Fostering Residential Demand Response through Developing Proactive and Elastic Demand Approaches. An Overview DR

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Abstract

Demand response (DR) is one of the major stakeholders in the smart grid and has been used as an energy reconciler between supply and demand. After a literature overview, the importance of the paper is enhanced by having a theoretical and behavioral-based analysis of DR in power systems. In this work, the potential factors that influence more DR among customers and the residential market as a whole have been discussed. The customers? elastic demand approach can pave the way for adapting a responsive demand mechanism that ensures the system reliability and cost effective measures. Alternatively, this approach can make the program more effective and supportive in serving the social welfare as whole.

Index terms— demand response, demand elasticity, pricebased demand response, incentive-based response, customer behavior.

Muhammad Hussain ? , Yan Gao ? & Zhihong Xu ? benefits for both entities (customers and suppliers) by focusing on consumption and supply pattern. Home energy management systems can play an important role in residential energy usage and home appliance technology coupled with rising populations. According to the World Business Council for Sustainable Development, approximately 40% of global energy consumption and 30% of carbon footprint are attributable to residential and commercial buildings [3]. This will likely lead to frequent blackouts and power curtailment during peak periods as well as rises in electricity prices.

The Demand Response (DR) is one of the potential solutions under smart energy management schemes that create a balanced manner between consumption and supply. According to the U.S. Department of Energy (DOE), demand response is a program established to incentivize the customers to change their normal consumption in response to changes in the electricity prices or when there is an emergency situation in the system [4]. The program further classifies into price-based DR (PBDR) and incentive-based DR (IBDR) [5]. In PBDR, customers reduce their normal consumption for price rise signals or emergency situations [6] [7]. The PBDR programs including real time (RTP) and time of use (TOU) energy pricing, which reduce power consumption during peak periods by utilizing peak and off-peak price differentials. IBDR refers to customers receiving financial benefits from reducing electricity consumption during the time, when the system experiences stress while providing additional power demand [4].

An important factor in the design of DR program understands how demand changes in response to incentives or tariff changes, which in economic terms is called the elasticity. Before the deregulation of the electricity network, elasticity was mainly used as a tool to understand customer load consumption and load forecast analysis [6]. In today's power market, elasticity is a powerful tool that is used to design demand response programs, especially for small customers.

DR programs that blend together customer education initiatives, enabling technology investments, dynamic pricing and customer behavior can achieve demand impacts that can alleviate the pressure on the power system. The objective of this paper is to foster the he electricity management from production to transmission pose a permanent challenge for smart grid and power utilities. The increasing power demand with limited power amount puts pressure on power system, especially when it comes to widening peak-valley. With the development of information and communication technologies, demand side management (DSM) has become an important way improving the reliability of power systems by interacting both supply and demand [1]. The smart grid technology has made it possible to limit the customers' role in receiving the data and load rate through application of smart appliances at both demand and supply side. However, since DR provides an opportunity for the customers to regulate the real time grid conditions, the customers also deserve some of the benefits for their participation [2].The customers have two options in performing energy consumption, whether to participate voluntarily or for utility satisfaction. In this case, the volunteers forego their satisfaction over system reliability but the utility satisfaction will count when the total benefits, received by the customers, are more than comfort deviation (loss of satisfaction) due to peak reduction. The potential of DR further ensures the DR by active participation of demand side sources. As consumers become more aware of daily price fluctuations and respond through load curbing and shift to non-peak times (i.e. doing laundry at night). It has been witnessed in the literature that there are some cases where the immediate price signals and incentives are not available by communication infrastructure limitations. However, the rapid penetration of the smart metering systems has enabled real-time monitoring of the electricity consumption in the households. For instance, in Finland more than 80% of the households are equipped with smart metering technology capable of measuring the accumulated electricity consumption for each hour of the day. Thus, the dynamic pricing is technologically possible and such products are expected to appear to the market.

