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Demand Response: Managing Electric Power Peak Load Shortages with Market Mechanisms

A Review of International Experience and Suggestions for China

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Introduction

Electric power "demand response" (DR) programs are implemented by electric power utilities, with government support, to cause changes in consumers' electricity use, usually to reduce or shift electric power peak load demands. Demand response programs rely on market-based mechanisms, through either special incentives for consumer changes in demand, the pricing system, or both. Utilities in developed countries use these programs as one means to manage peak load shortages as they emerge, rather than having to resort to administrative rationing. They are also a far less expensive alternative to adding and operating costly peak load power generation and supply infrastructure, or quick-ramping-up capabilities, to fully meet demand.

Electric power supply companies in developed countries are obligated by laws and regulations to serve all consumer electric power demands. Failure to meet demand is met with public and government outcry, and typically carries (either directly or indirectly) very high financial penalties. For example, in the United Kingdom, utilities that fail to meet service obligations are assessed fines that are 2.5 percent larger than any gains associated with the lack of investment that led to the service interruption.[1] Developed over the last several decades, demand response programs have become one of the key measures by which utilities address this issue, safeguarding against reliability problems from spikes in demand. The programs also reduce the need for expensive investments in or payments for generation, transmission, and distribution capacity that would only be used occasionally. Experience has demonstrated that DR programs can be counted on as highly reliable load management tools. In addition, demand response programs are now increasingly being used to help smooth the integration of variable power generation sources, such as wind and solar power, into electricity supply systems. Demand response resources developed from DR programs can and should be included in integrated power sector planning for the future.[2] Depending on the circumstances, demand response programs also may deliver reductions in power sector emissions when they generate overall kWh savings in addition to peak load KW savings, and those kWh savings result in reduced generation from particularly polluting peak load plants.

[1] OFGEM, 2012.
[2] RAP, 2013.

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In China, the obligation to serve demand placed on the power companies that own and operate the country's power supply system is more limited than in developed countries. China has always had shortages of capacity to serve demand (sometimes severe shortages), and it is understood that, at times, power companies cannot fully meet all of the demand that customers may have for electricity at prevailing prices. Accordingly, China has long instituted and operated administrative measures for controlling load and for rationing electricity during times of shortage. These control and rationing systems were a normal and logical feature of the planned economy. As China moved towards a market economy in the 1990s, however, the power demand control and rationing systems remained; and, though they have been refined in certain ways, they are still in place today.[3] A key reason is that it remained difficult for the power system to expand quickly enough to meet all demands. Electric power production grew at an astonishing average rate of 10.2 percent per year from 1991-2010, and 850 GW of generating capacity were added to the system. In addition, peak seasonal and daily demand growth have outpaced overall electricity consumption growth, due especially to the rise of air conditioning loads. Accordingly, power supply contracts between utilities and major customers continue to delineate agreed-on maximum loads, and any load above those amounts must be applied for and agreed to by utility and government authorities.

Termed "Orderly Use of Power Programs," China's administrative systems for rationing electric power during times of shortage are implemented by local power distribution companies, but they are the responsibility of local government. Fine-tuned every year prior to the peak load season (summer along the eastern and southern coasts), the programs are developed by the government and utilities together. Implementation of the programs by the utility is then ordered by the government when the utility forecasts a potential gap in its ability to meet load using agreed methodology. While efforts are first made to avoid load curtailment through various demand management and voluntary efforts, involuntary load curtailment orders may be issued according to load servicing priority designations defined in detail in the annual programs.[4] As 2011 national regulations protected residential customers from the administrative rationing system, the brunt of the involuntary load curtailments falls on industrial customers, who use more than 70 percent of the country's electricity. During the extraordinarily hot summer of 2013 along the coast, for example, many industrial enterprises without priority supply designations were required to shut some or all major production facilities down during a two-week period, causing serious disruptions to economic production.[5]

As China further deepens market economy reforms, increasing the introduction of market-driven "demand response" measures into the country's system for countervailing pending power shortages could be far more economically efficient and probably more equitable than the administrative rationing system. Consumers can determine the timing and amounts of load to curtail that are least disruptive and most beneficial to them based on the price or incentive signals set forth in the programs, minimizing economic disruption. In addition, relatively inexpensive demand response programs can save the country from excessive costly investment in peak load supply capacities, just as in other countries, resulting in a downward force on retail electricity costs and prices. Finally, demand response can play an important role helping to ensure system reliability as variable-generation renewable energy become increasingly integrated in power grids, including at the local grid level.

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[3] State Council, 1996.

[4] NDRC, 2011.

[5] Personal communication with enterprise staff.

With these interests in mind, this paper first provides a very brief overview of the development of demand response programs in developed countries, followed by details of four typical but different types of programs. New trends in demand response are next taken up. And, lastly, the paper concludes by outlining some potential demand response approaches that may be useful in China, and suggesting ways that demand response programs could be sustainably funded.

