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J. Han, M.A. Piette

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Solutions for summer electric power shortages:

Demand Response and its applications in air conditioning and refrigerating systems

Junqiao Han[1], Mary Ann Piette[2]
Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA94720, USA

Summary

Demand response (DR) is an effective tool which resolves inconsistencies between electric power supply and demand. It further provides a reliable and credible resource that ensures stable and economical operation of the power grid. This paper introduces systematic definitions for DR and demand side management, along with operational differences between these two methods. A classification is provided for DR programs, and various DR strategies are provided for application in air conditioning and refrigerating systems. The reliability of DR is demonstrated through discussion of successful overseas examples. Finally, suggestions as to the implementation of demand response in China are provided.

Key Words: electric power, DR (demand response), DSM (demand side management), DR strategy, air conditioning and refrigerating system

1 Introduction

The national electric power generation capacity in China reached 622 GW by the end of 2006. The annual growth in capacity was 101 GW, representing a global record for growth rate[1]. In spite of the quick expansion of electric power generation capacity, the electric power shortage is about 5,000 MW, and up to 6,000 MW during the summer peak load in 2007, according to the predictions of the China Electricity Council (CEC)[2]. On the other hand, utilization hours for electric power generation equipments has continued to drop since 2004 to values below 5,000 h in 2007, and will continue to decline in 2008, according to predictions of the State Grid Corporation (SGC)[2,3]. Derated output operation or even shutting down units of power generation during low demand periods not only increases energy consumption, but also affects equipment lifespan and is overall uneconomical.

Overviewing the conflict between electricity supply and demand across the year, we can find that unilaterally increasing generation capacity can not solve this inconsistency. On the contrary, such an increase would cause derating of unit throughput, increasing the cost of power generation and causing large and unnecessary waste of generating resources. In order to meet high peak demand in summer based on the existing generation

[1] Junqiao Han, Ph.D. (engineering), Visiting Scholar, Lawrence Berkeley National Laboratory
[2] Mary Ann Piette, Research director, PIER Demand Response Research Center, Staff Scientist, Lawrence Berkeley National Laboratory

capacity, the only one choice is reducing or shifting peak load through demand side management.

2 Electric demand response and demand side management

Electric demand response[4] (DR) refers to short-term changes by customers in their accustomed electric consumption patterns to reduce or shift electric load over time. These changes are made in response to incentive payments designed to induce lower electricity use, or to reducing load request signals sent by utilities when the wholesale price becomes high or when system reliability is jeopardized. This short-term behavior can improve electric grid reliability and inhibit rise in electricity prices.

Electric Demand Side management (DSM) refers to changing electricity consumption patterns of end-use customers over the short- or long-term through improving energy efficiency and optimizing allocation of power. This can be accomplished using either administrative means or incentives. DSM can realize energy conservation, optimizing allocation of resources and ensure reliability of electric grid. In contrast to traditional electricity management which increases supply to meet a growing demand unilaterally, DSM balances demand with supply by reducing or shifting the electric demand, therefore postpones construction of new power plant, transmission, and distribution infrastructure.

DR is one DSM solution developed for implementation at a specific time. It resolves the conflict between electric supply and demand quickly through the elasticity of electricity demand and market leverage. DSM can be realized by the effort of demand side only, whereas DR must be carried out by both supply and demand sides. The electric supply side designs and offers DR programs to customers. Customers voluntarily choose one or multiple DR programs, and take temporary measures to adjust their demand in response to supply.

3 Types of Demand Response and major programs

According to the above definition, DR can be classified into two types: incentive-based DR and time-based rates DR[4]. Incentive-based DR refers to customers get payments or preferential prices for non-DR periods from reducing electricity usage during periods of system need or stress. Time-based rates DR refers to customer reduction in demand when they receive price rising signals. Normally, customers obtain discounted retail rates at non-DR periods. These two types of DR are highly interconnected and complementary. Large-scale implementation of time-based rates DR can alter electric demand patterns and reduce the severity or frequency of price spikes and reserve shortages, thereby reducing the potential need for incentive-based DR.

According to the degree of system stress, DR can be also classified into two categories: reliability-based DR and price-responsive demand. The reliability-based DR refers to customers reducing demand in response to extreme system stress, thereby ensuring the reliability of the electricity grid. Price-responsive demand refers to customers altering consumption behavior in response to variable prices. The implementation of price-responsive demand can avoid extreme system stress or even an electricity crisis.

More and more sophisticated DR programs are being developed and implemented worldwide, representatives of which are introduced in 3.1 and 3.2.