The potential of dynamic pricing has been discussed in [7] and customers prefer incentive-based DR to compensate financially against peak reduction. The customer elasticity of incentive-based DR has been discussed in the study [8] where the load is divided into two categories, flexible and non-flexible, in order to integrate the actual responsiveness of incentives. But the consumption patterns in response to price changes are entirely varying with time and scale. Here the paper needs to include the PBDR along with IBDR and is because end-user behavior needs two things, reward on peak saving and punishment on over consumption. The paper [9] has discussed about the distinction between IBDR and PBDR and used IBDR as a useful program that further prefer IBDR as customer friendly and motivated program but the general acceptance or rejection of program is always based on proactive behavior. It's because, customers are of two types; risk aversive and risk taker, the moment every individual behaves according to his/her possibility or time space. Similarly, in [10] suggest that people subject to punishment are more anxious and less satisfied to respond the PBDR and secondly people are more likely to accept the IBDR on their following peak shaving.

This paper focuses on ways and sources to foster residential DR by having a thorough study of related literature. In the current literature, there more has been discussed about the price and income elasticity and its estimation with consideration of DR but still such factors and sources that make DR more effective and successful among the residential customers have not been discussed thoroughly. In this work, a theoretical background has been driven and proposed a schematic modification of DR on the base of demand side management and some consumer behavioral capacities have been driven that play more potentially.

Demand response (DR) refers to the responsiveness of the customer's normal consumption patterns in response to changes in the price of electricity over a specific time interval [11]. DR facilitates the reduction of power consumption and conserve the energy. In addition, it maximizes the capacity utilization of distribution system by reducing or eliminating the need to build new lines and power infrastructure. DR includes all intentional electricity consumption modifications by end-use customers that are intended to alter the timing, level of instantaneous demand, or total electricity consumption [12].

DR programs can roughly be classified into the following main categories according to the party that initiates the demand reduction action:a) Price-Based Demand Response (PBDR)

The price based DR program depicts the actual cost for the electricity from production to the distribution in a system. In PBDR, consumers are granted time varying prices that are defined based on the electricity cost in different time periods [5]. The utilities are charged different prices according to end-user consumption behavior. The time-of-use scheme is split into two periods of peak and off-peak with high and low rates, respectively. The dynamic tariff rates motivate customers in reducing electricity consumption and shifting load from peak to off-peak in order to balance between supply and demand. The program further contains a real-time price (RTP) and time-of-use (TOU) scheme that reflect the marginal value of continuous electricity according to real-time power supply and the price charges on time. Prices are not predetermined but are subject to hourly changes.

Price-based (DR) can change the consumption pattern of the customers by price leverage in the power market. The analysis of the regular pattern between customer's power consumption and changing prices is important in the research of DR, which will affect the price setting in power market and the economic benefit of market bodies. Price elasticity of demand is a common measure used in economics to analyze the responsiveness of the quantity demanded of a good or service to a change in its price.

1 b) Incentive-Based Demand Response (IBDR)

Incentive-based (DR) schemes, incentive payments are paid to customers against the reduction of power when the system gets jeopardized or stressed [13]. In this program a set of demand reduction signals are issued by utility companies or the DR aggregators to the customers in the form of voluntary demand reduction requests or mandatory commands. Under the program utility providers can manage to supervise the demand side through direct controlling of the appliances or interrupting loads at certain space of time.

2 c) Communication -Based Demand Response (CBDR)

In this type of DR program smart technologies are commonly used in the residential areas and are connected with some local area networks (LAN) that enable the utilities to receive and update the electricity consumption data from customer side. One of the most advanced communication tool is advanced metering infrastructure (AMI) that measure hourly usage data and signal further to the provider in real time [14]. There are certain cases in the residential sector that power bills often arrive at month's end with only an aggregate usage number, which makes tracking energy usage difficult for consumers. This is why, the lack of smart technology can create information vacuum between demand and supply that further affects more power outages and line losses in power system [15].

3 II. Overview Of DR At household Level

4 d) Rate-Based Demand Response (RBDR)

The rates are predetermined and charged dynamically based on various times of the day/week/year and the available reserve margin. Customers are informed before going to use and inserting appliances. The customers would pay the highest prices for peak hours and lowest prices for offpeak hours. The customer would respond voluntarily to the changes in the electricity prices.

5 e) Demand reduction bids

DR enables customers to manage the consumption pattern by scheduling appliances from peak to off-peak interval and share the saving amount of energy in trading market with demand aggregator. The bids would normally include the available demand reduction capacity and the price asked for. This program encourages mainly large customers to provide load reductions at prices that are convenient and adjustable [16].

