Opportunities and Challenges of Clean Energy Development in China

Wenliang Zhang, Weisheng Wang, Yuehui Huang. Yiguo Jiang

***Abstract* -In the next decades, clean energy, such as hydro power, nuclear power, wind power, and later solar power, will take big roles in Chinese power system. Large scale and/or distributed renewable and nuclear power generation will be connected to the grid. However, as large scale renewable energy integrated into grid, the grid has to be carefully planned and strengthened to meet the transmission requirement, taking into account of economy and technology limitation. Also, the intermittent feature of wind power and solar power will burden the dispatch and operation of power system for significant penetration in some areas with attractive resources. To release the impact of the fluctuant characteristic, current standard for wind power integration also needs to be updated. Strict requirements should be put on wind farms. Furthermore, traditional thermal power plants dominated Chinese power system has to be changed gradually to accommodate more intermittent energy and to achieve cost-effective outcome. Much effort has to be made to coordinate conventional and renewable power supplies before its large scale integration, including theoretical research and pilot projects.**

***Index Terms* – clean energy, opportunities, challenges, planning, solutions.**[1]

I. INTRODUCTION

Environment and climate have suffered severely in the past decades for extensive CO2 emission by fossil fuel application. Also the supply of the fossil fuel gradually dries up nowadays since the demand is increasingly enormous all over the world. These two issues have forced the energy supply and energy consumption must be transited into renewable and sustainable pattern to continue the life of earth.

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As a developing country, China, in the coming years, the energy demand will continuously increase for its extensive industrialization and urbanization. In 2020, the expected primary energy demand in China will reach to 4,500,000,000-4,900,000,000 tce, which challenges the expected economy development since there is big difference between energy demand and supply. To solve this problem, in The 2009 United Nations Climate Change Summit Conference, our president had promised that the share of non-fossil fuels in the primary energy consumption will reach to 15%. This goal will only be met by extensively clean energy exploitation. The main utilization of clean energy is to generate power except for direct solar thermal and biomass fuel application. Thus, in the next decades, clean energy, such as hydro power, nuclear power, wind power, and later solar power, will take big roles in Chinese power system. Large scale and/or distributed renewable and nuclear power generation will be intergraded in the grid. Conservatively, 140GW hydropower, 63GW nuclear power, 64GW wind power and 10GW solar power will be newly installed in the next ten years, which provide excellent opportunities to manufacturers, suppliers and investors to make new economy bright spot.

However, as large scale renewable energy integrated into grid, the grid has to be carefully planned and designed to meet the transmission requirement taking into account of economy and technology limitation. Also, the intermittent feature of wind power and solar power will burden the dispatch and operation of power system for significant penetration. Proper standards have to be formed to ease operation troubles. Furthermore, traditional thermal power plants dominated Chinese power system has to be exchanged gradually to accommodate more intermittent energy and to achieve cost-effective outcome. Much effort has been made to coordinate conventional and renewable power supplies before its large scale

integration, including theoretical research and pilot projects.

In this paper, the opportunities and challenges of clean energy, especially wind power, development in Chinese power system are presented. Potential solutions are provided to increase the capability of the grid to integrate more intermittent power.

II. PLANNING OF CLEAN ENERGY IN CHINESE POWER SYSTEM

In the next ten to twenty years, clean energy generation in China will mainly be hydro power, nuclear power, wind power and solar power, where hydro power, nuclear power, wind power will be the focus in the first ten years and solar power will be the compensation. After 2020, solar power generation will also be widely used for its acceptable cost. The planning of these kinds of power is detailed in the following paragraphs.

A. Hydro power

China is rich of hydro power resource. Based on a study in 2005, the potential hydro power generation capacity is about 524GW, with annual production 2470TWh, which is in the top one place of the world. However, the distribution of hydro power resource is imbalance throughout the country. Generally, hydro power resource is rich in the west part of China, especially in southwest where the possible capacity accounts for 66.7%. Comparatively, in the central and in the east, it is much less.

