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Review

# Electricity demand response in China: Status, feasible market schemes and pilots

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ABSTRACT

Demand Response (DR) has been extensively developed and implemented in the US and Europe. However, DR hardly exists in many developing countries for similar problems such as rigid power market and state monopoly. With the increasing imbalance between supply and demand in China's power industry, the government has issued new policies on DR and approved the first batch of pilot cities. China is setting a good example of how to encourage DR under monopolistic electric market and open up the market to aggregators and DR suppliers. This paper summarizes the current DR status, feasible DR market schemes and DR pilot projects in China. First, electric power system reform, renewable energy policies and power industry development are reviewed, highlighting the problems associated with the current dispatch mechanisms of DR policies and markets. New DR programs and DR-related policies are also introduced. On this basis, the driving forces and challenges associated with DR in China are analyzed. The major challenge is the lack of a suitable market mechanism for the current Chinese power industry. Hence, this paper presents six feasible strategies that fully utilize the existing policies. Additionally, the latest DR applications in different pilot cities are summarized and analyzed.



**Contents**



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## 1. Introduction

The booming economy in China has resulted in a surging demand for electricity. With escalating demand and increased investments in renewable energy generation, electricity supply-demand mismatch is becoming increasingly prominent [1]. The power grid in China has exhibited higher peak loads, and the peak-valley difference has gradually widened. Especially during extreme weather events, network operation may be seriously jeopardized. There are two approaches to minimizing this threat: enlarging the peak regulation capacity from the supply side or implementing a demand response (DR) to relieve the pressure associated with peak loads [2]. Wang et al. [3] stated that peak shaving by means of demand-side bidding could yield greater economic benefits than operating at peak load by comparing the electricity price models of the two schemes. In addition, renewable energy has gradually attracted attention in China, whereas its integration to the grid is hard due to the feature of intermittency [4]. Currently, coal-fired reserve units are mostly used to offset the utilization of renewable energy because renewable energy is less reliable. Continually increasing coal-fired power plant capacities would result in the lower utilization rate of the renewable power generation. However, DR resources could promote the integration of renewable energy into the power grid, reducing the installation of units and the expansion of transmission lines.

DR, a measure used in certain circumstances (such as network congestion or emergency situations), has been extensively developed in the US and Europe, whereas it has only recently gained attention in China [5,6]. It can be 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." [7] DR also refers to a wide range of actions which can be taken at the customer side of the electricity meter in response to particular conditions within the electricity system (such as peak period network congestion or high prices) [5]. Unlike DR, Demand side management (DSM), which has been introduced in china for approximate thirty years [8], is a relatively broader concept that incorporates many actions, ranging from the replacement of energy-efficient appliances to the reduction of energy consumption to the shifting of times when electricity is used to the implementation of complex dynamic pricing mechanisms [9]. It can be universally divided into two categories: energy conservation and DR. Energy conservation is an approach that cuts the power load and promotes long-term stability, whereas DR is the most effective approach for minimizing temporal or short-term electricity shortages, which can be devastating (see Fig. 1).

DR can be generally categorized into price-based programs (also called time-based retail rates) and incentive-based programs [6]. Moreover, DR encompasses another special category in China that focuses on policy-guided programs because the Chinese power industry is currently based on the model of a vertically integrated monopoly. As the name implies, policy-guided programs are launched by administrations and serve as key measures of current demand side management (DSM) in China, which mainly focuses on mitigating the power deficit. The time-of-use tariff and tiered tariff are also widely used throughout the nation, but incentive-based DRs have not been used in any grid market in China, excluding pilot studies.

In July 2012, China's Ministry of Finance (MOC) and the National Development and Reform Commission (NDRC) jointly put forth "Interim Measures for management of central government funding for cities piloting DSM" [10], supporting the development of the power demand response, including scientific research, publicity, training, evaluation and assessment. For example, it explicitly states that DR participants are awarded ¥100 (15.4USD) for each kW load curtailment during the peak periods. In November 2012, Suzhou, Beijing, Tangshan and Foshan were approved to become the first batch of cities piloting DSM based on the respective reported implementation plans [11]. The pilot cities are capable of adopting flexible DR policies, taking full advantage of the time-of-use tariff and differential power pricing to achieve peak load shifting and power supply and demand equilibrium dynamically. These pilots also consider critical peak pricing and interruptible tariffs to develop in-depth and well-rounded DR. However, most efforts have focused on medium- and long-term curtailment in these pilot cities, while the quick and short-term DR was investigated until 2014. According to the NDRC requirements, an experimental program was conducted in Shanghai, which was the first short and fast domestic DR application. On April 9, 2015, NDRC together with MOC proclaimed the "Announcement concerning the improvement of the power emergency mechanism and the trial work on DSM in pilot cities" [12]. It also indicated that effective long-term mechanisms should be established, and specific characteristics should be highlighted based on the previous DSM pilot programs in Beijing, Suzhou, Tangshan and Foshan and the DR pilot program in Shanghai. These actions suggest that DR is becoming increasingly valued in China and is shifting from conceptualization to implementation.

Wang et al. [13] reviewed the DR in China in 2010, analyzed the scenario and made suggestions for DR implementation at that time. Nevertheless, dramatic DR changes have occurred over the past four years in China due to not only new policies but also approval of the first pilot cities nationwide. Especially during the past two years, experimental programs in pilot cities have been implemented under the current power industry mechanism, building momentum for future development in China. Hence, it can be

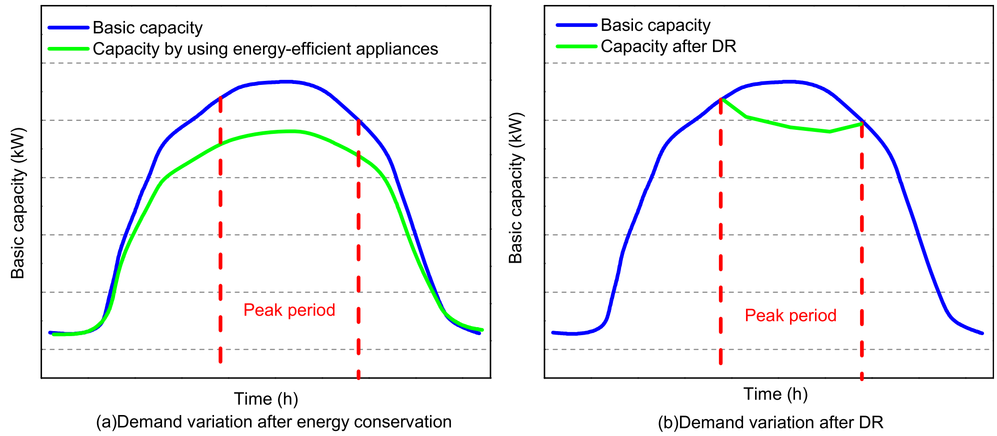


**Fig. 1.** Schematic comparison between energy saving and DR.

concluded that current DR exploration in China is a critical phase bridging the preceding implementation and subsequent large-scale implementation. Some scholars have published papers pertaining to DSM in China. Zhou et al. presented a study of the DSM and DR programs in China in the context of China's power industry reform [9]. Zeng et al. [14] also analyzed DSM development in China. However, their reviews emphasized DSM as a whole instead of management specific to DR in China because at that time, little attention had been given to DR. The major difference between this paper and the abovementioned relevant DSM studies is that this paper focuses on the current, state-of-the-art DR programs in China and presents suitable strategies for DR mechanisms on that basis. Section 2 summarizes the problems that the power industry faces and pinpoints the disadvantages of the current power dispatch mechanism. Section 3 explains the current status of DR in China, including a summary of previous DR studies, DR policies and the current motivation for and challenges associated with implementing DR in China. Section 4 suggests several feasible DR strategies based on previous studies and current circumstances. Specific emphasis is placed on the latest DR pilot programs in China in Section 5. In Section 6, the study's primary conclusions are presented.