6 f) Educating & trained customers

The installation of smart meters and technologies are not sufficient to make the customers educated about how and when to use these programs and take price response. For longer term, the market reforms and customer awareness about the pros and cons of DR program, customer interaction with smart applications will automatically make them alert in response at price increases. The communication infrastructure and smart meters are the essentials to facilitate about price response and demand response capabilities. Every user undertakes different measures under certain parameters, like economic benefits, utility satisfaction, less outages and system reliability. For making system reliable and efficient, customers need to be educated before implementing any pricing or technical policy in a power system. The general awareness among the end-users improve their knowledge about DR program and its acceptability at homes. This is the reason that households may perceive dynamic pricing as complex and not giving importance to personal preferences, because individual behavior shapes household consumption [17]. This study has been carried out with the underline scheme of residential demand behavior by considering a social welfare DR. In this work, focus is on consumers' preferences, motivations, benefits and system reliability under dynamic pricing mechanism. In Fig. 1, effort has been made to capture the origin of DR from the beginning of household end-users. There are different types of DR programs that have been discussed in the literature, mainly referred as pricebased demand response (PBDR) and incentive-based demand response (IBDR), respectively. Less focus has been put on measures and sources that instill the DR smoothly among the household end-users. The order and organization of factors motivating DR among the users have been highlighted that bring changes in consumption behavior of household. The study tried to capture different aspects linked to DR and likewise, the intrinsic link of DR with individual or social terms has also been discussed. More specifically, the purpose of this study is to obtain a wider understanding of the consumers preferences, and consumption behavior related to demand response with the following objectives, a) to draw a literature overview of DR program in respective of residential power scheduling; b) to educate each and every household understanding the DR by organizing conferences or door to door campaigns; c) to explore the factors that foster DR program among users and their motivation for taking part in DR; d) to obtain better understanding of parameters that could influence households' preferences between personal desires/satisfaction and voluntarism and being flexible in the electricity usage; and, e) at what extent DR contributes to the customers welfare.

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This work can be improved by integrating social parameters along with customers' preferences for making DR a willing priority for every customer.

Demand response programs that blend together customer education, enabling technology, and carefully designed dynamic rates can achieve demand impacts that can alleviate the system.

In this part of this paper, we thoroughly discuss and analyze the demand side factors that, by large, give an instrumental shift in consumer consumption pattern. We further, characterize our discussion of elastic demand, price and customer's elastic behavior approach in our next sections.

8 a) Definition and attributes of proactive and elastic steps in demand response

Despite the important role of elasticity in most kinds of DR designs, there are very few studies in the literature that shed a theoretical overview of DR. A thorough study is taken about the factors that promote and excel the DR program among the customers.

9 i. Elasticity of demand

An important factor in the design of demand response programs is understanding how demand changes in response to incentives or price changes, which in economic terms is called the elasticity. It was not so quick and smart communication, between enduser and utility, in the regulatory and traditional system [6]. In today's power market, elasticity is a powerful tool that can be used to design demand response programs, especially for small customers. In smart grid system, having use of DR programs, it is easy to check the customer's interaction level with utility prices through the demand elasticity. It has been discussed in both, IBDR and PBDR about the responsiveness of customers on following changes in price and given incentives. Both of programs, IBDR and PBDR, are recognized as simulators that instill the responsiveness or elasticity among the users on price signals [18] [19].

10 ii. Elastic and smart communication infrastructure

The two-way communication enables customer to receive price signals at every level of time. In return, household individuals set their appliances by taking DR measures against changes in prices and incentives provided by utilities. The combination of dynamic prices with enablingtechnologies presents the most effective measure reducing the electricity consumption during peak hours [20]. With advanced metering infrastructure and communication, there are several benefits to aggregating the response of small residential loads; they can potentially provide more reliable response compared to a small number of large loads; the smaller residential loads may be able to provide a more continuous response than large loads [21].

Customers are equipped with smart meters and communication that can measure consumption at every interval of time and let customers know the price change. In most cases, residential customers have installed AMI by utility providers to take quick and countermeasure against price changes [22]. A recent study, customers are equipped with the device able to reduce their energy consumption by 6.5% compared to a statistically balanced control group that did not have the device.

