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Setting up of Chinese Wind Power Prediction System

China Electric Power Research Institute

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CONTENTS

Abstract

With the world in almost permanent energy crisis due to the pressure of economic development, wind power is nowadays one of the predominant alternative sources of energy. The experience in advanced wind power countries indicates that wind power forecasting (WPF) technology is one of the effective measures to mitigate peak-load regulation pressure, reduce reserve capacity and increase wind power accommodation capacity for power grids. Recently, the leading countries in wind power in Europe and the United States have already established impeccable management mechanism in WPF, and their forecast is performed both in wind farm side and dispatching facility side. But in China, the WPF systems, though, are popular in dispatching side; the WPF systems in wind farm side are still blank.

This report, combining the international experience and national situation, studies on the tailor-made wind power forecasting system framework and implementation plan in China. The report first shows the operational principles and the control mechanism of the Danish and Spanish electricity markets. Then, according to the responsibilities of the TSO and the wind plants, considering the current status of the WPF technologies in China, the report proposes a framework of the management mechanism of WPF with Chinese characteristics and illustrated the main responsibility of the shareholders. At last, referring the advanced international operation mode and experience, the detailed implementation plan of the management mechanism of WPF is given in

the report.

Based on the deep investigation of international experiences and the complete analysis of the main responsibility of the shareholders, combining the current status of the WPF technologies in china, the research proposes a tailor-made framework and implementation plan of the wind power prediction system with Chinese characteristic. The research results will develop the advantages of all the participants to boost the development and application of WPF technology.

1 Introduction

R&D system of WPF technology is a systematic engineering. The European countries have conducted R&D of WPF system and had it applied in service since early 1990s. WPF technology is widely developed and applied in these countries over the past about 20 years. They actively develop and construct WPF systems and bring wind power into electricity market and grid dispatching system. The experience in advanced wind power countries indicates that wind power forecasting (WPF) technology is one of the effective measures to mitigate peak-load regulation pressure, reduce reserve capacity and increase wind power accommodation capacity for power grids. Meanwhile, this technology also plays an important role in instructing maintenance plan of wind farms, increasing utilization of wind energy and improving economical benefit of wind farms.

Recently, in most of the advanced wind power countries WPF systems are installed in both sides of wind farms and dispatching facilities and related management systems are established. WPF is a mandatory requirement in many countries and utilities, such as in Spain, Ireland, and PNM and ERCOT (Electrical Reliability Council of Texas) in the United States; California ISO (CAISO) stipulates that the wind farms in its jurisdiction have free choice of WPF system providers rather than those listed by CAISO, although wider forecast error is allowed for the listed WPF providers for grid integration. Priority for grid connection is granted to wind farms in Denmark and Germany based on their

Renewable Energy Law. But grid operators do not set the liability for wind farms to forecast their generated power in Grid Integration Agreement and Electricity Purchase Agreement.

The research and experience abroad also indicates that WPF should be carried out in joint effort of the operators of wind farms and power grids. The WPF in wind farm side should be performed by wind farm operators to serve themselves for acquiring desired generation schedule and competitive bidding in electricity market to ensure their financial benefit. WPF performed by dispatching facilities helps them in scheduling adequate power system operation to ensure that the systems possesses enough reserve capacity for any emergency to guarantee safe and stable operation of the systems. Recently, the leading countries in wind power in Europe and the United States have already established impeccable management mechanism in WPF, and their forecast is performed both in wind farm side and dispatching facility side. But in China, the WPF systems, though, are popular in dispatching side; the WPF systems in wind farm side are still blank.

As the China's National Energy Administration (NEA) issued "Interim procedures for management of power forecast in wind farms", it becomes an urgent need to establish a reasonable and impeccable managing mechanism of WPF and to perform an orderly thorough management and assessment of the WPF system in the both sides. Healthy operation and development of WPF systems must rely on a thorough managing system of WPF. And the healthy and effective system

of management and assessment for WPF will become a strong support from NEA for perfection of the policy system for developing renewable energy industry and ultimately serve all the sectors of wind power industry, such as the governmental authorities concerning power supply, regulation organizations, power grid companies, wind power developers and wind farm operators. It helps in establishing a coordination mechanism of WPF between grids and wind farms, and developing the advantages of all the participants to boost development and application of WPF technology.

Following the principle of promoting the wind power technology and improving actively accommodation, this report studied the management mechanism of WPF by considering the development patterns of China. Based on deep investigation of international experiences and complete analysis of the main responsibility of the shareholders, combining the current status of the WPF technologies in China, the research proposed a tailor-made framework and implementation plan of the wind power prediction system with Chinese characteristic. The research results will develop the advantages of all the participants to boost the development and application of WPF technology.

2 Development Status of the Wind Power Forecasting Abroad

Nowadays the wind power prediction system have been widely applied in Denmark, Germany, Spain, United States and other developed countries. It had become an important support system of the wind power optimal dispatch. Recently, in most of the advanced wind power countries WPF systems are installed in both sides of wind farms and dispatching facilities and related management systems are established.

The wind power prediction system is classified into 0-4 hours ultra-short term forecasting and 0-48 hours short term forecasting. At present, a great many of different approaches and technologies have been applied for wind power forecast, such as time series analysis, statistic analysis, ARMA Model, Kalman filter, artificial neural network and so on. With the development of wind power industry, moreover, the effective forecasting is playing a more and more important role in the economic operation, its benefit to utilities is also increased with the improvement of forecasting accuracy. Although these methods obtained definite forecasting effect, the forecasting precision and stability still need to improve.

3 Analysis of International Experience

3.1 Introduction

In order to understand and study the European electricity market, the experts team of the project payed a visit to Denmark and Spain to investigate the structure and responsibility for each parts of their WPF system. The main investigated organizations are:

- Energinet.dk
- Danish Meteorological Institute
- Risø DTU National Laboratory for Sustainable Energy
- DONG（Danish Oil Natural Gas）Energy
- Vestas Company
- Red Eléctrica de España

3.2 Brief introduction of the investigated organizations

3.2.1 Energinet.dk

Energinet is an independent public enterprise under the Danish Ministry of Climate and Energy. It owns and operates the energy motorways of the main electricity and natural gas systems, and also co-owns the Nord Pool Spot, Nord Pool Gas, and the European Market Coupling Company. Its annual revenue is DKK 8-9 billion.

Due to its public and non-profit characteristics, Energinet is different from usual TSOs。Energinet is responsible for overall short-term and long-term security of electricity and gas supply. The company is in charges of planning and expanding the Danish electricity and gas systems.

Energinet supports research, development and demonstration of new technologies for environmentally friendly power generation.

As the co-owner of the electricity transmission system connecting the Sweden, Norway, and Germany, Energinet not only takes part in Nordpool which is composed by Denmark, Norway, Sweden and Finland, but also joins the Germany electricity market. The voltage grades of the transmission line in Energinet are 400kV and 132-150kV. In 2010, Energinet's transmission power is 47,114GWh.

3.2.2 Danish Meteorological Institute

Danish Meteorological Institute (DMI) is a Danish official weather research organization. DMI is responsible for Denmark, Greenland and Faroe islands meteorological forecast and meteorological observation. DMI was established in 1990 by combining Meteorological Research Institute (founded in 1872), Civil Aviation Meteorological Service Center (founded in 1926) and National Defense Meteorological Service Center (founded in 1953).

DMI has super computers, satellites, radars and automatic measurement equipment, and other advanced technology. Its responsibility is to provide social meteorological service, monitoring weather, climate and environmental conditions, especially the basic meteorological information for economic and environmental planning in the military, aviation, shipping and highway traffic.

The most famous service of DMI is to provide the weather forecast for the media. In addition, it also provides meteorological service in

energy, fishery, agriculture, sports, insurance institutions, construction and other fields.

DMI provides weather forecast for Energinet and other generation companies. Since both Energinet and DMI belong to Danish Ministry of Climate and Energy, DMI's meteorological service price for Energinet is cheaper than others.

3.2.3 Risø DTU National Laboratory for Sustainable Energy

Risø DTU National Laboratory, established in 1956, is the most famous energy scientific research institution in the world. The famous Danish physicist, Nobel Prize winner Bohr played an important role for the establishment of the laboratory. In January 1, 2008 Risø Laboratory merged into Technical University of Denmark.

Risø DTU National Laboratory had many excellent works in wind energy field. The famous wind resources evaluation software WAsP was developed by the Laboratory. The Laboratory also focuses on the study of the wind power forecasting method. It had developed the earliest prediction system in the world Prediktor.

3.2.4 DONG Eneryg

DONG Energy is one of the leading energy groups in Northern Europe. The Danish government holds a 76.49% stock in DONG Energy. DONG Energy was established in 1972, its former name was Danish Natural Gas. The company was renamed as DONG Energy in 2002.

DONG Energy's business is based on procuring, producing,

distributing and trading in energy and related products in Northern Europe. In 2005, DONG Energy bought five Denmark electric power company: Elsam, Energi E2, Nesa, KE Holding and Frederiksberg Elnet Group. Its business spread to thermal electric production & sales, heat energy production & sales, and wind power generation.

The renewables business area is one of the main players in the achievement of DONG Energy's objective to move from coal-based energy supply to a sustainable and renewable energy supply. Renewables develops, constructs and operates wind farms and is well on the way to meetings its target of capacity of at least 3,000 MW by 2020. DONG Energy owns 45% of the Danish offshore wind power and several world famous offshore wind farms, such as Horns Rev Offshore Wind Farm, Middelgrunden Offshore Wind Farm, and Nysted Offshore Wind Farm.

DONG Energy's Generation business area also includes generating and selling electricity and heat. The CHP plants in Denmark are its core activity. In 2010, thermal electricity generated by Generation in Denmark accounted for 53% of total thermal electricity generation in Denmark. Heat generation accounted for 36% of total heat generation in Denmark, equivalent to the consumption of more than 800,000 households in Denmark.

3.2.5 Vestas Company

Vestas Company is the world's largest wind turbines producer. Its main business is production, sales, installation and service of the wind turbines. In 2010, Vestas Company delivered wind turbines of 5,842MW,

which accounts for 14.8 percent of the global market. The company’s income was 6.92 billion Euros in 2010.

