Roadmap of retail electricity market reform in China: assisting in mitigating wind energy curtailment

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Abstract. Among the renewable energies, wind energy has gained the rapidest development in China. Moreover wind power generation has been penetrated into power system in a large scale. However, the high level wind curtailment also indicates a low efficiency of wind energy utilization over the last decade in China. One of the primary constraints on the utilization of wind energy is the lack of an electricity market, in which renewable energies can compete equally with traditional fossil fuel generation. Thus the new round electric power industry reform is essential in China. The reform involves implementing new pricing mechanism, introducing retail-side competition, promoting the consumption of renewable energy. The new round reform can be a promising solution for promoting the development and consumption of wind energy generation in China. Based on proposed reform policies of electric power industry, this paper suggests a roadmap for retail electricity market reform of China, which consists of three stages. Barriers to the efficient utilization of wind energy are also analysed. Finally, this paper introduces several efficient measures for mitigating wind curtailment in each stage of reform.

1. Introduction

The development of renewable energies is thriving all over the world. According to REN21’s 2016 report [1], worldwide investments in renewable technologies amounted to more than $286 billion in 2015, with countries like China and the United States heavily investing in wind, hydro, solar and biofuels [2]. As a kind of clean energy form, wind energy is relatively abundant and widely used all around the world, such as Europe, Asia, and the United States. Wind power generation has been penetrated into power system in a large scale. As of 2015, more than 100 countries are adopting wind power on a commercial basis [1].

As one of the major contributors of CO₂ emissions, China has made a great effort in developing renewable energies for mitigating air pollution from overuse of fossil fuels. China has constructed many wind power plants, especially in north-western areas, and total installed capacity of wind power generation grows every year. By 2015, the installed capacities of off-shore wind generation in China had reached 145GW, which accounted for 32.5% of the global generation capacities [3,4]. However, the variability and uncertainty of wind power bring a lot of difficulties in power system in term of
operation and reliability. Therefore, compared with conventional hydropower and thermal power generation, it is a more serious issue for efficient and effective utilization of wind power resources.

Wind curtailment is one of the severe problems in the utilization of renewable energies in China [5]. In many regions of China, fast increasing installed capacity with low load growth caused widespread overcapacity. Especially in the north-western areas, a lot of wind power generation equipment was forced to deactivate. The curtailment ratio was up to 16.3% in 2015, while the number was only 10.5% in 2014 [3]. One of the primary constraints on the utilization of wind energy is the lack of a competitive electricity market, in which wind power can compete equally with traditional fossil fuel generation [6]. Although the external environment has improved remarkably since the last power industry reform in 2002, the pricing and planning mechanism of China’s power industry remain monopoly and opaque [7]. These problems have become increasingly serious and raised public concern. Given on this, the central government has carried out a new round of power system reform in 2015 [8]. The new reform is regarded as the key to solving these problems.

Actually, the new reform serves as a continuation of the last round of reform. A lot of work has been done and achievement has been made since the last reform in 2002 [7]. By now, the generation side has already been relatively competitive although the electricity consumption side (retail side) is still regulated by the government [9]. As a consequence, retail market deregulation is one of the most important task in the new round of reform.

In the following sections, roadmap of retail electricity market reform is proposed and the reasons for wind curtailment in China are revealed. The paper clearly demonstrates that wind curtailment will be mitigated in the process of the reform.

2. Roadmap of retail electricity market reform

The conventional power industry is characterized as a high degree of monopoly. After big users’ direct power purchase from generation companies was permitted into electricity market, a competitive market is formed at generation side [10]. However, the monopoly of power industry in retail and consumption side caused an imbalanced situation. Thus the government published a series of reform policies in 2015 to build an efficient pricing mechanism and establish a competitive electricity retail market. In this section, a roadmap of retail electricity market reform is proposed to demonstrate how the new reform will be carried out step by step.

2.1. Power industry reform in China

The power industry of China has been in a process of reforms since the 1980s. In 2002, a reform was launched by the central government to bridge the gap between power supply and demand [7,8]. The reform has made a series of achievements, including the enhancement of operation efficiency of power industry and the fulfilment of power demand all over the country.