## 2. Chinese electricity market: status, problems and solutions

### 2.1. Status quo of Chinese electricity industry

With rapid economic growth, China has observed a dramatic increase in power generation and consumption in recent decades. Fig. 2 illustrates that both power generation capacity and power demand in China have grown rapidly over the past twenty years [15]. The structure of the Chinese power system is still dominated by fossil fuels, especially coal, and renewable energy only accounts for a small share of total power generation [9,16,17]. However, the structure of power generation in China is changing [18]. The ratio of thermal power generation in total declines annually from 2000 on, dropping from 82% to 65.4% in 2014.

In spite of its high generation cost, renewable energy is more eco-friendly and yields greater social benefits than does coal-fired power generation [19]. China has established the use of renewable energy sources as a strategic plan for reducing greenhouse gas emissions [20]. Due to the establishment of China's "Renewable Energy Act", renewable energy has expanded rapidly over the last decade [21–23]. In recent years, increasing manufacturing capacities and decreasing costs have led to remarkable solar growth [24]. Additionally, nuclear power has rapidly developed in China [25].

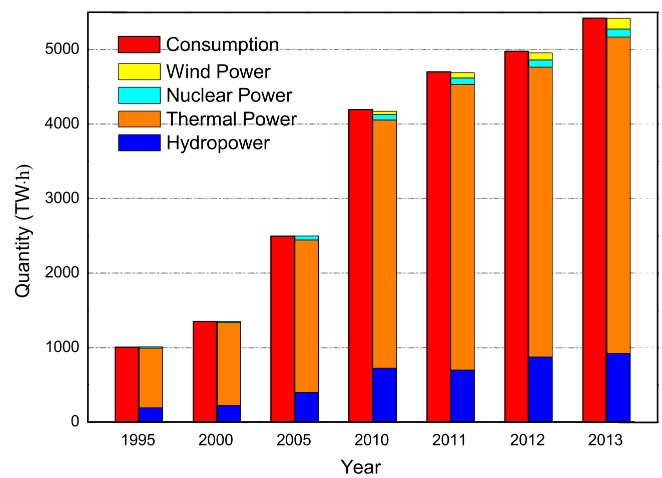


**Fig. 2.** Bar chart of China's power generation capacity and consumption of different energy sources [15].

The shares of installed capacities associated with different energy sources in 2014 are illustrated in Fig. 3.

By 2013, China's installed capacity overtook the US capacity, reaching 12.5 billion kilowatts. At the end of 2015, the installed capacity was more than 14.6 billion kilowatts, reflecting a 7.5% annual growth. Due to feed-in tariff adjustments, wind power investments exceeded those in the hydroelectric, thermal and

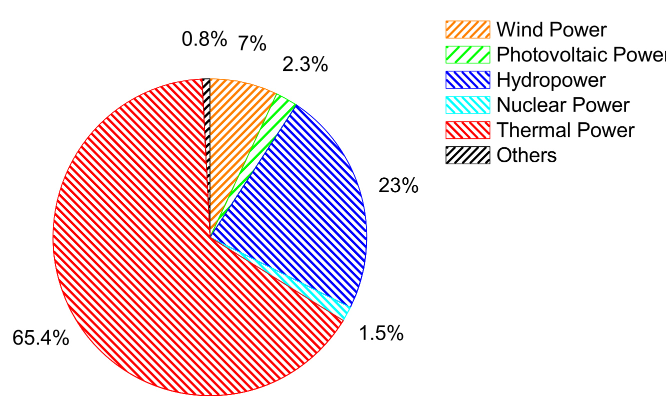


**Fig. 3.** Pie chart of the shares of installed capacities of different energy sources in 2014 [15].

nuclear sectors. Photovoltaic grid-connected systems exhibited impressive growth based on installed capacity and power output, while thermal power generation declined [26].

As estimated by both the International Energy Agency (IEA) and the Chinese government [27], large-scale generation capacity expansion would still be required to support the rapid economic development and satisfy the increasing power demand in China over the next two decades. Currently, China faces a unique dilemma regarding the development of the power industry:

First, now that China's renewable energy industry is booming, resolving obstacles associated with integrated the renewable energy sources into the power grid is becoming increasingly critical as a result of their randomness, fluctuations and uncontrollability.

Second, the annual working hours of thermal power generators continue to decrease due to the rapid increase in installed capacity, as depicted in Fig. 4 from 2001 to 2014. The average utilization of power equipment in 2014 fell to the lowest level since 1978, totaling 4286 h [28].

Third, power supply strains due to extreme climate events and machinery maintenance still occur frequently. For example, although the discrepancy between power supply and demand in 2014 was less serious than in 2013 because of cool weather and a declining economy, power shortages still occurred in North China [28].

In turn, DR can facilitate the integration of renewable energy into the power grid. DR can effectively shift peak loads and alleviate temporal power shortages. It is a promising approach for overcoming the issues that exist in the current power industry and shows great potential in China.

### 2.2. China's electric power market system

China's power sector has long been blamed for its high degree of administrative monopoly, improper government interference and insufficient market competition in the past [29]. To change this situation, nationwide power industry reform has occurred over the past two decades, which intends to gradually open up the China's power market and form a competitive market mode facilitating the development of DR [30]. In this section, the process of the power system reform is presented, with the demerits of the current power market pinpointed. It is noted that the electric power system reform is not an overnight change, and we need to assess the social benefits of DR in current China's power market. Therefore, the estimation of implementing DR in Shanghai is illustrated in Section 2.2.3.

#### 2.2.1. Electric power system reform

The Ministry of Power ceased to exist in 1998 and was replaced by State Power Corporation (SPC), whose goal is to overhaul and streamline power grids [31]. In December 2012, the former SPC was split into five power generation groups and two state grid companies (State Power Grid and China Southern Power Grid), separating the power generators from the grid operators [32]. Different generation groups provide power products to users through power grid bidding. Thus, the relationship between the supply and demand determines the price of the electricity, and the competitive market exposes the power producers to the uncertainties of market demand [33]. However, the power market is still based on a monopolized power grid, with both a sole buyer and sole seller. As for the power producers, the grid companies are the single buyers, while for the end-use customers, the grid companies become the sole seller [9]. In 2015, the State Council issued “the Several Opinions on Further Deepening the Power System Reform” and noted some key problems, such as the lack of a market mechanism and pricing system [34].

Since initiating reform in 1998, an open and competitive power market has not yet been formed. Government functions will play crucial roles in DR implementation based on the current electric power system.

#### 2.2.2. Disadvantages of the current power market system

An electric power market mainly consists of four parts: power generation, transmission, distribution and end-use customers. In China, grid companies serve as the sole buyer from the generation side and the sole seller to the user side, undertaking the roles of power transmission, distribution, selling and dispatching and monopolizing both sides (see Fig. 5).

Dispatch and management by the State Grid are the principal methods used to maintain market equilibrium. Power grid dispatch is based on a uniform power price, called benchmark price, which is fixed at all times, as shown in Table 1. The generation side is limited by the unified control of the State Grid.

When power shortages occur, increasing supply (by increasing generation output) or reducing demand (by DR) are the feasible methods used to achieve a real-time balance. In China, increasing the supply is the only approach before DR implementation, i.e., more power plants are being built to satisfy the demands and peak loads. This results in many unused plants during off-peak periods. Still, the five generation companies continue to build new plants because under the current dispatch mechanism, building more plants is the only solution. The State Grid companies have to