Vestas Company was founded in 1945. At first, its main business is the production of household appliances. The company turned the household appliances business to agricultural machinery in 1950 and to hydraulic carne in 1968. Vestas Company went into the wind power industry in 1979 and began to focus on the wind turbines production in 1989. In 2003, Vestas Company became the world's largest wind turbines manufacturing enterprise by merging NEG Micon enterprise of Denmark.

At present, Vestas Company offers a variety of wind turbines:

V52-850kW

V60-850kW

V80-1.8MW/2.0MW

V90-1.8MW/2.0MW

V90-3.0MW

V100-1.8MW

V112-3.0MW

Vestas Company is the earliest foreign wind turbines enterprise who enters the Chinese market. In 1983, the first grid-connected 55kW wind turbines produced by Vestas were introduced by Shandong Province.

Since Vestas Company’s business does not contain wind power operation, it does not forecasting the wind power. But the company can provide the advices for the influences of the wind turbines’ reliability to the output wind power.

3.2.6 Red Eléctrica de España

Red Eléctrica de España (REE) was established in 1985. It was the first company in the world dedicated exclusively to power transmission and the operation of electrical systems. The State-owned Industrial Holdings Company, Sociedad Estatal de Participaciones Industriales (SEPI) holds a 20% stock of REE. Any single shareholder from those holding 80% stock does not hold more than 5% stock of REE.

REE operates the mainland system and the island systems. Its Renewable Energies' Plan for Spain (August 2005) is 20,000 MW by the year 2010 and Renewable Energies Plan for Spain 2010-2020 is 35,000 MW. The Official Network Planning for 2016 contemplates is 29,000 MW.

REE is different from Energinet of Denmark. In Denmark, Energinet is not only the power system and the grid operators, but also the electric market operators. But in Spain, the electric market is operated by other company.

3.3 Danish electricity market

3.3.1 Brief introduction of the electricity market

As the connecting notes of the Nordic electricity market and the European electricity market, Denmark not only takes part in Nordpool which is composed by Denmark, Norway, Sweden and Finland, but also joins the European electricity market. Due to the limitation of the electric transmission capacity in different countries, Denmark mainly participates

in Nordic electricity market.

Denmark is the only country in Europe that belongs to two synchronous areas. For historical reasons Western Denmark belongs to the Continental synchronous area and Eastern Denmark belongs to the Nordic synchronous area. Both the Continental synchronous and the Nordic synchronous areas operate at 50 Hz AC, but the areas are not synchronized. As a result, the interconnector between Western Denmark and Germany is AC, and similarly the interconnector between Eastern Denmark and Sweden is also AC. On the other hand, the interconnectors between the Nordic synchronous area and the Continental synchronous are DC, including the interconnector between Western Denmark and Eastern Denmark. Fig 3-1 shows the Denmark's interconnectors to the Continental and the Nordic synchronous areas. Due to the historical background, Western Denmark and Eastern Denmark are also separate electricity market price areas.

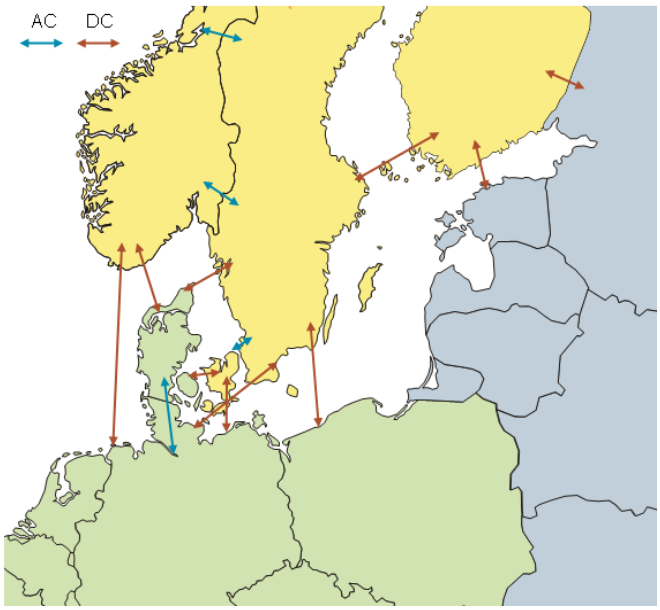

Fig 3-1 The interconnectors to the Continental and the Nordic synchronous areas

Figure 3-2 illustrates the wind power capacity in Denmark from 1988 to 2012. With the liberalisation of the power sector in 2000, the unsuccessful attempt to introduce a green certificate system to compliment the liberalised market and a change of government policy for wind power remuneration in 2002 the deployment of wind turbines met an abrupt halt. This has been the case until 2008, when deployment of turbines once again begun to gather momentum in Denmark due to the introduction of a new feed-in tariff.

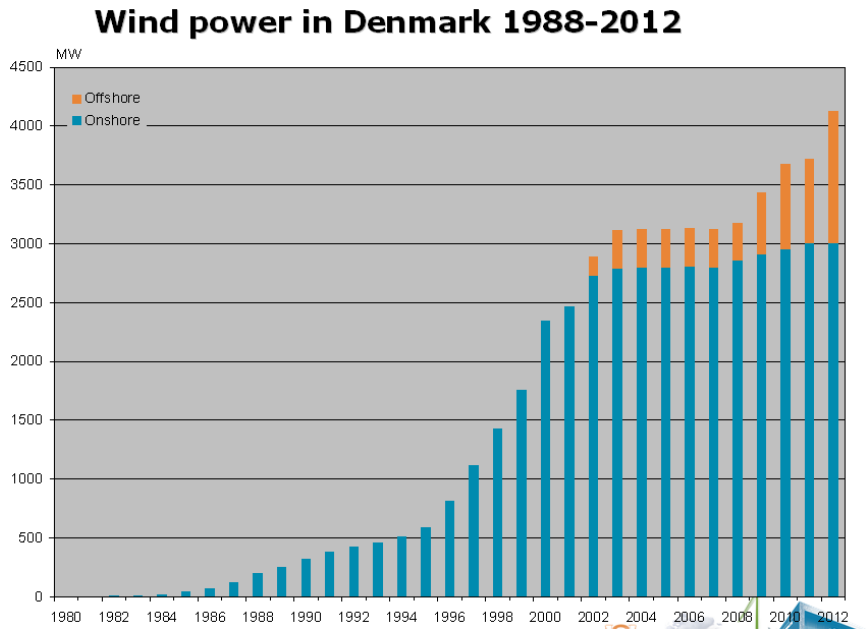

Fig 3-2 Wind power capacity in Denmark

3.3.2 Definition and classification of the market

The Nordic electricity market (Nordpool) is a market environment including Denmark, Norway, Sweden and Finland. Figure 3-3 shows the four Nordic countries.

Fig 3-3 Four nordic countries

The Nordpool electricity market includes future market, day ahead market (spot market) and intraday market. All markets are hourly markets. Additionally, the TSOs operate reserve and regulating markets. Fig 3-4 shows the time division of the Danish electricity market. In the reserve market, the reserves for the coming day are purchased at 9:30. The Day ahead market is set at 12:00. Intraday market starts at 14:00 the day before operating day until one hour before delivery hour. Regulating market is continuously operated from 0:00 to 24:00.

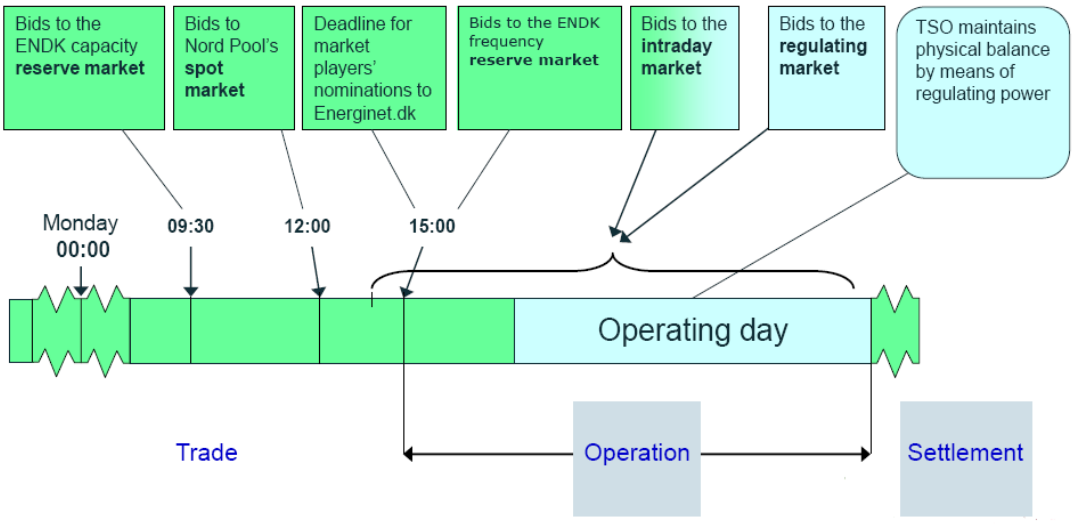

Fig 3-4 The time division of the Danish electricity market

3.3.3 Pricing mechanism of the market

1. Reserve market

In reserve market, the single buyer is the TSO. The sellers are all of the power plants which can offer the reserved capacity. The reserved capacity is mainly used to guarantee safe and stable operation of the systems for any emergency. The prices for a reserved capacity are low in reserve market in Denmark but the price for the activated energy can be very high. Participants submit bids to the market. No matter whether the reserved capacity is used in the day, TSO need to pay for it. The payment which is used for the reserved capacity comes from the income of the electricity rates.

2. Day ahead market (spot market)

In day ahead market, all the power plants and the demanders are the market participants. The market price is determined by marginal pricing of the supply and the demand. The day ahead market is mainly used to ensure the 24 hours generation plan and the electricity prices of the next day, according to the bidding results. Figure 3-5 and 3-6 give the price setting curve of the Nordic market, where the red one is the supply curve and the green one is the demand curve. The cross point of the curves is the electricity price of that hour. The different productions follow the same price.

