Study of Various Electricity Load Management Models Under Campus Scale Smart Grid Environment

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Abstract

Electricity consumption management becomes more and more important with urban development and it provides an efficient way to prevent large scale blackout, to reduce environmental pollution as well as to extend the usage period of underground mineral resources. In this paper, we first study various intelligent electricity pricing models such as direct load control, time of use, critical peak pricing and real time pricing etc. which can shift load consumption from peak time to off-peak time. Then, we propose our campus scale demand response platform which integrates various electricity pricing models into it. In this way the electricity operator or utility can apply their specific pricing model to the users or participants who can efficiently manage their electricity consumption in home. Two types of demand response programs are illustrated with detailed working process and simulation results are also provided to show the effectiveness of demand response program.

Keywords*: Smart Grid, Demand Response, Energy Management, Advanced Metering Infrastructure*

1. Introduction

Smart grid [1-3], known as the next generation electricity grid, is expected to solve the main pitfalls of the current electricity network which is the backbone of power industry. In general, the smart grid must help the utility companies or invest owners to efficiently control their assets and services. Also, the smart grid needs to be robust and self-healing to system anomalies and attacks. Finally, the smart grid needs to support two-way interactive communication between electricity users and providers with the aid of smart technologies like demand response program and advanced metering infrastructure etc.

The current electricity network has the following pitfalls which need to be solved by smart grid:

1) Due to the unidirectional communication from utility side, users are lack of information like the current power supply, their historical usage pattern etc so that they can not interactively participate in some demand response programs to reduce their electricity cost.

2) The current electricity transform efficiency is relatively low. Usually, electricity is generated by burning fossil fuels such as coal, oil and natural gas to turn water into steam. Here, the chemical energy is first converted into heat energy. Then, steam will turn steam turbine at high speed under high pressure and turn heat energy into mechanical energy. Finally rotating turbine will generate electricity in a magnetic field, which finally converts mechanical energy into electrical energy.

3) Due to the traditional flat rate price policy, the electricity demand increases very steeply during certain peak time and vice versa during off-peak time. This is not desirable since more electricity generation devices are needed during peak time, which only lasts for short period at high cost.

One possible solution to alleviate the above problems is to introduce intelligent demand response (DR) programs. DR can defined as "Changes in electric usage by end use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized." [4, 5] With the aid of DR programs, many benefits can be achieved. For example, the two way communication can be realized and energy can be more efficiently utilized by reducing peak load and refilling off-peak load. Thus, both utility and users can make financial gains. In the mean time, system reliability can get ensured and blackout probability can get reduced.

In this paper, we first study various electricity load management models. Then, we build our campus scale demand response platform to monitor electricity use in different buildings and integrate various electricity price models into the platform. The working process of two types of price models is explained in detail with simulation results.

2. Related work

Generally, there are two methods for energy consumption management which are reducing consumption and shifting consumption. The first way can be realized by increasing user's awareness of more careful consumption pattern and providing them with more energy efficient devices. The second method is to shift their energy consumption from peak time to off-peak time. Methods of load shaping include peak clipping, load shifting, valley filling, strategic conservation and flexible load shaping [5].

DR programs are keeping to growing and evolving in recent years with aid of advanced metering infrastructure and communication technologies. Some of the pricing programs include direct load control (DLC), time-of-use (TOU), critical peak pricing (CPP) and real time pricing (RTP) programs etc [6-14]. As can be seen in Figure 1 [15], there is a big increase of 117% in the number of entities offering DR programs: 126 in 2006 vs. 274 in 2008 and about 10% increase in the number of entities offering dynamic pricing to retail customers. In the next section, we will study and compare more about these DR programs.