At the end of 2009, the installed hydro power has been 183GW (pumped hydro not included), which is only 34% of the possible installation. This is much less than that of the developed country. As shown in Fig. 1, most of the hydro power is concentrated in Central China and South China, accounting for about 74% of total installed all over the country. Tibet is with the smallest installation for its small power demand.

Since hydro power is the cheapest clean energy, in the long roadmap, hydro power installation will reach 320-350GW in 2020, and 430GW in 2030.

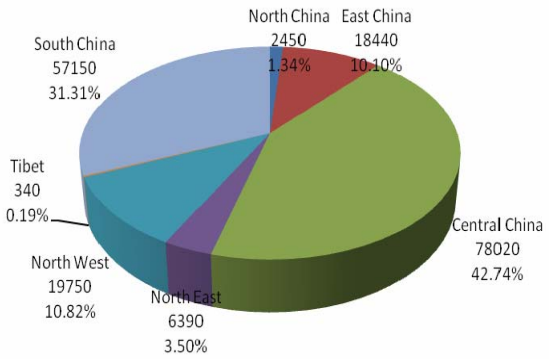

Fig. 1 Installed hydro power of regional grid at the end of 2009. (Unit: MW)

B. Nuclear

Based on a survey of the land, the reserves of uranium are over 200 million ton in China. From the view of resources, we have the advantages to develop nuclear power. However, at the end of 2009, the installed nuclear power capacity is only 9.08GW, which is very small at the moment. However, another 21.92GW nuclear power is under construction. According the requirements of nuclear power station, statistically, the possible sites for nuclear power installation is about 300-400GW.

To reach the goal of 2020, the installation of nuclear power should be 72-80GW, with a total contribution of 30% of clean energy production. Therefore, the increase of nuclear power will be great in the next ten years, especially in load increasing east coast areas. For limitation of other resources along the coast, the nuclear power should be the main new installation in these areas.

Table 1 2030 planning of clean energy (GW)

	2009	2020	2030
Hydro	183	320-350	360-430
Nuclear	9.08	72-80	150-160
Wind	16.1	80-100	150-160
Solar	<0.2	10-20	60-70

C. Wind Power

For the weather dependable characteristics, the effective using hours of wind farms is much lower than conventional power plants, with less annual electricity production for per kW installation. However, the lower price and zero emission make it the best choice for future

power supply. In 2020, the installation will reach to 80GW-100GW, with annual production about 160-200TWh, being equivalent to 49,000,000-62,000,000 tce. At that time, energy provided by wind power will account for 10% of clean energy production.

The wind power can be installed on shore or off shore. Before 2020, most of the wind farms will be installed onshore since there is enough land to development it. North China, north west, north east and Jiangsu coast, with very good wind resources, will be the best place to develop wind farms. Seven wind bases, with capacity over 10GW for each, will be planned at these places. Figure 2 shows the planned capacity for these wind bases in 2020 and 2030. The capacity of Mengdong, Mendxi and Gansu will be the largest capacity area. In 2015, 2020 and 2030, the installation at these seven wind based will account for 76%、79%、82% of the total wind power installation respectively. Except for the large-scale, concentrated wind farms, distributed wind farms will also be installed at other places, especially for remote area where the grid is unavailable.

Also, several offshore pilot projects along the coast will be constructed to study the offshore wind power generation technology. After 2020, the cost of offshore wind power generation will be reduced to acceptable level and it will be the keystone for wind power development. More capacity will be installed off shore.

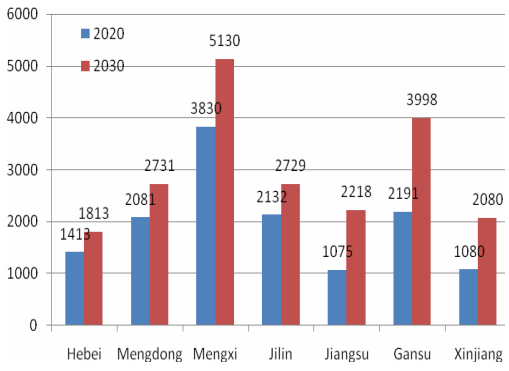

Fig. 2 P otential capacity of the seven wind bases (Unit: MW)

D. Solar Power

The distribution of solar resources is shown in Fig. 3. Generally, the west is better than the east. The north is better than the south. Currently, the main application of solar power generation is PV. There is very small share of solar thermal plants in China.