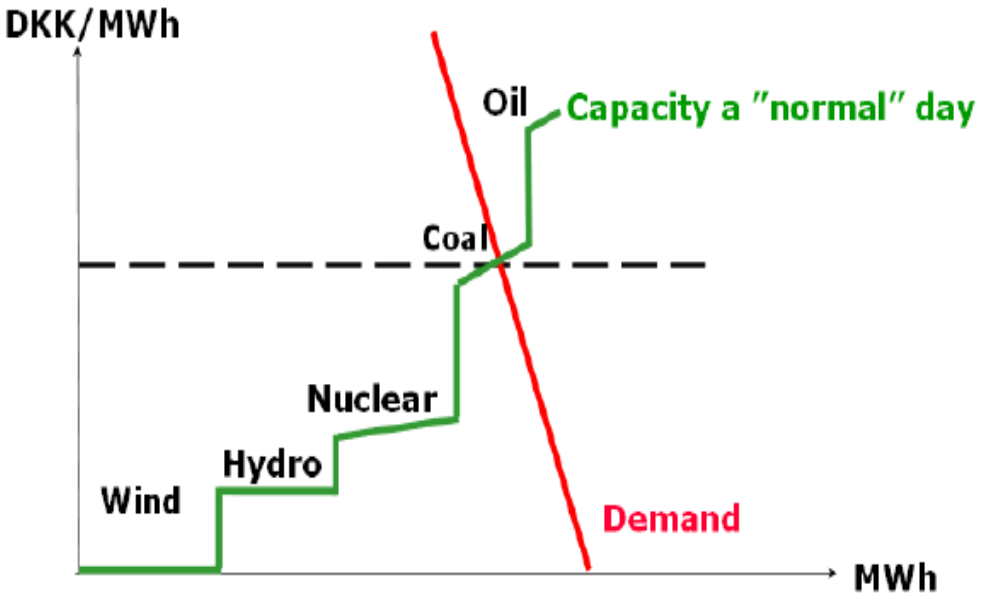

Fig 3-5 Price setting of the market (no wind)

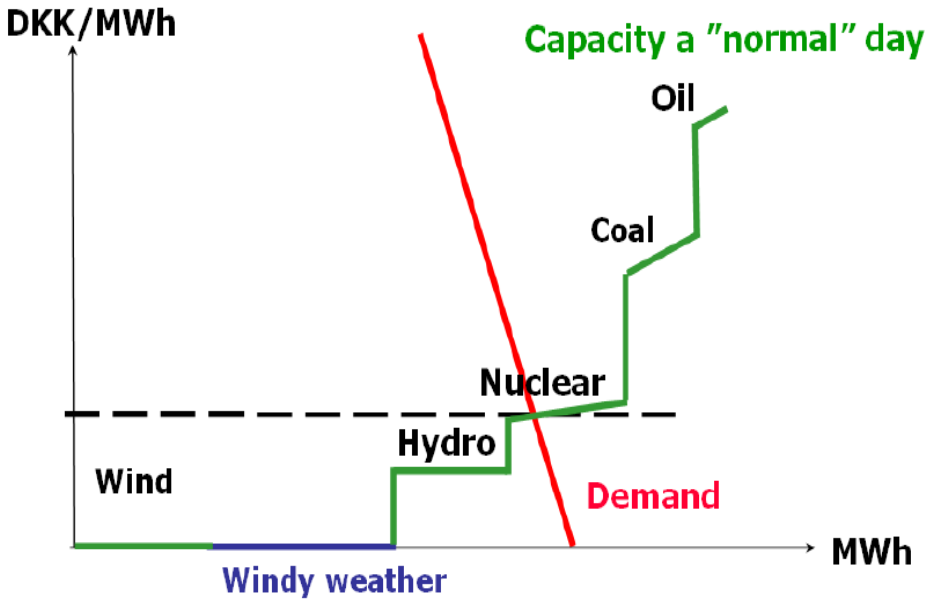

Fig 3-6 Price setting of the market (wind)

From the figure we can see that there are big bidding differences in market among different productions. Because of the low operation costs and the governmental subsidy, the submitted bid of wind power was lower than other powers. The output of the wind power obviously influences the price of that hour. The more the wind power outputs, the

lower the market price will be. When the outputs of the wind power are larger enough, to sell the wind power successfully, the bidding could be negative electricity price. Even so, the wind power plants can earn the profit due to the balance of the subsidy. In the market of negative electricity price, the wind power plants supply the most of the electric power. Parts of the thermal power plants sell the electric power to avoid the loss of turn off operations.

3. Intraday market

The intraday market is the trade that takes place during the day of operation when the day-ahead market is closed. After the day-ahead market is closed, the day ahead plans would be adjusted according to the real condition due to the faults of hydroelectric generating units, faults of transmission line, forecasting errors of the wind power and so on.

The intraday market trades hourly power from 14:00 the day before delivery day until one hour before delivery hour. Market participants can use the intraday market to balance their positions. In general, the later the generation plan adjusts, the more the cost goes up. For example, when the wind power plants find the output of the wind power can not satisfy the generation plan of the day ahead market in the next hour according to the updating forecasting results, they need to buy the electricity gap from other power plants. The electricity price is usually higher than the price of the day ahead market; when the wind power plants find the output of the wind power is more than the generation plan of the day ahead market, they can also sell the extra power. But the electricity price is much less than the price of the day ahead market.

4. Regulating market (Real time market)

Regulating market is from 0:00 to 24:00. In order to supervise the generation plan and guarantee the stable operation of the systems, TSO adjust the outputs of the power plants in regulating market. The regulating market is administered by TSO. To make a balance between demand and production, TSO buys (sells) the power from (to) the market participants according to the difference between the generation plan/demand and the real power outputs/demand. The payments mentioned above are undertaken by all the market participants.

In regulating market, the electricity price is quite different with the day ahead and intraday market. If the power generation, such as wind power, is more than its generation plan, the extra part will be sold by TSO with a price much lower than that in the day ahead and the intraday markets, and the price even could be negative. If the wind power is less than its generation plan, the extra part will be bought by TSO whose price is much higher than the day ahead and intraday market.

3.3.4 Ancillary services

Ancillary services are services that ensure reliability and support the transmission of electricity from generation sites to customer loads. Energinet.dk applies ancillary services to avoid fluctuations in the frequency and interruptions of supply.

Energinet.dk buys 3 different types of reserves, and uses each type of reserve to balance the power system, depending on the reaction time.Within 15 minutes of the reaction time the primary reserves will be

used. Within one hour the secondary reserves will be used. If the reaction time needed is longer than one hour, the manual reserves will be used. Figure 3-7 错误！未找到引用源。 illustrates the function of different reserves.

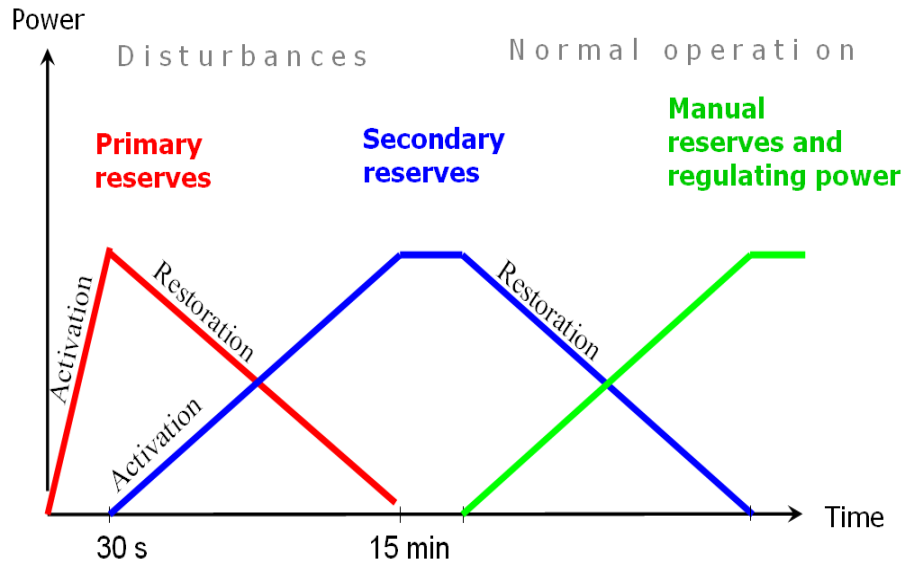

Fig 3-7 The function of different reserves

The need for ancillary services is dynamic throughout the year in terms of volume and the nature of the ancillary services. There are also regional differences between Eastern and Western Denmark. Consequently, the volumes and services on offer are adapted to requirements for specific periods of the year in Eastern and Western Denmark. The needed ancillary services in November 2011 are described below:

Primary reserves:

The primary reserves are used to adjust the frequency in the respective synchronous areas. There are two different setups in Western Denmark and Eastern Denmark. Primary reserves are shared reserves with Continental Europe (3000 MW) for Western Denmark (± 25 MW)

and with the Nordic Region (1200 MW) for Eastern Denmark (± 22 MW). Western Denmark shares the 3000 MW with the whole Continental Europe area. The 3000 MW has been selected to withstand a 10-year extreme event. The Nordic primary reserves of 1200 MW correspond to the largest production unit in the Nordic Region.

Secondary automatic reserves:

The secondary automatic reserves are used to balance a subsystem, i.e. Western Denmark. There are differences between the setups in Western Denmark and Eastern Denmark. When the secondary reserves are activated, they replace the primary reserves so the primary reserves are available again. The secondary reserves are cheaper in operation than the primary reserves, because the secondary reserves do not have to react as quickly as primary ones.

Western Denmark (± 90 MW):

- Energinet.dk pays a monthly capacity price for the reserves

- The secondary reserves are mainly provided by conventional power stations

- The reserves are calculated on the basis of the yearly max load

Eastern Denmark (± 160 MW):

- Energinet.dk purchases secondary reserves in blocks of 4 hours

-The secondary reserves are only provided by conventional power stations

- The reserves are calculated on the basis of the largest unit in each Nordic country

Manually activated reserves:

Manual reserves are used if the reaction time needed is longer than one hour. The manual reserves are selected to cover the largest production unit in Western Denmark and Eastern Denmark respectively. Manual reserves are a part of the merit order list of the regulating market. When producers sell manual reserves, producers commit to place a bid in the regulating market.