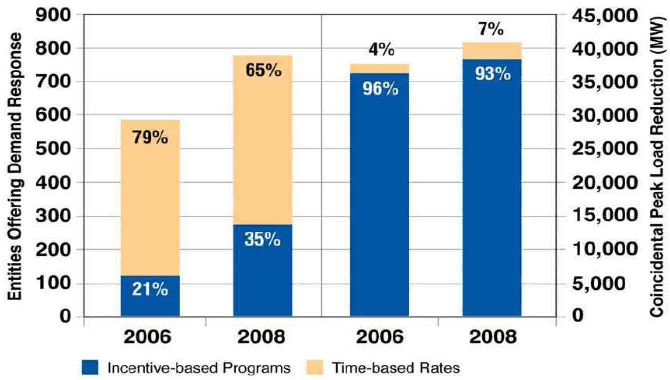

Figure 1. Estimated size of DR resources in the United States

Table 1 provides more DR programs initiated by the U.S. state utility or agency together with the relevant website, through which the readers can learn more about relevant pricing programs.

Table 1. Some DR programs in the U.S.

State	Utility or Agency	Program Type	Homepage Website
CA	Pacific Gas & Electric	Demand Response Programs	www.pge.com
CO	Platte River Power Authority	Custom Load Shifting	www.prpa.org/
CO	Southeast Colorado Pwr Assoc.	TOU Rate - Thermal Storage	www.secpa.com
CT	Connecticut Light & Power	Peak Reduction/Curtailment	www.cl-p.com
FL	Florida Keys Electric Coop	Peak Reduction HVAC Cycling	www.fkec.com
FL	Florida Power & Light	Load Shifting/Curtailment	www.fpl.com
MO	Kansas City Power & Light	Summer Curtailment Credit	www.kcpl.com
NJ	PJM Interconnection	Load Response Programs	www.pjm.com
NY	ConEd (New York)	Load Reduction Incentives	www.coned.com
NY	Long Island Power Authority	Summer Peak Reduction	www.lipower.org
OR	Bonneville Power Administration	Demand Exchange Program	www.bpa.gov
OR	PacifiCorp	Voluntary Curtailment	www.pacificpower.net
PA	PECO Energy (Exelon)	Curtailment Options	www.exeloncorp.com
WA	Puget Sound Energy	Voluntary Load Curtailment	www.pse.com
TX	TXU ED (Oncor)	Emergency Load Management	www.oncorgroup.com

3. Comparison of various electricity pricing models

As is shown in Figure 1 above, DR programs can mainly be categorized into two classes which are time-based and incentive-based programs. The former one includes TOU, CPP, RTP etc. and the later one includes DLC and demand bidding/buyback programs etc.

As one of the important components of smart grid, DR programs gain fast growth after the establishment of the 2005 Energy Policy Act: "the policy of the United States that time-based pricing and other forms of demand response…shall be encouraged, the deployment of such technology and devices that enable electricity customers to participate in such pricing and demand response systems shall be facilitated, and unnecessary barriers to demand response participation in energy, capacity and ancillary service markets shall be eliminated."

3.1. Time-based programs

Time-based demand response programs provide users with time variant electricity price to meet the current supply from electricity utility so that users can interactively change their electricity devices use pattern to achieve financial benefits. In other words, if the price differentials between hours or time periods are significant, users can respond to the price structure with significant changes in energy use to reduce their electricity bills if they adjust the timing of their electricity usage to take advantage of lower price periods and avoid consuming when prices are high.

Time-of-use (TOU) program usually divides a day into several periods and charges different prices for different time periods. The participant are provided with smart meters and/or advanced metering infrastructure devices so that they can obtain electricity price information and manage their energy usage pattern during 24 hours a day. Table 2 gives an example of TOU program.

Table 2. A TOU program example

Program	Period	Charge	Application Time
TOU	Off Peak	$0.048/kWh	Weekday 10pm-10am, weekends, holidays
TOU	Mid Peak	$0.075/kWh	Weekdays 10am-3pm and 7pm-10pm
TOU	Peak	$0.183/kWh	Weekdays 3pm-7pm

Critical peak pricing (CPP) program is a hybrid of TOU and RTP below which usually divides the time periods into an additional period, namely the CPP period when the electricity price is much higher than peak time. In Table 3, we can clearly see the difference between TOU and CPP programs. It is worth noting that CPP program is not frequently called and it usually happens 10 to 20 times a year.

