^{T}(LMP_t \times L_t) \,/ \sum_{t=0}^{T} L_t$

Table 2.2 Retail rate for compensation method, LMP

Table 2.3 compares all retail rates and customers' payments,

Retail Generation Rate	Consumer Payments
$RR_1' > RR_1$	$CP_1' > CP_1$
$RR_2' = RR_2$	$CP_2' > CP_2$
$RR_3' = RR_1$ and $RR_3' > RR_2$	$CP_3' > CP_1$ and $CP_3' > CP_2$

Table 2.3 Comparison of two compensation methods

2.5 Benefits of Order 745

In this chapter, benefits of applying Order 745 will be introduced. In this way, people can notice the advantages of applying Order 745 and the court may change the idea about rehearing the Order.

2.5.1 Effectiveness

As mentioned at the beginning of the article, one of great benefits of the Order 745 is it facilitates DR to balance energy supply and demand. It is needed to keep the wholesale energy markets operating effectively. During that process, DRR encourages its customers to reduce electricity consumption in response to price signals which will be introduced in the Demand Response part later.

2.5.2 Functioning and Competition

In Order 745, the FERC greatly removes barriers of participating in wholesale energy market for demand response resources to support competitive wholesale energy markets. Under the Open Access Transmission Tariff, demand response programs are supposed to be treated same as generation and they are allowed to participate into the wholesale energy market without restrictions. Furthermore, to ensure functioning of demand response, transmission provider is required to share it transmission pathway to all resources, including demand response, without bias. Therefore, those resources can compete with each other equally. Associated with Order No. 719, RTOs and ISOs can accept bids when demand response performs as ancillary services competing with other resources on a comparable basis under the permission of the Commission. The Commission also required each RTO and ISO to modify its existing market rules to reflect energy price during an operating reserve shortage. All the processes mentioned above can effectively encourage the innovation and participation of new generation and demand resources.

In addition, order 745 enormously helps demand response to increase competition although great competition may bring fluctuation of the energy price for the wholesale energy market. Therefore, the Commission is responsible for regulating the compensation methods that ensures electric energy at fair, reasonable and practical rates. In Order 719, demand response can expand the wholesale competition that turn out to be effective only when consumers are being provided with enough supply options, development and innovation of demand response are highly encouraged, performance of demand response resource is improved, energy cost is affected and then saved, and customers perhaps get rid of risks.[12] To ensure the functioning and competiveness of wholesale energy markets, several ways are going to be demonstrated. First of all, demand response not only facilitates RTOs and ISOs in balancing supply and demand but also helps electricity maintain at just and reasonable prices when its bid is directly guided into the wholesale market. The customers will provide a feedback signal, which informs the RTO or ISO and energy market that they would like to reduce energy consumption, in response to the reduced-load signal stimulated by RTO/ISO and energy market. According to report provided by PJM, a small amount of decreased load will lead a larger amount of dropping price. For example, a three percent reduction in load has equivalent effect of a 6 to 12 percent price decline at peak load hours. In a word, demand response has the ability to flatten load curve. High-priced resources also will be less dispatched with help of demand response. Ultimately, the cost of producing energy will be lowered as well. Secondly, demand response provides electricity reliability in the short-term and resource adequacy in the long-term. More importantly, it can mitigate generator market power. A power supplier has to undertake the risk that it may not possess the ability to dispatch the electricity if the bid price is too high. The downward pressure comes from participation of demand response. Last but not least, when energy outage or blackout suddenly happens, demand response resources are capable of bringing electricity grid back into balance quickly. For example, in the winter of 2014, when people in the Northeast area greatly used electricity to keep warm inside their house, a disaster came to them. Because of severely cold weather, up to 20% of power plants were off-line. Luckily, demand response stimulated customers to reduce their electricity usage by 1,900 MW in parts of the Midwest and Northeast which is covered by ‘PJM Interconnection’.[13] Hence, demand response can potentially support system reliability, which means to prevent forced outages and blackouts from happening, and solve the challenges and problems from unexpected loss of generation to sustain functioning of the wholesale energy market.

2.5.3 Compenstation Method

There are several reasons, such as unique state authority and transmission congestion, which may cause difficulties unifying compensation methods. Therefore, the Commission gives its permission to each RTO and ISO so that they can develop their own compensation methodologies. In this case, the compensation levels for demand response will differ tremendously among RTOs and ISOs. There are listed three different compensation methods below. For example, in PJM Interconnection, it pays demand response with the LMP minus the generation retail rate. Although the ISO-NE tested both LMP and LMP-RR payment, demand response is still compensated by LMP when prices jump over the threshold level. Usually, the setting threshold points are quite different between the RTOs. According to Midwest Independent Transmission System Operator Inc.'s (Midwest ISO), demand response resources are paid LMP in both day-ahead and real-time markets.

There is a saying that one of the reasons causing so many disputations is various compensation methods among ISOs and RTOs. In this research, there eventually proposes one optimal method for compensating demand response based on current methods. The method probably can mitigate controversies.

2.6 Discussion in Order 745

There are many discussions on compensation level of demand response resources, net benefit test, measurement and verification, cost allocation and the Commission jurisdiction. The Commission here hopes to reach uniformity and conclude the final determination through plenty of comments on those different subjects.

2.6.1 Compensation level

If both generation and demand response resource offer equivalent service to RTOs and ISOs, the NOPR will promise to comparably treat and compensate generation and demand response providers for their cost. It states as well that the proposed compensation was intended to encourage participation of demand response resources in wholesale energy market. Moreover, investment fee will be fully covered as an encouragement method if it is related to technology of demand response such as advanced metering. Before the final determination, the Commission expected various comments on compensation, especially on comparability and flexibility of generation and demand response resources. Commenters also give opinions about approaches to compensate demand response. For instance, when payment of LMP should be effective by hours or in what kind of condition LMP should apply in hours. Additionally, the Commission sought comments on net benefits test in supplemental NOPR.

Some commenters announce that a MW increment of generation is physically comparable to the same amount of electricity decrement. For the purpose of balancing supply and demand in both energy markets, they have same influence. These commenters believe that demand response can play as a superior service to generation by providing a quick response in advanced meter system and saving money from constructing new energy generation facilities. Therefore, substitution of demand response for generation will create great system flexibility when some parts of the generation do not functionally work. Moreover, they insist that distinguishing the physical characteristics between generation and demand response is not only difficult but also unacceptable at present. Demand response will improve the competition of market that forces manage load and indistinguishableness treatment in advance. Therefore, they suggest that demand resources must be paid LMP same as generator is paid if their bids are accepted by the grid operator for the purpose of reaching grid balance. Other commenters hold different opinion against that generation is physically equal to demand response. For example, Public Service Electric and Gas (PSEG) argues that one MW drop of consumed energy created by demand response is incommensurable compared to the contribution made by a MW energy generated by generation. In its defense, demand response is usually used to operate only in a limited number of times during the peak period. According to a report of PJM, demand response only effectively performs 10 times and six hours between each response during the entire summer peak period. In contrast, generators are available for deliver power from time to time except when there is scheduled maintenance and unpredictable outages. The argument sticks with the idea that although demand response resources can become backups for generation resources, the service provided by the generation resources still is superior to service provided by demand response resources because demand response has huge positive effect only for a short time. For a long period operation, demand responses becomes unnecessary most of time. They continue pointing out that demand response aims to reduce energy consumption while generators are able to serve electricity consumption. Their argument is that demand reduction does not turn on the lights. Demand reduction can only allow extra electron created by the reduction to serve a different customer. More importantly, generating plants are able to support a power system functionally without any demand response. On the contrary, demand response cannot serve a power plant alone. Moreover, traditional generators can provide system with ancillary features such as governor response or reactive power voltage support. Those features cannot be guaranteed by demand response resources.