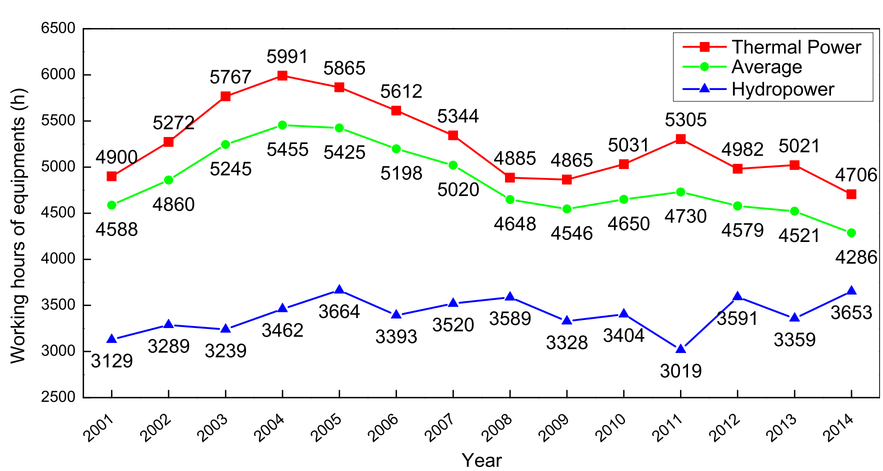


**Fig. 4.** Annual working hours for power generating equipment from 2001 to 2014 [28].

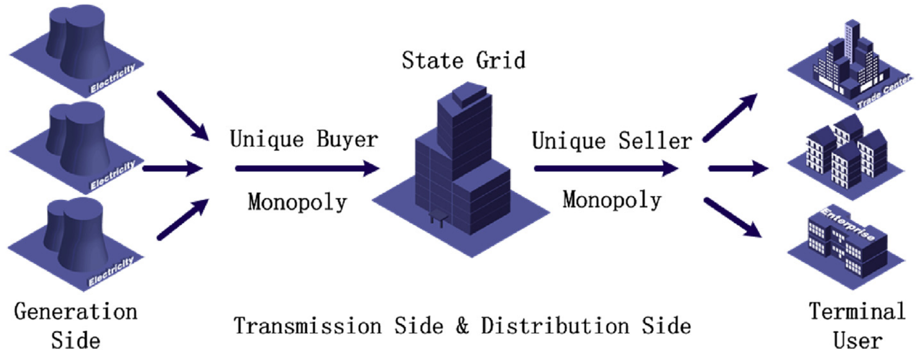


**Fig. 5.** Schematic diagram of the relationships between the four sides.

**Table 1**
Benchmark price.

| Type | Hydro | Thermal | Wind | Nuclear | Photovoltaic |
|---|---|---|---|---|---|
| Price range(CNY/kWh) | 0.2–0.4 | 0.3–0.5 | 0.51–0.61 | 0.43 | 0.8–1.1 |
| Average price(CNY/kWh) | 0.265 | 0.45 | | 0.43 | |

purchase power products from the newly built plants during off-peak periods to ensure that they remain economical, reducing the utilization hours of existing plants even further. Indeed, the current power dispatching mechanism of the State Grid is not based on market driven behavior. The inevitable consequences associated with the consistently decreasing utilization rates of existing plants and the considerable investments in newly built power plants will eventually be suffered by terminal users.

The dispatching mechanism will not be able to cope with the growing social demands and the increasing gap between peak loads and valley loads for various reasons. The dispatching mechanism could mitigate the problem of peak-valley power difference, but it brings about tremendous social losses. First, the average utilization rates of power plants continue to fall, and the intermittent operation of equipment has made them vulnerable to damage. Second, small units in backup plants consume more coal than large units that generate the same amount of power, leading to a continuous increase in coal consumption per unit generating capacity. Third, power plant construction wastes land resources. Finally, power grid expansion results in the decrease in the power generation utilization rate, the increased maintenance and repair costs, as well as grid losses.

In summary, there has long been concern associated with increasing the supply in China's power dispatching mechanism, resulting in the potentially effective DR being ignored. This is because the State Grid acts as the single power seller for end-use customers. Therefore, profits can still be guaranteed through directly increasing purchase prices of terminal users in the case of increasing costs. However, insufficient understanding of DR, particularly lacking regarding the potential profits of DR, is another major cause.

### *2.2.3. Economic benefit evaluation of DR in China under the current market system*

DR can serve as a virtual power back-up plant that averts and reduces the peak load. However, the current dispatching mechanism focuses on building more power plants and expanding the power grid to meet the load. In this section, using Shanghai as a case study, a DR benefit estimation is presented based on the current power mechanism in China. Issues related to short supply were partly mitigated by the favorable climate (see Fig. 6) in 2014. However, the huge difference between the peak load and valley loads still exists. The highest electric power load reaches 26 GW, while the lowest only reaches 8 GW. The total hours at more than 90% peak load only amount to 90 h, accounting for only 1% of the whole year. However, there are 7400 h at 40–70% of the peak power load. The installed capacity of local power plants in Shanghai totals 15 GW, and power purchasing outside of Shanghai is approximately 10–15 GW. The purchasing power amount is determined in the beginning of the year and it has the priority to the power generated by the local plants. That is to say, the local power plants are complemented according to the original dispatching mechanism. As a consequence, they are almost reduced to back-up plants during off-peak periods when power purchasing is sufficient.

According to the statistical data from the latest cost handbook [35], the average cost of setting up a gas turbine power plant is approximately 3000 CNY/kW, and the cost of a coal-fired power plant is 4500 CNY/kW. The corresponding power grid construction cost is approximately 1000 CNY/kW [35]. A peak load power plant consumes 380–500 g/kWh of coal, and a common power plant consumes 290–340 g/kWh of coal [36]. The empirical evidence demonstrates that DR is able to realize a 3%–9% peak load shift [6]. Therefore, in this case, a 5% (approximately 1.35 GW) peak load is assumed to shift to a valley, and the total electricity sales remain the same. Thus, the costs from expansion of the power grid for peak shifting can be saved. Detailed calculations of the benefit estimation of DR are summarized in Table 2.

From the above analysis, a savings of approximately 123 billion RMB from power plant buildup, power grip construction and the coal consumption can be obtained by shifting 5% of peak load based on DR. Since the power load shifts from the peak to the valley, the total electricity sales will not change substantially. And this amount of savings can be used for the construction of DR systems, the customer tapping and DR incentives, etc.

On the other hand, DR enhances the utilization of generating equipment and increases the usage hours of the power grid, prolonging the lifetimes of units and reducing maintenance fees. DR saves the relevant land resources by not building up new power plants.

It is noted that the largest problem brought about by China's dispatching system lies in that it fulfills the peak load by expansion of the power grid. The presented cases only evaluates the biggest

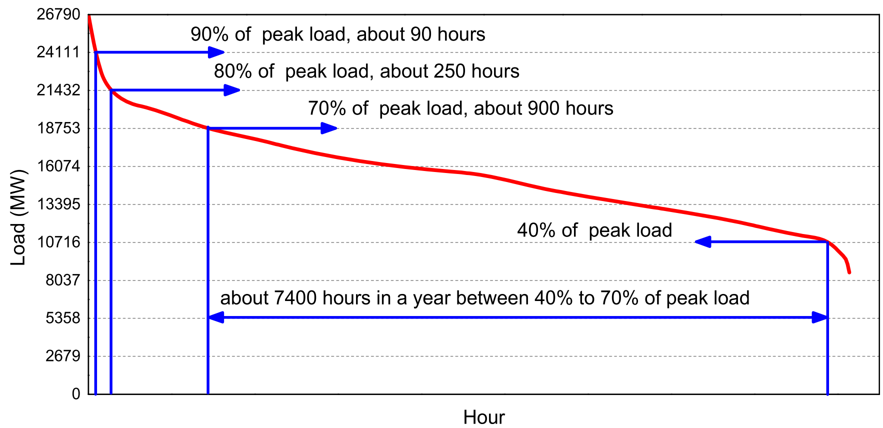


**Fig. 6.** The distribution of the electric power load in Shanghai in 2014.

**Table 2**
The results of the benefit evaluation of DR.

| Sources of benefits | Calculation | Result(CNY) |
|---|---|---|
| Savings from power plant buildup | Unit construction cost × Shifted loads | ~40.5–60.75 billion |
| Savings from power grid construction | Unit construction cost × Shifted loads | ~13.5 billion |
| Savings from coal | (Coal consumption by load-shifting power plants − Coal consumption by common power plants) × Shifted loads × Coal price | ~1 billion |
| **Total savings** | | ~123 billion |

contributors to the savings. The overall benefits of DR needs to be further investigated by considering the factors such as payback effects, cash flow mapping and so forth.

## 3. Status quo of DR in China

### 3.1. Current DR programs in China

Due to the long-term monopoly condition in China, the related DR is largely dependent on the power policies. As mentioned in Section 1, current Chinese DR programs can be divided into price-based programs, incentive-based programs and policy-guided programs. More details are summarized in Table 3.