3.1 Incentive-based demand response

3.1.1 Direct load control

Direct load control (DLC) programs refer to programs in which a utility or system operator remotely shuts down or cycles a customer's electrical equipment on short notice to address system or local reliability contingencies in exchange for an incentive payment or bill credit. DLC programs are typically implemented for residential or commercial customers. They also limit the number of times or hours that the customer's appliance can be turned off per year or season.

3.1.2 Interruptible/curtailable rates

Customers on interruptible/curtailable rates/tariffs receive a rate discount or bill credit in exchange for agreeing to reduce load during system contingencies. If customers do not thus curtail, they can be penalized. The typical minimum customer size to be eligible for interruptible/curtailable rates is from 200 kW. Customers on these rates typically must curtail use within 30 to 60 minutes of being notified by the utility. The number of times or hours that a utility can call interruptions is capped.

3.1.3 Emergency demand response programs

The emergency DR program is developed for reliability-triggered events, but curtailment is voluntary. The programs provide incentive payments to customers for reducing load, but customers can choose to forgo payment and not curtail when notified without penalty.

3.1.4 Capacity market programs

Customers commit to providing pre-specified load reductions when system contingencies arise, and are subject to penalties if they do not curtail when so directed. Capacity market programs can be viewed as a form of insurance. In exchange for being obligated to curtail load when directed, participants receive guaranteed payments.

3.1.5 Demand bidding/buyback programs

Demand bidding/buyback programs encourage large customers to provide load reductions at prices for which they are willing to be curtailed, or to identify how much load they would be willing to curtail at posted prices. These programs are typically called one day ahead based on predictions of electric demand. Day-of events also can be called when necessary. If customers bid but do not then reduce their load, they are subject to a penalty.

3.2 Time-based rates demand response

3.2.1 Time-of-use rates

Time-of-use (TOU) rates vary seasonal or daily periods by small difference. Typically, high demand months of a year or hours of a day based on the historical experience are set to be higher price rates, and lower rates are set at off-peak times. This is the oldest and the most prevalent DR program, and can be implemented in particulars seasons or throughout the year. Implementation experience of TOU rates shows that they can partially influence patterns of electricity demand. TOU rates, because of their long-term implementation, are considered to exceed the category of DR.

3.2.2 Critical peak pricing

Critical Peak Pricing (CPP) is a relatively new form of TOU rates that relies on very high critical peak prices, as opposed to the ordinary peak prices in TOU rates. CPP events may be triggered by system contingencies or high prices faced by the utility in procuring power in the wholesale market. The CPP rates are typically predetermined and the number of event days per year is capped in behalf of customers.

3.2.3 Real-time pricing (RTP)

Real-time pricing (RTP) rates vary continuously during the day, directly reflecting the wholesale price of electricity. RTP rates also can be called one day ahead based on hourly predictions and experience, so that customers can plan ahead to reduce demand in response to supply.

4 Demand Response applications in air conditioning and refrigerating systems

Introductions to DR have been published in recent years[5-8], but no papers introduce what kind of strategies can ensure demand successfully in response to supply. In this paper, DR strategies used in air conditioning and refrigerating systems are systematically introduced. Electricity consumption by air conditioning and refrigerating systems accounts for a very important portion of annual electric consumption of civil buildings. Especially in public buildings, these can represent as much as 50%~60% of the whole building energy consumption. Turning on and off the air conditioning and refrigerating systems doesn’t change indoor temperature and humidity immediately because of the heat storage of building envelopes and internal mass. A person feels comfortable with the indoor thermal environment within an allowable range of temperature, humidity and air speed. Also, the acceptable indoor operative temperature rises with increases in outdoor temperature[9]. So, small increases in the indoor operative temperature or changing air speed won’t affect thermal comfort of occupants in a short time. Therefore, the air conditioning and refrigerating systems become important and effective objects of DR strategies.

Ten major DR strategies[10] used in air conditioning and refrigerating systems are listed below. One or multiple strategies can be chosen to realize DR according to the character of air-conditioning and control systems.

1) Global Temperature Adjustment (GTA)

Increasing the space temperature setpoints for an entire facility, thereby reducing the electric load of air handling and refrigerating equipments. It can be implemented by changing setpoints in one step or several steps, or by increasing over time. It is a very effective strategy and can be used in all air conditioning systems.

2) Passive Thermal Mass Storage (PTMS)

Decreasing the indoor operative temperature to pre-cool the building and indoor air during off-peak, and increasing the setpoints of the air-conditioner during peak periods. PTMS shifts the electric demand from peak to off-peak using the character of building and internal equipment in storing and releasing heat. It can be used in buildings with high thermal mass and good heat storage and insulation.

