Roadmap of Developing Active and Reactive Power Dispatch and Control System of China Grid Considering Large-Scale Wind Integration

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Abstract: Large-scale wind power is integrated into the backbone grid of China increasingly and the penetration of wind power grows higher and higher. In order to eliminate the impacts of wind power on conventional Active and Reactive Power Dispatch and Control (ARPDC) system, it is urgent to modify present system. Firstly, traditional ARPDC system is introduced briefly. Secondly, the basic characteristics of Chinese wind power are analyzed and summarized, including fluctuation, low-predictability, low-controllability, centralized development, long-distance transmission and integration into backbone grid. Thirdly, based on the characteristics of wind power, the framework of the new ARPDC system is proposed. In short, the ultimate goal of the new ARPDC system is that the wind power should play almost the same role as conventional power generation units. Finally, the status quo of the development of ARPDC system suitable for large-scale wind power integration in China is introduced, and the roadmap of developing new ARPDC system is discussed.

Keywords: Power system control, Wind, Automatic frequency control, Hierarchical control, Load dispatching.

1. INTRODUCTION

The need to diversify away from traditional fuel generation is driving the deployment of non-conventional renewable energy. Among various renewable energies, wind power is the most promising one, and has drawn much attention worldwide. Especially, ambitious targets have been set by Chinese government, and the total wind power capacity increased 100% per year in recent four years. In the end of 2009, the total wind power capacity of China (22.6GW) has ranked No.3 in the world, and China has formed the development trend that large-scale wind power has been integrated into the backbone grid.

Wind power generation is much different from conventional generation. Its fluctuation and randomness features have brought massive challenges in various fields of power systems, especially on the aspect of Active and Reactive Power Dispatch and Control (ARPDC). Therefore, it is necessary to improve conventional ARPDC method in the view of wind power features.

At present, there are numerous references discussing the participation of wind power in frequency control and voltage control of power systems.

On the aspect of frequency control, most of the countries with rich wind power require that the wind power should take part in the tertiary frequency control, while there are rare countries ordering wind power to join in secondary and primary frequency control. In German (DNEA, 2005), TSO (Transmission Systems Operator) sufficiently takes account into the wind power prediction errors, load prediction errors and the fault rate of plants together to make the generation schedules and manage the reserves. In Japan, considering the wind power fluctuation, power companies improve the load frequency control (LFC) method to keep the system frequency in the allowable range (Tohoku Electric Power, 2010). In Italian, wind generators are requested to participate in primary frequency control (Italian Government-department of European affairs, 2007). If the system frequency ranges from 50.3 to 51.5 Hz, the wind farms in Italian should adjust their output power from 2% to 5%.

On the aspect of voltage control, most countries focus on the abilities of wind farms to participate in primary voltage control. Usually, wind farms are ordered to operate on the specified power factor in many countries, such as Denmark (Eltra and elkraft, 2004), German (VND (verland der netzbetreiber), 2003) and Ireland (Licensed distribution network operators of Great Britain, 2006). In Italy, wind farms are required to regulate the voltage of PCC (Point of Common Coupling) around the allowable values. When the faults occur in the power systems, the abilities of low voltage ride-through (LVRT) are fairly important for the grid to recover. This ability is demanded in many countries, such as America, France, Denmark, and Spain (European parliament, 2001, European parliament, 2008, Wiser, *et al*, 2008). Until now, there are still seldom reports that wind farms have participated in the secondary voltage control to support the voltage of area power grid, or in the tertiary voltage control to optimize reactive power flow.

In this paper, firstly traditional ARPDC system is introduced briefly and the basic characteristics of Chinese wind power are analyzed and summarized. Then, based on the characteristics of wind power, the framework of the new ARPDC system is proposed. Finally, based on the status quo of the development of ARPDC system, the roadmap of developing new ARPDC system is discussed.

