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REVIEW OF DYNAMIC PRICING PROGRAMS AND EVALUATING THEIR EFFECT ON DEMAND RESPONSE

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Abstract- Demand response can provide benefits in a variety of ways, such as reducing the need for peak capacity, improving system reliability, reducing the consumption of energy, and reducing externality costs. To change consumers consumption patterns such as moving consumption from peak hours to off peak hours or consuming more in off peak hours and less in peak hours we must provide incentives to manage energy use more efficiently and enable consumers to save money and use demand side programs. The paper outlines pricing programs and evaluates the cost effectiveness of advanced metering infrastructure deployments. Also we evaluate the effect of dynamic pricing programs on demand response.

Keywords: Dynamic Pricing, Demand Response, Smart Grid, Peak Shaving.

I. INTRODUCTION

Many existing power systems are challenged continually with increasing load demand, skyrocketing expansion costs, new generator interconnections, aging equipment with limited capacity, and delays in approvals for building major new transmission facilities. Due to the need to meet peak demands the system must have plant capacity to meet these loads. If we can improve utility operations and reduce peak demand, the cost savings can cover a substantial portion of the multimillion dollar investment. When peak demand is reduced, the need for new power plants to serve peak times is reduced then avoiding the cost of building a new peaking capacity can result in significant savings. The utility world has changed drastically in the last years. New technologies like Smart Meters and fully functional Smart Grid concepts have made large inroads into the utility space and no one should want to be left behind. Utilities also face additional pressures from regulatory bodies who are continuing to encourage carbon reduction and greater customer flexibility [1-3].

Utilities need to balance these new requirements with the financial obligations of providing reliable power while attempting to meet shareholder expectations. Each of these goals are not necessarily complimentary, thus utilities need to determine how to address each one. Some of the ways utilities are addressing these concepts is through the rollout of dynamic pricing for reducing peak load, demand response to shed load during emergency situations or other trying times, large scale distributed generation to reduce usage of fossil burning plants, localized distributed generation or demand response to improve grid balancing or reduce outages.

Using smart meters as a means of providing smart prices to customers that would induce demand response, obviating the need for expensive peaking capacity and energy. The energy crisis was accentuated by the lack of demand response. Demand response can reduce the consumption of energy and costs [4]. Dynamic pricing will make demand more elastic and has the effect of changing the diurnal load pattern by flattening peaks and shifting those loads to off peak hours, since peak prices tend to be higher than the fixed rates customers would otherwise face whereas off peak prices are lower which is the exact change in the load pattern which may increase system flexibility and allow greater use of renewable energy resources. The use of location prices can help alleviate transmission bottlenecks and further reshape the load pattern in different parts of the transmission network to more closely follow the availability of renewable energy [1-9]. While each of these present great opportunities they are also riddled with challenges. Issues arise from how to forecast appropriately the level of customer participation in programs, how to include demand response or distributed energy resources into a utility's operational portfolio, and how to execute much localized demand response to address grid specific issues [10-11]. Each of these challenges are complex and while not all opportunities will be addressed by each utility, any combination of each of these will require a solution that can address operational concerns of how much load will be reduced and how does that impact a utility's procurement generation of power.

In this paper we discuss current research activities in the area of demand response, pricing schemes and then discuss the potential benefits of demand response. In other sections we evaluate the pricing programs effects on consumption patterns and their success in persuading costumers to move their consumption to off peak hours.

Table 1. Demand response programs

Incentive Based Programs IBP	Direct Load Control
	Interruptible Load
	Demand Bidding
	Emergency Demand Response
	Spinning Reserves and Non-Spinning Reserves
	Capacity market
	Ancillary service market
	Load as Capacity Resource
Price Based Programs PBP	Time Of Use, Super Peak Time of use
	Critical Peak Pricing, Extreme Day Critical Peak Pricing
	Flat rate
	Real Time Pricing, Critical Peak Real Time Pricing
	Peak Time Rebate, Variable Peak Pricing

II. PRICING PROGRAMS

There are several pricing programs that have been used all over the world. They can be classified in two groups:

• Static pricing (flat or fixed rate).
• Dynamic pricing.

