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The design of provincial ancillary service markets in China under the new-round electric power industry reform

Zhongming Xiang², Chao Guo¹, Huahua Wu², Jun Zhang², Changzheng Shao¹ and Yi Ding¹,³

¹School of Electrical Engineering, Zhejiang University, Hangzhou 310027, China;
²State Grid Zhejiang Electric Power Corporation, Hangzhou 310007, Zhejiang Province, China.
³Email: yiding@zju.edu.cn

Abstract. This paper aims at developing a provincial ancillary service market framework, which helps improve the system operation and wind power integration ability. Firstly, the traditional plan-based management framework of the ancillary services in China is introduced. Then, the current pilot programs on developing market-based ancillary services management systems in China are introduced. The comparisons between China’s ancillary services management framework and that in mature electricity markets, such as PJM market, are made. Based on the experiences summarized from the mature electricity markets, the key issues of building an efficient ancillary service market are analysed. Finally, the framework of provincial ancillary service markets in China is proposed. The proposed framework illustrates how ancillary services could be procured and scheduled in a provincial electricity market.

1. Introduction
It is the primary goal of system operator (SO) to make sure the power systems operate with security and safety. For ensuring the power system security and stability, a variety of operations beyond generation and transmission are required. These operations and functions have come to be known as Ancillary Services. Ancillary services are the specialty services and measures for ensuring the safety and stable operation of power grids that supply will continually meet demand[1, 2]. Usually, ancillary services include the frequency control, reserves, reactive power and voltage control and system blank and restoration. Other classifications used in different countries or electricity markets can be found in [3].

Ancillary services management is an significant and challenging task by any point of view [4]. On one hand, ancillary services are necessary for the safe and reliable operation of the power system as discussed above. On the other hand, we have every reason to allocate the ancillary service resources in the most cost-effective way [5]. In other word, the minimum-cost rule should be addressed in the provision of ancillary services as other commodities. Considering the importance of the ancillary service management, it should be integrated in the market structure to ensure sufficient ancillary services are provided in the economic way[6].

Some countries or electricity markets have already finished the establishment of ancillary services markets. One of the representatives is the PJM market, in which various ancillary services are provided and cleared through auctions or long-term contract, and the price of ancillary services are determined by the market [7]. However, the ancillary services are not involved in the electricity
markets at present in China [8]. The traditional management mechanism of ancillary services in China is based on “two rules” released by State Power Regulatory Commission in 2006. The management mechanism is not market-based, so that it is difficult to guarantee fairness between ancillary service providers. Furthermore, it is not guaranteed that ancillary service providers could recover the related costs. As a result, ancillary service provider may be not willing to provide ancillary services. The above two issues restrict the development of renewable energy, especially wind power, which requires additional ancillary services for absorbing its fluctuating power output. China is already aware of the problems and put forward the establishment of ancillary service markets under the new-round electric power industry reform. Although many electricity reform policies have been introduced and experimental projects have been carried out, there is no consensus on how to build an efficient ancillary service markets in China.

This paper summarizes the development process of China's ancillary service management reform and makes a comparison with mature ancillary service markets in other countries. Then, a provincial ancillary service market framework is developed to improve power system operation efficiency and the ability of wind power integration.

2. China’s ancillary service management and the comparison with that in mature electricity markets

2.1. Ancillary service management in China

The ancillary service management framework in China has undergone a long developing process. At first, the ancillary services are managed based on the “Implementation rules for ancillary service management in grid-connected power plants” and “Implementation rules for operation management in grid-connected power plants”, which were officially issued by State Power Regulatory Commission in 2006 [9]. In the following, the two detailed rules and regulations are referred to as “Two Rules” for simplicity. In addition, it has been witnessed some provincial or regional pilots on building the ancillary service markets under the new-round electric power industry reform.

2.1.1. Two rules. Under the two rules, ancillary services are divided into two types—elementary ancillary service and commercial ancillary service. The basic ancillary services are considered to be the responsibilities of generators and therefore are unpaid. Commercial ancillary services refer to ancillary services provided by generators except elementary ancillary services, and the generators will be compensated for providing commercial ancillary service. The following paragraphs introduce the five different commercial ancillary services that the “two rules” mentioned.

1) Automation generation control(AGC) service

The AGC is actually the frequency regulation service. The aim of AGC is to meet power system frequency and tie lines power control requirements. Generators will adjust their real-time output within the prescribed power generation range, following the scheduling instruction.