2. BRIEF INTRODUCTION OF TRADITIONAL ARPDC SYSTEMS

The Active Power Dispatch and Control (APDC) system is responsible for balancing the active power generated from the units and the active power consumed by the loads. Traditional hierarchical APDC framework is shown in Fig.1, which can be divided into three parts as follows.

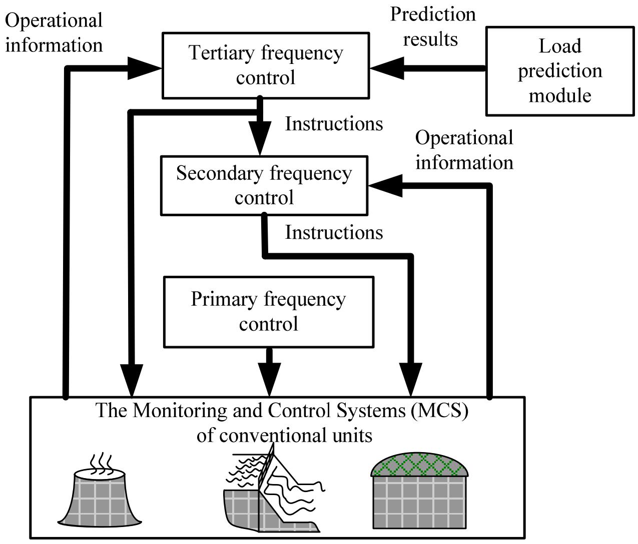

Fig. 1. Framework of conventional Active Power Dispatch and Control (APDC) system.

(1) Primary frequency control is used to damp the frequency deviation caused by stochastic loads, but cannot eliminate the deviation. This function is accomplished by the governors of generators.

(2) Secondary frequency control is a centralized automatic control process. It can remove system frequency deviation and control tie-lines power flow to the references.

(3) Tertiary frequency control mainly solves the economical dispatch problems, which should be based on the load prediction results.

The Reactive Power Dispatch and Control (RPDC) system takes charge of balancing the generated reactive power and the adopted reactive power in local areas and maintaining the pilot bus voltages stable. Traditional hierarchical RPDC framework is shown in Fig.2, which can also be divided into three parts.

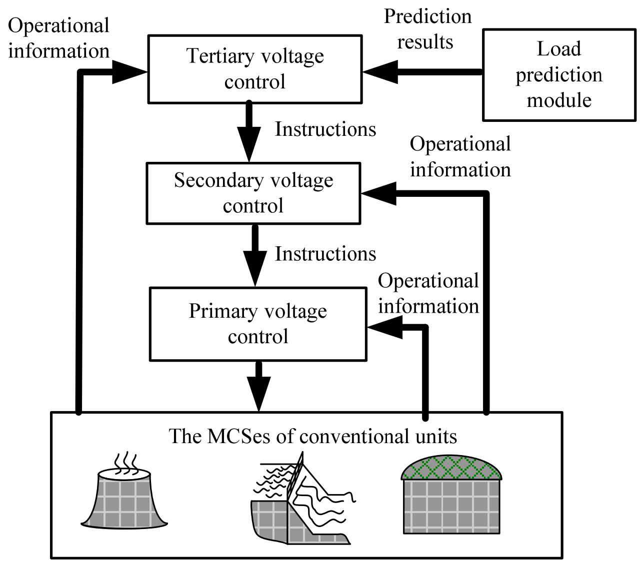

Fig. 2. Framework of conventional RPDC system.

(1) Primary voltage control is a kind of local control. It keeps the corresponding bus voltages around the reference values that come from secondary voltage control.

(2) Secondary voltage control is a kind of area control. It sets the reference values for the primary voltage control in order to hold the voltage of pilot buses (some important buses) stable.

(3) Tertiary voltage control uses the information from the whole systems to optimize reactive power flow and compute reference voltage values for secondary voltage control, and meets economical and stable requirement of the whole systems.