11 iii. Elastic consumption behavior and voluntarism

In this part, the residential household reacts to the price changes with different level and quantity. If we talk about the DRM, there are numerous factors involved that influence customer's attitude towards a certain plan of action. But, somehow the economic factor has more effective involvement with consideration of dynamic prices and other financial incentives on consumption. In traditional power grids, customers are charged with predetermined and predefined rates at each consumption period that result the customers remain reluctant while participating into smart grid operation. Usually, customer reluctance with DR is not by the customer consumption pattern or behavior but because of other factors like, customers living standard, demographical changes and by other alternative energy sources. The customer participating in the DR program generally categorize into two different levels; the customer taking risk is not usually sensitive or elastic on peak price changes but those who are active and have elastic behavior response the following changes and receiving incentives. Likewise, the customers who have knowledge about environment can have the power shifting passion to the green energy or off-peak time interval. Fig. **??** shows the different reactions of customers on elasticities. Consumer's response at dynamic pricing and other incentives is only possible by deregulated and technology installed market. [23]. However, it depends on consumer behavior that, sometimes, prefer energy conservation over individual satisfaction and willing to accept discomfort against given incentive or reward [24]. Sometimes, customers prefer social benefits over individual comfort and voluntarily participate in DR program.

12 Figure 2:

Customers consumption behavior at different price and time intervals. Adopted from (KIRSCHEN et al) [18].

13 iv. Elastic financial rewards or penalties on consumption pattern

The residential DR remains active as customers are convinced with greater availability of incentives to reduce peak demand that, as a result improve system reliability. It has been witnessed in [10] [25], that the customers subject to penalties are more anxious, less satisfied and less likely to respond, similarly on the other hand, customers are frankly to accept incentives than penalty of higher costs. More often, end-users maintain using the electricity until their marginal benefit is equal to the price paid. By using demand response management, that rely on dynamic pricing and incentives, as the main objective for altering electricity usage by shifting or directly control the load. Though, using prices to control demand is economically efficient as both the consumer and the utility benefits. It creates incentives for consumers to engage in energy conservation and efficiency and increases the options available to the utility provider to maintain security of the supply network [26]. Incentives and penalties have the equal and far lasting impact over consumption pattern, in the sense that small customers are usually risk averse and prefer incentives over penalties. Similarly, there are small customers that are risk taker and manage the consumption accordingly .

14 V. Fostering Dr And Social Contribution

Demand response program can be considered as a subset of customer consumption behavior and smart communication infrastructure that work together for the smart grid. The real time pricing signals and demand levels are transmitted through the smart communication and customers are notified with relevant penalties and incentives at the same time. Fig. 3 shows the measures that enhance the DR smoothly among residential households. The electricity consumption remains different among different customers, the reason is income elasticity of demand and general consumption behavior. In an elastic situation, customers actively participate in the demand response by acquiring financial and technical opportunities at home by suppliers [27]. Enduse customers participate in these DR programs by using either distributed generators or energy management strategies to reduce the load in response to price signal from energy provider. The customers are notified about the varying prices by home displays at each interval of time to set the residential load economically and technically equal. For instance, the real-time price (RTP) and time-of use price (TOU) are the basic pricing mechanism that substantially create an economical DR environment among the customers. Economic DR participates in energy markets not only during emergencies but any time spot energy prices become high. This can make electricity markets more competitive and efficient by increasing the elasticity of demand. Allowing DR resources to compete against generating capacity also limits supplier market power. This can impact on mitigating peak prices and reducing price volatility [28].

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The induction of DR into regulated and constrained electricity market can have potential for lowering the peak costs and have supervise over market power generators. Furthermore, it can increase the long run energy efficiency and system reliability by reducing peak and conserving energy. It has been witnessed in the literature that the monetary benefits are the sole motivation for users to participate in the program [29] [30].