Economically, there are two totally opposite attitude about the comparability of demand response and generator. Some people indicate that any compensation methods for demand response beyond LMP minus the generation (or G) component of the retail rate are unjust and unreasonable because demand response provider will receive overcompensation at this point. It does bring demand reduction but break the economic efficiency. The double-payment is also one kind of overcompensations when compensation is LMP. In double-payment, demand response providers will receive not only the cost savings from not consuming an increment of electricity at a retail rate but also a LMP compensation for not consuming the increment of electricity. Simultaneously, any compensation except LMP-G, like paying LMP, will gain company unreasonable profit and break the efficient balance even benefits of consuming electricity exceed advantages of being compensated at LMP. From Dr. Hogan's viewpoint, in order to achieve economic efficiency, demand response compensation has to be implemented at the LMP under real-time pricing situation. But in reality, it is impossible currently. While he believes that compared to pay LMP, it is better to balance demand responses and generations if payment to demand response compensation is the amount of LMP-G or other approaches. Based on the argument of the New York Commission, when the payment to demand response is LMP-G, there would be a problem in tracking retail rates among multiple utilities would result in an administrative burden of tracking retail rates for the multiple utilities. The administrative burden of tracking rates may produce undue confusion for retail customers. There would be administrative difficulties for state commissions and ISOs/ RTOs as well.[14]

Some commenters would like to believe that demand response resource acts like a sale and resale energy resource because it purchase the power in the day-ahead market and resell it in the real-time market. Some of them even assert that demand response providers perform much better than a reselling energy because it actually possesses the electricity. On the other hand, other commenters state that there won’t be too much demand reduction if demand response providers compel their customers to purchase and resell electricity. They firmly believe that it is erroneous and flawed to treat demand response as one kind of energy being purchased and then resold. Actually, the Commission officially rejected former definition of demand response as a reselling energy in EnergyConnect. Under the Commission’s description, demand response is more like a service rather than a reselling energy.

Other demand response supporters disagree with Dr. Hogan’s judgement that paying LMP for demand response will break the balance between demand response resources and generators. They think compensation to demand response at LMP providers does not create more advantage for demand response over generators. They demonstrate that Dr.Hogan’s arguments ignore various locations in the wholesale power markets, exaggerate limits of the Commission’s jurisdiction, misunderstand affects caused by unstable condition such as fuels pricing, environmental attributes, participation, and so on. The arguments also fail to account for other complex parts such as difference among prices, equipment operational requirements, etc.

Besides physical and economic aspects, a lot of commenters separately compare the environmental effects triggered by both generation and demand response resources. Environmental Defense Fund (EDF) reports that current market prices easily neglect issues created by generation. Traditional generations generate power with air pollution and greenhouse effect; power plants occupy huge lands; maintenance fee of those plants are high. These social impacts will become especially fluctuant at high load period. It is obvious that demand response does not produce greenhouse emission at all. Therefore, demand response should be compensated more than LMP. On the contrary, some people suggest that paying LMP for demand response is meaningless because it merely encourage load to be switched off but still being compensated. Under this situation, some generations which are not under management of advanced meters produce more greenhouse gases and air pollution.

Some commenters suggest not paying demand response LMP in all hours because it won’t bring net benefits to customers from time to time, especially at off-peak time. They hold opinions that demand response providers can be only praised at LMP when advantages of dispatching demand response carrying energy reduction from are over cost of paying demand response resources as net benefits or cost-effectiveness test describes. According to experience, net benefits can reach enormously huge at peak period which potentially means demand response has apparently positive affect at peak period and a cost effective test may be unnecessary. Thus, some commenters consider that the purpose of either of these two tests would be to decide in what condition payment of LMP can apply. The equilibrium point will be set at the time when the benefits created by reducing load are equal to the payments to demand response. People those who against use a net benefit test firmly believe that a net benefits test is not only one reason to reduce competition but also costly and complex to implement. No matter what the compensation for demand response resources will be, the generation and demand response should be properly compensated based on the contribution they devote to the system. Moreover, the rules can be applied to both resources.

From all feedback stated above, those feedback are split in different groups. The Commission gets to summarize and conclude those opinions into several compensation levels for demand response resources. One part of them is paying the LMP for demand reductions in all hours in both day-ahead and real-time energy markets, another group insists that it is appropriate to compensate demand response LMP for energy consumption reductions it contributes only when it is cost- effective, and the rest opposes compensation LMP for demand reductions under any conditions believing that it will lead a distortion or over-compensation. When the Commission makes the judgment of these diverging comments, it will both consider restriction from economic analysis and take the practical realities of how markets work into account as well because the compensation method involves no technical part when policy associated with regulatory mission. Since the Commission concludes three general conditions, it begins to response to those conditions respectively. First of all, based on the various comments and record from ISOs, the Commission agrees that compensation of LMP to demand response resources should be set under the conditions that the payment is cost-effective determined as the net benefits test described. When the following two conditions meet, any payment except the

LMP from an RTO or ISO to demand response is unjust and inappropriate. Moreover, the marginal value of the resource is revealed. The first condition is that DRR is capable of providing the service as a substitution to generation resources in order to help to maintain the balance between supply and demand. The requirement of the first condition is availability of dispatching demand response anytime when it is needed. The second condition is that payment of LMP for DRR is proved to be cost-effective when demand response is dispatched as an alternative resource.