A Brief Overview of Demand Response Programs

There has been a wide variety of experiences with different demand response models throughout the world in the more than 40 years since the first major DR programs, mostly in the United States and Europe, were initiated. As central air conditioning became more common in the US in the 1970s and led to sharper peaks in demand on hot days, utilities began introducing incentives for customers to interrupt or curtail their load when called upon by the utility (i.e., dispatched). This served to ensure system reliability and save the utility the cost of providing extraordinarily expensive power on peak days. These incentives usually took the form of either lower overall rates for participating customers or monthly credits on their bills.[6] While the original DR programs were often focused on a small number of customers and limited by the technology of the era, DR has been growing rapidly in the last decade and become more sophisticated and reliable. The expansion of DR has been aided by newer metering and communications technologies, by improved approaches as we learn from the shortcomings of earlier programs, and by the rise of third-party providers.

Types of Demand Response Programs

The US Federal Energy Regulatory Commission (FERC) divides demand response programs into two categories: incentive-based programs and time-based programs.[7] Incentive-based programs rely upon payments or reduced prices for customers who reduce or eliminate demand when called upon by the electricity system operator; time-based programs rely on customers' response to changes in the price of electricity over time. It should be noted that many programs include elements of both.

Typical categories of incentive programs include the following:

- Direct load control: Customers allow the utility or third-party DR provider to remotely cut power or cycle their electrical equipment, such as AC units, water heaters, or even lighting, under specified circumstances and parameters.
- Emergency demand response: Customers are directed by the system operator to reduce load during emergencies in order to ensure system reliability.
- Interruptible load programs: Load is curtailed or interrupted when called by the system operator. In some cases, the system operator may be able to effect the demand reduction remotely or even cut power to the customer entirely.
- Load as a capacity resource: Customers make previously specified reductions in load when called on by the system operator; from a system reliability perspective, these reductions are equivalent to increased generation.
- Spinning and non-spinning reserves and regulation services – These programs provide the system operator with the ability to alter demand in order to manage daily supply and demand imbalances, often in real time.

[6] Hurley, 2013.
[7] FERC, 2012.

Time-based programs include:

- Critical peak pricing: High retail energy prices are charged during a limited number of days or hours in order to discourage consumptions at times of abnormally high wholesale electricity prices (or integrated system supply costs). This may or may not be combined with direct load control.
- Peak time rebates: Customers receive rebates in exchange for reductions in consumption from a specified baseline during peak days or hours.
- Time-of-use pricing: Prices vary, according to a prescribed schedule, at different times of the day and week, typically by intervals of an hour or more, to reflect the general, time-differentiated pattern of underlying power costs.
- System peak response transmission tariffs: Pricing incentives are provided to customers who reduce demand during peak time so as to reduce transmission costs.
- Real-time pricing: Prices fluctuate during intervals of an hour or less to reflect actual wholesale prices of electricity.

Reliability of Demand Response Programs

As demand response programs have evolved, they have become an increasingly reliable power system resource. While some early demand response programs faced problems with customers failing to curtail load when called, such as a ski resort in Vermont that refused to turn off its snow making equipment during a holiday weekend crucial for its business, these problems have largely been addressed in the more advanced demand response programs.[8] One way in which the reliability of DR programs has been ensured is through direct load control, which removes any possibility for non-compliance as the customer's appliances are dispatched directly. This tactic has, however, proven less and less necessary as will be seen below in the Baltimore Gas & Electric (BG&E) example, since customers have proven increasingly likely to react to incentives to reduce demand as the frequency of DR events rises. In addition, a greater number and diversity of DR program participants mitigates the risk of any one customer failing to comply when the system operator calls for DR dispatch.

Selected Programs

In this section we discuss four representative examples of long-standing demand response programs. The first, from Xcel Energy, represents a purely incentive-based program. The next three examples incorporate aspects of both approaches by also varying electricity prices during times determined by the system operator to be times when demand response is needed to mitigate peak loads. Of the three mixed programs, the Pacific Gas & Electric (PG&E) program focuses on large industrial and commercial customers, while the BG&E example and Électricité de France (EDF)'s Tempo program focus on residential customers. However, the concepts and operating principles of the residential programs could also be applied in programs for larger customers. Together, these examples provide a fairly representative sampling of how different incentives and mechanisms are applied in successful DR programs.

[8] Hurley, 2013.

An interruptible load direct incentive program for large customers: Xcel Energy

Xcel Energy, an electricity distribution company operating in Colorado, makes monthly payments to customers willing and able to curtail load when dispatched. In order to qualify for Xcel's program, a customer must be able to shed at least 300 kW of demand when called upon. Compensation for customers opting into the program is between $4 and $9 per kW of agreed curtailable load per month. Monthly credits are increased above the minimum $4 when:

- Customers are willing to accept only ten minutes notice prior to curtailment instead of the standard one hour;
- Agreed curtailable load is in summer rather than winter;
- Customers are willing to be dispatched for more hours per year (options include 40, 80 or 160 hours);
- Agreed customer curtailable load may be less than the normal minimum duration of 4 hours or which do not need to be limited to four hours in a 24-hour period; or
- Customers receive higher voltage service.