However, the reform failed to achieve the predetermined targets. Because there are still a number of problems unsolved, including the twisted pricing mechanism, irrational power system planning, and inefficient utilization of renewable energy and so on. These problems have not only hindered the development of power industry in China, but also brought a negative impact on the business operation of upstream and downstream of corresponding industries.

Therefore, Chinese government has issued “Relative Policies on Deepening the Reform of Power Industry” (No. 9 Document) in 2015 and launched a new round of power industry reform [11]. Policies were carried out to form a new pricing mechanism, new policies about renewable energy generation and power system planning process to solve the problems in the existing power system.

In the policy document “Implementing suggestions of promoting the reform of retail electricity market”, it is pointed out that retail electricity business is open to social capital and more options are given to end users [12]. Government tries to bring competition in retail electricity market for improving the quality of services and change the conventional mode of electricity selling, in which the electricity grid is the only permitted electricity seller.
Moreover, China has established some pilots to put the measures proposed in the policy document into practice. By now, China has two retail market reform pilots, including Guangdong Province and Chongqing Municipality and several comprehensive reform pilots [13].

Guangdong province leads the country in implementing the reform. After one-year practice, the achievements of the reform are encouraging in Guangdong. Guangdong has put forward some constructive proposals. For example, as a new market participant, retail companies can participate in the market by trading directly with generation companies on behalf of electricity users. Moreover, Guangdong sets up complete rules for monthly electricity trading based on centralized and transparent auction [14].

2.2. Roadmap of retail electricity reform
Following the requirement of NO.9 document [12], this paper analyses the roadmap of electricity retail market reform in China. In the proposed roadmap, the retail market reform process can be divided into three stages, as shown in Fig 1 [11,12]. Each stage is analyzed in the term of market characteristics, customers, electricity sellers and power sale services, as shown in Table 1 [11,12].

![Figure 1. Roadmap of retail electricity market reform](image)

**Table 1. Features of each stage in a glimpse**

| Market characteristics | First stage | Second stage | Third stage |
|------------------------|------------|--------------|-------------|
| **Market characteristics** | big users’ direct electricity purchase | construction of retail electricity market | power system reform in development of energy internet |
| **Customers** | large commercial and industrial users who match the access conditions | other market users | users utilizing different energy forms |
| **Main sellers** | power generation group subsidiaries | independent power selling companies | multiple energy integration companies |
| **Power sale services** | power supply service based on a long-term contract | customized/personalized services and diversified packages | integrated energy solutions |

2.2.1. First stage

The first stage is characterized by that big users can purchase electricity directly from the generation companies. During the first stage, the permitted market seller is still decided by the government or power industry administrative departments. Among all the electricity sellers, those which are subsidiaries of generation companies have monopolistic superiority in the retail market in term of financial strength, hardware and software conditions, and so on. The main trading types are
long-term contract and monthly electricity transactions, which is currently only available to industrial and commercial users who match the access conditions to participate in direct purchase.

Big users’ direct power purchase is still the mainstream form of electricity selling during this stage. For generation companies, signing a contract can efficiently protect their benefits when they face the serious problems of excess generation capacity and slow power consumption growth. For big users, they can reduce costs and strengthen economic vitality. It is well known that renewable energies, such as wind and solar power, have low marginal operation cost. However, this advantage cannot work in this trading mode. Actually, the most proper power trading mode is that sellers and users can choose their counterparty freely and negotiate the quantity and price of electricity equally.

2.2.2. Second stage During the second stage, the construction of a competitive electricity retail market will be put a higher priority. During this stage, the government should set different accession standards for different electricity sellers according to their customers’ type for encouraging electricity sellers to participate in the market. Moreover, electricity sellers are expected to offer diverse value-added services and personalized services and packages to their consumers.

During this stage, the government should take effort to develop users’ market awareness, help them to break the traditional thinking model in electricity consumption and encourage users to participate in the retailer market actively. Besides, users’ awareness and ability of participating in the market should be developed. Users, in this way, will be aware of what benefit they can receive in a competitive retailer market, what services they can obtain from electricity sellers and how to choose the most suitable sellers.

2.2.3. Third stage During the third stage, multiple energy transaction is added into retail market due to the development of energy internet. As a consequence, multiple energy integration companies are gradually established and they offer energy supply, demand side management and integrated energy services to energy consumers in energy internet pilots.