As introduced before, it is cost effective when dispatching DRRs reduce the amount of customers' bill. While it still may lead an increased cost per unit to with the decreased amount of load. There are three components that may result in the difference, the LMP value of demand response, the total amount of dispatched demand response, and the changing capability of energy market that is the most important key component. However, from customer's point, cost-effective condition is that when implementing demand response does bring a demand reduction at LMP, the total amount, which customers pay for demand response resources, is greater than the money spent in getting access to the resources. For example, assume that a market has capacity of 200 MW and $50/MWh LMP without DR. Currently, there is dispatched a 10 MW of demand response where LMP is $40/MWh. With the participation of demand response, the total payment to generators and load will become $8,000 instead of former $10,000 while the reduced LMP is now being paid by 190 MW which is less than the previous load, 200 MW. After calculation, every remaining customer only needs to pay 42.11/MWh ($8,000/190) that decrease a lot from the previous payment, $50/MWh. Therefore, it is cost-effective to pay LMP to demand response in this example. In comparison, customers have to endure a net loss when the reduction of total cost does not bring a decrease of each customer's payment. For instance, similar example to last one, change the adding LMP of demand response to $48/MWh. The total payment to generators and load will become $9,600 instead of former $10,000 while the reduced LMP is still being paid by 190 MW. This time, every remaining customer needs to pay 50.53/MWh ($9,600/190) that increase slightly compared to the previous payment, $50/MWh. From this result, it can be referred that payment of remaining customer apparently increases. Hence, customers experience a net loss. In this situation, implementation of the net benefits test can appropriately help RTO or ISO judge which condition customers will go through. Without the net benefits test as a reference, the RTO's or ISO's economic dispatch would have no choice but to select the lowest bid demand response even it potentially increase payment of customers. From second example, it can be concluded that dispatching of demand response resource would bring a higher price payment to remaining customers than payment to the next unit of generation if the demand response resource is not much cheaper than the generation. Then customers will suffer a net loss. While the lowest demand response resource will still stay at first dispatching order because of most competitive price. This situation cannot be considered as a cost-effective condition so that demand response cannot be allowed to join in the market. In order to prevent similar situation happening in the reality, the billing unit effect must be taken into account as a standard to decide whether and demand response resources when demand response is ready for implement. Therefore, in order to prevent a net loss for customers, the application of the net benefit test is necessary to determine when the total benefit produced by reduced LMP from dispatching demand response resources surpasses the cost of those resources under requirement of the Commission.

Even some commenters point out that it is incorrect to pay consumers for not consuming electricity, the Commission states that DRR is worth being compensated for consumption reduction because demand response can achieve the function as generation can, keeping the balance of the market. Those commenters who point out the inappropriateness inadequately understand an extraordinary characteristic of demand response resources. It is necessary and important for demand response to offer an instantaneous balance to maintain reliability of the market. Therefore, the Commission makes its statement that demand response resources should be compensated at LMP for the contribution it can provide to the organized wholesale energy markets.

Although great efforts has been proceeded to facilitate demand response, barriers still remain and prohibit the willing of demand response to participate in the wholesale energy market. The Commission wants to exclude barriers here. Appling appropriate compensation method can accelerate the removing barriers processes. The formation of these barriers usually contains several parts. First of all, the change of dynamic retail prices is unpredictable; real-time information is confidential under each power companies; there are not enough technologies and incentive methods informing their customers about the changing retail price; the connection between wholesale and retail prices is vague and undefined. The Commission concludes that paying LMP can help to remove current barriers for new demand response providers and potentially informed them that they will be fairly compensated. Elimination barriers for demand response certainly will increase investment of demand response resources. It also encourages more people and groups to research and develop the resources. Moreover, the Commission also recognizes that removing barriers does not mean that DR providers will be preferential treated. Instead, it raises great competition for both generation and demand response. During the completion, demand response resource has to not only balance supply and demand but also carefully face competition from other demand response providers. Therefore, the Commission needs to clarify the correct competition methods as well after simply removing barriers. In this part, the Commission points out that demand response resources shouldn't be paid LMP-G in all hours. First of all, as mentioned before, when net benefits test decide that demand response resources are cost-effective, demand response resource ought to be compensated at LMP. Additionally, these arguments fail to realize that existing barriers to demand response is the main reason leading an imperfect market. Paying LMP to demand response has been proved to be right compensation way to remove barriers. Moreover, the comments of paying LMP-G are built on the supposition that demand response is regarded as an energy which may be purchased and sold in the energy market. This assumption has already revised by the Commission. The Commission encourages in a single pricing rule that will not be easily changed even difference in market structure, state regulatory environment, and resource mixed during the ISOs and RTOs. When demand response can balance under the net benefits test, no matter what differences are, it is a cost-effective and alternative resource in the wholesale energy markets. It can be compensated at LMP. Only further report and data release that there are huge differences may bring change to payment of demand response resource, the Commission will check and make decision on that payment method. Meanwhile, any one of conditions happens, the balance will be broken. The net benefit test cannot be satisfied and the demand response is not cost-effective any more. The Commission's findings in this Final Rule do not reject other approaches to compensation. Actually, the Commission authorize each ISO and RTO to develop own compensation method only if it is just and reasonable.

2.6.2 Net benefits test

This part is mainly about whether net-benefits test should be applied or not. As mentioned in the last part, net benefit test is usually used to regulate when it is necessary to compensate demand response with energy price related to LMP. There were still different opinions about how to use net benefit test before the Commission made its final call. First of all, some commenters think it is unnecessary to utilize net-benefit test. They suggested using a static threshold, a net-benefit trigger, which is determined by ISO or RTO. As an example, NYISO compensates demand response resources when the price hits the threshold. Currently, the NYISO uses $75/MWh as its static bid threshold in the day-ahead demand response program. Different with setting a stable and static threshold point, other commenters believe that it cannot actually represent for changes occurred in electricity. It may even bring inefficient dispatch of demand resources. Instead, they assert that using a dynamic bid threshold can become more determinable when LMP payment applies. For those people, they think that static bid threshold prevents the participation of demand response programs. Therefore, a static threshold cannot simply deal with changeable energy market prices while a dynamic one can. However, other commenters still think that net benefit test is very important to decide when compensation of demand response at LMP will be cost-effective. Therefore, identification of those hours is essential as well. .

In order to resolve problems discussed above, the Commission prepare two distinct requirements for implementing the net benefits test. First of all, before the Commission decide the cost effectiveness condition for demand response resources, either ISO or RTO is required to run the net benefit test. Each RTO and ISO needs to identify a price threshold by analyzing historical data and supply curve of previous year. RTO and ISO have to take monthly basis into account as well. In a summary, based on the historical data such as supplying curve, the ISOs and RTOs make a judicious decision on exact point to set the monthly threshold. Moreover, the threshold price needs to be updated every month to keep the data vivid. Actually, the approach of setting threshold price adopted here may be available in the situations that the payment to demand response is cost-effective even it is not LMP or that demand response is compensated at LMP but it is not cost-effective.

Some commenters indicate that if demand response resources were paid LMP-G, a net benefit would become unnecessary. Meanwhile others argue that a net benefits test may ruin the former decision that DRRs have to be compensated at the LMP. Therefore, the Commission notes that a demand response resource should be compensated and treated equally as a generation resource should be because it is able to balance demand and supply in the energy market under cost effective condition, regulated by net benefit test. Hence, there is no reason to simply compensate demand response resources less than LMP for not using net benefit test.

The Commission also requires each RTO and ISO to develop an additional research besides constructing the net benefits. The research must contain the exact time information when LMP payment to demand response resources can directly bring customers net benefits. In order to make the result more accurate for dynamic dispatching of RTO and ISO, the dispatch algorithms of RTO and ISO need to be combined with billing unit effect. The billing unit effect theoretically helps make sure that dispatched demand response resources are in cost-effectiveness level. It cannot be denied that the more information of dispatch algorithms Commission can grasp, the more precise result, data will be. Therefore, it is necessary for RTO or ISO to develop an investigation, no matter in which form, individually or comprehensively, examining both costs and effects of a dynamic net benefit test implement when demand resources is being dispatched in both day-ahead and real-time energy markets. More importantly, the billing unit effect needs to be taken into consideration as well.