2) Compensable peak regulation service

Compensable peak regulation service is a special kind of ancillary service in China. Providing such service, generators need to be under deep cyclic operation or even shut down.

3) Reserve service

System operator assigns some generators to save their generating capacities to provide system reserve for maintaining the balance between supply and demand under emergency conditions. Spinning reserve and non-spinning reserve are included. Spinning reserve is provided by the synchronized resources and only spinning reserve is compensated in the early stage.

4) Reactive power regulation service

Generators will absorb or inject reactive power to the system when operating beyond the specified power factor range. The reactive power regulation service can be classified into three categories, including late phase reactive power compensation, leading phase reactive power compensation and phase-modulation compensation. The late phase reactive power compensation is corresponding to the
situation that late phase power factor exceeds the basic adjustment range. The leading phase reactive power compensation is corresponding to the situation that leading phase power factor exceeds the basic adjustment range. The phase-modulation compensation is based on prescribed compensation factor.

5) System blank and restoration

The service refers to the capability of recovering from the power system blackout without external power supply support. In East China Power Grid, the related costs are compensated to the generators monthly. Moreover, the compensation of hydropower units is different from that of other types of units.

According to two rules, ancillary service is dispatched based on and the pre-determined sequence rather than biding and clearing in the markets. System operator arrange the ancillary services based on generator properties and situation of power grid. There are two compensation techniques mentioned in two rules: the first one is based on the reasonable rate of return, and the other is compensating the generators based on their contributions.

2.1.2. Provincial and regional pilots. Under the background of a new-round of power system reform, many provincial power grid and regional power grid began to explore the construction of ancillary service market [10]. We present the following two pilots:

1) Northeast peak regulation ancillary service market

Northeast grid was the first special ancillary service reform pilot. The key parts of northeast ancillary service market are to solve peak regulation problems. The market was designed to explore the peak regulation potentials of thermal power units, aiding the integration of relatively less-flexible wind power and nuclear power.

In the market, thermal power units submit peak regulation capacity and quotation in the day-ahead market, and then the sequence will be determined based on quote information and unit performance parameters. These units will be dispatched by system operator to meet peak load regulation requirement according to the sequence determined at intraday scheduling stage. The cost of revenue and expenditure is settled with fifteen minutes time resolution.

2) Guangdong frequency regulation market

Guangdong power grid has a strong requirement for frequency regulation, where the load is heavily affected by weather and temperature. However, the fast frequency regulation resources are relatively scarce. The providers and compensation price are determined by market mechanism, and frequency regulation ancillary service market separates from the power market in the early stage.

The trade model of Guangdong frequency regulation ancillary market is simple, adopting day ahead bidding of units and centralized clearing in intraday scheduling. Note that, performance factor for generators is introduced in the market to reflect the quality of services. The quotations of ancillary service providers will be modified by the performance factor. Therefore, if a provider wants to be dispatched in the ancillary service market, it needs to have a lower quotation and better performance factor. The quotation submitted by the last dispatched generator is set to be the clearing price. As for the market settlement, the compensation for the capacity provided during the given period will still follow the two rules, while the real dispatched frequency regulation mileage will be compensated based on the clearing price.

2.2. The ancillary service markets in mature electricity markets

In this section, we choose two regions to analysis their successful ancillary service markets. The issues such as ancillary service requirements and market operation process are analysed, together with the compensation mechanism used. The regions where ancillary service markets are well developed will provide many experiences regarding their implementation. This paper mainly focuses on the following ancillary services: frequency regulation, reserve, voltage control and black start service.
2.2.1. Ancillary service markets in PJM. American PJM power market serves eight states, and all qualifying members can participate in it. Regulation service and spinning reserve service are included in the market [11, 12].

Regulation service requirements is set to be 1.1% of the forecasting load, and PJM will timely adjust this ratio according to the control standards set by the North American Electric Reliability Commission. Only the units in the PJM controlled area are allowed to participate in regulation market, and these units must meet a series of standards stipulated in the market rules. Regulation service providers submit quotation one day in advance. Sufficient capacities are procured day-ahead from participants' bids to meet next day's hourly demand as well as reserve requirements. PJM regulation market will calculate unit priority prices based on the quotations and estimated unit opportunity costs. PJM will select units for providing regulation services with the goal of the minimizing the total cost of electric energy, regulation service and other ancillary services. Load serving entity is responsibility for all the cost of regulation service.