The most common program is the fixed pricing per kWh of energy consumed. The problem today is that consumers have no interest in cutting power use during the price spikes and they become insensitive to price changes in electricity markets. Most of the inefficiency stems from this insensitive demand. Another problem with fixed pricing is its unfairness. A fixed pricing program causes the consumers who use relatively less power during expensive peak periods to subsidize others.

Pricing must provide incentives to manage energy use more efficiently and enable consumers to save money. Most customers pay a constant flat price for power rather than responding to the changing hourly price of the wholesale market. Flat rate customers have no incentive to shift consumption away from times of peak demand. Dynamic pricing is a term used to describe any rate design that aims to give customers a truer signal of the economic costs of meeting their demand than simple average cost rates. Here we listed some of pricing programs available. These programs are described in Table 2. This is certainly not an exhaustive list, but merely a starting point for further consideration.

Dynamic pricing of electricity is receiving increasing attention in the industry today because it holds the potential for significantly improving the efficiency of electricity markets in both restructured and nonrestructured states. Under dynamic pricing, customers have a strong incentive for using less power when it is most expensive to generate and deliver, thereby helping to bring demand and supply into equilibrium at lower prices than would otherwise be the case.

III. DEMAND RESPONSE AND ENERGY EFFICIENCY

Demand response and energy management have financial and reliability benefits for electricity suppliers and the overall system, also is about increasing responsiveness of electricity demand to changes electricity prices. Demand response can provide benefits in a variety of ways, such as reducing the need for peak capacity, improving system reliability, reducing the consumption of energy, and reducing externality costs [2-4]. It can reduce the consumption of electrical energy and result in savings due variable operating expense from the operation of power plants. The other benefit from demand response is when it reduces peak demand.

When peak demand is reduced, the need for new power plants to serve peak times is reduced then avoiding the cost of building a new peaking capacity can result in significant savings. When the utility encounters a problem, it can send a signal alerting the consumer of the complication so that the consumer can react by reducing their load during this critical time period. This communication can happen manually, such as via email or telephonically, or automatically as in many of the smart meter pilot projects that are in use today. Demand response reduces electricity use with a variety of technologies like simple manual controls to automated digital systems. Demand response can harness direct load control devices, load management controls, smart thermostats, advanced metering infrastructure, and digital energy management systems.

Digital controls can cycle and curtail discretionary loads and automatically be triggered by price or reliability. Energy efficiency usually refers to devices or practices that provide the same level of output or benefit by using less energy. Energy efficiency usually focuses on reducing overall energy use, not just at certain times.

Table 2. Pricing programs

Program	A brief description
Flat Rate	A fixed pricing program that applies during a day
Time of use "TOU"	Divides a day to peak, partial peak and off peak blocks with higher price during peak hours and a discounted price during partial and off peak
Super Peak TOU	Charges like TOU but with shorter peak duration, leading to a stronger price signal
Inclining Block Rate "IBR"	Customer usage is divided into blocks and usage is charged at higher rates in the higher blocks
Critical Peak Pricing "CPP"	during the peak period on event days customers must pay higher price
Variable Peak Pricing "VPP"	CPP rate with added variability
CPP TOU Combination	TOU rate that is applied during most peak hours of the year and higher peak price applies on event days
Peak Time Rebate "PTR"	Charges like flat rate combined with a rebate for demand reduction during peak times of event days
Real Time Pricing "RTP"	A pricing program with hourly variation with capacity costs allocated equally across all hours of the year
Critical Peak RTP	Charges like RTP with the exception that capacity cost adder focused only during event hours

Demand response improves the overall efficiency of the electricity system but differs from traditional energy efficiency in that it is more dynamic and controllable, meaning that it can be dispatched to meet rising demand in lieu of turning on a power plant. Demand response focuses primarily on reducing use during the peak period, and involves providing customers with price signals or time-based incentives to encourage them to reduce their peak use. Demand response can react to conditions in the market or to threats to system reliability. While energy efficiency can benefit from certain policy changes, such changes are not necessary for customers to be able to buy energy efficient items and begins implementing energy efficiency practices. Demand response is different, requiring regulators to approve technology investments by utilities and also approve the introduction of time based pricing and other time based incentives.