3. BASIC CHARACTERISTCS OF CHINESE WIND POWER

3.1 Fluctuation

Compared with traditional energy resources such as fossil power, hydropower and nuclear power, renewable resources (such as wind and solar) are more variable as a result of weather. As is well-known, wind as the primary energy of wind power, it cannot be stored and depends on the local meteorological situations and geographical conditions. The probability distribution of the rate of output power change of a wind farm in Northeast China is as shown in Fig. 3.

The fluctuation of wind power can be analyzed in two dimensions: In the time dimension, the regularity of fluctuation is less obvious and the amplitude of fluctuation is bigger in the long time than that in the short time; In the space dimension, wind power has the feature of area smoothness. Or, the fluctuation of wind power in a wide area including several large wind farms becomes relatively smoother.

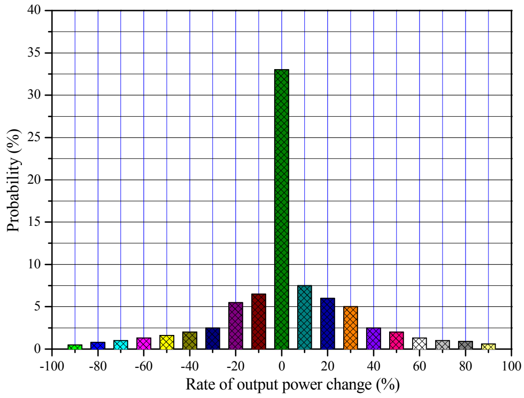

Fig. 3. Probability distribution of the rate of output power change of a wind farm in Northeast China.

3.2 Low-Predictability

Just like the experience that the grid operators have in managing the variability of load, in order to cope with the intermittent and variability natures of wind power, the wind power should also be predicted. However, presently the precision of wind power prediction still can not be compared with that of load prediction. Furthermore, wind forecast for longer time horizons tend to be less accurate than forecast over shorter time horizons.

At present for the advanced wind power prediction, such as the AWPT system in German, the prediction precision only reaches average deviation of approx. 10% (based on the installed wind power) for the period from 1 to 48 hours and approx. 5% for the period from 3 to 6 hours (Ernst, *et al*, 2010). In China, the prediction precision is even worse, about 10-15% for short-term forecast. Above feature of wind power prediction is called low-predictability in this paper.

3.3 Low-Controllability

Controllability of wind power refers to the ability to regulate active and reactive power through the control measures. The controllability of wind power is lower than that of conventional generators because of the following two reasons:

(1) The maximum output power of a wind farm is constrained to the captured wind energy. Meanwhile, wind farms usually operate on the maximum output state in many situations to meet the demand of environmental protection or cater to some contracts, which causes that they cannot response to the active power dispatch command from grid operators.

(2) The abilities of wind generators to control active and reactive power vary between fixed turbines and variable ones. Variable speed wind generators such as double fed induction generators can realize decoupled active and reactive power control. Nevertheless, fixed speed wind generators are not capable of controlling their reactive power, and their capabilities of active power control are weaker than that of variable speed wind generators. Currently some advanced pitch angle regulators and VAR compensators have been introduced into wind farms, which can improve the active and reactive power control ability to some degree.

3.4 Special Characteristics

It should be pointed out that above characteristics of wind power are common, not only in China but also in other countries. Meanwhile, there also exist some special characteristics of Chinese wind power as follows:

(1) Centralized development

In many other countries, wind power is distributed developed, but in China wind energy is developed in a centralized manner. This is mainly because of the wind source distribution character. In China, the areas with rich wind resources mainly locate in North, Northwest, Northeast and East coast of China. Thus, seven wind power bases all above one million kilowatts has been planned to build in Inner Mongolia (east and west), Xinjiang, Gansu, Hebei, Jilin and Jiangsu provinces (see Fig.4).