At the end of 2008, the total installation of PV is only 140MW. Figure 4 shows the installed PV capacity in the past twenty years.

Solar power generation is currently in the pilot project stage for the high cost and low efficiency. Technology development will be obtained by research and some pilot projects. In the short planning, roof PV system will be popularized in middle and big cities, especially for PV industry developed areas, like Changjiang River delta, Zhujiang River delta, Shangdong, Hebei areas. Large-scale PV stations will be constructed as pilot project in the northwest desert or Gobi with good solar resources and large land.

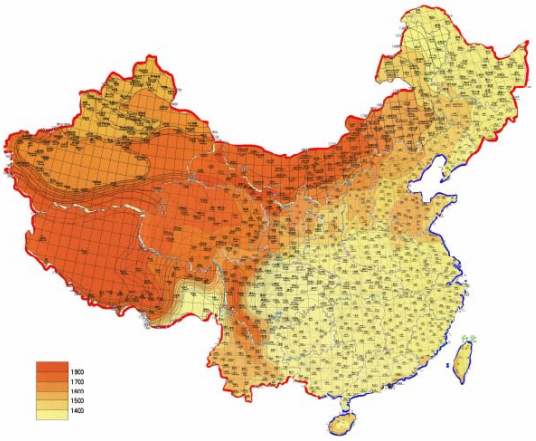

Fig.3 Solar resource distribution in China (kWh/m2)

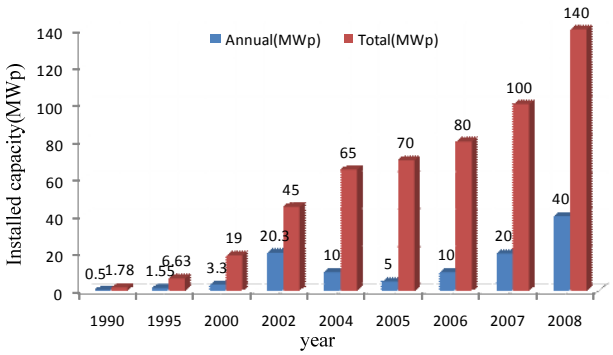

Fig. 4 Annual and total installed PV capacity from 1990-2008.

In 2020, the total installation of PV will be about 10-20GW. After 2020, solar power generation will be mainly large-scale grid-integrated stations, with capacity over

10MW for each, constructed in northwest desert. In 2030, large-scale stations and distributed roof systems, small stations, remote applications will share equally.

III. EXPERIENCE AND MAIN CHALLENGES

In power system, the generation is always equal to the demand to maintain system balance. If the control of the system can not maintain the balance of generation and demand, the voltage and frequency of the system will go beyond the required allowance. Large scale blackout will happen. The challenges of clean energy development are mainly related to wind power.

Since wind power and solar power is weather dependable, their outputs are fluctuant and intermittent. That is main challenges of the grid. In the past years, the safety and stability of the system is challenged for large scale intermittent power integration, especially for sharply increasing of wind power. Figure 5 shows the increase of wind power in a provincial grid. As demonstrated in the figure, the increase of wind power is very fast. Within half year, the capacity almost doubled. From the operation experience, load following, voltage control, frequency control and standardization problems have been met with substantive wind power integration.