IV. SMART GRID TECHNOLOGIES AND DEMAND RESPONSE

The smart grid is revolutionizing how utilities think about their existing distribution systems [2, 3]. Everything from smart reclosures down to smart transformers is changing how the grid is monitored and epitomized. Include new distributed generation that is increasing in use from residential and commercial customers due to rebates and incentivized pricing structures, and the grid has become a lot smarter and volatile than it used to be.

While this volatility can be a challenge, there are major benefits and challenges to a smart grid and especially in concert with demand response and distributed generation. Adding large quantities of demand response or DG to the grid can result in deficiencies that include a potential decrease in power quality, decrease in reliability, unbalanced power flow and potential risk to public and worker safety.

An objective of the Smart Grid is to provide technology and systems (integrated into appliances and consumer devices used in everyday activities) that will allow consumers to automatically manage their energy use and costs. From a consumer perspective, the current grid delivers electricity to their home and it includes everything from the electric meter outside their home back to the power plant. A key feature of the smart grid is demand response, where the consumer, utility or designated third party can reduce the consumer's energy consumption during critical usage periods. Demand response technologies are by definition smart grid technologies. They include products or services that help in the active monitoring and dynamic control of electricity usage. Smart grid architecture would include, but not be limited to, key components such as: Advanced metering infrastructure, data communications, intelligent devices and tools for monitoring, control, and optimization, and other components.

A smart grid will utilize advanced meters at all customer service locations. These meters will have two way communications, be able to remotely connect and disconnect services, record waveforms, monitor voltage and current, and support time of use and real time rate also other pricing structures. The meters and other technologies also allow new and better information to be generated and used by both the customer and electricity providers. This information can be presented to customers via in home display devices, which help customers track and better understand their electricity usage. Electricity pricing information that is delivered to the user, will provide the ability to adjust demand of electrical energy use. Demand response not only reduces demand on the grid during peak periods but in almost all cases produces a conservation effect that lowers overall electricity i.e. the amount that is reduced on peak is not replaced in the off peak period. The deployment of demand response and smart grid technologies can lead to higher and more sustainable levels of energy efficiency.

Table 3. Efficiency of programs

Criteria / Program	Peak shaving ability	Benefits for costumer	Peak reduction ability	Ease for understanding
CPP TOU Combination	medium	high	high	medium
Critical Peak Pricing	low	high	high	medium
Critical Peak Real Time Pricing	medium	medium	high	low
Super Peak Time of use	medium	low	medium	high
Real Time Pricing	medium	medium	low	low
Peak Time Rebate	low	medium	high	medium

V. QUANTIFYING COST AND BENEFITS OF ADVANCES METERING INFRASTRUCTURE DEPLOYMENT AND DYNAMIC PRICING

Utilities are considering the system wide deployment of smart meters but depending on the utility, there is a large gap between benefits and metering costs. One way of solving this problem is to use smart meters as a means of providing dynamic prices to customers that would induce demand response, obviating the need for expensive peaking capacity and energy. While utilities continue to rush to meet these demands, they also need to consider how best to achieve the full return on their meter investments. AMI implementations are normally funded through rate adjustments, or board approved capital expenditure projects that are justified through the benefits of remote readings, connects and disconnects. Those benefits only scratch the surface of the benefits that smart meters can provide. Many utilities are evaluating other benefits, whether that is through load reduction from new demand response programs, or dynamic pricing programs that will shift or reshape load, reduce peak periods, or contribute to spinning reserves. Smart pricing would eliminate an important inequity in existing rate designs. It is important to evaluate the costs and benefits of dynamic pricing and smart metering. At least the utility needs meters, communication and billing systems. Then providing the ability to adjust demand of electrical energy use and cost saving is the benefit that the utility can achieve.