Figure 3-8 shows the total costs of ancillary services in the Danish power systems. The costs of ancillary services are correlated with the day-ahead prices. The day-ahead prices depend, among other variables, on the reservoir levels in the Nordic Region. Energinet.dk aims to reduce the costs of ancillary services, but it does not control the day-ahead prices, which partly determine the costs of ancillary services. The market controls the day-ahead prices.

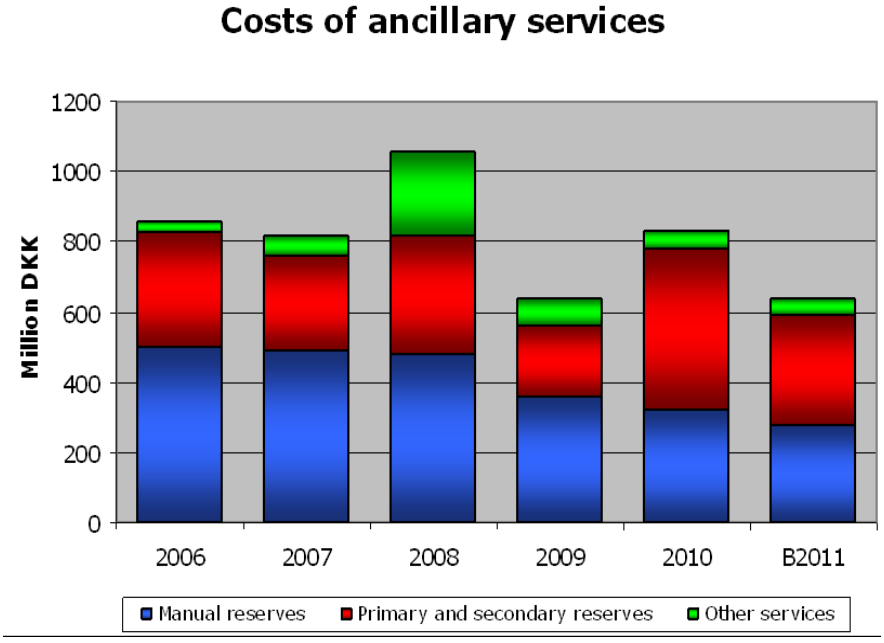

Fig 3-8 The costs of ancillary services in the Danish power systems

3.4 Spain electricity market

3.4.1 Law and regularity

Thanks to the modification of its Electricity Law (in 1997) and Royal Act (in 2004 and 2006), the mechanism of feed-in tariff for wind power matured and hastened a stable market circumstance for wind power to enhance healthy and fast development of wind power industry, and made the industry in Spain in a leading position over the world.

Spanish Royal Decree 436/2004 issued in 2004 clearly formulated the pricing system and accessory service for wind power. It ruled that a double-track pricing system is applied for wind power, i.e. a system combined with fixed price and premium mechanism; meanwhile the Act also presents clear liability requirement for wind farms, i.e. the wind farms with 10MW capacity and above must report their WPF results to grids and accept examination from grids. To guarantee the safe and stable operation of the electric systems and insure the benefit of the wind plants, Spanish Royal Decree 661/2007 issued in 2007 contains the legal and economic framework for Special Regime production which including the obligations that the renewable energy plants must fulfill in order to allow a favorable integration in the electrical system. It includes the following aspects:

(1) Real time telemetry each 12 seconds to the TSO for all wind power plants with an installed capacity greater than 10 MW and association into generation control centers. The items include active power, reactive power, wind speed, direction, temperature, and

pressure etc.

(2) Power factor control with the possibility for the TSO to modify the ranges in real-time for plants larger than 10 MW.

Spanish Royal Decree 436/2004 issued in 2004 modified the RD 661/2007 to include the requirement of real-time telemetry every 12 seconds for plants or clusters of plants larger than 1 MW. It also includes the need for association into control centers for clusters of plants of the same technology larger than 10 MW. It modifies slightly the power factor ranges for RES and introduces the possibility to develop voltage control with these types of plants.

3.4.2 Electricity Market

The electricity market is composed by Spain and Portugal. The market's classification and bidding system are similar with the Nordic electricity market. Figure 3-9 shows the framework of the day ahead market and the intraday market.

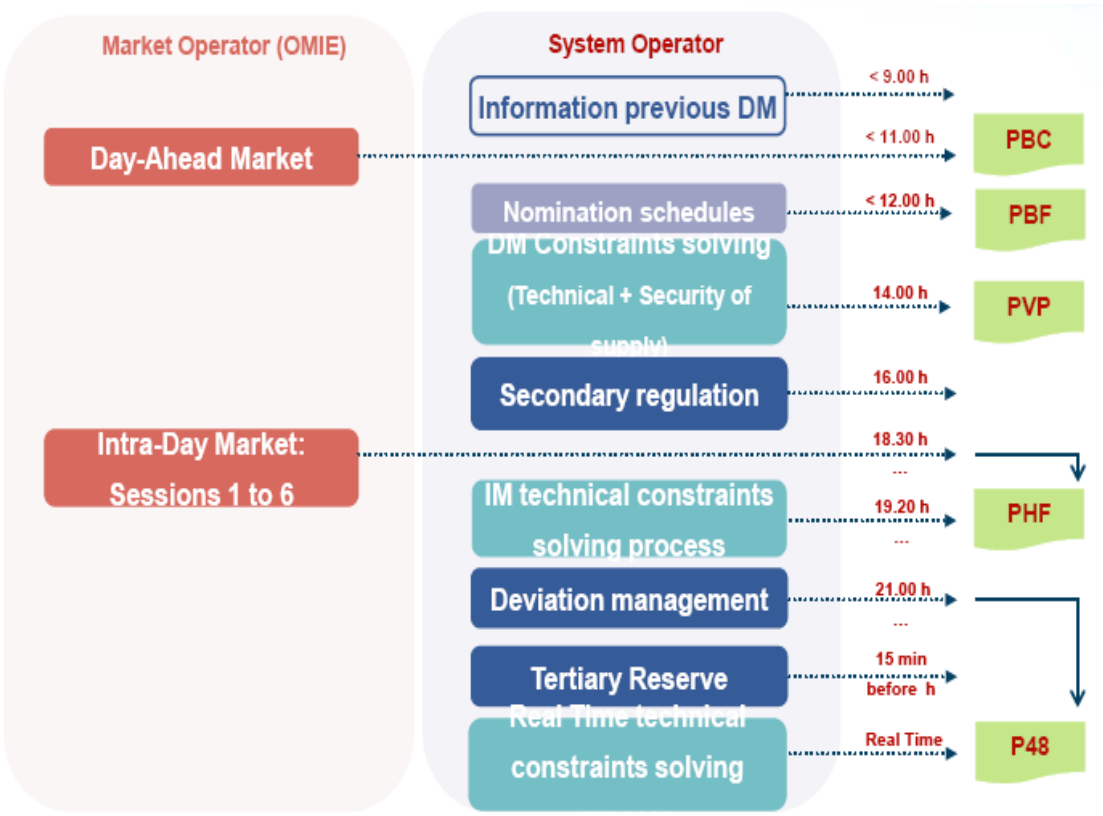

Fig 3-9 The framework of the Spain electricity market

Unlike Denmark, there are two pricing ways, the fixed price and the market price, in Spain. The wind plants can choose the price way once a year. Figure 3-10 gives the comparison of two pricing ways.

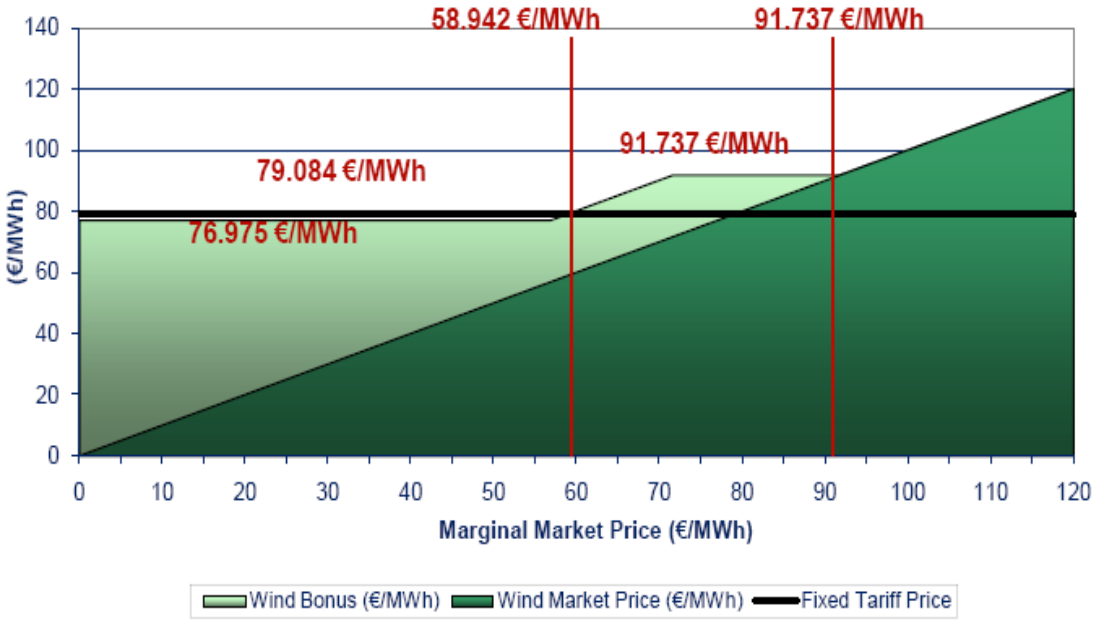

Fig 3-10 The pricing system of the intraday market

Fixed price: If the wind plant chooses the fixed price, the real price is the black solid line as shown in the figure, namely 79.084€/MWh.

Market price: If the wind plant chooses the market price, the real price is the sum of the market price and the subsidy.

All the wind plants need to join the bidding in electricity market. The subsidy changes as the market price. The lower the market price is, the higher the subsidy will be. For example, when the price of the wind power is zero, the wind plant obtain all of subsidy, namely 76.975€/MWh. When the price of the wind power is higher than 91.737€/MWh, the wind plant can not obtain the subsidy.

As for any type of generation, agents are penalized for their deviations and pay for the balancing energy needed to counteract their deviation. Reserve bands are calculated by the TSO and paid by the final consumers.