3) Duct Static Pressure Decrease (DSPD)

Decreasing the setpoints of duct static pressure, thereby modulating either the speed of the fan or the position of inlet guide vanes. DSPD is typically used in VAV systems.

4) Fan Variable Frequency Drive Limit (VFDL)

Limiting or decreasing the fan variable frequency drive (VFD) speed or inlet guide vane to reduce fan power. It is typically used in VAV systems.

5) Supply Air Temperature Increase (SATI)

Increasing supply air temperature setpoints to reduce the cooling load. The fan VFD and inlet valve position in the VAV systems must be locked before changing the setpoints.

6) Fan or End-units Quantity Reduction

Shutting off part of multiple fans or end units to reduce fan and cooling load. The fan VFD and inlet valve position in the VAV systems must be locked before changing the setpoints.

7) Cooling Valve Limit

Limiting or reducing the cooling valve position to reduce cooling load by chillers and pumps because of a reduced chilled water flow.

8) Chilled Water Temperature Increase

Increasing chilled water discharge temperature to reduce chiller power due to an increased efficiency.

9) Chiller Demand Limit

Limiting the chiller compressor capacity to maintain supply water temperature higher than setpoints.

10) Chiller Quantity Reduction

Shutting off some of multiple chiller units can force the operating units to run in full load, which can increase chiller efficiency and reduce electric demand combined with the absence of chiller units.

After a DR event, system operations need to be recovered to normal operation, and a rebound strategy should be considered in case the peak demand is shifted to a sub-peak period.

5 Successful examples of demand response

DR has had countless successful experiences since it appeared at the beginning of 21st century. For example, 2006 was the second-hottest U.S. summer in history. Ten continuous days with temperatures exceeding 38°C were reported throughout the inland regions of California, with record highs along the coast and bay area. Woodland Hills (outside Los Angeles) reported a new record of 21 days exceeding 38°C and an all-time record of 48°C on July 22. The heat wave put unprecedented pressure on the electricity grid. However, no rolling blackouts were ordered in California during the period due to the help of DR implementation which reduced load on the grid by 1,500 MW, over 2% of total statewide demand. In other areas of the U.S. using DR programs, New England ISO reduced load by 530 MW, Exelon Corp by 1,100 MW, Northeast Utilities by 95 MW, and MidAmerican Energy by 250 MW. According to a national statistics survey, the total potential resource contribution from demand response is estimated to be about 37,500 MW[4]. DR was proven to be a reliable and credible resource that provides load reduction when requested.

6 Conclusions

Demand response is an effective lever between the economy and the conflict of supply and demand. It is an efficient short-term tool for quickly adjusting imbalance of supply and demand. DR can not only prevent overinvestment, and ensure safe and economical operation of electric grid, but also maintain stability of electric prices and promote fairer electric marketing by introducing new competition mechanisms in the electricity market. It thus has very important economic and social significance.

The reform of electricity markets in China is still in the initial stage. It is very important to import DR to maintain healthy development of competitive markets. DR is now considered to be a reliable resource in the electricity world. As a big energy consuming country, China is starting late in this field. Learning from the successful experience of DR in oversea, China can mitigate or resolve summer electric power shortages with the existing power resources if DR is implemented successfully. Also, efficiency of the whole electricity system will increase, thus realizing a win-win situation of energy conservation and environmental protection.

China should start research on DR and at the same time, broadcast internally the message of electric supply and demand. China should develop proper DR programs based on national conditions and electric markets, and formulate policies to support the implementation of DR.

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Reference:

1. State Electricity Regulatory Commission, Annual report of electricity regulation, 2006
2. China Electricity Council, 2006-2007Analysis and prediction of national electricity supply/ demand and economic situation, 2007
3. State Grid Corporation, 2007 Analysis and prediction of national electricity market, 2007
4. Federal Energy Regulatory Commission, Assessment of Demand Response & Advanced Metering, staff report, August 2006
5. C. Zhu, Pay more attention to the response of demand in Demand Side Management, Distribution & Utilization, Issue 5, Vol. 22, 2005
6. Y. Li, B. Wang, H. Song, Demand side response and its application, Power Demand Side Management, Issue 6, 2005
7. P. Song, Optimizing the electricity peak load management by demand response, Popular Utilization of Electricity, Issue 9, 2004
8. C. Zhu, Electric demand response programs, Rural Power Management, Issue 10, 2003
9. B. W. Olesen, G. S. Brager, A Better way to predict comfort: The New ASHRAE Standard 55-2004, ASHRAE Journal, August 2004
10. N. Motegi, M.A. Piette, D.S. Watson, S. Kiliccote, P. Xu, Introduction to Commercial Building Control Strategies and Techniques for Demand Response, LBNL-59975