16 b) Environmental DR

Conventional power plants do not maintain the quantity demand and supply efficiently; when end-use customers demand increase, more power plants are constructed to meet the additional demand. Similarly, new technologies are used for generating power during peak time that, on the other hand, pose some harmful environmental impacts. The additional generation of electricity from fossil fuel in power plants releases several contaminants, such as SO2, NOx and CO2 into the atmosphere [31]. The demand side management empower the customer at making decisions that indirectly increases the system reliability, decreases cost and emission reduction and creating some revenue benefits the households.

There are two approaches to protect the environment. The use of emission free renewable energy and nuclear reactors is the first approach focusing on diversification of energy supply. The second is focusing on the demand side conservation of energy, by using energy efficient buildings and appliances. From generation perspectives, many energy policies have been initiated to encourage people to use renewable energy at micro level. Also there is encouragement to use large scale renewable energy mainly onshore and offshore wind turbines and photovoltaic farms.

17 c) Social welfare DR

Demand response (DR) refers to the dynamic demand mechanisms to manage customer consumption of electricity in response to supply conditions, in one of the most important function of smart grid [32]. In the smart grid, it is possible to realize the customer's active participation into demand side management (DSM) that further improve the functionality of DR among the households. The customer participatory DR is based on the combination of social welfare and system reliability, for instance, the maximization of the distributed generation consumption or the power limitation [33]. Similarly, the active DR in a household contains numerous advantages such as reduction of electricity bills, peak load reductions and rationality with energy consumption. At result, customers have opportunity to bid the shaved load into the market when the prices exceed the customer's bid. As many incentives are offered in curtailment of power and organizing the appliances at peak intervals.

18 d) System reliability DR

Demand response (DR) program have been designed and developed for households' optimum satisfaction from utilization in power market. The program further motivates customers on peak shaving and valley filling in order to keep a balance between supply and demand in normal situation and in emergency time. It is associated with the short-term changes targeted for the critical hours when demand is high or reserve margin is low. In the short-term period, DR can improve the reliability of the power system and provide potential benefits for both the utility and the customers. On peak time, the program can reduce the power by scheduling the appliances from peak to offpeak and therefore postpone the construction and investments for the new power plants.

Previous studies have also identified the importance of induction of advance metering infrastructure (AMI) and building automation controls for enabling DR and energy efficiency [34]. In some cases, customers can not participate in these DR programs by using either distributed generators or energy management control strategies to reduce their load in response to a price or emergency signal utility [27]. However, the DR program connects users with smart and secure infrastructure to keep them up-to-date about consumptions, prices and the peak mode for grid safety.

19 e) Renewable energy sources (RES)

The smart grid has enabled the demand response as tool to adapt low electricity consumption pattern by customers from having low-electricity price during off-peak interval. Moreover, DR provides other potential advantages such as building self-electricity generators, lower volatilities in market prices, constructing renewable energy sources as alternative or stand-by generators and providing system reliability. The renewable sources have been preferred to adapt at emergency or peak hours to attain comfort level and reduce further demand at peak hours. In this context, 33% of the energy will be integrated from renewable energy sources in the United States by 2020 [35].

20 VI. Conclusions

The combination of advanced communication infrastructure and dynamic prices are considered the most effective program for reducing electricity demand during peak hours. Customers and utility providers are connected with smart meters by signaling price and demand updates at each time intervals. On the base of customer's consumption pattern, the utilities are entitled to set the price and incentives for reducing peak demand. Similarly, incentives and price-based demand response are used as tool for inducing customers on peak shaving and contributing system with renewable sources. But it depends on the consumer behavior whether to achieve the limited satisfaction or act voluntarily for social benefits (e.g., by selecting voluntarism or self-satisfaction options for longer purpose). For that, households need to go through a learning experience, activating the behavioral changes in interaction with the DR program, continuing the newly acquired behavior. Many different factors besides the prices, incentives and penalties, play an important role in this process: a) to educate each and every household about the importance of DR by organizing conferences or door to door campaigns; b) there is need to develop an elastic demand approach that could react to price changes by utilities. In order to make DR effective, elastic demand approaches through the application of information and communication technology (ICT), consumption pattern, rewards and penalties are recommended for residential customers. More research on elastic demand approach through empowerment of ICT, educating consumer and integrating demand side sources is thus needed. [1]