3.4.3 Emergency control

Until now, the installed capacity of the renewable energies is 20,000 MW in Spain. In order to accept more wind power, Spain’s grid company issued lots of administrative regulations and presents clear requirement for wind farms, i. e. the wind farms should possess the active and reactive power control capability and the low voltage ride-through (LVRT) capability. To keep the balance of the power, the grid company provides the control target every 15 minutes to ensure the priority of the wind power. This control target is usually the installed capacity of the wind farm. In case of emergency, the grid company balances the outputs of the

wind power by controlling the cycle gas units. The loss is paid by the final consumers. So there are few restrictions for the wind power. Only 0.2% percentage of the wind power is limited in 2010.

3.5 The function of the wind power forecasting

3.5.1 Wind power forecasting in TSO

Wind power forecasting (WPF) technology is one of the effective measures to mitigate peak-load regulation pressure, reduce reserve capacity, guarantee safe and stable operation of the systems, and ensure the participants' financial benefit. For TSO, the function of WPF is as follows:

(1) Determine the reserved capacity in reserve market according to the forecasting results. The assessment of the requirement and the bidding are influenced by the forecasting accuracy;

(2) In regulating market (real time market), the buying (selling) of the extra wind power based on the updating forecasting results every 5 minutes. It is very important for TSO to keep the stable of the power system. The forecasting results influence the financial benefits of the participants due to the payment of the electricity buying (selling) afforded by the power plants.

The related work and responsibility of the Danish TSO and the Spain TSO are listed below:

(1) Danish TSO

Energinet.dk is the TSO of Denmark whose main task is to

guarantee safe and stable operation of the electric systems. Figure 3-11 shows the position of Energinet.dk in the whole power generation. Its responsibility is electric storage and transmission.

Fig 3-11 The resposibility of Energinet.dk

Energinet.dk mainly uses two predictions tools: one external and one internal. The external forecasting method includes 0-12 hours prediction every 5 minutes and 0-48 hours prediction every hour. The forecasting results take four different numerical weather predictions into consideration. The internal forecasting method includes 0-6 hours short term forecast and 12-36 hours day ahead prediction. The combined forecasting result is based on three meteorological prognoses.

(2) Spanish TSO

Red Eléctrica de España (REE) is the TSO of Spain whose grids connect with France, Portugal and Morocco. REE was the first company in the world dedicated exclusively to power transmission and operation of electrical systems. Its installed capacity of wind power is about 21.3% of the total installed capacity. Figure 3-12 shows the REE’s control center.

Fig 3-12 The control center of REE

Beside study of the forecasting method by itself, REE buys three wind power forecasting system. The combined forecasting result is based on three meteorological prognoses. The precise forecast can be obtained through the weighted results based on four forecasting tools to guarantee the stable operation of the electricity system.

3.5.2 Wind power forecasting in wind farms

For wind farms participation, wind power forecasting is the base in the electricity market. The short term forecast and ultra-short term rolling forecast are the most important items for generation schedule, bidding in market, the payment of the extra power and so on. Its main functions are as follows:

(1) In day ahead market, the wind farms join the market according to the short term forecast. The forecasting result influences the 24 hour's electric quantity and bidding price of the next day directly. If the forecasting result is so bad, the wind plants will pay the expensive

compensation for their mistakes in intraday market.

(2) In the intraday market, the wind farms adjust the hour's generation plan based on the updated ultra-short term forecasting result in real time to correct the short term forecast. The higher the forecast accuracy is, the less the payment of the extra power will be. The narrower the gap between the generation plan and the real output is, the less is the TSO's adjustment required in regulating market. As a result, the wind farms' payments for that are reduced.

In general, the accuracy of WPF determines the economic benefit of the wind farms. It is the most important technique tool for the wind plants to participate the market.

The related work and responsibility of DONG Energy and the typical power plants in Denmark are listed below:

DONG Energy is the largest energy company in Denmark. Its business is based on procuring, producing, distributing and trading in energy and related products in Northern Europe. There are many conventional steam plants and wind plants in DONG Energy participating in the electricity market. DONG Energy joins all kinds of the market, i.e. reserve market, day ahead market, intraday market and regulating market. They want to create maximum value by trading products and services on relevant markets. Beside buying the forecasting products from other organizations, they also perform relevant research in forecasting field and optimize the forecasting products by themselves. DONG Energy bids in electricity market and determines the ratio of the wind power and other

generations (such as biomass, coal, oil, gas). They develop the generation plan according to the market and send it to Energinet.dk. The real outputs of the power should be consistent with the generation plan, or they need to pay the loss of the difference between the real and the plan.

In reserve market, the electric quantity and the electricity price are traded. To get better wind prognosis for next year, the forecast of DONG Energy includes monthly forecast and yearly forecast which are served as the reference of trading in the medium and long term market.

In day ahead market, DONG Energy forecast the wind power of next 24 hours. The result is served as the reference of the trade of the day ahead market.

In intraday market, ultra-short term forecasting is used to adjust the generation plan for dealing with the emergence, such as the wind storm, the sudden power break, and the icing of wind turbines-hub caused by frost and fog. DONG Energy reduces the economic loss by consulting with Energinet.dk and adjust the generation plan in time.

3.5.3 Discussion of the wind power forecasting technology

National Laboratory for Sustainable Energy (Risø) in Denmark is leading the way in wind power forecasting technology research. Its Prediktor system based on the NWP+WAsP+Power Curves is used in east of the Denmark from 1993. In 1994, the Zephyr system was developed by Risø and Technical University of Denmark (DTU). Since its setting-up, Zephyr have been applied in Denmark and expanded to Spain, Ireland, America, Japan and so on. The valuable experiences with the system

include:

(1) The combination of the numerical weather predictions and statistical forecasts;

(2) Using the numerical weather prediction data which is close to the hub height of the wind turbines;

(3) Establishing the power curves based on the wind direction & speed of the numerical weather predictions and the real output of the wind power;

(4) Considering the uncertainty and probability of the forecast;

(5) Obtaining the ensemble prediction result by combining the several numerical weather predictions;

(6) Measuring the errors of each variable;

(7) Reducing the forecasting errors by extending the forecasting region;

(8) Training the meteorological knowledge for the technical staff of the electricity transmission enterprises;

(9) Providing the consulting services under the special situation.

3.6 Meteorological service

The Danish Meteorological Institution (DMI) provides the paid meteorological service productions for Energinet.dk and supplies the numerical weather predictions data for the power plants. DMI offers the global background field information of the European Center for Medium-Range Weather Forecasts (ECMWF) for Energinet.dk. Energinet.dk employs the numerical weather prediction production of

DMI, ECMWF and the ConWX company. Dong Energy uses the numerical weather prediction production of DMI, the UK's Meteorological Office and the German Meteorological Institution. The forecasting method is the ensemble prediction based on the WPPT statistical model.

The SIPREOLICO wind power forecasting system of Red Eléctrica de España adopts the numerical weather prediction production of Agencia Estatal de Meteorología (AEMET) and ECMWF. Through the eight wind power forecasting models, the result of the ensemble prediction can be obtained. By combining the forecasting productions of AEOLIS Forecasting Service Company of Holland, IIC of Spain, METEOLOGICA professional prediction of Spain, and wind power forecasting company, it obtains 48 hours prediction every hour and 10 days prediction.

3.7 Summary

1. The free, open and flexible market mechanism for wind power enhanced healthy and fast development of wind power industry, and made the industry in Denmark and Spain in a leading position over the world.

2. The wind power forecasting (WPF) technology is one of the effective measures to increase wind power accommodation capacity for the power grids. The WPF systems should be installed in both sides of wind farms and dispatching facilities;

3. The wind power forecasting technology is the most important items for the wind plants to bid in market. The forecasting accuracy influences the participants' financial benefit directly;

4. In order to increase wind power accommodation capacity, it's urgently necessary for China to establish the WPF management system. Drawing lessons from foreign advanced experience and combining the situations of China, it is expected that an impeccable, healthy and highly flexible WPF management system will be established in the near future;

5. The accuracy of the wind power forecasting is closely related to the numerical weather predictions. The application of the meteorological service needs to be strengthened based on the existing numerical weather prediction productions.

6. Detailed data collection on the actual production from wind farms and wind turbines are very important for the management of the electricity systems and the grids.

7. Large power companies should be interested in WPF if the production on their power plants were dependent on the wind power production, i.e. if wind power has the priority access to the grid as stated in the China Renewable Energy Law.

4 Development Status of the Wind Power Forecasting in China

With the world in almost permanent energy crisis due to the pressure of economic development, wind power is nowadays one of the predominant alternative sources of energy. Since the first grid type wind farm was established in Rongcheng, Shandong Province in 1986, wind power began to develop in China gradually. Since 2004, China's wind power entered a period of rapid development. By the end of 2011, China has reached 62364 MW of wind-power installed capacity. Figure 4-1 shows the capacity of grid integrated wind power in recent years.

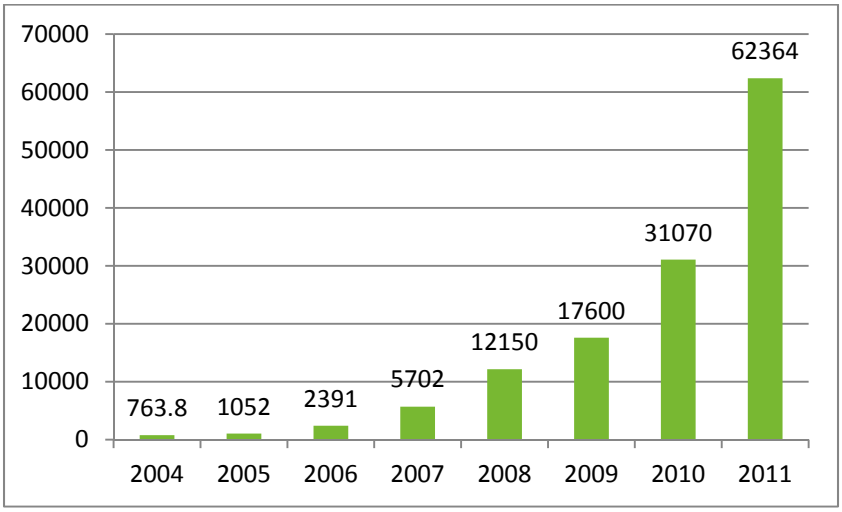

Fig 4-1 The installed capacity of integrated wind power in China (2004-2011)

Wind power forecasting technology is one of the effective measures to mitigate peak-load regulation pressure, reduce reserve capacity and increase wind power accommodation capacity for power grids. This technology also plays an important role in instructing maintenance plan of wind farms, increasing utilization of wind energy and improving economical benefit of wind farms. The WPF systems installed in

dispatching departments of power grid companies are helpful in effectively grasping wind power output in the area, making overall arrangement and actively accommodating.