In sum this incentive policy gives customers higher rebates for providing more useful demand response assets to the system operator. The system operator's need to dispatch customers involved in the program can vary greatly from year to year. For example, there were only 20 events in which customers were dispatched in 2008. However, in the following year there were 41.[9] Programs such as Xcel's remain quite common in the United States, although many states are moving away from the model of monthly credits for large customers, as the standardized monthly credits often do not reflect the ever-shifting value of the reductions in usage to the system and do not increase when customers are actually dispatched for more and more events.

A time-of-use tariff program: Tempo

France's Tempo program, which Electricite de France (EdF) has been operating successfully since the early 1990s, provides an excellent example of a program that utilizes TOU pricing for small retail customers. As with nearly any TOU pricing program, participation requires the installation of interval meters to measure how much electricity was used at different times on different days. Participation is entirely voluntary. Customers who do not participate pay a standard kWh charge for all of their electricity use. For customers who opt into the Tempo Program, prices vary depending on the time of day (peak vs. off-peak) and by day of the year, with days divided into 300 low-priced "blue" days, 43 higher-priced "white" days when peak loads are expected to rise above normal, and 22 top-priced "red" days when system peak loads are expected to be highest. As shown in the pricing schedule for 2014 in Table 1, participating customers enjoy prices much lower than those paid by other customers during the 300 blue days each year — almost 40 percent lower for off-peak use, and still 27 percent lower for peak use. During peak load hours on white days, however, they must pay just a little more than other customers. On red days, then, prices for participating customers are far higher than for other customers — almost five times higher for peak load use. Hence, participating customers must manage their

[9] Xcel Energy, 2014. More information is available at http://www.xcelenergy.com/staticfiles/xe/Marketing/Files/CO-Business-ISOC-Info-Sheet.pdf.

electricity use carefully during the 22 red days per year in order to save money overall on their electricity bills. In 2014, on-peak red prices were 6.6 times off-peak blue prices.[10]

Table 1. 2014 Prices for the Tempo Program for Small Retail Customers

	Days Per Year	Off-Peak Price Ec/kWh	Peak Price Ec/kWh	Constant Price Ec/kWh
Non-Participants	365			13.72
Participants:				
Blue Days	300	8.4	10.03	
White Days	43	11.85	14.00	
Red Days	22	21.42	55.94	

Source: Electricite de France (EdF), 2014

EdF determines and announces the color type of day by 8 pm on the previous day. Customers with display units, which can be plugged into any socket in the house to pick up signals sent by EDF's ripple control system, are informed of the upcoming day color as well as the current price of electricity, and are then able to make decisions about decreasing consumption by turning off appliances and heaters. Some customers also have installed systems to automatically cut their consumption when the price exceeds a specified level. The program's success can be seen in participating customers' 15 percent and 45 percent reductions in consumption on white and red days, respectively, compared with blue days.[11]

EdF has introduced a number of additional TOU pricing programs following on from the Tempo Program. Included is a real-time pricing program that allows customers to choose to pay the market price of electricity at any given time.[12]

A mixed program for large customers: PG&E

One demand response program that combined an incentive-based approach with a time-based approach was offered by PG&E in the late 1980s. The program aimed to combine (a) general TOU pricing for most customer categories where suitable metering existed; (b) options for customers to obtain lower than standard, firm power prices (both per kWh energy and per KW peak demand) for agreeing to curtail or totally interrupt their power use when called upon; and (c) variations in the level of price discounts for customers agreeing to load curtailment or interruption based on the maximum extent of those disruptions allowed. Although the resulting tariff was quite complex (see Table 2), customers were provided with a range of options to select, and the monetary incentives for customer participation were provided entirely within the electricity pricing system.[13]

TOU pricing was set for all customers except for some smaller consumers in the A1 and the A10 categories. This provided some incentives both to firm power service customers and to demand response program participants to reduce peak load use. For A6 and A11 customers, who had no other demand response program options, on-peak prices were set at 3.8 and 2.4 times off-peak prices.

[10] EDF, 2014. More information (in French) is available at https://particuliers.edf.com/offres-d-energie/electricite-47378.html.
[11] Crossley, 2008.
[12] EDF, 2014.
[13] Wilson, 1993.