2.6.3 Measurement and Verification

As defined by the Commission, demand response curtailment can be regarded as reduction in actual load while the NOPR did not set either verification or measurement for it. Therefore, RTO or ISO has to take its own responsibility verifying and measuring the availability and effectiveness of demand response programs. This part discusses that every demand response participant develop unique baseline which is founded by RTO and ISO based on historical data. Moreover, the baseline will become the standard representing for the total dispatched amount of demand response to the wholesale market. Similar to compensation methods, each RTO and ISO has its own measurement and verification technique. Techniques are different depending on the characteristics of demand response providers. Some commenters think that measurement and verification become especially important because they greatly affect the completeness of a demand response program. The compensation method about paying DR LMP in all hours is challenged here as well because there will be errors to measurement and verification. Paying LMP in all hours not only swings the accuracy of measurement and verification but also misrepresents customers' normal electricity usage, especially during a long period. Therefore, ISO-NE suggests that pay demand response LMP in a limited amount of hours or days so that a demand resource could successfully and effectively clear in the energy market. Another saying is paying LMP in all hours gain demand response unjust profit for demand response because of baseline technique. Any shifts from baseline will be rewarded. It is totally different from the original goal getting compensation when load is shifted from high to low LMP hours. The management of shifting loads for all hours may become more and more difficult in the future even that paying LMP in each hour is not a current issue. Some commenters believe that in order to avoid disputation on measurement and verification method, the measurement and verification method should be uniformed. However, each RTO and ISO has own operation standard. Therefore, it will be difficult for the Commission to unify all measurement and verification of different RTOs and ISOs just like compensation methods. The Commission clarifies the importance of measurement and verification to demand response programs. Moreover, the Commission admits the diversity of measurement and verification for various RTOs and ISOs. But those measurements and verifications must serve under certain rules, Phase I and Phase II organized by the North American Energy Standards Board (NAESB). The Commission continues to state that paying LMP to demand response has already be declined by net benefit test. In conclusion, the Commission claims that ISOs and RTOs have to run their measurement and verification under current requirements and develop appropriate modifications. Each RTO and ISO has to submit documents explaining how its measurement and verification protocols set baselines.

2.6.4 Cost Allocation

Most commenters think that the cost allocation is one way to keep demand response compensation level just and reasonable. Moreover, cost allocation is highly believed to have close connection with net benefits. There are five methods for cost allocation listed by commenters and usually each regional company is supposed to select and employ its own a method.

Since cost allocation can address the negative balance which caused by the difference between the money owed by RTO to resource and the profit directly obtained from loads, the commission eventually decides that a cost allocation method is necessary to warrant that ISOs and RTOs are capable of recovering the total expenditures coming from demand response. Most of methods of cost allocation suggested are abandoned. A correct cost allocation method defined by the Commission is that each RTO and ISO allocates its costs based on the same proportion amount of demand response which is dispatched to all entities. From the report submitted by the RTOs and ISOs, the modified cost allocation method appropriately assign separate cost to those entities who take advantages on the demand reduction.

2.6.5 Commission Jurisdiction

Some commenters show their concerns about how to standardize demand response compensation in the wholesale energy market. They think it will significantly affect generation retail rate involving compensation for demand response. The concerns also catch several state commissions' and LSEs' attention because commission jurisdiction potentially affect the compensation of demand response. As an example of commission jurisdiction, wide implement of advanced meters and demand response programs have already raise efficient usage of energy. Because of the success of implement, the Commission's decision plays an important part in helping demand response program work better in the wholesale energy market. However, the Commission's jurisdiction to set the compensation for demand response is questioned by other commenters. Those commenters assert that it is retail regulatory authority to not only consider locational policies but also set appropriate compensation level. There are some commenters announcing that even the retail regulatory cannot directly interfere the wholesale market, it impose changing retail rate design or reducing probability participation on demand response through commission compensation level. On the contrary, some commercial customers support the Commission's authority on setting the compensation level. The Commission is used to be officially offered such broad authority including correct market flaws. In addition, retail rates represent for a combination of locational condition. Therefore, the Commission cannot require demand response compensation to be LMP minus retail rate. It is beyond the Commission's jurisdiction.

To address disputation, the Order first admits that the Commission is authorized to determine compensation level for demand response. This means that ISO and RTO has to accept demand response bid which is regulated under the Commission.[15] Actually, it is tough to merge the Commission's jurisdiction with state and federal jurisdiction because the Commission cannot perform any rules or actions beyond state laws or decisions. Furthermore, the Commission also cannot remove barriers for demand response regardless of state's regulation. However, the main purpose of the Final Rule is not encroaching state's right. It is to facilitate the Commission to make sure that the rates are charged at just and reasonable, not preferential. Therefore, the Commission doesn't need to restrain demand response compensation because of some commenters' opinions about abusing state regulatory authority. The Commission is to keep the wholesale energy at just, reasonable, not unfair or preferential rate.

Chapter 3 Demand Response and Locational Marginal Price

3.1 Deamond Response

Demand response basically helps its customers reduce energy consumption. The customers are willing to produce a reduction from their normal electric energy consumption in response to the signal of an increasing price of electric energy or incentive payments that are designed to conduct lower consumption of electric energy. Especially when electricity usage reaches at critical time or electricity price is high enough, demand response resource will inform their consumers to reduce electricity consumption. Demand response can also be regarded as a method of managing consumer consumption of electricity. Generally, when demand response occurs, there are two ways that how customers response to requirement of reducing electricity consumption due to high price. First, customers directly reduce their demand according to retail rates based on wholesale prices. Secondly, customers provide demand response as an alternate resource to balance supply and demand in case that emergency happens in organized wholesale energy markets.

3.1.1 Difference between DR and dynamic response

Demand response mechanisms usually shut off in respond to explicit request which may in many forms. The dynamic demand devices passively shut off when there sense stress on the grid. For example, when frequency of the grid drops, the dynamic demand devices choose to close for take back the balance of the grid. On the contrary, if the frequency passes the threshold, the dynamic demand devices will turn on creating more load consuming extra power.

3.1.2 Demand response resource

Generally, DR resource represent for a resource that is able to offer demand response. Wide implement of demand response resources is believed to have positive benefits. Those benefits can enhance reliability and stability of DR operation, minimize congestion and transmission constraints, avoid unstable price, increase the economic efficiency of deregulated electricity markets, and mitigation of potential market power.[16] Moreover, all of these benefits can also bring profits, reduction in electricity price, to its customers. In a word, as an alternative resource to generation, DR resource greatly achieves its function balancing the system when demand response resource is cost-effectively dispatched.