China Electric Power Research Institute (CEPRI) is the first wind power forecasting research organisation in China. It has developed wind power forecasting model based on statistical methods such as artificial neural network, support vector machine, and so on. However, one of the important problems of the statistical method is the lack of history data. In order to overcome the shortcomings of the statistical methods, CEPRI developed the hybrid approach which combines the statistical method and physical method effectively. At present, CEPRI has mastered WPF technology for any wind farms and developed the first WPF with China's own intellectual property right.

Furthermore, the other research institutions, universities, and turbine manufacturers also joined in the research and development of wind power forecasting and made a large amount of research achievements.

5 Development and Application of the Wind Power Prediction System in China

5.1 Research status of the wind power forecasting in China

Starting of WPF in China is relatively late. The first WPF system with independent intellectual property rights in China was successfully developed by CEPRI in November 2008 and put into operation in Jilin Power Dispatching Center. Since then, thanks to scientific research and technical innovation, the WPF systems with independent intellectual property rights have gained wide application in power dispatching facilities in China and played an important role in production practice. So far, WPF systems are popular in power dispatching sides already, and the work of WPF is incepted in a few wind farms, but WPF in wind farms is still far beyond popularity. Many regional grids and provincial grids have built the day ahead wind power forecasting system in the three north area. It is convenient for them to issue the day ahead wind farm generation schedule based on the forecast results. However, the day ahead WPF results still need to improve. Though the RMSE errors of the most of regional grids and provincial grids are within 20%, the value of the error is within 95% guaranteed probability. Through the tests in Jilin Grid and Heilongjiang Grid, we can see that each 1-percent improvement of forecasting accuracy can increase the wind power accommodation capacity by 40MW in Jilin Grid and each 1-percent of the forecasting accuracy can increase the wind power accommodation capacity by 67MW in Heilongjiang Grid.

According to the experience gained in advanced wind power countries in the field of application and management mode of WPF technology, combining development planning of wind power in China of “building large bases and integrating into large power grids” and the requirements of establishing WPF hierarchy in a mutual complement and mutual backup manner, NEA issued “Interim procedures for management of power forecast in wind farms” in July 2011, mandating that all wind farms in China which are already integrated into power grids and in operation shall be equipped with WPF capacity and carry out WPF according to the requirements. The management mechanism of WPF to be established, which should effectively assess the WPF systems in both sides of power dispatching and wind farms, will become a key issue influencing healthy and stable development of wind power industry in China.

Until now in China, the WPF systems, though, are popular in dispatching side; the WPF systems in wind farm side are still blank.

For TSO, the important grid dispatching centers of the wind power in china hadn’t built the WPF systems until the end of December 2011, such as Jilin province, Heilongjiang province, Northeast regional grid, Jiangsu province, Ningxia province, Gansu province, Northwest regional grid, Xinjiang province, Liaoning province, Fujian province, Shanghai city, Shandong province, Inner Mongolia province, North China regional grid, and Shanxi province. And now, the WPF systems have already covered the capacity of 40000MW. The WPF systems are equipped with

the functions of the day ahead forecasting and ultra short term forecasting.

Parts of the provincial dispatching centers, such as Gansu, Shandong, Shanxi, Xinjiang and so on, have developed the clusters smart control systems of the wind active power. The systems possess functions of adjusting the on-line generation plan and control in real time. It can utilize the resources sufficiently and maximize the wind power output. Heilongjiang Grid built the peak-valley adjustment system of the wind power based on dynamic monitoring platform. Jilin Grid developed the on-line planning system based on wind power forecasting. The system can schedule the day ahead generation plan of each wind farm according to the short term forecast and ultra short forecast. To accept more wind power, the generation plan can be adjusted online based on the operation procedure.

For wind farms, recently, some of the regional and provincial power grid companies had conducted assessment of WPF results of the wind farms under their administration. These practical experiences are of great importance for establishing an impeccable management system of WPF in China. “Implementing Regulations for grid integration management for the power plants in Northeast China” released by Northeast China Grid Company in December 2010 stated that wind power generation enterprises in the area should conduct short-term WPF and report the forecast results to dispatching facilities. The Regulations also ruled that the dispatching facilities should assess the WPF in its reporting ratio,

accuracy and acceptability based on daily and monthly assessment. “Assessment Procedures for Centralized Dispatched Generating Units Operating in Jiangsu Power Grid (Trial Implementation)” jointly released by Jiangsu Economic and Information Committee and Electric Power Supervision Office in July 2011, formulated the procedures of assessment and refund for wind turbines, the preliminary requirements of reporting time, data sampling format and prediction accuracy for WPF results and the related punitive measures. At the end of 2011, Xinjiang Power Grid Company preliminarily formulated the assessment criteria and model for WPF results as the basis for evaluating and ranking the wind farms in its jurisdiction. This method is now in its trial step.

From the domestic position it can seen that WPF should be carried out in joint-effort between wind farm operators and system operators. Establishing reasonable management mechanism of WPF and the efficient management rules will utilize the advantages of all the participants to boost development and application of WPF technology.

5.2 Development of WPF system in dispatching side

The WPF development performed by dispatching facilities helps them in scheduling adequate power system operation to ensure that the systems possesses enough reserve capacity for any emergency to guarantee safe and stable operation of the systems.

At present, most of the provincial (regional) dispatching centers in China have installed the WPF system. Based on the study and constructive experience of the WPF system, the researchers designed the

development and applications of the WPF system. The system includes the technology study and application policy of WPF:

(1) In technology study respect, it is necessary to accelerate the research of the wind power forecasting algorithm in wind farm. The details mainly lie in two aspects:

- Studying the whole wind power forecasting algorithm for province, optimizing the provincial WPF system;
- Studying the regional wind power forecasting algorithm by taking the smoothing effects between provinces into account, establishing the regional WPF system;

(2) In application policy respect, it is important for the government to establish a reasonable policy which can accelerate the development of the WPF in a healthy and orderly way. The details are as follows:

- Constructing the WPF system systematically;
- Adjusting the WPF system in time based on the constructing and test running situation.

5.3 The development of the WPF system in wind farm side

According to the foreign WPF experience and the domestic characteristics, the WPF development in wind farm side should be performed by wind farm operators to serve themselves for acquiring desired generation schedule and competitive bidding in electricity market to ensure their financial benefit.

With the rapid development of the wind power in China, there are

many problems, such as diversity of wind turbine types, disunity standards, lack of basic data and so on, which influence establishment of the WPF system in dispatching centers of the power grids. The wind farms need to complete their basic information, standardize the constructing and operating, and refine the WPF system.

The development and application of the WPF system include technology study and application policy of the WPF.

(1) In technology study respect, it is necessary to accelerate the research of the wind power forecasting algorithm in wind farm, utilise the detailed information of the wind farm effectively, study the refined method for wind farm's WPF. The details mainly lie in three aspects:

- Studying high-precision numerical weather prediction techniques for the WPF in wind farm;
- Studying data assimilating technology of the real-time wind towers and improving the wind power forecasting accuracy;
- Establishing a normative basic database in wind farm.

(2) In policy application respect, it is important for the government to establish a reasonable policy which can accelerate the development of the WPF in a healthy and orderly way. The details are as follows:

- The wind farms need to configure the wind power forecasting system or have the ability of the wind power forecasting. The wind farms need to report the forecasting results according to the dispatching agreement;
- The wind farms should have at least one wind tower which

can supply the wind information and the real time data around the wind farms;

- In order to ensure the forecasting accuracy of the WPF system, the wind farms should adjust the WPF system in time based on their own expanding condition;
- The WPF system in wind farms must fulfill the protecting requirements in power system.

6 Wind Power Forcasting System Framework

According to the international experiences and national research results, it is a general trend to develop forecast in both wind farms and grid companies. In wind farm side, WPF is performed by wind farm operators to serve themselves for acquiring scheduled power generation and market bidding to ensure their financial benefit. The dispatching facilities are mainly responsible for predicting and dispatching the total wind power output within their administration to help them in scheduling adequate power system operation to ensure that the systems possess enough reserve capacity for any emergency to guarantee safe and stable operation of the systems.

Based on the conditions in China, WPF systems should be installed in both sides of wind farms and dispatching facilities. The WPF systems installed in dispatching departments of power grid companies are helpful in effectively grasping wind power output in the area, making overall arrangement and actively accommodating, especially for the case that the WPF system of the wind farm can not be built in a short time. The WPF systems installed in wind farms help them to improve and update the basic information according to the developing conditions and status to establish a refined WPF. Only with these measures the prediction results reported to the grid dispatching departments will be effective. Therefore it is necessary to establish related management and assessment system to manage WPF in the both sides.

6.1 Main relationship of the shareholders

Establishing WPF hierarchy suitable for the wind power development mode in China heeds joint participation of related governmental authorities of power sector, power supervision department, grid dispatching facilities, wind power developers and operators, meteorological service agents, prediction providers and the others concerned. Based on the management system of WPF abroad and incorporated with the development status of WPF in China, the main responsibilities of the related organizations in the WPF hierarchy are as follows:

-- **Related governmental authorities**: formulating associated policies and standards and guiding efficient and orderly development of wind power industry;

-- **Electric power supervision organization**: implementing supervision on dispatching centers and wind farms according to WPF systems;

-- **Power dispatching center**: performing prediction of wind power output, receiving the forecast results and generation schedule from wind farms, evaluating the wind farms and formulating and issuing generating schedule of the power plants;

-- **Wind farm operations**: predicting the power output of wind farms and formulating generation schedule; reporting forecast results and generation schedule to dispatching centers in regional/provincial levels according to assessment criterion requirements of WPF; being

equipped with capacity of automatic data communication with dispatching facilities the wind farms are subordinated to, setting up relevant safety strategy and ensuring the safety, reliability and stability of the data communication; strictly implementing the orders from dispatching centers, seriously carrying out the generation schedule issued by the dispatching facilities and performing energy production according to specified generation schedule;

-- **China's National Meteorological Administration (CMA)**: providing grid dispatching facilities, wind farms and power prediction providers with meteorological data meeting requirements of forecast management systems;

-- **Forecasting service providers**: providing grid dispatching facilities and wind farms with WPF service meeting requirements of forecast management systems.