In price-based programs, users consume less power at times of maximum demand, resulting in lower prices at other times [37,38]. The pricing mechanism is important for implementing successful DR programs, especially during the initial phase of implementation [39].

Among the price-based programs, time-of-use tariff is adopted in the retail side nationwide except in Tibet, which is shifting to a market-driven approach to load management. With reference to the domestic policies, the price difference between the peak and valley loads varies regionally. Normally, the peak rates are 2–5 times higher than off-peak rates. It was estimated that 21.86 GW was shifted by the time-of-use tariff in 2014, accounting for 73% of the power gap; the average load rate of the power grid was 85.72% and increased 1.84% over the last year [40]. In addition, eight provinces also adopt CPP strategies [41]. Four provinces that are rich in hydroelectric resources have already implemented season-of-use prices [41].

The two-part pricing strategy was originally designed for industrial enterprises. The tariff is generally divided into two parts: the basic tariff and the used tariff. The basic tariff is based on the load demand which users sign up contracts with utility companies [42], in the form of “yuan/kW/month” [43]. Users will pay more as the signing demand increases. They are fined if actual consumption exceeds the signed limit. The used tariff is generally calculated according to the actual consumption of the users. This pricing strategy can enhance the utilization of the equipment on the user side, hence improving the power grid load rate.

Incentive-based programs are essentially call option approaches in which users sell the right, but not the obligation, for the utility to reduce some of the customer's load in exchange for an up-front payment or a per kWh discount [44]. Interruptible tariffs have been introduced in some regions. For example, Jiangsu province initiated the strategy and paid 10000 yuan for per MWh curtailment in 2002 [45]. Hebei province put forward an interruptible tariff incentive of 1yuan/kWh in 2003. Similar strategies were also tested in Shanghai, Fujian and Zhejiang [46]. The subsidy is normally around 0.3–2 yuan/kWh [41]. Approximately 99–185 MW interruptible loads were shifted on three peak days during summer 2005 in Shanghai [41].

Policy-guided programs are specific types of DR under the current Chinese power system. The most severe electricity shortages in

**Table 3**
Current DR programs in China.

| Price-based program | Incentive-based program | Policy-guided program |
|---|---|---|
| • Time-of-use (TOU) tariff<br>• Critical peak pricing (CPP)<br>• Two-part pricing | • Interruptible/curtailable tariff | • Power rationing<br>• Orderly power |

2003 resulted in nationwide power rationing among the 18 provinces. Since then, DSM has strengthened to ensure orderly power utilization [47]. Local governments impose direct load controls through power monitoring systems on some customers who are supposed to quickly respond to the orders and curtail their loads. Based on the definition of the program, it is actually a special type of incentive-based program in which observant customers gain without being penalized or with the power restriction loosened.

Except for the policy-guided program, the categories of DR programs in China are similar to those in U.S [7] and some European countries [6]. But there exists large distinctions, in essence, in these programs. The electricity industry restructuring took place in 1990s U.S., which aimed at facilitating the development of regional, competitive wholesale electricity markets. However it gave rise to the imbalance between the supply and demand. Eventually, different types of DR programs became the solutions [48,49]. Three biggest power firm, located in eastern U.S. electricity markets, introduced there distinct incentive-based DR programs respectively, such as Day-Ahead Load Response, Emergency DR Program, and Special Case Resource program [6]. The DR customers include the industrial, commercial and residential sector. The most important feature in U.S. DR lies in that it has formed a competitive power market and become a mature industry. Likewise, in Great Britain, a relatively free power market was developed and DR has been implemented for several years [6]. In the industrial and large commercial sectors, energy intensive users are able to agree TOU and/or interruptible contracts with suppliers. And in some other European countries like Sweden and Finland, interruptible tariff programs were employed through legislation to control the power consumption in large industrial end-users.

Though going through the power system reform, China's power market is still under the status of monopoly. The DR programs are far less mature than those in U.S. and some European countries. The current features of DR programs in China can be summarized in the following bullet points:

- The government function and relevant policies are still the dictating factors on the DR programs.
- The existing DR programs, even the price-based programs and incentive-based programs are set based on the policies.
- The DR customers are mostly industrial users.

Among the current DR programs, TOU tariffs, interruptible tariffs, two-part pricing and orderly use schemes are mainly aimed at industrial users. However, with power consumption increasing in tertiary industry, commercial and residential buildings in China will gradually become important targets of DR in the future. As power marketing reform advances, the electric power sales market will be opened, and the current policy-guided programs require a corresponding transition. Therefore, establishing innovative and effective mechanisms in the context of power system reform is required to move forward.

### 3.2. DR-related policies in China

In the early 1990s, DSM was first introduced in China. The DSM Directive Center was established by the State Power Corporation in 1998, resulting in publicity regarding the concept as well as theoretical DSM research. From 1996 to 2000, demonstration projects were successively launched in different provinces. Initial emphasis was placed on the energy saving in the early stages. The power failures in 22 provinces in 2003 resulted in the formation of a new pricing mechanism, which used price to create a dynamic supply and demand balance for electricity [33]. In the meantime, DR research began to obtain increasing attention. As an integral part of DSM, DR-related policies are mainly covered by DSM policies. In this section, the DR-relevant parts are extracted and summarized, as illustrated in Fig. 7.

In 2004, NDRC and the State Electricity Regulatory Commission (SERC) issued the “Guidance on the reinforcing DSM”. In addition to energy efficiency, it proposed several measures for peak load management, such as load shifting, power storage, orderly power utilization and limitation, etc. [50]. In 2010, the NDRC, MOC and six other ministries jointly published the “Regulations on the DSM”, which involved DR-relevant provisions to improve the TOU pricing system, promoting energy storage during off-peak periods and implementing interruptible tariffs in some regions. The regulation also included incentives to develop DSM [51]. However, overall, the development of DSM in China still focuses on energy saving efforts, and DR has only been initiated and developed in certain regions in China.

DSM efforts have focused on the industrial field because the industrial sector has been the largest electricity consumer, accounting for more than 70% of China's total electricity consumption. In 2011, China's Ministry of Industry and Information Technology (MIIT) announced the “Guidance on the better implementation of DSM in the industrial sector” [52]. Note that orderly power utilization strategies also concentrated on the industrial field around this time.

On July 16, 2012, China's Ministry of Finance (MOC) and National Development and Reform Commission (NDRC) jointly issued “Interim Measures for management of central government funding for cities piloting DSM” [8]. The measures explicitly stated that DSM funding must be used to support efficiency power plant programs (EPP) and develop DR. This approach also determined specific criteria for incentives. On April 9, 2015, the NDRC together with MOC issued the “Announcement concerning the improvement of the power emergency mechanism and the trial work on DSM in pilot cities” [12]. Strengthening the mechanism of innovation and practicing DR were again stressed in this announcement.

Based on the DSM policies listed above, it can be concluded that DR has not aroused widespread concern until recently in China. The policies issued before 2011 merely mention provisions related to DR, while the provisions after 2012, in addition to becoming more common, more explicitly and carefully list terms and wording associated with DR. As reiterated in the latest 2015 DR policy, research and development of a DR mechanism under China's current power system is a top priority.

### 3.3. Driving and restraining forces of DR in China

In this section, driving forces and restraining forces associated with DR are summarized. As stated above, the domestic power system is the foundation for the development of DR, and DR-relevant policies should further influence the development process. Therefore, the major impetus for DR development is the need for structural reform of the power industry and implementation of DR related policies.

First, the reform of China's power industry, which has consistently grown over the past few decades (see Section 2.2), is the driver of DR development. Many efforts have been made to implement DR programs, especially those that reform electricity-pricing mechanisms. If the domestic power system is reformed, a new power market competition pattern will form, providing a solid foundation for long-term DR development.