Here is the statistics directly revealing how much electricity and money are saved through DRR. According to US 2006, a reduction of 5% of peak demand, about 37,853MW, has been created in the US, thereby avoiding construction of 625 combustion turbines which may save the cost around $2.4 billion. Then with savings from avoided transmission and distribution, it can rise to $3 billion per year. The reason causing these benefits is advanced metering infrastructure (AMI) which is one of DRR programs.

Moreover, the number of peak load reduction increases to 5.8% in 2008.[17] In the summer of 2011, the number even reaches at 8.5%.[18]

Even there are so many benefits in DRR programs, existence of DRR's barriers still cannot be ignored. For instance, both residential and small commercial customers would not like to participate in those programs. They do not care about time-varying pricing either. Because compared to their other expenditures, saving from their total electricity costs are relatively small. For some large industrial customers, they also do not perceive the importance of load management. Normally, they are obligated to reduce demand under demand response programs. Besides low participation in DRR, the continuing changing policies about how to control DRR create ambiguous future of demand response resources. Furthermore, state regulators cannot accept the modified measurements quickly and it takes time to make a decision through conferences. Last but not least, judgement may differ between state regulators and the Federal Energy Regulatory Commission. State regulators probably particularly focus on the states' right and profits. Take this as an example, only state regulators can deal with the costs caused by implementation of DDR under no matter FERC support or not. Locational tradition, culture beliefs and absence of related knowledge also becomes barriers for wide demand response resources application. For instance, most of customers still think electricity price is static and unchangeable.

3.1.3 Demand response programs

The main purpose of demand response programs is to decrease customers' electricity consumption or shift peak consumption based on their preferences and lifestyles. Moreover, demand response programs can be split into two categories, time-based programs and incentive-based programs.

The time-based programs are about to handle dynamic price as the rate are fluctuant synchronously with the change of the real time cost of electricity. Therefore, the time-based programs will flatten the load curve in order to provide a reasonably high electricity price at peak time and relatively low electricity price during off-peak period. The time-based programs contain Time-of-Use (TOU) program, Critical Peak Pricing (CPP) program, and Real Time Pricing (RTP) program. As a common time-based program, TOU program determine the electricity price based on production costs in the same period. Thus, the price will be always cheap in low load period, moderate in off-peak period and almost high in peak period.[19] In summary, if the customers are willing to accept the price offered by the TOU program and shift their electricity consumption hours, there is no doubt that the peak demands will be effectively decreased and loads will be easily transferred from peak to off-peak period.

On the other hand, different from the existence of the direct price rate signals varying from time to time in the time based programs, incentive based programs mainly encourage customers participation. The programs provide inducement or incentive signals to their customers. According to incentive based programs, feedback from customers are difficult to estimate and measure. Instead, incentive-based DR programs rely on a more reliable and accurate instrument or software to manage costs and preserve reliability. The incentive based programs consists of Direct Load Control (DLC), Emergency Demand Response Program (EDRP), Interruptible/curtail able service (I/C), Demand Bidding/Buy Back, Capacitiy Market Program (CMP), and Ancillary Service

Markets (A/S). As one of the common incentive-based programs, DLC will remotely turn off or shift usage period of a customer's electrical equipment for a short time if the unpredictable condition, like system reliability contingencies, happens. In exchange, their customers enjoy bill credits or other compensation methods. By the way, operation of DLC program will typically be active at peak hours. Figure 3.1 illustrates the participation amount and load reduction for both time-based program and incentive-based program.

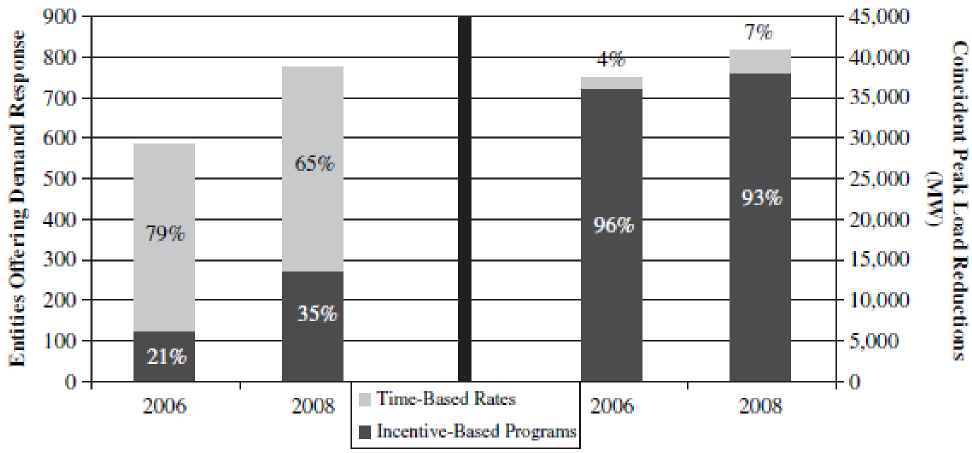

Figure 3.1Application of Demand Response Programs in 2008 in the U.S.

From the chart, there were about 275 entities who participated in the incentive-based DR programs in 2008. And those incentive programs were capable of providing nearly 38,000MW load reductions. On the other hand, time-based programs were able to produce another 2,700MW though the participation of the time-based programs reached 505 entities that is greater than incentive participators. About 93% of the peak load reductions in the U.S. were provided by all kinds of incentive-based programs.

3.2 Local Marginal Price

Basically, ISOs or RTOs calculate LMPs at certain nodes, zones or locations within the ISO or RTO footprint. LMPs used to compensate generators. In this research, LMPs are used as compensation to demand response. There are variations ways how RTOs and ISOs calculate LMPs. In the Final Rules of Order 745, nothing is intended to change RTO and ISO methods for calculating LMP. More importantly, LMP is the method to determine price at different locations

In ideal situation, the system has no constraints and losses so that electric energy can flow to any node without any decrement through the transmission lines. Therefore, all LMPs will be the same. The generator with the lowest energy price would effectively serve the whole system. In reality, LMP usually differs from most locations. The cheapest megawatt cannot access all location of the grid because of existence of constraints and losses. These two situations will be analyzed in 3.2.3 part.

3.2.1 Three components in LMP

There are three components in the LMP. It will be easy to understand in this way LMP = System Energy Price + Transmission Congestion Cost + Cost of Marginal Losses[20]. ($P_{Lmp} = P_{Ref} + P_{Loss} + P_{Congestioni}$)

The energy component of all LMPs is the price for electric energy at the reference point that is the load-weighted average of the system node prices.[21] In a simple word, the system energy price is optimal without congestion and losses. And price will be the same in every bus. Sometimes, it is known as clearing price. Congestion price is the price under binding constraints condition. The calculation of it contains two parts, marginal unit constraints and sensitivity factors. The congestion component reveals the marginal cost of congestion at a node or the node price of average load-weighted of the system at external node. The loss component at a particular node or external node reflects the cost of losses. The loss price represents price of marginal losses and it will vary from different location. More importantly, all those three components of LMP have to be calculated in both day-ahead and real-time situation.