However, for customers who did have additional demand response program choices such as those in the E20 category, which requires a maximum demand of at least 500kW, on-peak kWh prices were set at 1.5-1.8 times off-peak prices.[14]

Large E20 customers, then, could chose firm service at standard prices or either curtailable service or interruptible service, with substantial price discounts. To participate in the discounted programs, customers needed to be able to reduce their load to at least 500kW below their lowest average peak load of the previous six months, or to eliminate their load entirely when called upon. The demand response service programs required customers to manage their load according to prior agreements when called upon by the company—these programs did not involve direct load control. Accordingly, a schedule of substantial penalties was put in place to discourage customers from failing to abide by agreements. Fines for a second offense were double the amount of fines for a first offense.[15]

Under the curtailable service option, customers needed to pledge partial load reductions when called upon in exchange for their price discounts. Under the interruptible service options, customers pledged to eliminate their load fully when required, in exchange for yet larger price discounts.

Price discounts for participating large customers were of two types: (a) discounted charges levels or even elimination of the stiff $8.1/KW/month peak demand charge charged to firm service customers and (b) discounts in electrical energy prices (including on-peak, off-peak and shoulder rates). For customers with spiking load characteristics, the reduction in the peak demand charge could be financially critical---potentially resulting in even greater savings than the reduced energy prices.[16]

Under each demand response service option, customers could then select one of three options defining the limitations of the company to curtail or interrupt their load (Plans A, B or C in Table 2). The options varied (1) the minimum amount of warning time that the power company must give the customer prior to demanding agreed load reductions (10-60 minutes), (2) the maximum number of load reduction events that can be called per year (15-45), and (3) the total number of hours per year that load could be curtailed or interrupted.[17]

To participate in the demand response service options, customers were required to pay a flat monthly fee of $190-200, compared to the $100 flat monthly fee required of firm service E20 customers. For large consumers, this fee is relatively trivial compared to their total power bills. For smaller customers, it represents a modest additional cost. Such a flat fee can at least to some extent signal the transaction costs involved in managing customer accounts in the program, which are greater relative to the benefits for smaller customers.[18]

Overall, the tariff provided incentives to a wide range of customers with different characteristics to change behavior generally in line with the interests of the power system operator. For example, a customer that sporadically operated an electricity-intensive facility, such as an electric furnace, could have had a major reduction in its power bill through partial or total elimination of his peak demand charge and perhaps somewhat lower energy prices overall by agreeing to avoid operation during system peak stress times. Another customer, with more even load but abilities to rearrange work processing

[14] Ibid.
[15] Wilson, 1993.
[16] Ibid.
[17] Ibid.
[18] Ibid.

during the hours of that system peak load events were likely to be called could have gained benefits from overall lower energy rates, including lower shoulder and off-peak rates. Yet another facility, that operated intermittently and could have fairly easily withstood orders to eliminate load by scheduling operational shut-downs and start ups accordingly, could have had a dramatic reduction in its power bill by selecting an aggressive interruptible service package.

This pricing system is detailed in Table 2 below. This program represented a significant innovation for the time, both because of its variety of options and its combination of TOU pricing with curtailable/interruptible pricing.

Table 2. Demand Response Pricing Options of Pacific Gas and Electric Company, 1988

			Demand Charge ($/kW)		Energy Charge (¢/kWh)			Limits			Penalty ($/kW)	
	Type of Service	Fixed Charge $/Month	Peak	Max	Peak	Shoulder	Off Peak	Mins. Warning	No. of Events	Duration (hours)	1st Time	2nd Time
Firm Service	A1	0	0	0	10.404	10.404	10.404					
	A6	0	0	0	24.895	12.447	6.473					
	A10	50	0	2.85	8.658	8.658	8.658					
	A11	50	8.1	2.85	12.746	10.197	5.405					
	E20	100	8.1	2.85	7.633	7.269	4.264					
Curtailable Service (E20)	A	290	4.87	2.85	7.631	7.266	4.265	60	15	50	3.11	6.23
	B	290	3.4	2.85	7.626	7.261	4.264	30	30	100	4.89	9.79
	C	290	0	2.85	7.494	7.136	4.226	10	45	200	8.45	16.9
Interruptible Service (E20)	A	300	0	2.85	6.886	6.557	4.128	60	15	50	11.12	22.24
	B	300	0	2.85	6.392	6.088	4.036	30	30	100	13.34	26.69
	C	300	0	2.85	5.701	5.428	3.908	10	45	200	16.46	32.91

Source: Wilson, 1993

The 1988 PG&E power tariff that incorporates all of these options (Table 2) is complicated. But the tariff cleverly includes a broad range of adjustments in the pricing system to elicit demand behaviors in line with the interests of the system. Innovations incorporated in the overall tariff, any of which may be interesting for others interested in developing demand response programs to consider separately, include: (a) combination of TOU pricing together with a time-based demand response system involving dispatching of prior load reduction commitments; (b) use of peak demand charge discounts in addition to energy price discounts to incentivize demand response; (c) variations in both demand charge and energy price discounts according to load reduction commitment levels; (d) assessment of penalties for failure to abide by agreements; and (e) assessment of a flat monthly charge per customer, independent of energy demand levels, to transparently charge customers for the transaction costs of managing the program.