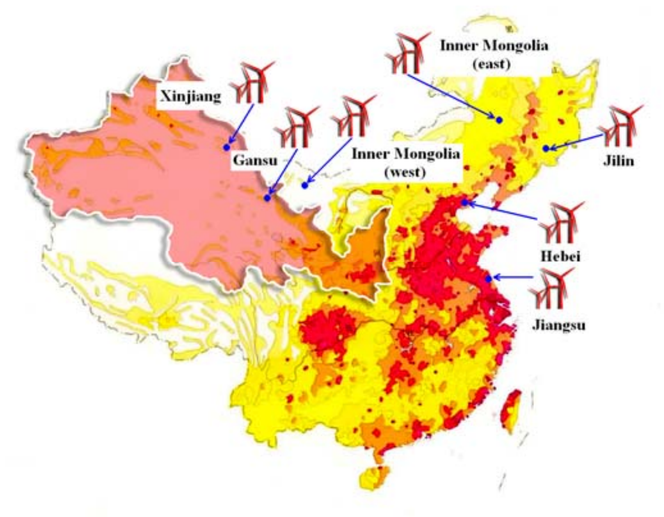

Fig. 4. Distribution of wind power bases and load centers in China.

(2) Long-distance transmission

In China, the distribution of wind resources and load centers is nearly opposite. As is known, the load centers in China are mainly in South, East and North China (such as Guangzhou, Shanghai and Beijing cities), and then some wind power bases, such as that in Inner Mongolia, Xinjiang, Gansu and Jilin are all far from the load centers. Thus, the wind power has to be delivered for a long distance because it is not able to be consumed locally.

(3) Integration into backbone grid

Since the wind power should be long-distance transmitted, the voltage level of wind power integration should be relatively high and wind power should be integrated directly into the backbone grid. For example, most wind farms in Jiuquan (in Gansu) are directly integrated through 330 kV step-up stations to 750 kV power grids. Compared with China, wind power is usually integrated into distribution network in other countries. In this circumstance, it's more difficult to make generation schedule, shave peak, regulate frequency and voltage, and improve reserve management.

4. FRAMEWORK OF NEW ARPDC SYSTEM

Based on the characteristics of wind power, the framework of the new ARPDC system can be proposed. Firstly, the ideal or the ultimate goal will be illustrated in this section. In short, the goal of the new ARPDC system is that the wind power should play almost the same role as conventional units.

4.1 New APDC System

Considering the characteristics of wind power, in the case of large-scale wind power integration, it is necessary to modify and improve the frame shown in Fig.1. The new APDC framework suitable for large-scale wind power integration is as shown in Fig.5.

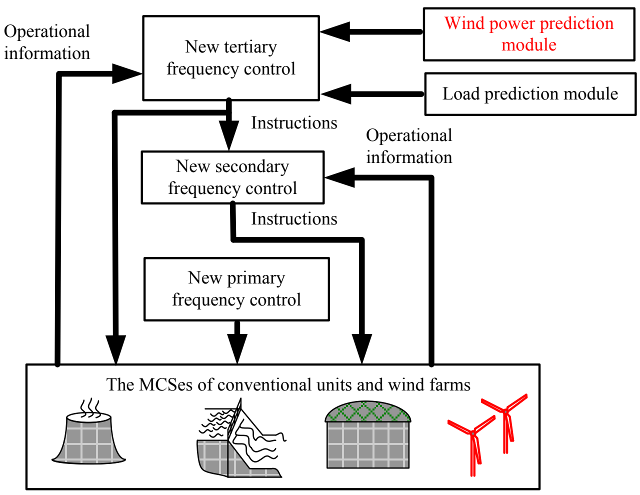

Fig. 5. Framework of the proposed APDC system considering the integration of large-scale wind power.

In the new APDC system, there are two new modules:

(1) The Monitoring and Control System (MCS) of wind farms. The functions of the MCSes of wind farms are similar to that of conventional units, or responding to dispatch and control commands from the master stations (operators), feed-backing the operating information of wind generators, monitoring and controlling wind generators to meet needed demands.

(2) Wind power prediction module. This module is used to forecast the power generated by wind farms.

In order to meet the challenges brought by large-scale wind power integration, some modules should be improved as following.