1

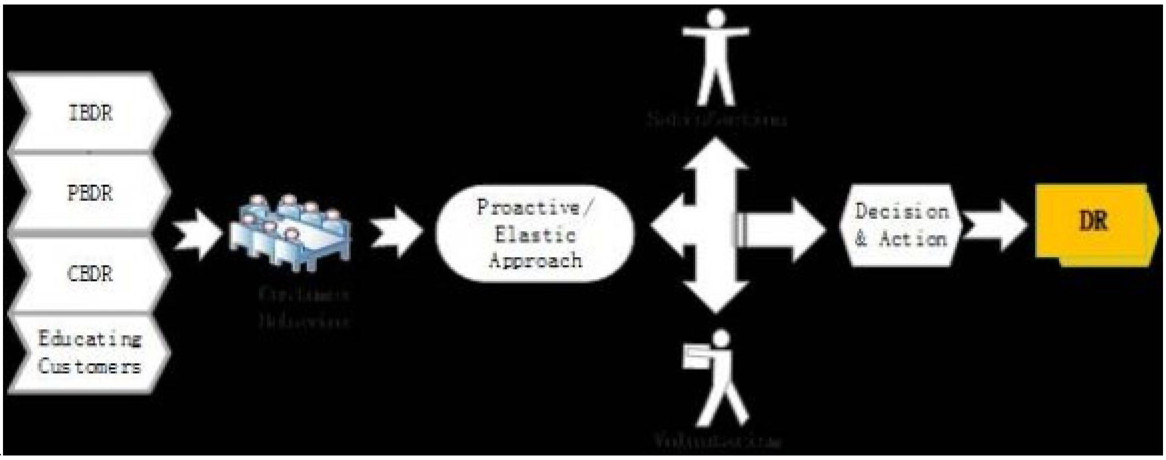

Figure 1: Figure 1 :

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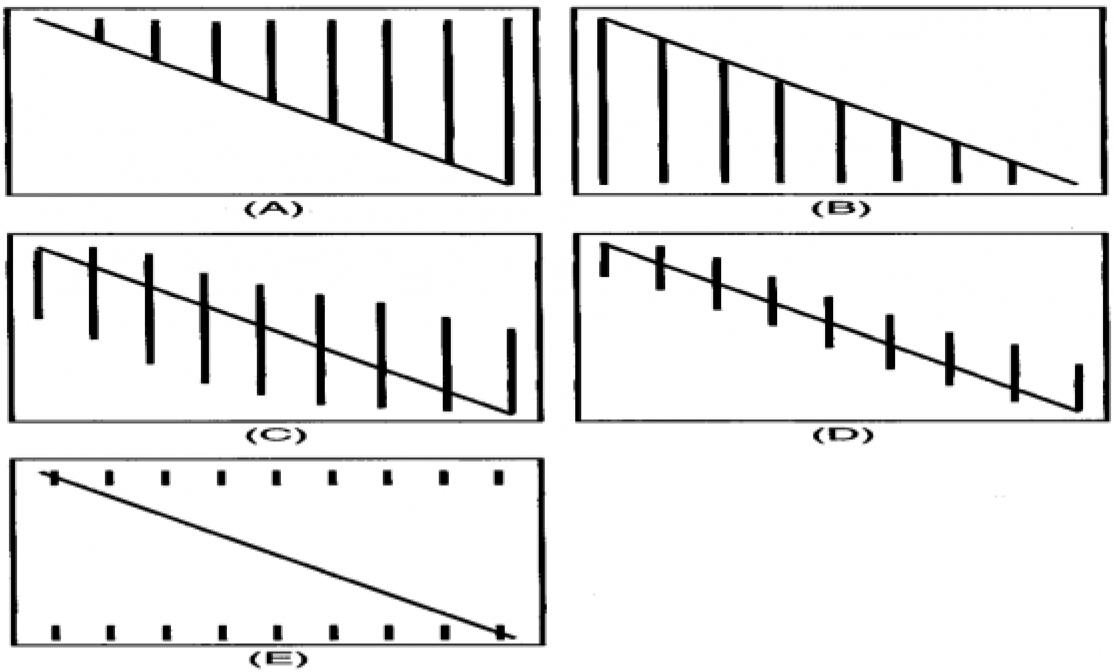

Figure 2: FFigure 3 :

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