An obvious disadvantage of this particular scheme is its complexity. In addition, however, the need to set price discount levels way in advance means that it is difficult to set pricing nicely in line with the actual electricity system benefits that will be achieved because actual evolving load patterns cannot be predicted very well in advance. While such pricing schemes may deliver broad benefits to both the system and customers overall, evaluation following each year will inevitably reveal cases of overpricing and underpricing. Moreover, this problem is further exacerbated by the uncertainty as to the number and length of demand response events that will be called each year. This not only causes further price setting complications for the system operator but also uncertainty for customers as to which program to select to best meet their needs. Finally, the program provides no space for participation of customers that are willing to curtail their load, but only at certain times; instead all participants were required to curtail or interrupt their load whenever called, with no say in when that might be.

PGE has now abandoned this earlier demand response program in favor of some new approaches. The company now operates three separate DR programs. One program is an incentive-based program that offers monthly payments similar to Xcel's program described above. Another program, taking advantage of forward capacity markets as further described below, allows customers to bid their reductions into the day-ahead market operating in California. The third program allows customers to choose when they might be dispatched to curtail load in exchange for an incentive. In addition, PG&E has maintained the TOU pricing, which can still be combined with any of the programs.[19] This greater diversity of program options was developed to allow customers more flexibility in demand response, as well as to comply with the 'US FERC's Order No. 745 (described below).

A mixed program for residential customers: BG&E

One of the most advanced set of DR programs for residential customers in the U.S. is operated by Baltimore Gas & Electric (BG&E) in the State of Maryland. BG&E has operated a direct load control program for air-conditioners for some years under its PeakRewards Program. This program is similar in concept to many in other US states. Participation is voluntary and customers can choose their level of participation. Customers agree to have their air-conditioners cycled on and off when BG&E calls either a "non-emergency event" or an "emergency event." During a non-emergency event, called when the wholesale price of electricity is very high or to assist with localized system reliability needs, the air conditioners of all participants are cycled off for up to 50 percent of each hour during the event. For emergency events, customers have cycling options; they can choose to be curtailed 50 percent, 75 percent, or 100 percent of the time during such events. Compensation is substantial: Customers choosing 50 percent cycling receive $50 per year (plus a $50 initial bonus) while customers choosing 100 percent cycling during emergency events receive $100 per year (plus a $100 initial bonus).[20]

BG&E also has implemented a new, innovative program called Smart Energy Rewards. The program followed a statewide initiative, supported by the U.S. government, to install new, digital smart meters for all residential customers served by the company. BG&E expects to call five to ten "Energy Savings Days" each summer, selected when peak loads are forecast to be especially high. BG&E notifies customers by email or mobile phone text the day before an Energy Savings Day event is called. During an event, participating customers receive a rebate of $1.25/kWh of reduced consumption as compared with a baseline determined by the average consumption on days with similar weather. This rebate for peak load electricity savings is almost ten times higher than the average residential electricity price in BG&E's service territory. Customers are notified by email or text the day following an Energy Savings Day of their electricity savings and the amount of credit being applied to their next bill. Customers earned, on average, rebates of $6 to $10 per Energy Savings Day in 2013.[21] BG&E bids the load reductions into the regional electric energy market according to the rulings described in the Evolving Trends section further below, and BG&E is compensated based on the market value of the reductions.

[19] PG&E, 2014. More information is available at
http://www.pge.com/mybusiness/energysavingsrebates/tips/demandresponse/index.shtml.
[20] BGESmartEnergy.com, 2014.
[21] Ibid.

One thing that differentiates this program from many others is that it is the default option for all residential customers with smart meters. Customers wishing not to participate in the Smart Energy Rewards Program must opt out of the program, as opposed to opting in, which has been a traditional element of demand response program design. This approach has proven quite successful, with opt-out rates of less than 1 percent as the program can only decrease a customer's electricity bill and does not include any direct load control unless the customer elects to participate in the parallel PeakRewards Program.

The electricity system benefits have been significant. In the launch year of 2013, the program had 300,000 participants who reduced load by an average of 15 percent during the five events called that year, for a total reduction of 5 percent across the system. One of the more remarkable findings with this program has been that the percentage reduction increases as the peak load increases, and as the frequency of events increases. These successes have led BG&E to plan an expansion of the program to over 1 million customers in 2014.[22] This experience shows that DR programs can be applied to nearly all customers and provide significant and reliable reductions to peak load.