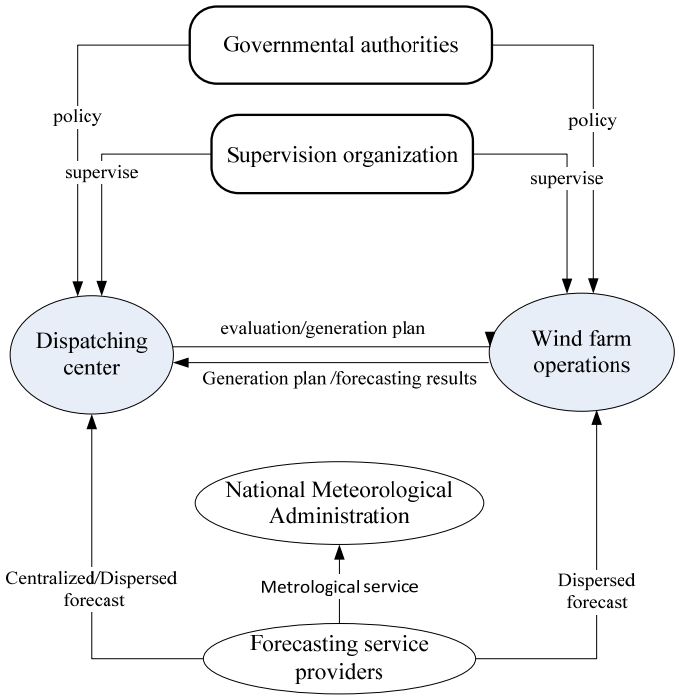

Fig 6-1 Framework of wind farm WPF system

The relationship between the organizations in WPF system framework is shown in figure 6-1, where the dispatching centers in three levels, i.e. national, regional and provincial.

6.2 Responsibilities of the dispatching facilities

Figure 6-2 shows the relationship of the dispatching centers in three levels. The responsibilities of the dispatching facilities in different levels are as follows:

Fig 6-2 Structure diagram of the dispatching centers

1. State Grid Dispatching Center

   (1) Ranking and notifying with the WPF results sent up by the regional dispatching centers;

   (2) Guiding operation of the regional grids based on forecast results, giving full play for mutual support between the regional grids.

2. Regional grid dispatching centers

   (1) Performing WPF of direct-subordinated wind farms and reporting the forecast results to national dispatching center;

   (2) Receiving forecast results and generation plan sent up by the direct- subordinated wind farms, assessing the wind farms according to WPF management systems

   (3) Formulating and issuing wind farm generation schedule based

on the forecast results and generation plan sent up by the wind farms, taking into account the load-following capacity available of the grids;

(4) Receiving forecast results sent up by the provincial dispatching centers under administration, ranking and notifying.

3. Provincial dispatching centers

(1) Performing WPF of the wind farms under administration and reporting the forecast results to regional dispatching center;

(2) Receiving forecast results and generation plan sent up by the wind farms, assessing the wind farms according to WPF management systems

(3) Formulating and issuing wind farm generation schedule based on the forecast results and generation plan sent up by the wind farms, taking into account the load-following capacity available of the grid.

Figure 6-3 and figure 6-4 show the flow charts of data reporting and order issue for dispatching centers and wind farms, i.e. the wind farms shall send up the basic data of the wind farms and WPF data to dispatching centers, regional/provincial dispatching centers need to send up the WPF data to State Grid Dispatching Center.

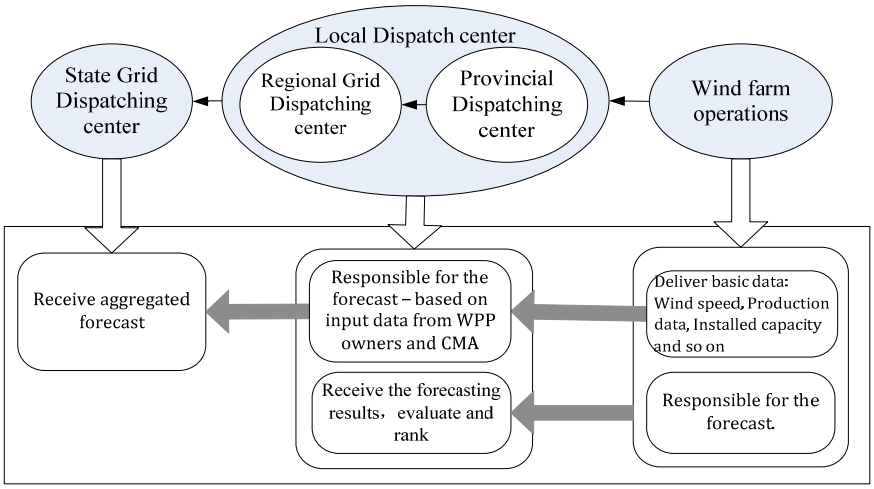

Fig 6-3 Flow chart of data reporting

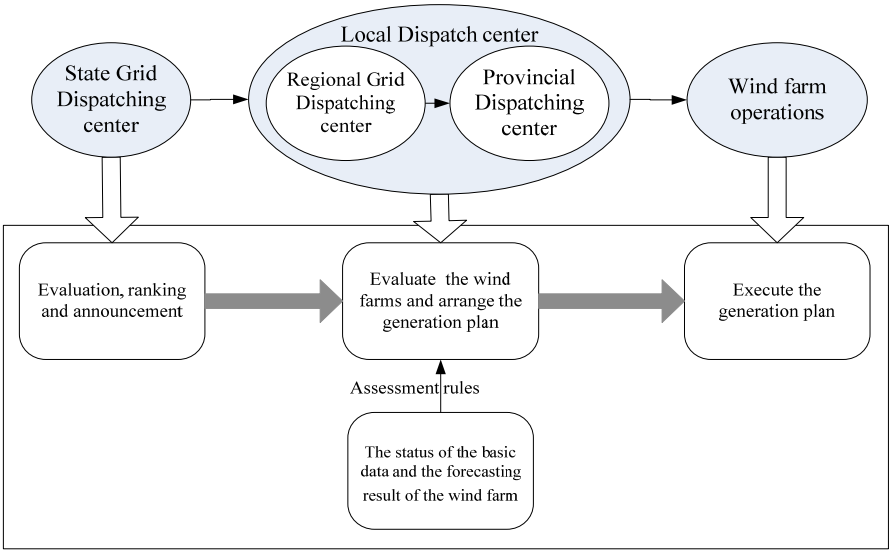

Fig 6-4 Flow chart of order issue

6.3 WPF system in TSO

According to the criteria of prior dispatching of wind power, the existing dispatching decision supporting system in TSO was optimized based on the long, short and ultra short term wind power forecasting from three time scales namely long term, day ahead and intraday. The new improved system which is called prior dispatching system of the power

grid, can maximize the accommodated capacity of the wind power. The framework of the prior dispatching system is shown in figure 6-5.

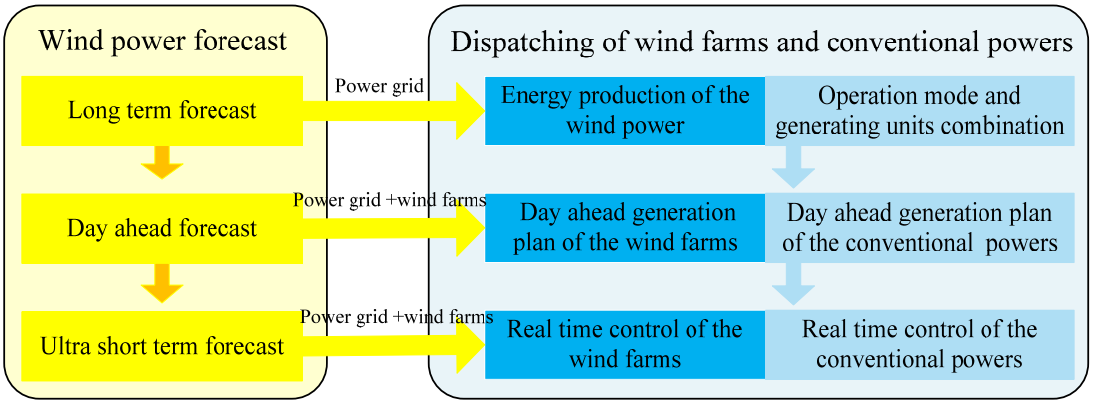

Fig 6-5 The prior dispatching system of the wind power based on WPF

(1) The long term prior dispatching of the wind power

Firstly, the TSO should take the wind power into consideration in yearly generation plan. The energy production forecasting should be arranged according to the wind power-building and the wind data of many years. The wind power should be arranged with priority in the yearly energy production balance. According to the integrating situation of the wind farms, TSO should analyze the stable level in the mode of delivering the superpower of the wind power deeply and disposing the reactive compensation equipment and safe measure reasonably. In the case of ensuring the safety of the power grid, the TSO should study and dig the accommodated capacity and control capability of the power grid.

Secondly, the TSO should take the wind power into account in monthly generation plan. In order to arrange the repairing plan and the starting-up mode of different kinds of the generation units, the TSO

should forecast the energy production of the wind power and its distribution by combining it with the historical wind and operation data. Therefore, according to the forecasting results, the TSO can dispatch the wind power with priority during the monthly generation planning.

(2) The day ahead prior dispatching of the wind power

In the day ahead planning, the TSO should dispatch the wind power prior with the precondition of stable operation and continuous supply of the power grid. The TSO should arrange the reserved capacity reasonably according to the wind power forecasting errors and load forecasting errors which are obtained by the day ahead wind power forecasting curves, the day ahead load forecasting curves and the interconnection power planning curves. Based on the prior dispatching of the wind power, the TSO schedules the generation plan of the wind farms and other conventional power.