Second, increasingly more policies have supported DR implementation because the government plays an important and guiding role in China's power market. This is supported by the fact that DR pilot programs have been successively initiated by the Chinese government in different regions (see Section 3.2). In addition, DR

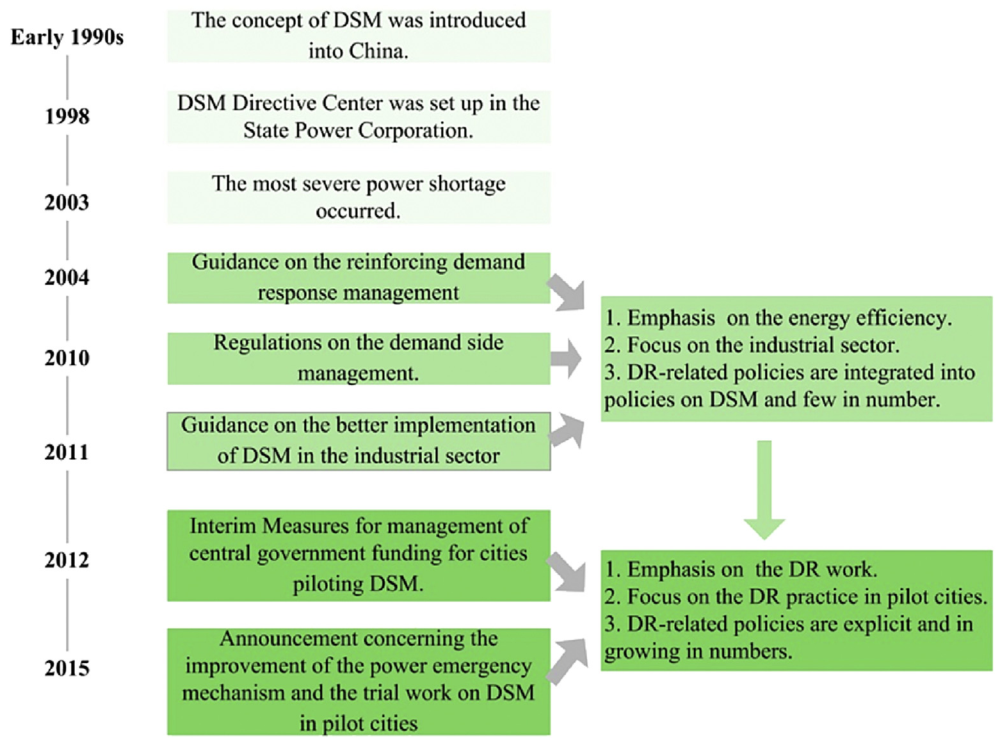


**Fig. 7.** Roadmap of DR-relevant policy development in China.

encompasses a larger portion of DSM-relevant policies, and the provisions are becoming increasingly specific.

However, we note that China's power industry requires further reform. To solve many issues and promote efficient, reliable and sustainable development of China's power industry by fulfilling the potential of DR, many challenges must still be addressed. The challenges include poor recognition of DSM and DR, cost and technological issues, the shortage of monitoring and management systems, the vagueness of an open power market, the weaknesses of laws and policies, etc. [8,14]. Based on reviews of the status quo of China's power industry in Section 2.1, power system reform in Section 2.2 and the current DR-related policies in Section 3.2, two main challenges are specifically highlighted.

One challenge stems from the existing problems in the Chinese power system. Currently, the power market is partly open only to the generation side and oligarchic competitive market, which is characterized by incomplete information. Without open markets and vigorous competition, DR will not easily develop in China [9]. As stated in Section 2.2, the State Grid Corp., China's monopolized power distributor, adopted a benchmark price strategy rather than a bidding transaction strategy and formed a bilateral monopoly on both sides of purchases and sales. In this dispatch mode, the power-generation firms tend to build more generators to handle the ever-increasing peak load without worrying about power sales. Thus, the potential of the DR is neglected. Therefore, efforts should be made to destroy the monopoly by challenging traditional mechanisms and configuring power resources through an electric power market. Only in this way can DR manifest its value.

Another constraint is based on the lack of feasible DR mechanisms under the current power system. Because the reform of the China power system is a long-term process, a development strategy that is suitable for the current transition period is desperately needed. The announcement issued in 2015 [12] emphasized strengthening institutional-based and mechanism-based innovation related to DR research. Therefore, in this transition period, determining proper mechanisms related to DR is another unprecedented challenge facing China.

It can be seen that increasing policies which favor DR are being formulated in China and the China's power market becomes gradually open and competitive from being monopolistic, both of which creates the advantageous condition for the development of DR in China. Nevertheless, the monopolistic feature of China's power market is inveterate enough to be able to emulate and follow the empirical experience in the leading countries, which to some extent decelerates the development of DR in China. The near future of DR in China might have the following features:

- The mainstream DR programs are still policy-intervened.
- The development of TOU and interruptible tariffs is contingent on the issue of the relevant policies.
- The subsidized orderly power utilization will become an indispensable DR program.
- The customers will be granted more rights and freedom.

In the following section, we provide six potentially feasible strategies, which incorporates the aforementioned features of DR in the near future.

## 4. Feasible DR schemes under the current situation

The case study presented in Section 2.2.3 demonstrates that DR can bring benefits to all stakeholders, particularly end-use customers. Power utilities can improve traditional dispatch mechanisms by practicing DR from the demand side. However, the implementation of DR in China must adapt to trends associated with Chinese power system reform. In this section, strategies for applying DR to the current power system are proposed.

### 4.1. Adoption of cap-and-trade schemes

The contracted quota is the maximum power load for which the institutional customers sign contracts with the power utility in a payment cycle. If the actual consumption exceeds the limit, the cost would considerably increase. Additionally, if consumption failed to reach the quota, the customer still needs to pay the signed cost, and the surplus power could not be sold. Although the quota can effectively control the maximum load of the users at different times, enhancing the equipment efficiency on the user side and improving the load rate of the power network, however, for the users, the contracted quota is not associated with any tangible benefits.

For a regional power network, the peak load of the entire user group should be controlled rather than that of a single customer [53]. With increasing power system reform, pricing tariffs should also change to benefit users. Therefore, a power cap and trade system is suggested, as illustrated in Fig. 8. The single customer still signs contract quota with the power utility, but the customers in the same regional network can make trades on their surplus power. Trading users can sell or purchase power loads according to their own situations. If a portion of a quota is sold, the users cannot consume more than the new quota limit or they will be fined. Likewise, the new quota is added to the capacity of the users who purchased it during a given payment cycle. In some cases, power utilities can also purchase capacities from users during emergency power shortages. In this scheme, the total load limit of a user group can be controlled, and the single user can gain profits through the transaction, which is more flexible.

The contracted quota has been implemented in China for years, which is an effective means to control the maximum load. The cap-and-trade scheme, which are designed on this basis, does not require any new equipment but a trading platform, thus not having technical problems. Since the quota transaction between customers makes the mechanism more flexible, the probability of the fining for excessing the quota is lowered and the power utility may have less revenue from the fining. However, the power utility can buy back some quota to ensure the balance during the power tension, which will avoid the economic losses brought by the power deficit. Therefore, the cap-and-trade scheme still guarantee the profit of the power utility. It is a pilot scheme and worth developing.

### 4.2. Encouragement of the curtailment service providers (CSP)

Curtailment service providers (CSPs) who act as intermediaries between the power utilities and end-use customers to deliver the DR capacity, are popular in the US and Europe but are only currently emerging in China.

In 2008, the Ministry of Housing and Urban-Rural Development of China (MOHURD) issued a new policy and offered subsidies promoting sub-metering [54]. Subsequently, thousands of large commercial buildings in China have installed sub-metering systems. The sub-metering platforms are now mainly utilized for energy monitoring, building performance assessment and building energy efficiency analysis [55]·[56]. The sub-metering systems effectively meet the metering and telemetry access requirements of CSPs to customers' meter data. CSPs will likely establish a significant foothold in China and thus expand the DR industry based on the current sub-metering platforms. CSPs will also attract more new customers who will enroll and participate in DR programs.

The establishment of sub-metering platforms is one of the distinctive features in China's energy monitoring and management and the platform owners offer energy management service for end-users. Therefore, the DR Service can be a new service in the power management and the platform users provide a large proportion of customers for implementing DR. In Section 5.1, more detail will be provided regarding the sub-metering platform owners served as CSPs in Shanghai pilot. The CSPs based on the sub-metering platform can have a solid customer basis and it is a feasible means which went through the pilot experiment.