Evolving Trends

Compensation System Issues

Systems for compensating customers are now changing across the United States to provide greater operational flexibility and to better match compensation with actual system benefits. This can be achieved by using the wholesale electricity markets now developed in many of the highest-load US regions. Although the programs whereby utilities offer predetermined price discounts or monthly credits for customers in exchange for agreeing to interrupt or curtail load were critical for getting demand response to become a useful operational tool to manage peak load, it is difficult for the pre-determined incentives to match actual system benefits well. As noted in the Xcel Energy example, the frequency with which customers are asked to curtail load can vary greatly from year to year, creating problems for customers seeking to determine whether enrollment in the program is worthwhile for them. This variation also makes it difficult for power companies and regulators to determine the most efficient level of compensation for participation in the programs, as they cannot precisely determine the necessary level of participation and its value to the system months in advance. In the past, this issue often led to a greater degree of participation in DR programs than was necessary, and a higher price paid for DR assets than the market required. For instance, some utilities went years without dispatching customers enrolled in their curtailable load programs, and then, when DR dispatch needs finally arose they found customers unwilling to curtail load when dispatched even though the customers had been receiving payments or lower rates for years.[23]

Demand Response Bidding into Forward Power Markets

As a result of the problems associated with compensation for DR, the FERC has encouraged DR resources to participate directly in the wholesale electricity markets, and ultimately issued FERC Order No. 745, requiring that DR resources be compensated according to the actual value of their consumption reductions to the system, as determined by the locational marginal price (LMP) of

[22] Personal communication with Neel Gulhar and Jacob Levine of O-Power (telephone interview, July 8, 2014).
[23] Hurley, 2013.

electricity in the wholesale market.[24] [25] As per the order, the type of large customers or aggregators of customers that previously would typically be involved in monthly credit programs must now bid their load reductions directly into the wholesale market, and will only be dispatched and compensated as determined by the market operator. This reform alleviates the aforementioned problems with discounted rates or monthly compensation for customers with interruptible/curtailable load, since customers are not compensated if they do not provide actual reductions when called upon. Inadequate DR participation is also avoided as the compensation level to customers is increased until participation reaches the necessary market-clearing level. Additionally, this reform provides a market-based mechanism to compensate utilities such as BG&E for the sort of residential DR program described above.[26]

New England ISO

Today, a program that complies with FERC Order No. 745 has been implemented by the Independent System Operator of New England (ISO-NE), in the northeastern part of the U.S. In order for holders of DR resources to take part in the program and participate in the wholesale electricity markets in New England, an entity must either be able to curtail at least 100kW of load or reach that amount by aggregating smaller customers. They must also have interval meters that meet the requirements for accurate and timely communication of electricity consumption. These DR market participants may then submit bids to reduce load between 08:00 and 18:00 one day ahead of any demanded curtailments. These bids are accepted for one or more hours during the day if their cost is equal to or less than the value of the supply side generation alternative (i.e., the day-ahead LMP). Even if bids have not been accepted as lower than the day-ahead LMP, participants may be compensated for reductions in demand if their offer prices are lower than the provisional real-time LMP on the operating day.[27]

This approach has proven quite effective, with DR resource potential (the total amount of DR resources registered to participate in a demand response program and be bid into the capacity markets) in the ISO-NE reaching 2,769 MW, or 10.7 percent of peak demand, in 2012. This represents the largest DR resource potential as a percentage of peak demand of any ISO in the United States, establishing the ISO-NE's approach to DR amongst the most effective in the country. Not all of the registered bids are called. For example, approximately 200 MW of the far higher registered potential was actually dispatched in the ISO-NE at the highest peak demand of 2013, as this was the amount of the bids that were priced at or below the day-ahead LMP.[28]

Third-Party Demand Response Aggregators

Third-party demand response providers have proven useful for promoting DR in many cases, by aggregating DR into marketable resource packages. Typically, providers recruit customers for DR programs, establish contracts to compensate them for their load reductions, and provide expertise and

[24] FERC, 2011.
[25] Compensation accounting requirements under Order No. 745 are the subject of an ongoing legal battle. On May 23, 2014, the US Court of Appeals for the District of Columbia overturned the FERC order; however, FERC was granted a stay on that ruling until December 16, 2014, as the agency prepared an appeal to the US Supreme Court. That appeal was filed in January 2015.
[26] DR resources can be bid into either the wholesale electricity market (in kWh for specified time frames), or into forward capacity markets (in KW) where those exist. Bids for electricity markets are for load reductions of a given amount of steady kWh over the specified time period.
[27] ISO-NE, 2013.
[28] FERC, 2013.

equipment to help them reduce their loads when dispatched. They then either bid the aggregate of these load reductions into the wholesale markets or contract with an electricity distribution utility for compensation. These aggregators add value by serving as a bridge between the utility or market and the customers, reaching out to potential participants, educating them, and easing their participation in the DR programs. In addition, they bundle customers into groups in order to diversify the risk of individual customers failing to curtail, thereby increasing the predictability and reliability of the resource, and to tailor different bundles of customer DR resources depending on whether the bundles will be bid for use as a capacity resource, as an energy resource, or as spinning reserves. The impact of these third-party providers can be seen in the rapid expansion of DR across the US in the past decade; between 2006 and 2012, reported potential peak reduction more than doubled, with the largest increases coming from wholesale customers, including third-party providers.[29] In addition, these providers have spread to many countries across the world, from Europe to South Africa to New Zealand.