Only units in the PJM controlled area are allowed to participate in regulation market, and these units are divided into two types as follows: The first type is the units that are on-line and in economic dispatch state. It can start climbing from the current operating point. The other type is units that are departure from economic dispatch operation, but it can provide spinning reserve. PJM is responsible for calculating the total hourly spinning reserve requirements. The unit priority price of providing spinning reserve is modified from the spinning reserve quotation, the estimated unit opportunity cost and the cost of providing electricity. PJM will select units that will provide spinning reserve services with the goal of minimizing the total cost of electricity energy, spinning reserve and other ancillary services. Market participants need to undertake reserve responsibility according to their own load proportion.

PJM uniformly arranges reactive power and voltage control and system blank and restoration services according to the specific conditions of different regions. Suppliers who meet the specified requirements provide corresponding services, while the service demanders without self-supply capability have to purchase from PJM.

2.2.2. Australia ancillary service markets. Australia's national electricity market management company limited (NEMMCO) is responsible for system operation and managing the ancillary service market. Ancillary services in Australia includes frequency control service, network support control service and system restart service [13, 14].

Australia opened the spot market of frequency control ancillary service in 2001. NEMMCO determines the requirements of the frequency control service by proper operating procedure. The regulation requirement is determined dynamically in each 5-minute dispatch interval. Resource owners submit specific offers for frequency service, and the operator will utilize these offers together with energy offers as input data for market clearing. Australia conducts a simultaneous co-optimization with frequency control service and energy to determine the service provider and prices. Frequency control service charges will be allocated to both customers and generators. Customers and generators will share half of the charges separately.

Network support control service and system restart service are mainly purchased by grid company, and market entities provide these services in medium- and long-term agreements. In order to ensure the safety and reliability of the power system, the market operators can bid for network support control service and system restart service to market entities in accordance with market rules. Generally, the market operator needs to negotiate with the grid company under such conditions.

2.3. Comparisons and conclusions

In this paper, the investigation of “two rules”, provincial and regional pilots and mature ancillary service markets has been done. From the analysis of these markets, it is obvious that the transaction mechanism and acquisition mode of ancillary service market need to match the existing dispatching mode to ensure adequate supply of ancillary services. By comparing the domestic and foreign
ancillary service markets in table 1, there are two obvious differences: one is differences in types of market-based ancillary services, and the other is difference in the way clearing the market.

| Market mode                  | Acquisition mode | Compensation mechanism                                      |
|------------------------------|------------------|-----------------------------------------------------------|
| Mature ancillary service markets |                  |                                                           |
| AGC                          | bidding          | Based on regulation capacity and clearing price           |
| Reserve                      | bidding          | Based on reserve capacity and clearing price              |
| Reactive power and voltage control | Bilateral contract | Based on opportunity cost                                |
| System blank and restoration | Bilateral contract | Based on opportunity cost                                |
| Two rules                    |                  |                                                           |
| AGC                          | Unified scheduling | Capacity benefit and mileage benefit or only mileage benefit |
| Reserve                      | Unified scheduling | Capacity benefit                                          |
| Reactive power and voltage control | Unified scheduling | Late phase/leading phase/Phase-modulation compensation |
| System blank and restoration | Unified scheduling | Capacity benefit and scheduling cost                      |
| Provincial and regional pilots in China                  |                  |                                                           |
| AGC                          | bidding          | Capacity benefit based on “Two rules”; Mileage benefit based on clearing price |
| Reserve                      | bidding          | Capacity benefit based on clearing price; Incremental generation benefit based on electricity price |
| Reactive power and voltage control | Unified scheduling / Bilateral contract | Late phase/leading phase/Phase-modulation compensation |
| System blank and restoration | Unified scheduling / Bilateral contract | Capacity benefit and scheduling cost                      |

3. The design of China’s provincial ancillary service market
The electricity market reform has begun in many provinces in China. As an important part of the electricity market, ancillary service market has attracted wide public concern. This paper proposes an efficient ancillary service market framework applicable in China’s provincial power systems. In the framework, how ancillary services are procured and scheduled in a provincial electricity market is illustrated in figure 1.
3.1. The key questions to ask

In the design of an efficient ancillary service market framework, the following five key questions need to be discussed at first:

1) Ancillary services that need to be considered in the market

The current ancillary service products are committed by East China Grid covering regulation, reserve, peak regulation, reactive power regulation and system black start service. Peak regulation service, which is unique in China, will be gradually cancelled with the development of ancillary service markets.