### 4.3. Development and extension of price-based programs

TOU tariffs are widely used for power load adjustments, which are becoming more stable and developed in China. Therefore, TOU tariffs should be maintained and expanded in ways that are more diverse and detailed. For instance, "TOU tariffs on special days" are suggested. This strategy is based on one-week or even one-day weather forecasts to determine the price difference between peaks and valleys, accounting for weather factors in different seasons. Additionally, critical peak pricing and two-part pricing are also effective measures for load control [57]. However, critical peak pricing is currently employed in limited regions in China [41].

The issue of DR policies in recent years facilitates the development of TOU. Various types of TOU could mitigate the imbalance brought by the consecutive high temperature, the repair and maintenance of the equipment and so forth. However, as stated in Section 2.2.2, the power price mechanism is determined by the State Grid, and hence the state or local government policies impose a tremendous impact on the development of TOU. The policy-guided TOU cannot fully reflect the market supply and demand conditions. Thus, the effects of TOU in China on mitigating the imbalance are weakened.

### 4.4. Improvement of orderly power limitation

Orderly power limitation, as a compulsory policy-based DR program, is a traditional enforcement strategy that mainly controls the peak load of industrial customers in China. Since it does not offer subsidy for the users, it is hard to trigger their initiative and

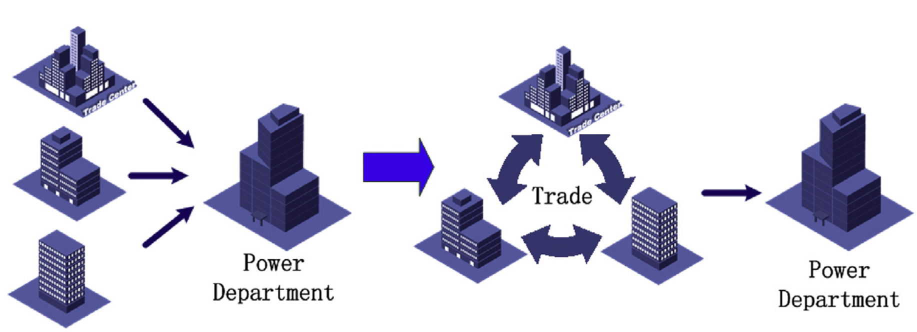


**Fig. 8.** Illustration of the power generation cap-and-trade scheme.

has been gradually challenged by different types of customers. However, it is still the foundation of the emergency DR and continues to play an important role in DR programs at this stage. Hence, some subsidized policies that motivate customers should be added to the DR strategy. For example, in the Shanghai DR pilot, 2 yuan/kWh curtailment subsidy is set to award the DR participants during peak periods. There exists other subsidies such as 100 yuan/kW curtailment in other pilot cities [10]. However, these kinds of subsidies are targeted in the DR experiments in pilot cities. In the process of orderly power limitation, there does not exist such kind of subsidy. So the current feasible subsidized scheme is to follow the relevant policies in China, meanwhile adding some subsidizes in the orderly power limitation, which will enhance the users' initiative.

### 4.5. Implementation of subsidized DR programs

Similar to the subsidy to the orderly power limitation, other DR programs can lure more customers through offering subsidies at the beginning. Subsidized DR programs represent a transition from policy-guided programs to incentive-based programs. For a long time, Chinese governments set up specialized funds for energy efficiency [58] and peak shaving [59]. These funds can also be utilized for DR incentives. On one hand, the “national mandate” of the policies ensures a curtailed power load. On the other hand, some subsidies or incentives will lure more customers to participate in DR strategies. By increasing the number of DR participants, the compelling features of these policies will be weakened, and complete incentive-based programs will likely form. Therefore, subsidized DR programs are more suitable for the current status. The subsidized form can follow the 100 yuan/kW curtailment in pilot cities [10], but it needs to be tuned based on the different types of the programs in the future.

### 4.6. Implementation of DR star ratings

Considerable progress has been achieved via energy conservation and emissions reduction. This progress can be largely attributed to the target responsibility system and the assessment system (Star Ratings of the green commercial buildings) in China, which has aroused the widespread attention of the architecture practitioners on the building energy efficiency and built environment [60,61]. DR strategies can also mimic and learn from this mode, rating and assessing the customers' performances according to their curtailed power loads at peak times to promote and motivate users to participate in DR. It is hereby noted that DR Star Ratings are merely supporting measures for developing DR in China.

## 5. DR pilot projects in China

Shanghai, Foshan, Beijing, Suzhou and Tangshan are five cities that have implemented short DR programs in China [62]. These city pilots are different from previous TOU tariff, orderly power use and energy efficiency programs from a demand side perspective. Several trials have been conducted associated with the programs, such as the formulation of incentive policies, DR platform establishment, customer development, curtailment, end-user feedback, etc. The authors investigated and participated in the DR programs in Shanghai and Foshan. In this section, empirical evidence and outcomes are detailed in Section 5.1 and Section 5.2. A brief summary of DR city pilots in other cities is presented in Section 5.3.

### 5.1. Shanghai pilot

#### 5.1.1. Introduction

The peak and valley power loads in 2013 were 28 GW and 16.6 GW, respectively, and only 60 h exceeded 25 GW. The weather in summer 2014 was cooler, but the difference between the peak and valley loads was still large. The peak and valley power loads in 2014 were 26.9 GW and 8 GW, respectively, and only 90 h exceeded 90% of the peak load. The composition of the power supply in Shanghai included 15 GW generated from local power plants and 10–15 GW from purchasing. Thus, almost all the local plant generation was used during the peak times. If units malfunction, power shortages will occur.

Based on the development tendency of DR and the practical situation in Shanghai, the NDRC and State Grid utility gave the Shanghai Municipal Commission of Economy and Informatization (SMCEI) the assignment of piloting the DR strategies of local enterprises and in commercial buildings during continuous high temperature days or power shortages.

The framework of the DR pilot is shown in Fig. 9. The DR center serves as the medium that receives and distributes DR quotas, releasing DR tasks to the load aggregators or industrial customers. The load aggregators are the load serving entities that gather customers to participate in the pilot, subscribe to the curtailment tasks from the DR center and distribute loads to the customers. In the Shanghai pilot, the load aggregators are actually the operators of the district-level sub-metering platforms, which are used to send notifications, monitor the response actions and evaluate the effect of DR.

Metering and telemetry conditions provide a good foundation for implementation of the DR pilot in Shanghai. Real-time communication between the power grid and the majority of users has been essentially achieved. Furthermore, 600 blocks of large commercial buildings have established sub-metering platforms, providing favorable conditions for load aggregators to develop strategies and supervise the curtailments of commercial buildings.

The total power consumption in buildings are submeterred into four categories in China: lighting and plug, air-conditioning, power

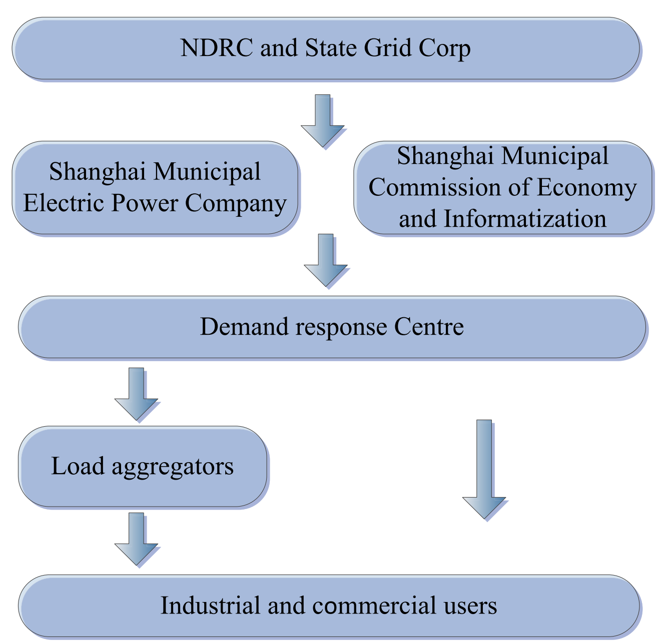


**Fig. 9.** The DR pilot framework in Shanghai.

and special submeters. Data on these submeters are normally collected every 15 min. The major power consuming equipment is also gauged, such as the chiller, the chilled and cooling water pump, the elevators, and so forth. The commercial buildings taking part in the Shanghai DR pilot all have such sub-metering platform, with the function of data collecting and uploading. The higher level platform (district level, city level) can collect and storage real-time power consumption. In addition, the sub-metering platform undertook the important tasks of analyzing the history power consumption of users, deciding the DR strategies of users and the power monitoring of users during the DR period.