New Opportunities Being Created by Advanced Metering Technologies

The introduction of advanced metering has provided demand response programs with a major boost. With classic accumulation meters, it is difficult to implement time-based programs or compensate customers based on their actual load reductions as it is not possible to know, based on the metering information, exactly when a customer's electricity consumption took place. However, advanced metering technology has become more common in the past decade, with the penetration rate in the US increasing from 0.7 percent in 2006 to 22.9 percent in 2012.[30] This increase in the use of advanced meters not only facilitates time-based programs and DR participation in the wholesale electricity markets but also can help customers reduce load efficiently by providing accurate data about their electricity use over time. In the case of BG&E, advanced metering provided the foundation for the utility's Energy Savings Days program. In addition, the data collected by BG&E's advanced metering is used to provide customers with graphs of both their hourly electricity use for every day of the year and how their electricity use compares with that of their neighbors. This helps customers identify electricity savings opportunities and track results of changes in behavior. In addition, advanced meters give the utility a more accurate real-time picture of the activity of demand response resources.

Developing Demand Response Programs in China

A wide variety of electricity demand response programs could be developed in China today and such programs certainly could improve the operation of the power system and make a substantial economic contribution to the country and to consumers. Well-designed demand response programs can reliably help to mitigate load peaks at low cost, reducing the need for developing expensive peak load supply and saving the country money and resources. Used as a market-based tool as a part of the orderly use of power programs, demand response initiatives can also reduce disruption in industrial production, by using consumer response to incentive and price signals to find the most economic measures for electric power load reduction during times of shortage. Demand response programs can be used to reduce and help eventually eliminate the need for the involuntary load curtailments that cause loss of production and great complaint from local industry, at much more reasonable cost than investment on the supply side alone. Large-scale development of demand response programs in line with their great economic potential, however, will require some policy adjustments relating to orderly use of power programs and electricity pricing. Prior to that, and to gain experience and help demonstrate the practical potential

[29] FERC, 2012.
[30] Ibid.

under China-specific conditions, it is important to immediately develop more pilot programs on the ground in China.

Increasing Introduction of Pilot Programs

Demand-response pilot programs can be included as one measure to be adopted during times of less severe shortage categories of local orderly use of power programs, e.g., when shortages are not quite severe enough to require involuntary load curtailments or when some types of curtailments are just beginning to be implemented. Local governments and utility departments could design programs considering examples from the variety of programs implemented successfully abroad.

Implementation of pilot programs, even fairly small pilot programs, can provide key learning on, among other things: (i) effective institutional arrangements between consumers, local electricity distribution utility departments, and government supervising entities; (ii) practicalities of metering, defining and calling demand response events, recording results, etc.; (iii) experimentation with different technical approaches (direct load control, customer-managed load reductions in response to event calls and based on contractual agreements, and time-based approaches relying on the electricity pricing system); (iv) assessment of the practical potential and best customer class choices; and (v) assessment of the reliability of demand response as a peak-reducing resource. It would be especially useful if analysts could calculate the involuntary load curtailment successfully avoided by specific pilot programs.

The demand response program being piloted in Shanghai in 2014 provides a good example. Other municipalities could very usefully try pilots as well, including municipalities currently participating in the national pilot DSM cities program or applying for any successor national program. Demand response pilots could also be included in broader municipal energy efficiency-demand response-distributed generation integrated planning and implementation programs, as has been discussed with Southern Grid Company as a cooperation concept with municipalities in Guangdong Province.

Effective customer participation requires incentives. For pilot programs, relatively modest levels of external funding or small-scale funding through utility revenues may be sufficient for starting out. Some industries may be willing to initially participate for relationship and reputational reasons. Ultimately, however, consumer incentives (e.g., financial credits on electricity bills, incentives through the pricing system, or, perhaps farther into the future, payment for DR bids into wholesale markets) need to be part of sustainable demand response programs of significant scale. Although less expensive, demand response resources need to be paid for just as supply resources need to be paid for.

Substantial and worthwhile progress in scaling up pilots can be achieved, in principle, wherever a sustainable source of revenue can be allocated for supporting demand response incentives, especially through the pricing system. For example, introduction of critical peak load prices would offer an excellent source of sustainable revenue for demand response programs. In addition, the linking of critical peak load pricing with demand response incentive offerings can provide consumers with a welcome choice: pay higher prices for electricity during peak load prices, or pay less (perhaps amounts similar to now), taking advantage of discounts for various demand response load interruption options.