VI. PRICING PROGRAM EFFICIENCY EVALUATING CRITERIA

Suppliers in competitive electricity markets regularly respond to prices that change hour by hour or even more frequently, but most consumers respond to price changes on a very different time scale, they observe and respond to changes in price as reflected on their monthly bills. From the viewpoint of standard economic theory, efficient pricing occurs when marginal cost of supply is equal to marginal value of demand, which also ensures to maximize consumers plus producers surpluses. It must be recognized that existing residential tariffs and rate structures do not provide sufficient economic incentive to spur maximum consumer participation in the use of Smart Grid technologies.

The current structures do not support the cost, innovation and creativity required to make the smart grid a success. Time differentiated pricing schemes are found to be more efficient than the fixed pricing schemes, because of two reasons: they reflect the marginal cost of electricity more accurately than fixed pricing schemes and therefore improve the efficiency of resource allocation and they motivate customers to reduce their electricity consumption in peak loads and shift to off peak periods and therefore reduce the need for new capacity requirement. Success of the smart grid requires dynamic rate structures that are designed to support a total systems approach.

Dynamic pricing is an essential component to consumers and energy providers participating in the benefits of the smart grid system. Strong consideration should be given to the development of uniform pricing and usage information standards that provide for a harmonized way of communicating local rate and timing information. It is expected that the price sensitive consumers would change their consumption patterns such as moving consumption from peak hours to off peak hours or consuming more in off peak hours and less in peak hours. One approach to quantifying customer choice in the context of dynamic pricing looks at the gains in consumer surplus when customers are exposed to marginal instead of average costs.

Consumer surplus is simply the difference in the value that a customer derives from their consumption and the amount that they spent. In an average cost world consumer surplus tends to shrink or go in relation to changes in average prices. The situation changes when timedifferentiated prices are introduced and customers have a choice of shifting as well as reducing their consumption in response to price variations. As customers make rational decisions to modify consumption based on own and cross price elasticity, economic efficiency will improve along with both bill savings and consumer surplus. This formulation thus introduces a new metric that can be used to measure the customer value of demand response options.

From the viewpoint of standard economic theory, efficient pricing occurs when marginal cost of supply is equal to marginal value of demand, which also ensures to maximize consumers plus producers surpluses. A pricing program efficiency evaluating criteria can be: simplicity, ease of understanding, incentive to reduce peak demand and load shifting also value of reliability studies are important because they explicitly introduce the customer perspective into the valuation process.

VII. EVALUATION RESULTS

Considering topics above and experimental data collected from deployment of multiple pricing, demand side programs also considering models for estimating demand response impacts and a model for estimating financial benefits, efficiency of programs were identified and results are described in table 3. In this table we used Low, Medium and High to describe the ability of each rate considering evaluation criteria.

Direct load control programs (one of the demand response programs that we listed in Table 1) and time of use rates are traditional methods those are currently used for achieving demand response. We compared direct load control (DLC) and time of use programs to demand response programs incorporating advanced metering and dynamic rates. Direct load control systems do not motivate customer response, and they raise equity concerns because there is no direct relationship between benefits achieved and incentives paid. Time of use rates are relatively inefficient and ineffective compared to critical peak pricing or real time pricing. CPP/TOU is the most effective program.

VIII. CONCLUSIONS

In order to ensure the reliable delivery of electricity through the grid, there is a whole system of peaker power plants and reserve generation capacities, of which some run at less than full power so they can be quickly ready to handle spikes in power demand. Due to the need to meet peak demands the system must have plant capacity to meet these loads. If we can improve utility operations and reduce peak demand, the cost savings can cover a substantial portion of the multimillion dollar investment. Demand response can reduce the consumption of energy and costs. Recent studies on dynamic pricing found that across the critical peak pricing programs induced a drop in peak demand and usage.

With technology in place to respond automatically to demand response, these falls will be increased. The findings are significant to any operations organization and cannot be ignored when included within the utility's overall generation portfolio plans. Through these studies and existing programs, utilities now have the ability to utilize demand response and pricing programs to consistently reduce or shift peak demand, offset intermittent renewable, relinquish short term contacts and even utilize them to contribute to spinning reserves. Dynamic pricing programs like CPP/TOU, CPP and CP RTP will make demand more elastic and has the effect of changing the diurnal load pattern by flattening peaks and shifting those loads to off peak hours.

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