#### 5.1.2. Results

Sixty-four end-use customers participated in the Shanghai DR pilot (31 industrial enterprises and 33 commercial buildings). Among them, 31 industrial customers were original users participating in orderly power limitation, who were experienced in the peak load control. Compared to the original program, the pilot DR experiment could own them 2 yuan per kWh curtailment subsidy, so they acted positively towards the pilot. The other 33 commercial customers were mostly customers from the sub-metering platform, who paid more attention to the energy management than common building owners. The total estimated DR capacity was more than 100 MW. The trials were conducted 13:30–15:30 on July 22, 2014 and 13:00–16:00 on August 29, 2014. There were not preset compulsory curtailing target in these two trials and the customers could limit their own power loads according to their conditions. The realized DR capacity was approximately 50 MW in the second experiment. As new participants in Chinese DR-based strategies, commercial buildings reduced their peak loads by 10% during the two trials, validating the feasibility of DR in commercial buildings. The results of the experiments are detailed in Table 4.

In the second trial, three of seven participating industrial companies had a substantial effect on the DR and met the requirement of the subscribed curtailable volume. The corresponding strategies used to reduce loads included shutting down electric boilers in advance, turning off workshop AC units and employing backup renewable generators. However, the other four industrial companies failed to accomplish these tasks due to production plans.

In general, the Shanghai pilot established a groundbreaking DR platform and a model that can be replicated in other regions, promoting a nationwide DR strategy. The value of the Shanghai pilot is summarized as follows:

- It validated the feasibility and value of commercial sub-metering platforms and industrial energy management systems based on DR.
- A DR trial was successfully conducted and valuable feedback was collected from end users. For example, discontinuous industrial production has significant DR potential, and large commercial buildings exhibited 10–15% load shaving capacities.
- This pilot helped to establish the user baseline load. By comparing the methodology used to calculate the customer baseline load in the US and considering the features of the Shanghai power market, weather conditions, etc., an approach for calculating the customer baseline load in Shanghai DR is presented. The detailed method is explained in Table 5.

Here, $N_{DRi}$ represents the average power load during the response period on the ith day. $N_{2hbDRi}$ is the average power load two hours before the response period on the ith day.

Because the Shanghai DR pilot is new and tentative in China, there are still some issues with the strategy. These problems can also be summarized as follows:

- A discrepancy exists between the DR center data and the customer self-metering data. The end-use customers cannot accurately monitor their own load conditions because the center does not provide them with real-time data.
- The amounts and types of incentives are insufficient. Only 2 yuan per kWh are paid for load shifting, which is not enough to motivate different types of end-use customers to take part in the DR strategy.
- The pilot lacked publicity and promotional efforts, resulting in parties poorly understanding the DR strategy as a resource for power balance and generation competition.

### 5.2. Foshan pilot

#### 5.2.1. Introduction

As one of the first DSM pilot cities, Foshan committed to DSM from 2013 to 2015 in an attempt to save and shift its 450 MW peak power load. In July 2013, the maximum power load reached 10.5 GW, surpassing 10 GW for the first time. In 2014, the total supply of the local utility was 0.556 million GWh and the investment in grid construction was as high as 22.83 billion yuan.

In this context, the NRDC implemented a DR strategy, stipulating that at least 60 MW of the power load be shifted using DR, and the subsidy was 130 yuan per kW. Similar to the Shanghai DR platform, the Foshan DR pilot also uses a city-level DR management platform to publish information and collect feedback based on the load management system of the local power supply bureau. Fig. 10 illustrates the framework of the Foshan DR pilot. The end-use customers are composed of load aggregators and industrial enterprises that voluntarily sign DR contracts with the city government. Foshan Power Supply Bureau forecasts the next-day peak load in advance, releases the load shaving based on the DR management platform and distributes DR tasks to the load aggregators and industrial companies. The participants monitor the DR process and make corresponding adjustments to their strategies through the platform.

#### 5.2.2. Results

The standard of temporal subsidy for DR pilot in Foshan was 130 yuan/kW. Eight DR events were conducted in Foshan in 2015, among which the fewest participants was 29. As many as 100 customers participated in the October 22nd DR pilot. Regarding the DR completion rate defined in Eq. (1), the lowest was 71% (the fourth pilot) and the highest reached 166% (the fifth pilot). The detailed completion status is depicted in Fig. 11. The predictions of customers' curtailment loads are quite accurate. Customers were

**Table 4**
Experimental results from the commercial buildings in the Shanghai pilot.

| Time | Number | Curtailment goal (kW) | Realized curtailment (kW) |
|---|---|---|---|
| 13:30–15:30 on July 22, 2014 | 4 (1)[a] | 1320 | 1400 |
| 13:00–16:00 on August 29, 2014 | 28 (1) | 5000 | 4950 |

[a] The number in parentheses denotes the number of commercial buildings that automatically responded to the order.

**Table 5**
The moving average method for calculating the customer baseline load in Shanghai based on the DR pilot.

| Data window | Data filtering | Climate correction factor | Data selection | Baseline method |
|---|---|---|---|---|
| Ten-day historical power load data before the DR pilot day | Exclude the day when $N_{DRi}$ is smaller than 25% of the average value | $\sigma_i = \frac{N_{2hbDRi}}{N_{DRi}}$ | Choose 5 days as typical days when the climate correction factors are closest | Moving average of $N_{DRi}$ in five typical days as the baseline load |

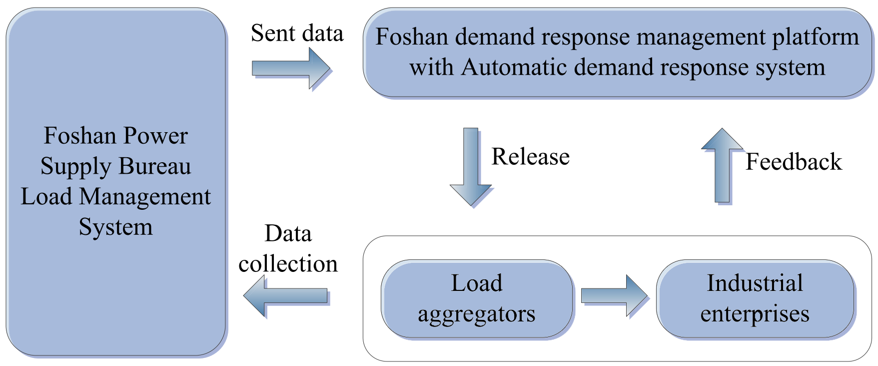


**Fig. 10.** The framework of the DR pilot in Foshan.

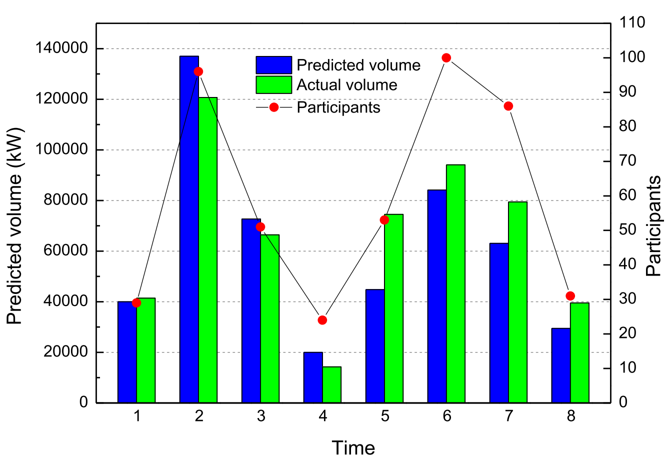


**Fig. 11.** Results of the Foshan DR pilot.

very cooperative during these eight DR events.

$$CR = \frac{V_{actual}}{V_{predicted}} \times 100\% \quad (1)$$

CR is the completion rate of the DR events and $V_{actual}$ is the actual reduced load (kW).