Table 3. A CPP program example

Program	Period	Charge	Application Time
TOU-CPP	Off Peak	$0.048/kWh	Weekday 10pm-10am, weekends, holidays
TOU-CPP	Mid Peak	$0.075/kWh	Weekdays 10am-3pm and 7pm-10pm
TOU-CPP	Peak	$0.168/kWh	Weekdays 3pm-7pm
TOU-CPP	CPP	$0.30/kWh	Weekdays 3pm-7pm, 10 times per summer

Real time pricing (RTP) usually charges different prices on an hourly or minutely based period and it provides electricity to reflect the real market electricity cost. Thus, the price is not known far in advance and no two days have the same rate structure. In this way, the users can largely reduce their electricity cost by avoiding high price period. For example, users will prefer using cheap price period electricity like in the midnight or early morning while avoiding using electricity during very high price period. This also means that utility can reduce their cost by avoiding additional electricity generation equipments and in the mean time users can reduce their electricity bills to certain degree based on their participation in the DR program.

3.2. Incentive-based programs

Incentive-based programs are initiated by electricity providers and/or utilities to give users load reduction incentives. Load reduction is needed or called when the electricity price is too high or system reliability problem arises. For example, when electricity supply can not meet user demand during certain season or peak period, utility will encourage users to reduce their electricity usage during that time by providing them incentives. Usually, customers' baseline energy consumption level is needed to measure the amount of incentive. It is interesting to note that sometimes a penalty is also added inside the contract if the users can not meet the load reduction condition or even overuse during that time.

Direct load control (DLC) program enables utility or system operators to remotely shut down some users' electricity devices like air conditioner and/or water machine in order to achieve load reduction. This program is mainly offered to residential or small commercial customers.

There are several kinds of demand bidding or buyback programs where customers offer bids to reduce their electricity usage during certain period. This program is mainly offered to large commercial or industrial customers. Demand bid program (DBP) pays an incentive to reduce electric loads based on a voluntary bid made for a scheduled load reduction on the following non-holiday weekday. Under this program, participants receive a credit equal to the product of the qualified kilowatt (kW) energy reduction and the incentive price of up to $0.60/kWh. Capacity bidding program (CBP) is a mandatory program that pays you a monthly incentive to reduce your load to a predetermined amount when an electric resource generation facility reaches or exceeds heat rates of 15,000 BTU/kWh.

4. Campus scale demand response platform

Inspired by Table 1 and project in [12], we propose our campus scale demand response platform as is shown in Figure 2. In each of the campus buildings, we install smart electric meters which can send electricity information to individual users. The utility or independent system operator (ISO) can setup their specific electricity pricing policy and remotely control the users' electricity usage pattern through a standard utility interface which is stored in a server named demand response automation server (DRAS). Similarly, the users can interactively participate in various pricing policies through standard participant interface which is also designed and stored in the DRAS. Each user is like a client who can monitor and acquire the timely electricity price information by sending packet request through internet from their own monitoring devices such as a PC or smart meter.