(1) New primary frequency control

The control effect of primary frequency control is related to the inertia of the whole power systems. If traditional units are replaced by the wind farms with variable speed generators, the systems' inertia will decrease. In a word, the variable speed wind turbines do not participate in primary frequency control presently.

In order to make wind turbines to take part in primary frequency control, some improvements of wind turbines have been discussed in (Teninge, *et al*, 2009, Keung, *et al*, 2009).

(2) New secondary frequency control

Presently, it has been possible for wind farms to participate in secondary frequency control. However, it should be noted that: i) Specific control and communication equipments, specific market rules should be valid for the MCSes of wind farms and wind turbines. ii) The output power of wind farms can not exceed the maximum value, which is determined by wind. iii) When the wind farms participate in secondary frequency control, the benefit of wind farms themselves will inevitably be decreased (Except certain compensation can be given).

(3) New tertiary frequency control

Compared with conventional task, the new tertiary frequency control should consider both the results of load prediction and the results of wind power prediction. Then, based on these prediction results, historical and present operating states of power systems and various dispatching rules and algorithms, rational decisions (unit commitment, economy dispatch, etc.) can be determined.

4.2 New RPDC System

The new RPDC framework suitable for large-scale wind power integration is as shown in Fig.6.

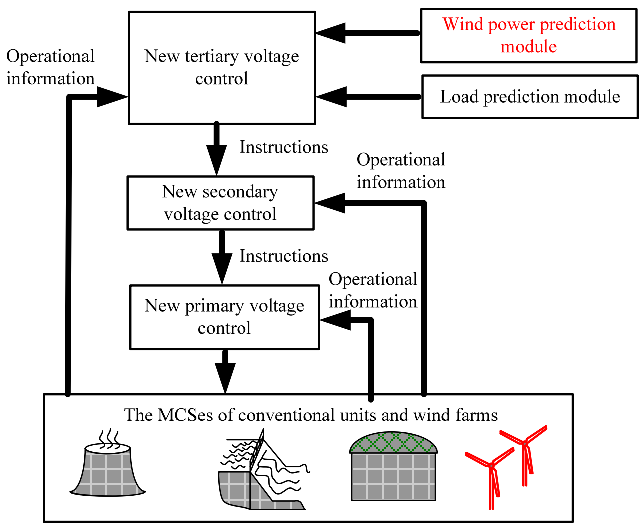

Fig. 6. Framework of the proposed RPDC system considering the integration of large-scale wind power.

The functions of MCSes of wind farms and wind power prediction module in Fig.6 have been discussed in Section 4.1. In the following, the functions of new primary, secondary and tertiary voltage control will be discussed briefly.

Compared with conventional units, the primary voltage control problems of wind farms is more complex. As there are various VAR control apparatuses in wind farms (wind generator itself, capacities, SVC, etc.), how to coordinate these devices is the difficulty.

The emphasis of traditional secondary voltage control problem is only the coordination of conventional generator sets and some grid VAR compensators. After the integration of large-scale wind power, the coordination among the VAR control apparatuses in wind farms, conventional generator sets and grid VAR compensators should be considered. Meanwhile, the characteristics and abilities of VAR control of wind farms should be analyzed emphatically.

The new tertiary voltage control should consider the prediction results of wind power.

5. STATUS QUO AND ROADMAP OF DEVELOPING NEW ARPDC SYSTEM

5.1 Status Quo and Roadmap of Developing New APDC System

As for the ideal or ultimate goal of the new APDC system as shown in Fig. 5, the Monitoring and Control System (MCS) has been constructed in most of the installed wind farms. Meanwhile, elementary wind power prediction has been accomplished, although the precision is still not very high. For the frequency control, wind power prediction results have been used in the dispatch (tertiary frequency control) to report possible output power of wind farms. Present optimization goal of dispatching is: On the condition of safe operation of power grid, the wind power should be utilized as more as possible. Meanwhile, most of wind turbines are un-dispatchable, and only the conventional units participate in the auxiliary services.