3.2.2 Day-Ahead and Real-Time LMP

Literally, the day-ahead LMP must be calculated in the day-ahead market. It applies different kinds of information, like the energy offers and bids price, from participants of all available location in the day-ahead market. The calculation is based on some components such as constrained unit, dispatching model flows, system conditions, least-cost, and so on. The main purpose of calculation is to minimize the three components of LMP, the costs of energy, congestion, and transmission losses through a linear method.

The calculation of the real-time LMPs uses each market participant's energy offer information. The optimized dispatch of energy is key component of this calculation. Similar to the calculation of the day-ahead price, the calculation of the real-time LMP utilizes a linear method to optimally minimize the cost of three LMP components. But this calculation also needs to minimize the costs for lasting operation. The actual changeable system condition should be put into consideration as well.

3.2.3 Simple examples of LMP

Ex.1 System with no constraints displayed as Figure 3.2

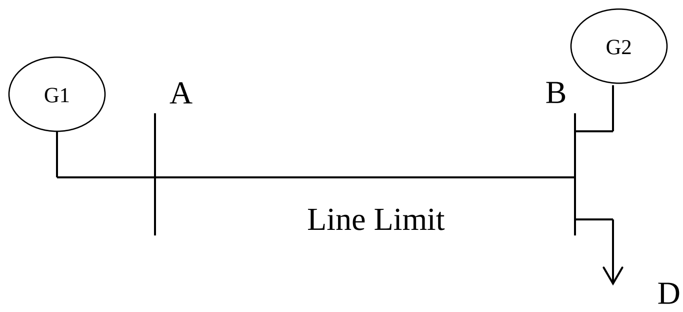

Figure 3.2 A simple example of two generators and two buses

In this example, G1 has capacity of 150MW, and the energy price is 20$/MWh

G2 has capacity of 150MW as well, and the energy price is 25$/MWh

Load, D, demands 90MW

Line Limit is 100MW

Since the demand from load is 90MW which doesn't exceed the line limit, the whole energy from G1 is directly delivered to load. Therefore, it is unnecessary for G2 to supply any energy. G1 is the only one marginal assert in this example. The LMP at A and B bus will be the same. $LMP_A = LMP_B$ = 20$/MWh

Ex2. System with a binding constraint

Same diagram but with different data,

G1 has capacity of 150MW, and the energy price is 20$/MWh

G2 has capacity of 150MW as well, and the energy price is 25$/MWh

Load, D, demands 120MW

Line Limit is 100MW

In this situation, demand becomes 120MW. While energy generated from G1 can only achieve 100MW due to the line limitation. The rest 20MW need to be supplied by G2. Price at the location of each marginal asset is always equal to its offer or bid price. Then there will be two marginal asserts and unique LMP at different locations. LMP_A = 20$/MWh and LMP_B = 25$/MWh

In conclusion, in no constraints area, some low cost generation can be dispatched to cover the demand so that the price will be decreased. On the other hand, LMPs differ at different locations because of congestion in the system. Moreover, it is impossible to sever all loads with low cost. Higher-cost generation has to be dispatched to supply the rest demand from load which may relatively increase price at these locations.

3.2.4 LMP calculation in matlab

When the case becomes more and more complicated, it is difficult to judge how much power needs to be produced through each generator in order to get minimum payment. Therefore, matlab will facilitate to optimize the process. First, here is a simple example helping us know how to calculate LMP in the matlab.

Ex1. Two units, U1 and U2, are required to generate such amount power in order to satisfy such amount of power demand.

Unit 1: $40/MWh, P_{min} = 0MW, P_{max} = 800MW;

Unit 2: $50/MWh, P_{min} = 0MW, P_{max} = 600MW;

Demand: P_d = 700MW, 50 MW at bus 1 and 650 MW at bus 2.

And transmission line constraint is L MW which will be given later.

Figure 3.3 represent for a simple LMP calculation example in the Matlab.

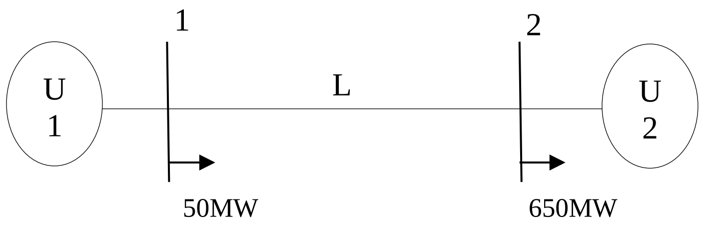

Figure 3.3 LMP calculated in matlab

To get result from matlab program, some formulations have to be established ahead.

Minimize: $40P_{g1} + 50P_{g2}$; to get minimum total cost

Subject to: Pg1 + Pg2 = 700; the amount of energy generated by two units must satisfy the total demand

$0 \le P_{g1} \le 800$

$0 \le P_{g2} \le 600$; low bound and up bound

$P_{g1} - 50 \le L$; unit one should supply energy no more than demand at but 1 plus line constraint L

Aeq * x = beq

Aineq * x ≤ bineq; eventually, x will be solved representing for energy generated at unit 1 and 2 respectively

In this example, we assume that L equals 500MW

Matlab code:

```
f = [40; 50];

Aineq = [1, 0];

bineq = [550];
```

```
Aeq = [1, 1];

beq = [700];

lb = [0; 0];

ub = [800; 600];

x0 = [];

options = [];

[x, fval, exitflag, output, lambda] = linprog(f, Aineq, bineq, Aeq, beq, lb, ub, x0,options)
```

Solution:

P_{g1} = 550MW and P_{g2} = 150MW

Total cost = 29,500

Energy marginal price: $50/MWh

Based on this example, the load at G1 node increases from 50MW to 51 MW, several equations will change

$Pg1 + Pg2 = 701$

$P_{g1} - 51 \leq 500$

Then solution:

P_{g1} = 551MW, P_{g2} = 150MW

Total cost = 29,540

Since total cost increment is: 29540-29500 = 40, so the LMP at G1 is: $40/MWh.

Similarly, if the load at G2 node increase to 651MW, the solution will be:

P_{g1} = 550MW, P_{g2} = 151MW

Total cost = 29,550

Since total cost increment is: 29550-29500 = 50, so the LMP at G2 is: $50/MWh. Then use same approach to verify the former raised problem.