Introduction of Broadly Applicable Non-Interruptible Power Tariffs: An Approach for Developing Demand Response in Line With its Potential

China is the only large country with a well-developed and sophisticated power system and an advanced industrial sector that routinely relies on administrative rationing of electricity during shortages, while also not allowing industry to invest in sufficient stand-alone back-up generation of its own. In other sophisticated industrial economies, industry would not accept the great disruption to economic production caused by loss of electricity supply for days and sometimes weeks at a time almost every year. Especially as electricity demand growth has recently softened somewhat from its previously torrid pace, China needs to undertake the reforms necessary to be able to ensure steady, reliable power supply at all times for economic production by paying consumers, and avoiding the economic losses caused by involuntary load curtailment. Large-scale demand response programs can be an important part of a more economically efficient system, as a mechanism to both reduce costs and address reliability needs.

In principle, the central reform requirement is to introduce non-interruptible power supply to consumers currently facing possible curtailment under current orderly use of power schemes, together with a higher non-interruptible electricity tariff. Revised power supply agreements between the electricity distribution utility and consumers would reflect this change, and such consumers would be protected from electricity shut-off except during emergency situations. In return, such consumers would have to pay more for electricity, in line with a new non-interruptible power supply tariff.

Increased revenue collection from the non-interruptible power supply tariff can be used, at least in part, to finance demand response incentives for customers. Such incentives could include direct incentives for load control or customer-managed load curtailment during shortage events.

Consumers could continue to opt for interruptible power supply, at lower prices, in an arrangement similar in principle to current non-priority customer status under current orderly use of power plans, but with power supply agreements more explicitly and clearly defining curtailment requirements and procedures.

Industrial consumers, then, would have a choice: they could obtain non-interruptible power supply at somewhat higher prices, or they could opt into demand response programs whereby they obtain supply which is interruptible under defined conditions and pay less. There is little doubt that customers currently subjected to load curtailments under orderly use of power plans would very much welcome the choice, and that the choice would greatly help to reduce economic disruption in production.

Such a reform can remain revenue-neutral — average prices overall could remain unchanged. Such a reform also would be far less expensive for the country than a massive program to ensure reliable power supply during times of shortage through investments on the supply side alone.

In essence, such a system would end up with a similar arrangement to that used in North America and Europe, where electricity companies must guarantee full supply to customers, and a blend of demand response programs are in place, yielding benefits for the country and welcome discounts to consumers.

Integrating Demand Response Programs into Future Electricity Wholesale Markets

A number of localities have expressed interest in developing wholesale electricity markets, if power sector reform continues in ways to make such markets possible. Reforms allowing greater flexibility and transparency in generator-transmission system operator-distribution company contractual relationships, together with generator dispatch reform to greatly improve economic efficiency, could underpin wide and meaningful development of wholesale markets. Demand response programs could usefully become an element in electricity wholesale markets, as in the United States, and integration of demand response programs with wholesale market operation can, at least in principle, help optimize the system benefits of these programs.

Demand response options can be bid into either future electricity or capacity markets.[31] One issue that requires special attention for the effective bidding of demand response measures into power markets is inclusion of locational details — bids need to define location, and bids (and their prices) need to be accepted by matching bids with locations where they system is most constrained during a given period. It should be noted that FERC's Order No. 745 calls for bids to be compared with locational marginal prices. Another issue worthy of attention is the important role of third party aggregators. These aggregators have played an important role in enabling demand response bidding into electricity markets in the US to work effectively, by bundling and packaging demand response measures to best meet the operational requirements of the markets.

It should be remembered, however, that demand response programs do not need to be integrated into electricity wholesale markets to be effective. Fairly simple programs, involving utility-paid incentives or price discounts for participation in interruptible load schemes, as discussed previously, could still provide major economic efficiency benefits today, by reducing costs of both interrupted factory production and peak load service.

Conclusions

Development and expansion of electricity demand response programs can provide many important benefits to China. DR programs can:

- Provide an important tool to help move away from China's economically very inefficient and production-disrupting system of administrative power rationing during times of shortage or system stress towards an efficient market-based system;
- Save the country money, resources, and environmental damage by avoiding unwarranted over-investment in peak load generating capacity through development of far less expensive demand-side resources; and
- Provide power consumers with more choice in their service options, saving them money and enabling them to avoid expensive work stoppages.
- Aid the efficient integration of variable renewable energy supplies into power grids.

[31] For a recent discussion of power market development for energy efficiency and demand response gains in the Chinese context, see Crossley, 2014.

To develop DR programs, Chinese entities should consider the experience gained abroad over the last decades, and adapt the most promising program design concepts to China's circumstances. Local pilot projects should be further developed immediately to test ideas and gain experience. To deepen pilot projects into sustainable programs, revenues from the power tariff, such as revenues from critical peak load pricing, can be used to provide customers with price discounts or other incentives in exchange for agreeing to well-defined load curtailments or interruptions when called. To begin to truly develop DR in line with its great potential for efficiency gains in China, we suggest broad introduction of a modified power tariff that includes both (i) non-interruptible power service at somewhat higher prices; and (ii) a series of price discounts or other types of incentives for customers willing to participate in demand response. Such a modified power tariff could be designed to be revenue-neutral, if desired.

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