2) How to determine the requirements for various ancillary services

The requirements for different ancillary service products will be set separately. Regulation requirements are related to the peak load, and the reasonable amount of regulation service depends on the system volatility and trends. The reserve requirements need to ensure that the power system has sufficient reserve capacity under the largest single contingency. The requirements of reactive power regulation and system black start service will be determined according to the relevant regulations of system safe and reliable power supply.

3) How to clear the ancillary service market

Regulation, reserve and energy can be co-optimized simultaneously in day ahead pre-dispatching, intraday rolling scheduling and real time operating. Reserve is pre-dispatched in day ahead and the reserve resources will be determined. Regulation resources are determined in intraday rolling scheduling. Ancillary service providers will submit quotations and capability in day ahead, and the system operator will modify their quotations and clear the ancillary service market based on modified quotations. Then, the system operator will schedule these services according to the market clearing results.

4) How to settle the ancillary service market

As for the settlement of regulation, two parts of the regulation benefits are considered, which are capacity benefit and mileage benefit. The capacity benefit of regulation should be capacity clearing price times the MW amount, while the mileage benefit of regulation should be mileage clearing price times regulation mileage. The capacity benefit of reserve service is consistent with the capacity benefit settlement method of regulation service, and the benefit of incremental generation part is settled according to the price of electric energy.

5) How to allocate the cost of ancillary service

Ancillary service cost can be allocated to customers or generators. If ancillary service cost is allocated to customers, it means that the responsibility of generators in providing ancillary services is indistinguishable. However, the power generation output of wind power and other renewable energy sources is uncontrollable and the generator output curve of generators from other provinces, which supply the imported electricity, is immutable. Therefore, the responsibility of these generators is larger than that of other units. For example, as the penetration of renewable energy increases, the reserve capacity required by the system increases. Based on this, the cost sharing of ancillary services is more reasonable to generators.

3.2. The framework of the ancillary service market

Through the discussion of the above key issues, the framework of an efficient ancillary service market can be developed. In the early days, the coal and gas generating units will be involved in the ancillary service supply. With the development of the ancillary service markets, other types of units will be gradually involved in the later stage. In addition to the renewable energy sources in the province, unified dispatching units and the generators from other provinces, which supply the imported electricity, will participate in the cost sharing of ancillary services. The whole framework of ancillary service markets is shown in figure 1:
Figure 1. The framework of the proposed ancillary service market.

Generation Company, grid company and system operator play an important role in ancillary service market. Grid Company has the responsibility to provide provincial power system parameter, such as the maintenance scheduling of transmission lines. Then, system operator releases information needed for fair market transactions. Generation companies will submit their quotations according to their own operation situation and information released by system operator. Subsequently, system operator will modify these quotations, which will be utilized for market clearing. Finally, the market clearing results will be used to guide the system operation. The structure and relationship between market entities are described in figure 2:

Figure 2. The structure of the market entities.
Compared with mature ancillary service markets abroad, the structure of the proposed ancillary service market is simpler with less actors involved. It is become that the simpler market structure is easier for the implementation in the early state.

3.3. Prospect for future development
There will be a long process of development in the ancillary service market. New requirements should be fulfilled in a mature ancillary service market. For example, ancillary services should be divided more carefully, and more categories are required. The types of ancillary services need to be further refined according to their performance. Probability-based requirement assessment methods are required to improve the economy and safety of power system. Wide application of wind power and uncertainty brought by wind power make probability-based requirement assessment methods get extensive attention and research [15, 16]. Demand response resources, as high-quality ancillary service resources, will play an important role in the future. For instance, both PJM[17] and Australia[18] utilize demand response to meet the peak load and reduce volatility in wholesale electricity prices.

4. Conclusions
The establishment of provincial ancillary service markets in China is a significant but complex task. The experience from mature market should be learned to help design a suitable provincial market. Key issues of constructing an efficient ancillary service market are discussed in this paper, and then the framework for provincial ancillary service markets in China is proposed. The framework, considering the actual situation of China, is expected to improving the economy and security of the system operation, as well as the ability of integrating the variable wind power. Moreover, ancillary service providers can receive scientific and reasonable compensation based on this framework. They will have greater incentive to provide ancillary services to ensure the safe and stable operation of the system. As for the system operator, it will have larger scheduling space to ensure the safety of power system.

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