(3) The intraday prior dispatching of the wind power

The TSO should consider the the ultra short term wind power and the load forecasting errors according to the uploaded monitoring data from wind farms and the wind power load forecasting results. Based on the real situation of the power grid, the TSO will adjust the outputs of different kinds of the power generation units timely and accept the wind power as much as possible only if the operation of the wind power is stable and safe.

6.4 WPF system in wind farms

NEA issued “Interim procedures for management of power forecast

in wind farms” in July 2011 under the condition that uniform criteria of the WPF system in the wind farms hadn’t been set up. It’s mandatory that all wind farms in China which have already been integrated into power grids and in operation should be equipped with WPF and carry out WPF according to the requirements. According to the international experience, The WPF in wind farm side should be performed by wind power plants independently.

In order to facilitate the WPF system in TSO, the wind power plants should deliver the basic data such as the wind farm characteristics, wind turbine information, wind speed, wind direction and installed capacity etc. The data will be a valuable contribution to the TSO and the quality of it should be an important reference for the ranking and prior dispatching of the wind farms.

To ensure the justice and improve the efficiency of the wind power, the wind plants should set up their own WPF system or have the wind power forecasting capability to submit these to the TSO. The wind plants should send efficient data according to the dispatching agreement. The accuracy rate and the qualified rate will be the criteria for the ranking and prior dispatching for the wind farms.

6.5 Time schedule of the WPF management system

Figure 6-6 shows the time schedule for establishing the WPF management system in China. It is expected that an impeccable, healthy and highly flexible WPF management system suitable for the conditions of China will be built by the end of 2014.

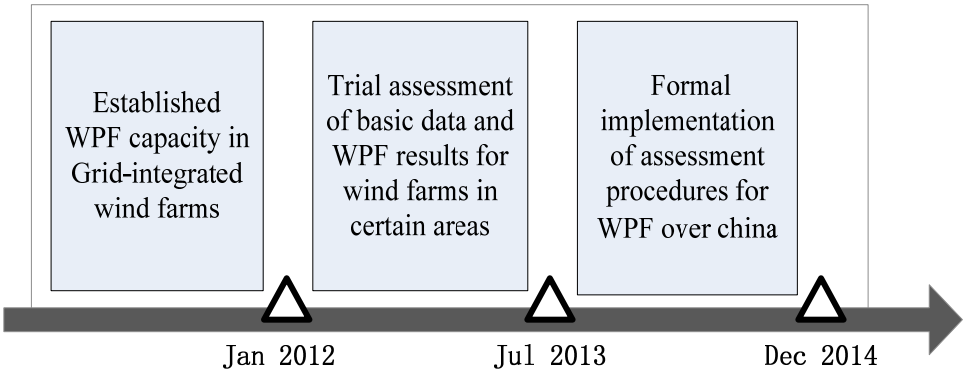

Fig 6-6 Schedule for establishing WPF management system

7 Wind power prediction system implementation plan

The assessment system of the WPF should be mainly used to standardize the management of it and aim to improve the efficiency and accuracy according to the <Interim Procedure of the management of wind power forecasting of wind farm>. A more far-reaching thought about the electricity production plan based on the WPF result is to provide a scientific and reasonable reference for the peak-valley adjustment and act as an important support to the decision-making of electricity production and the management of wind dispatching.

The reporting procedure of wind-power forecasting result should follow the principle which is from bottom to upper level namely from wind farm to provincial dispatching center, then to grid dispatching center, then to state dispatching center. The evaluation mechanism made by the dispatching ministry on the wind farm about the reporting data of the WPF can be described as below and it can be referred for the provincial or state dispatching center.

7.1 System requirements of the wind power forecasting

1. The wind power forecasting should be based on the wind farms operating data and meteorological data. The active power for some time to come should be predicted by the methods of data mining, statistic analysis, physical processes simulation and so on. The forecasting time scales include short term forecast and ultra short term forecast, where the short term forecast is 0-72 hours prediction every hour. The ultra short

term forecasting is 0-4 hours prediction every 15 minutes.

2. The wind farm should establish the wind power forecasting system according to the related policy. The WPF should have the function of short term forecast and ultra short term forecast. The wind farms should install the wind tower which can ignore the effects of the wake and the tower should be within 1-5kmof the wind farm. The items of the data include the wind speed and direction of 10m, 50m, and the hub height, temperature and pressure of one layer and so on.

3. The TSO should establish the WPF which covers the whole dispatching area. The WPF should possess the functions of the short term forecasting and ultra short term forecasting. It can also imply the presentation of uniform interface and the statistic analysis of the forecasting results.

4. The software of the WPF should at least include the numerical weather predictions processing module, the real-time meteorological information processing module, short term forecasting module, ultra short term forecasting module, system interface, database, data exchange interface and so on. The WPF of the TSO should supply the data exchange interface module, ensemble prediction module, prediction assessment module, information module and so on.

5. The hardware of the wind power forecasting system includes the meteorological data processing server, system server, safety isolating device, man-machine station, and etc. Besides that, the WPF of the TSO also includes the data communication server. The deployment of

the systems should satisfy the requirements of “The safe protection regulation for the power secondary system”. NEA issued “Interim procedures for management of power forecast in wind farms”

7.2 Running schemes of the system

1. The wind power forecasting system of wind farms should communicate and interact with the TSO’s wind power forecasting system. The wind farm should report the data including the related information of the day ahead generation plan and the real-time information of the intraday generation plan. The TSO should issue the wind farm’s assessment results every month.

2. The related information which is used in the day ahead generation plan includes 0-24 hours short term forecast and the expected capacity. The data should be reported once per day. In case of the holiday, the wind farm should report ahead the 0-72 hours short term forecast and its expected capacity.

The real-time information which is used in adjusting the intraday generation plan includes:

(1) The wind farm should report automatically the wind power forecasting data of 0-4 hours every 15 minutes;

(2) The wind farm should report its installed capacity every 15 minutes;

(3) The wind farm should report the wind data every 5 minutes.

3. The TSO should assess and rank the wind farms according to the completion of the data and the weighted results based on the accuracy

rate, qualified rate and so on. The TSO issued the assessment results of the prediction through the information modules. The result is one of the ranking basis of the wind prior dispatching.

4. The WPF data interacts between the wind farm and the TSO adopts the IEC 60870-5-102 protocol. The data transfer follows the E text formatting standard through the dispatching section Ⅱ. The wind farm acts as the server and the TSO is the client.

7.3 Ranking schemes for prior dispatching

According to the electric electricity market operation rules, the wind power forecasting is helpful in effectively grasping wind power output in the area, making overall arrangement and actively accommodating. Be guided by the principle of promoting the wind power technology and improving actively accommodation, the management mechanism of WPF needs to be established, which should effectively assess the WPF systems and ranking the wind farms, will encourage the active construction and operation of the WPF in wind farms.

The wind farms will be dispatched with high priority if they are the tops in the ranking list according to below evaluation mechanism. The evaluation mechanism follows a hundred percent system and ranks the wind farms day by day according to the result achieved in the day before the evaluation date. And the ranking list, in accordance with the <Interim Procedure of the management of wind power forecasting of wind farm>, is made out with the indexes of prediction accuracy and qualified rate which can be found in appendix. Then, the ranking is taken as the

reference for prior dispatching. For the hundred percent system used for evaluation, the prediction accuracy accounts for 60% and the qualified rate takes the remained 40% as below:

Table. 7-1 Evaluation Mechanism for Prior Dispatching

No.	Index	Weight (points)
1	Accuracy Rate	60
2	Qualified Rate	40
Total		100

The concrete evaluation method for each index is as below:

1. Accuracy Rate

The start level of the prediction accuracy rate is 80% which corresponds to 40 points and it will be the benchmark for the wind farms. 2 points can be achieved by 1% higher than the start level and vice versa. The all 60 points means that the rate is equal or higher than 90% and 0 point corresponds to the rate equal or lower than 60%.

2. Qualified Rate

The start level of the qualified rate for the wind-power prediction is 40 points which correspond to the rate of 100% and it will be the benchmark. 1 point will be reduced if the rate is lower than the benchmark by 1% and the rate below 60% will lead to 0 point.

The points calculated by the method above are used to rank the wind farms. And the referred rules is the points as the first, then the installed capacity, final the date of starting operation. The smaller is, for the

installed capacity, the topper. And for the date, the later is the topper. The final ranking sequence will act as the input for the dispatching organization to arrange the electricity generation plan.

0 point, however, will be the case only if one of the scenarios below occurs:

(1) No forecasting system was set up in the wind farm;

(2) No power forecasting curve was reported to the grid ministry;

(3) No wind-tower was built or no real-time observed data was transmitted to the grid ministry.

8 Conclusions

The report, combining the international experience and national situation, studies on the tailor-made wind power forecasting system framework and implementation plan in china. The report first shows the operational principles and the control mechanism of the Danish and the Spanish electricity market. Then, according to the responsibilities of the TSO and the wind plants, considering the current status of the WPF technologies in china, the report proposed the framework of the management mechanism of WPF with Chinese characteristic and illustrated the main responsibility of the shareholders. At last, referring the advanced international operation mode and experience, the detailed implementation plan of the management mechanism of WPF was given in the report.

9 Appendix

Assessment method of prior dispatching

1 Accuracy Rate (r_1)

$$r_1 = \left(1 - \sqrt{\frac{1}{N}\sum_{k=1}^{N}\left(\frac{P_{Mk} - P_{Pk}}{S_{op_k}}\right)^2}\right) \times 100\%$$

Where P_{Mk} is the actual power at time point *k*, P_{Pk} is the forecasting power at time point *k*. *N* is the sample points of one day. S_{op_k} is the installed capacity of the wind farm.

2 Qualified Rate (r_2)

$$r_2 = \frac{1}{N}\sum_{k=1}^{N} B_k \times 100\%$$

Where

$$\left(1 - \left|\frac{P_{Mk} - P_{Pk}}{S_{op_k}}\right|\right) \times 100\% \geq 75\%, \quad B_k = 1$$

$$\left(1 - \left|\frac{P_{Mk} - P_{Pk}}{S_{op_k}}\right|\right) \times 100\% < 75\%, \quad B_k = 0$$