During this stage, the government should accelerate the development of energy internet technologies, including information and communication technology, energy storage technology and energy conversion technology, to support the construction of energy internet pilots. Departments concerned should establish a trading platform where sellers can trade with customers by offering integrated energy solutions. Moreover, market mechanisms should be set up to encourage multiple energy sellers to provide customers with choices in different forms of energy utilization which can be switched freely.

3. Mitigation of wind curtailment

The roadmap of China’s electricity market reform illustrated the direction of the reform. As the reform moves forward, many existing problems, like wind curtailment, can be solved or mitigated to a certain extent. This section analyses reasons for wind curtailment and explains how to mitigate curtailment during each development stage.

3.1. Why wind curtailment occurs

3.1.1. The existing installed wind power capacity and wind curtailment Wind industry has been expanded year by year since wind was first used for electricity generation in 1980s. The wind power industry set new records in 2014, that is, more than 50GW of new capacity was installed in this year [15]. Another breakthrough occurred in 2015, with 22% annual market growth resulting in the 60 GW mark being passed [1].

To make better use of wind resource and develop wind generation, China has built wind farms with large installed capacity. Wind power installed capacity has boomed in recent year in China since a series of effective support policies were adopted.
Figure 2. Global and China’s installed wind power generation capacity

Figure 2 describes the dramatically increasing trend in installed wind power generation capacity [1,3,15]. Global wind power capacity had expanded rapidly to 432 GW in 2015, and wind energy production was around 5% of total worldwide electricity usage, and kept growing. In 2014, China ranks first in the capacity of installed wind power generation [3].

Table 2. Wind curtailments in 2014 and 2015

| Region (province) | The year 2014(%) | The year 2015(%) |
|-------------------|-----------------|-----------------|
| Gansu             | 14.4            | 37.9            |
| Jilin             | 27              | 36.7            |
| Heilongjiang      | 17.7            | 22.2            |
| West Neimenggu    | 14.7            | 21.7            |
| Xinjiang          | 13.2            | 29.1            |
| East Neimenggu    | 14.5            | 17.9            |
| Liaoning          | 16.2            | 16.4            |
| Hebei             | 14.3            | 14.3            |
| Shanxi            | 1.2             | 4.2             |
| Ningxia           | 0               | 2.58            |
| Yunnan            | 1.6             | 1.95            |
| **China**         | **10.5**        | **16.3**        |
However, too much installed capacity of wind power may cause large-scale wind curtailment. Wind curtailments in 2014 and 2015 are shown in Table 2 [3]. For example, in Gansu province, its electricity consumption in 2015 is about 13 million kilowatts while new energy installed capacity is beyond 17 million kilowatts [16]. Therefore, if excess wind power output cannot be sent to other province by trans-province channel, it has to be curtailed.

In fact, in many regions of China, fast increasing installed capacity with low load growth causes widespread overcapacity. Especially in the north-western areas, a lot of wind power generation equipment was forced to deactivate.

3.1.2. Reasons for wind curtailment The most important reasons for curtailment are insufficient transmission, local congestion and excessive supply during periods of lower demand [17-19].

First, inconsistency between the wind power development and the overall grid planning is a crucial issue [18]. The ability to transport electricity between provinces or regions is usually limited by the transmission capacities. China is rich of wind energy resource, which is mainly distributed in north and west areas. However, the power transmission and distribution cabling and grid all over the country have not been comprehensively considered for the large-scale penetration of wind power.

In addition, the peak regulation capacity of thermal power generation is weak [17]. At present, thermal power generation still lacks enough peak regulation capacity for stabilizing the variability and uncertainty of large-scale wind power penetration.

Furthermore, the grid enterprises lack sufficient impetus for purchasing renewable energies in the existing price mechanism since they are usually more expensive. Moreover, conventional generating units involved in the regulation are not given sufficient economic compensation, resulting in the lack of their impetus to participant in providing balancing reserves for accommodating the variable and intermittent renewables.

Therefore, a proper and competitive market mechanism is urgently needed.

3.2. Curtailment mitigation at each stage during the reform

3.2.1. First stage Since the publishment of NO.5 document in 2002, big users' direct power purchase was already a form of electricity trade. However, due to the monopoly of power distribution and selling, this trading mode led to a worse economic result for generation companies. Before the reform in 2015, users can only buy electricity from State Grid if they did not participant in direct power purchase. Thus, generation companies must decrease their price in power purchase agreement to capture market share, which reduced incomes of generation companies. In fact, for generation companies, they would rather sell electricity to transmission companies than big users. Therefore, only when sale market is deregulated can generation companies participate in benefit distribution through big users' direct power purchase.