The results of this DR pilot program support the feasibility and validity of the DR framework in Foshan based on the customers' reactions to the DR. The DR platform exhibits strengths associated with dispatching and coordination. The load management system and sub-metering system are also used during the experimental period.

The Foshan DR pilot program was conducted after the Shanghai pilot and avoided some of the problems encountered in Shanghai. However, the participants in the Foshan pilot program were mostly industrial companies; hence, the results obtained from this pilot unavoidably encompass inherent one-sidedness. Because the power use patterns in commercial and residential buildings are different and the corresponding stakeholders have different concerns, effectively promoting the initiative to commercial and residential end-users is crucial for the development of DR in Foshan.

### 5.3. Pilot projects in other regions

In addition to Shanghai and Foshan, DR pilot programs were also implemented in other cities in China. In this section, these pilots are briefly introduced and summarized.

#### 5.3.1. Beijing pilot

The peak power load in Beijing in 2012 reached 17.2 GW, and the deficit was approximately 7.42 GW. On July 13, 2015, the largest load reached 18.16 GW, topping the 2013 record of 17.76 GW. The power load associated with AC accounted for nearly 40% of the peak load.

As a city piloting DSM, the first DR trial was conducted in 2015. Unlike the pilots in Shanghai and Foshan, customer development was based on policy guidance. The participants of the programs were evaluated by experts after submitting applications. Because DR events are new in China, promotion and publicity to attract more customers was the top priority. Establishing such a policy threshold will influence the active participation of the customers and negatively affect long-term DR development. The DR incentives were divided into three categories according to the duration: 80 yuan/kW for 24 h, 100 yuan/kW for 4 h, 12 yuan/kW for 0.5 h. Between 11:00–12:00 a.m. on August 12, 2015, a short-term DR experiment was performed across the entire city. Seventeen load aggregators and 74 end-users participated in this trial [63]. The outcome of the experiment is shown in Fig. 12 based on different types of customers. Compared to industrial enterprises, commercial and residential buildings exhibited a relatively modestly reduced peak loads, especially residential customers. This is because previous DSM projects such as orderly power limitation programs mainly focus on industrial companies. Having added incentives, these programs seem to be more appealing to industrial customers. In addition, the policy threshold and the simple incentive measures do not motivate commercial and residential customers to participate in the initiative.

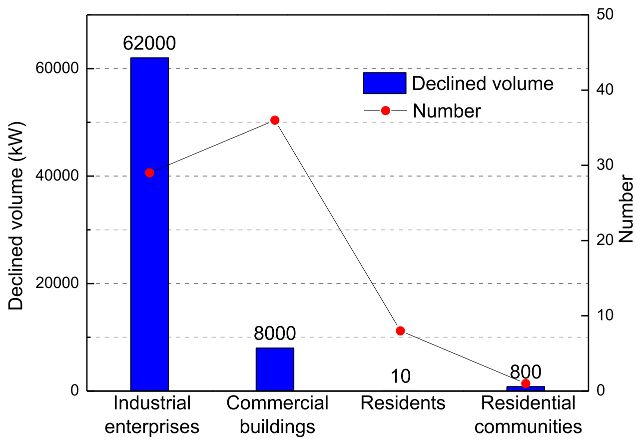


**Fig. 12.** Results of the Beijing DR pilot.

### 5.3.2. Suzhou pilot

The power imbalance of supply and demand aggravates in Suzhou during the peak time annually. The total power consumption in 2012 was 1.189 million GWh, and the peak power load was 18.2 GW. The power deficit reached 2.06 GW. In August 2015, the maximum load topped 22.18 GW, reaching an all-time high. To relieve the power strain during peak times, the "Notice on promoting and accelerating the DR work and power optimized utilization" [64] was issued in April 2015, offering a policy guarantee associated with implementing DR. The notice requires customers to reduce power consumption by at least 10% during peak times (10:00–11:00/13:30–15:30/20:00–21:00) every day, and each kW curtailment is eligible to receive a subsidy of 110 yuan. The DR experiments were implemented in Suzhou twice in 2015, and the detailed information was tabulated in Table 6.

### 5.3.3. Tangshan pilot

As the first batches of pilot cities for DSM, Tangshan has not implemented DR yet. Differing from Shanghai and Beijing, secondary industries are dominant in Tangshan. Steel and building material companies are particularly capable of shifting loads. The peak load rate in Tangshan is high, and the peak-valley difference has been partially alleviated by TOU tariffs. However, the maximum power load in Tangshan reached a record of 11.1 GW in 2014 [65]. Relying on only industrial enterprises to shift loads cannot ease the peak demand. Hence, DR from commercial and residential customers are also required.

The pilot experiment has not yet been conducted. However, the energy management platform has been established monitor power consumption in real time. The total transformer capacity reached 582555 kV A and the end-use side monitoring power was 464528 kW. Four additional monitoring stations are being constructed, providing a foundation for the implementation of DR in the commercial and residential customers [66].

## 6. Conclusions

Due to a booming economy and rapid development in China, electricity demands are also increasing rapidly, reaching a new record high in summer 2015. Renewable energy policies have been established to promote the development of renewable energy generation. However, due to intermittency, it is currently difficult to achieve large-scale power grid integration and sales. DR, an effective approach to balancing power supply and demand, can largely mitigate these two problems. An emphasis was once placed on energy conservation despite the early implementation of DSM in China. However, DR has become a relatively independent concept in recent years and has been given widespread attention.

This paper specifically focuses on the DR associated with Chinese DSM. Power industry development and power system reform are detailed in this paper. The current status of DR and the experiences and outcomes of DR pilot projects are also presented. The major conclusions are as follows:

- Despite the implementation of power system reform over many years, the State Grid Corp. still monopolizes the power market as a single buyer on the generation side and a single seller on the end-use customer side.
- DR development in China faces two pressing issues: 1) People are not aware of the benefits associated with DR, and the common practice for mitigating the peak load over a long period involves building more generators and power plants. 2) The appropriate DR market schemes are still lacking during this transitional phase of the electric industry.
- From a case study of benefit evaluation, DR can yield substantial benefits for all parties, including the power plants, the State Grid and the end-use customers, while simultaneously alleviating power strains.
- Six appropriate DR market schemes are proposed in this paper during this transitional phase: 1) adoption of cap-and-trade schemes; 2) encouragement of curtailment service providers (CSP); 3) development and extension of price-based programs; 4) improvement of orderly power limitation; 5) implementation of subsidized DR programs; and 6) implementation of DR star ratings.
- DR city pilot projects have been implemented in five pilot cities, illustrating the significant progress of DR development in China. However, problems still remain with the DR strategy: 1) customer development is not sufficient, and the incentives are unitary in the Shanghai and Foshan pilots; 2) the policy threshold in Beijing affects the engagement of commercial and residential buildings; and 3) except for the Shanghai pilot, the pilot projects are more beneficial to industrial enterprises.

In general, the implementation of DR is an effective approach for dealing with problems in the current power market in China. Additionally, the Chinese government and all parts of society are beginning to pay attention to the DR strategy. Although it is still in its primary stage, DR can potentially be developed and expanded with the support of relevant policies and experiences from the city pilots. And China is setting a good example of how to encourage DR under tightly government controlled electric market and how to open up the demand market to aggregators and DR suppliers.

**Table 6**
The summary of the DR pilot in Suzhou.

| Target | Time | Participants | Realized curtailment |
|---|---|---|---|
| Suzhou | 14:00–15:00 on July 30, 2015 | 24 independent customers and 5 CSPs | 0.23 million |
| Jiangsu Province (including Suzhou) | 14:30–15:00 on August 4, 2015, | 513 independent customers and 8 CSPs | 16.58 million |

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