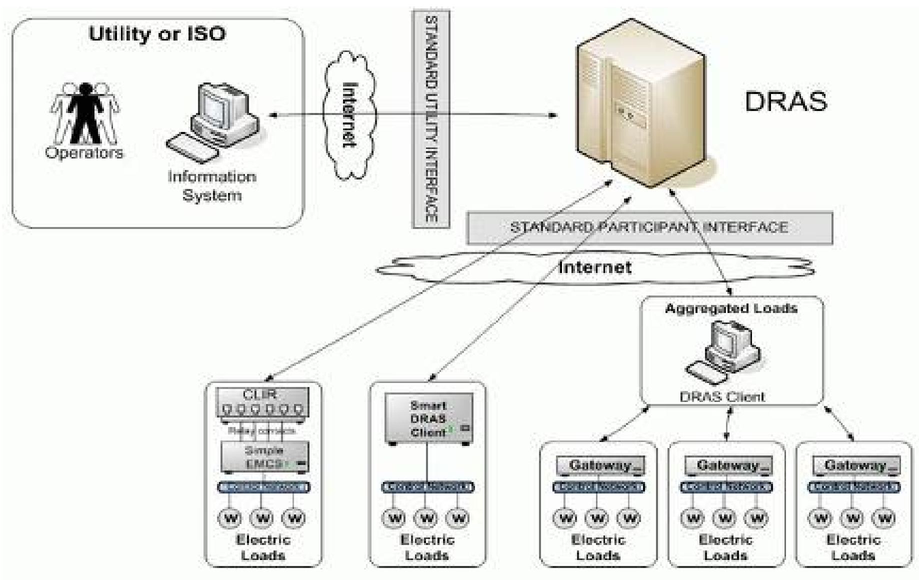

Figure 2. Campus scale demand response platform

Taking time-based RTP program as an example, the utility will release the current electricity price and update it in a real time manner. The users at home can access that information by connecting to the remote DRAS through their own PC or smart device. Then, the users can determine their electricity usage patterns to achieve financial cost reduction.

Taking incentive-based DLC program as another example, once the utility or system operator finds that the electricity demand is approaching the electricity supply, DLC program will be initiated. Based on the priority which is attached to each user beforehand, the system operator will shut down low priority user's electricity or reduce their usage amount to guarantee high priority user's usage quality. It is worth noting that these procedures can be easily implemented into the intelligent pricing models by adding specific algorithms or codes into the models. Due to the space limitation, we will not go into further details in this paper.

Figure 3 provides some simulation results of electricity load reduction and shifting by comparing the actual building electricity use with and without DR program. We can find from Figure 3 that:

i) The electricity demand is relatively high during day time (8AM to 6PM) and low during night time or off work time (from 7PM to 6AM);
ii) The mid peak time is from 12PM to 3PM and the peak time is from 3PM to 6PM and moderate price and high price are charged separately;
iii) The electricity load usage can gets reduced during mid and peak periods by using certain intelligent demand response program;
iv) Some of the electricity load is shifted from mid and peak periods (12PM to 6PM) to off peak periods (6am to 7AM) to achieve financial cost reduction.
v)

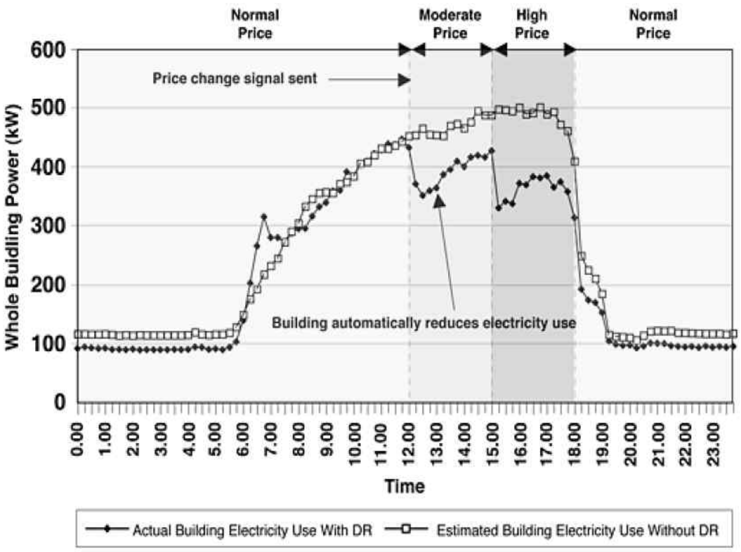

Figure 3. Comparison of building electricity use with and without DR

5. Conclusions and future work

One of the main objectives for many electricity utilities is to reduce and shift peak demand load by adopting certain demand response program such as TOU, RTP or DLC etc. In this paper, various electricity pricing models are studies which can be classified into time-based and incentive-based DR programs. These DR programs provide an alternative solution to solve the pitfall of current electricity network. We also propose a campus scale demand response platform to implement various pricing models under practical applications. The smart electricity meters are installed in different campus buildings which can send periodic electricity information to remote users via internet packets. Simulation results show that the building electricity usage has better performance with DR program in comparison with the one without DR program.

In the future, we intend to propose a technical paper to compare the performance of various pricing models under our campus scale platform in terms of electricity usage and reduction on a timely basis. Also, we plan to analyze and schedule the electricity consumption of different electricity devices through theoretical modelling and analysis.

6. Acknowledgement

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