In competitive market, generation companies can consider offers from sale companies or big users, which provide them with more trading choices. Companies can be more flexible in selling electricity and, hence, they can manage to plan their output and control curtailment.

Moreover, after retailer companies are permitted into market, generation companies can set up their own retailer companies to sell electricity which is generated by their generating units. Through their sales subsidiaries, they can easily sell electricity to users after paying “wheeling cost” to State Grid for transmission. Thus their wind power successfully enters the market, and through proper market strategies they can guarantee their generating capacity, which help mitigate wind curtailment a lot.

3.2.2. Second stage The establishment of spot electricity market is the fundamental solution to promote wind power utilization and mitigate wind curtailment.

In fully competitive markets, generating units which has the lowest marginal cost should be dispatched first. Compared with thermal power plants, wind power generation owns lower marginal cost because no raw energy like coal and oil is required for generating electricity. Therefore, in spot
electricity market wind power and other clean energy can be the main electricity resource, while thermal power generation is used to help balance the power system.

Spot price is the basic of spot electricity market, which reflects the supply and demand conditions. That is, when the power output is high, the power price is usually relatively low. Users therefore tend to use more electricity. In this way, wind power can get efficient utilization because the higher power output, the more users will use power. For example, the power price at night is much lower than daytime and hence users will shift part of their production and manufacture to night to decrease their cost. Also, people will charge their electric vehicles and do other energy-using activities at night. The power they use in fact is the wind power which should be abandoned.

3.2.3. Third stage With the development of energy internet, the tools for accommodating the renewables become diversified, which greatly helps mitigate wind curtailment and promotes power utilization.

Firstly, renewable energy output prediction methods using big data break the limitation of the conventional prediction method, which is helpful for scheduling generating units to maintain the balance of supply and demand in the power system. Secondly, the application of multiple energy system imparts flexibility to the operation of power system. In many energy internet pilots, coal-heating is replaced by thermoelectric converters which use excess wind power. According to wind power output and load characteristic in winter, thermoelectric converter starts to work when the load is low, thus excess wind power is converted to the heat we need. Besides, the power price is much lower than heat price when wind power is abundant.

3.3. Cases
Statistics show on-grid wind energy is about 120 billion kWh, while 32.3 billion of which is abandoned in 2016 [20]. The curtailment ratio is beyond 20%. Now the on-grid tariff is 0.47¥/kWh, the income of wind power industry is about ¥56.4 billion. In spot market, wind power is supposed to be dispatched first due to its low marginal cost. If the transaction price is about 0.4¥/kWh (including the subsidy), on-grid 150 kWh can bring ¥60 billion to wind power industry.

That result demonstrates that the existing pricing mechanism hinders the development of wind power and other renewable energy. Construction of spot market can mitigate wind curtailment and increase the profit of wind power industry.

4. Conclusions
Raising the utilization rate of renewable energy is the current trend of power industry all over the world. Among the renewable energies, wind energy has gained the rapidest development, especially in China. As one of the most important contributors of CO₂ emissions, China has made a great effort in developing renewable energies and wind power generation has increased significantly these years. However, the utilization of wind power generation is not optimistic, since the wind curtailment has become an increasing problem year by year. Therefore, China has published a series of policies to boost the new round electric power industry reform, which can be a promising solution for promoting the development and consumption of wind energy generation in China. Based on policies and documents that support China’s power industry reform, this paper proposes a roadmap of retail electricity market reform, which consists of three stages. In each stage, different characters and tasks are put forward to solve a series of problems in the existing system, including wind curtailment.

Besides, this paper analyzes factors that affect wind curtailment and clearly reveals the barriers to the efficient utilization of wind energy. Finally, this paper introduces several efficient measures for mitigating wind curtailment in each stage of reform. In conclusion, this paper demonstrates that wind curtailment will be mitigated in the process of retail electricity market reform and provides some approaches to efficient wind energy utilization. While specific pricing mechanism and technical models are not mentioned in this paper, successive research is required.
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