The next step of developing new APDC system is that the tertiary frequency control (dispatch) should consider not only the stable operation but also the economic operation of power grid, and the coordination of stable factors and economic factors. Here, the economic factors include the environmental factors.

Along with the development of advanced wind generation technologies and the increase of penetration rate of wind power, after the maturity of tertiary frequency control, wind power should actively participate in the secondary frequency control. As mentioned above, corresponding controllers, power market rules should be provided in this stage.

The issue of primary frequency control in China may be not as urgent as tertiary or secondary frequency control, because in the near future the wind power penetration in China will not be very high. Meanwhile, if the wind power participates in the primary frequency control, certain equipments are needed for the wind turbines. From the viewpoint of technological economics, in China there is no need for wind power to participate in primary frequency control in the near future.

5.2 Status Quo and Roadmap of Developing New RPDC System

At present, Chinese grid operators only require that the wind farm should regulate the voltage of the point of common coupling (PCC). Meanwhile, the requirements of the control precision of PCC voltages are not very strict.

The next step of developing new RPDC system is that the wind farms should increase their abilities in primary voltage control. Some effective measures should be taken to raise the qualification rate of the control of PCC voltage.

In the near future, more variable speed wind generators and VAR compensators (SVC, STATCOM) will be added in the wind farms, and then the reactive power control abilities of wind farms will be heightened greatly. Thus, when designing secondary voltage control strategies, the control ability of reactive power of wind farms should be utilized fully to support area voltage control.

If the reactive power flow of wind farms is big enough to impact on the grid flow, the wind farms should participate in the reactive power flow optimization of power systems to reduce the grid loss and enhance the voltage stability. Or, it is also possible for the wind farms to participate in tertiary voltage control.

5.3 Reasons of the Difference between the Roadmap of APDC and RPDC

From the discussion in Section 5.1 and 5.2, it can be seen that there are obvious difference between the roadmap of developing new APDC and RPDC systems. Fro the roadmap of developing new APDC system, tertiary frequency control is the most urgent, then it is the second frequency control. As for the primary frequency control, there is even no obvious need in the near future. For the roadmap of developing new RPDC system, primary voltage control is the most urgent, second voltage control is the next and primary voltage control is the last.

Above difference is because of the difference of the characteristics of voltage and frequency.

In power systems, frequency is a systematic variable. Then, the impact of wind power to the power grid is also systematic. Or, the imbalance of the active power supply and consume in all of the systems will be influenced. In order to remove this imbalance, systematic control measures (or the tertiary frequency control) should be taken firstly. Then, the area measure (secondary frequency control) is needed. Primary frequency control is only the last one.

Different from frequency, the voltage is a local variable. Thus, the voltage control problem near the wind farms (e.g. the voltage control of PCC) can only be solved by wind farms themselves, and thus the primary voltage control is very important. The contribution of remote VAR compensators for the voltage of wind farms is very limited. Meanwhile, for the VAR regulation capacity of wind farms is relatively considerable in the area, and the use of this ability is also flexible, and thus the wind power should participate in the secondary and tertiary voltage control in the near future.

6. CONCLUSIONS

Apart from the common characteristics of wind power (fluctuation, low-predictability and low-controllability), there still exist some special characteristics of Chinese wind power, including centralized development, long-distance transmission and integration into backbone grid. Based on these characteristics and the status quo of China ARPDC system, the future roadmap of developing new ARPDC system in China is analyzed in the paper.

For the active power dispatch and control, the tertiary frequency control (dispatch) should be improved to consider the coordination of stable factors and economic factors. Then, wind farms should actively participate in the secondary frequency control. As for the primary frequency control, there is no obvious need in the near future.

For the reactive power dispatch and control, wind farms should increase their abilities in primary voltage control, and raise the qualification rate of the control of PCC voltage. In the near future, wind farms should also participate in the secondary and tertiary voltage control

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