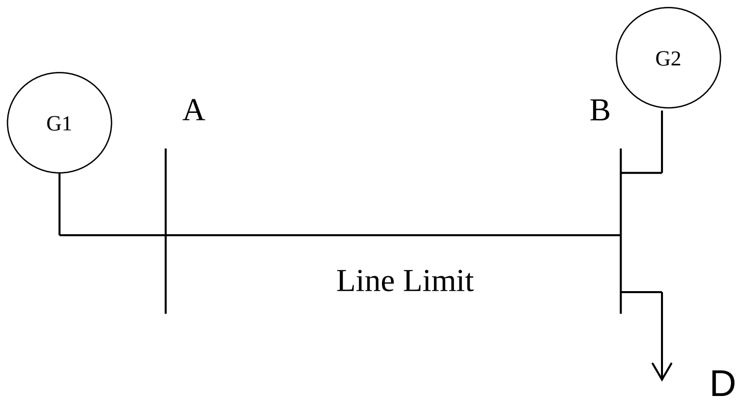

Figure 3.2 A simple example of two generators and two buses

Code:
```
f = [20; 25]; %cost coefficients
Aineq = [1, 0];
bineq = [100];
Aeq = [1, 1];
beq = [120];
lb = [0; 0];
ub = [150; 150];
x0 = [];
options = [];
[x, fval, exitflag, output, lambda] = linprog(f, Aineq, bineq, Aeq, beq, lb, ub, x0,options)
```

Result becomes: x = 100.00000; represent for energy distributed at G1

20.0000; G2

fval =2.5000e+003 ; total cost will be $2,500

Energy price is $25/MWh

Still change 1MW at bus 1 and bus 2 respectively

Then: If demand at but 1 becomes 1MW

Pg1 = 101MW, Pg2 = 20MW

Total cost = 2,520

Total cost increment is: 2520-2500 = 20, LMP1 = $20/MWh

Similarly, if D = 121MW

Pg1 = 100MW, Pg2 = 21MW

Total cost = 2,525

Total cost increment is: 2525-2500 = 25, LMP2 = $25/MWh

It is obvious that the result is same to the approach I used to work the problem objectively.

But in real world, line constraint will be more complicated than a constant number. The following example when line constraint is complex number, how to work out the problem. Before the example, here is a knowledge point needed to be known about p.u. system. In a p.u. system, when power is transferred from point 1 to point 2, like picture, Figure 3.4 tells how to perform complex number calculation in a p.u. system.

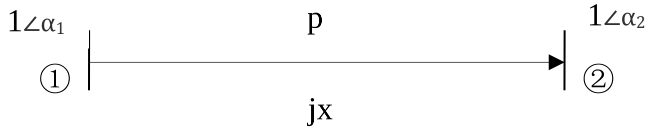

Figure 3.4 Complex number calculation in p.u. system

Then:

$p = (\alpha_2 - \alpha_1) / x$; α_2 and α_1 are in radius

In this case, constraints will be easily obtained in a complex problem.

Ex2. Unit 1: \$40/MWh, P_{min} = 0MW, P_{max} = 800MW;

Unit 2: \$50/MWh, P_{min} = 0MW, P_{max} = 600MW;

Unit 3: \$55/MWh, P_{min} = 0MW, P_{max} = 600MW;

Unit 4: \$60/MWh, P_{min} = 0MW, P_{max} = 700MW;

Demand: P_d = 1500MW, and load distributions are shown on the figure.

Transmission line impedances in per unit and constraints are labeled in the figure. S_{base} is set to 100MW. Figure 3.5 reveals a more complicated problem.

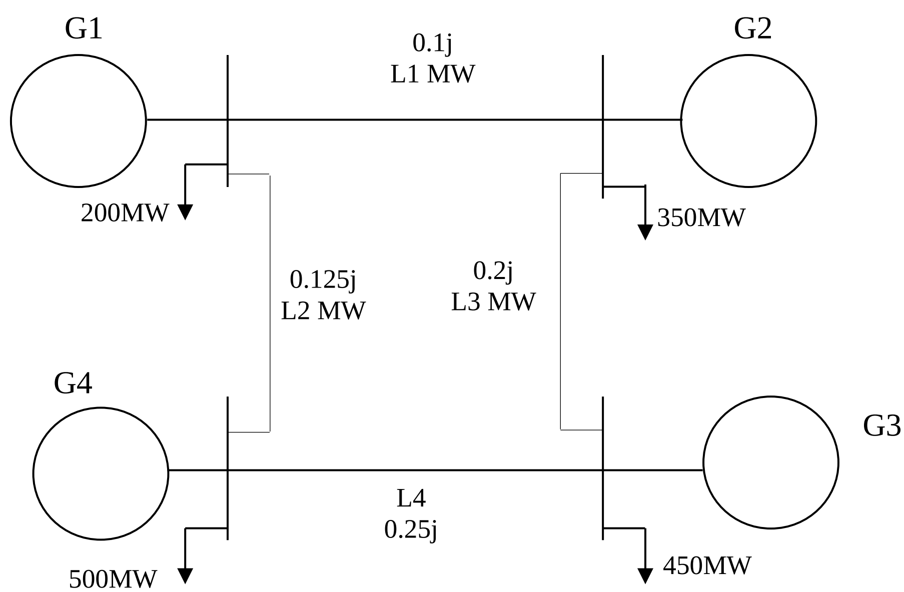

Figure 3.5 LMP calculation of a complex problem in the matlab

Bus 1 is chosen as the reference, $1\angle 0°$. Moreover, δ_2, δ_3 and δ_4 represent machine angle for G2 and G3 respectively.

Minimize: $40P_{g1} + 50\ P_{g2} + 55P_{g3} + 60P_{g4}$

Subject to: $P_{g1} + P_{g2} + P_{g3} + P_{g4} = 1500/100$

$P_{g2} = (\delta_2 - 0) / 0.1 + (\delta_2 - \delta_3) / 0.2 + 350 / 100$

$P_{g3} = (\delta_3 - \delta_2) / 0.2 + (\delta_3 - \delta_4) / 0.25 + 450 / 100$

$P_{g4} = (\delta_4 - 0) / 0.125 + (\delta_4 - \delta_3) / 0.25 + 500 / 100$

$\delta_2 / 0.1 \leq L1$

$- \delta_2 / 0.1 \leq L1$

$\delta_4 / 0.125 \leq L2$

$- \delta_4 / 0.125 \leq L2$

$(\delta_2 - \delta_3) / 0.2 \leq L3$

$- (\delta_2 - \delta_3) / 0.2 \leq L3$

$(\delta_3 - \delta_4) / 0.25 \leq L4$

$- (\delta_3 - \delta_4) / 0.25 \leq L4$

$0 \leq P_{g1} \leq 800 / 100$

$0 \leq P_{g2} \leq 600 / 100$

$0 \leq P_{g3} \leq 600 / 100$

$0 \leq P_{g4} \leq 700 / 100$

Aeq * x = beq

Aineq * x $\leq$ bineq

Simplify above formula and apply them into matlab.

If L = [250, 200, 200, 250] MW

Code:

```
[L1, L2, L3, L4] = deal(2.50, 2.00, 2.00, 2.50);

f = [40, 50, 55, 60, 0, 0, 0];

Aeq = [1, 1, 1, 1, 0, 0, 0;
```

```
        0, 1, 0, 0, -15, 5, 0;
        0, 0, 0, 1, 0, 4, 12;
        0, 0, 1, 0, 5, -9, 4];
beq = [15; 3.5; 5; 4.5];
Aineq = [0, 0, 0, 0, -10, 0, 0;
          0, 0, 0, 0, 10, 0, 0;
          0, 0, 0, 0, 0, 0, -8;
          0, 0, 0, 0, 0, 0, 8;
          0, 0, 0, 0, 5, -5, 0;
          0, 0, 0, 0, -5, 5, 0;
          0, 0, 0, 0, 0, 4, -4;
          0, 0, 0, 0, 0, -4, 4];
bineq = [L1; L1; L2; L2; L3; L3; L4; L4];
lb = [0; 0; 0; 0; -inf; -inf; -inf];
ub = [8; 6; 6; 7; inf; inf; inf];
x0 = [];
options = [];
[x, fval, exitflag, output, lambda] = linprog(f,Aineq,bineq,Aeq,beq,lb,ub,x0,options);
```

Solution:

x = [8.0000; 2.3750; 1.1250; 3.5000; -0.2000; -0.3750; 0.2500]

Total cost = $71,062.5

Chapter 4 The Proposed Compensation Method

This research proposes one possible compensation method for demand response, which could unify current compensation methods. In the approach, the basic concept is that the demand response providers will get compensation in amount of how much energy customers save. Figure 4.1 shows the basic concept of optimal compensation method.

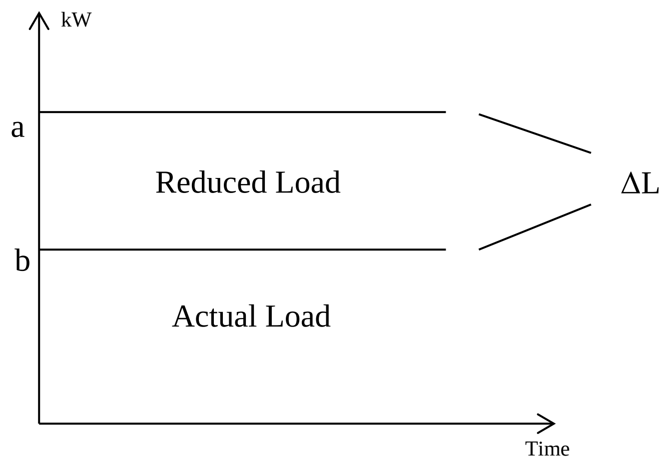

Figure 4.1 Brief introduction of compensation method

At point a, suppose there is a certain amount of kWs which is obtained in the day-ahead market. Point b represents the value actual load value detected by smart meter. Ideally, the compensation to demand response resources should be $(a – b) \times \Delta L$. The approach is mainly about to compare and combine all current compensation methods and then get one optimal method in this research. According to experience, net benefits can reach enormously huge at peak period which potentially means demand response has apparently positive affect at peak period. Therefore, a cost-effective analysis will be unnecessary at peak-load period. Demand response will be compensated at LMP during peak-load period.

The following chart similarly represents the energy consumption in one community. In this chart, there are two lines representing for energy assumption in day-ahead market and real-time energy consumption respectively. Figure 4.2 is a close simulation to a real problem.

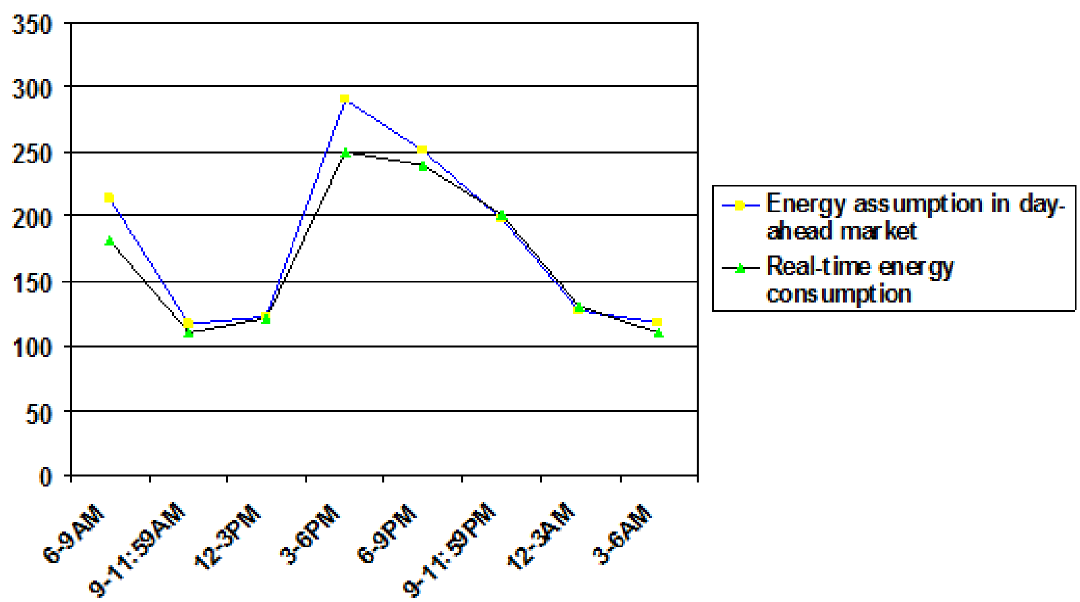

Figure 4.2 Statistic applied in real situation

Suppose LMP is 30$/MWh;

Total compensation = (289.9-250.17) × 30 × 3 = $3575.7 ; at peak period 3-6PM

This is a simple example which has similar to reality. But as mentioned before, day-ahead market is hourly calculated and real-time market calculate per 5 minutes. Therefore, the different units need to be carefully recorded and calculated when the data are measured. No matter how complicated data it is, the result will still be available with the help of advance metering technique and certain measurements.

At Low demand period, demand response can play as an emergent supply to generation in case that disaster and outage happens. Just like the example mentioned before, demand response resources were active to inform their customers to reduce energy consumption to maintain the grid balance because 20% power plant was off-line caused by a disaster happened in the Northeast area in the winter of 2014. In this situation, when demand response resources are active, they still need to be compensated at LMP. The contribution of demand response at emergent period cannot be ignored. Meanwhile, the customers of demand response resources will be compensated with certain credits for paying electricity bill in the future as well.

At off peak period, net-benefits test or cost effective test becomes especially important to determine whether demand response resources should be compensated at the price referred to LMP or not in this approach. If the net-benefit test or cost effective test proves that it is reasonable to pay demand response with price related LMP, demand response will be compensated at amount of $LMP - M_i$,where M_i contains the money of implementing cost effective test.

Chapter 5 Conclusion

The court is about to rehear the case, Order 745, in order to prevent a setback to demand response in the wholesale energy market. This research provides discussions of demand response, locational marginal price, and Order 745. There may be limitations on current demand response compensation methods, which may cause disputations among different parties. Based on existing methods, this thesis proposes a possible compensation method for demand response, which may be reasonable and may lessen disputations.

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University of Kentucky, Spring 2012-2013 General Academic Scholarship Shanghai
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WORKING EXPERIENCE
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EE 383 Lab (10/1/2013–5/1/2014) – Volunteer to work in the lab under permission of Dr. Meikang Qiu. Assist the professor and his TA with embedded system work.

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