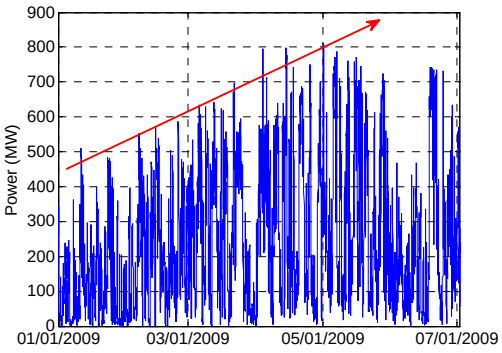

Fig. 5 Output of wind power

A. *Long distance transmission*

Most of the resources, like hydro resource, wind resource, solar resource, are concentrated on the east and north east areas. However, the load center is located at the east coast. For clean energy application, the power generated at the east part of China will be transmitted to the east, with several thousand km. The limited transmission capability has be the bottleneck of large-scale development of wind power and hydro power in the east. In Gansu wind base, the output of wind farms is limited to a very low level for the lagged grid construction.

B. *Load following*

Traditionally, the load profile is easy to predict since the daily profile will not change much for a short time period. The operation of the system will be planned based on load profile. With the integration of wind power and solar power, the operation of the system has to change a lot to accommodate the fluctuant power supplies. Figure 6 shows the impact on peak-valley difference of a regional grid with 3200MW wind power integration. As demonstrated in these figures, the peak-valley load difference increases obviously throughout the year. Moreover, the more the integrated wind power, the more severe the impact.

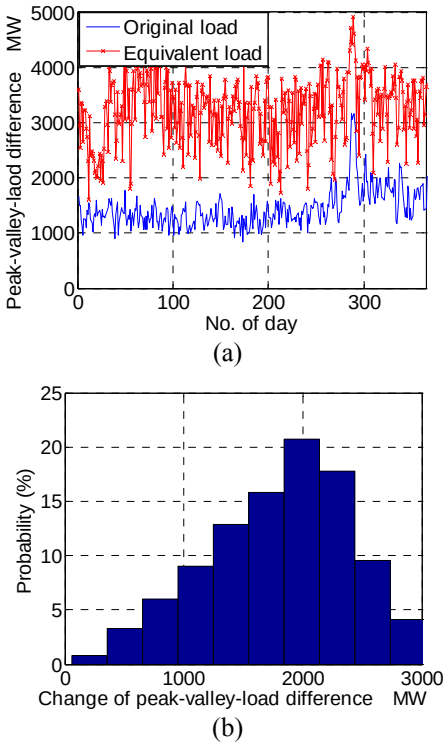

Fig. 6 Peak-valley difference analysis. (a) peak-valley difference; (b) statistical results of (a).

In the winter of north east, the output of wind power is very large, especially between middle night and early morning. However, at that time the demand is the lowest of the day. Moreover, a number of the generators have to maintain a

certain level of output power to ensure enough heat supply. Imbalance always occurred at these intervals since there are not enough flexible power supplies to stop running or to decrease to very lower level. Considering economic operation of the system, one of the choices for this imbalance is to curtail the output of wind power. Another choice is to reduce the supply of heat and thus reduce the output power to maintain the power balance. Generally, the former choice seems more reasonable even though a lot of wind power is curtailed.

Figure 7 shows the installation composing of Chinese power system. Over 70% of the installation is coal powered plants. Normally, they have very limited regulation capacity. Besides, the start and stop of the generators is very slow, from several hours up to ten hours. For significant wind power integration, the limited regulation capacity in the system can not meet the fluctuation requirement. Load following problems are always met in north China grid and north east grid since the wind penetration is high in these grids.

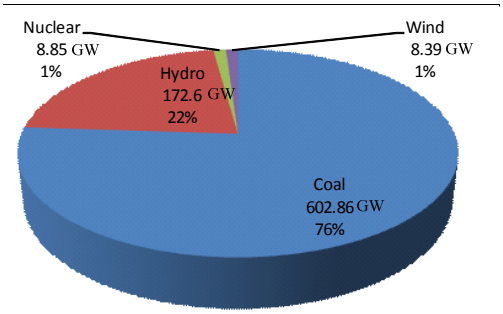

Fig. 7 Installation composing at the end of 2008

C. *Voltage control & reactive power*

In China, most of the wind farms are with large capacity and located at remote area, i.e. at the end of grid. Long distance transmission lines, normally over 100km, are constructed to connect the wind farm and the grid. With the increase of output power of the wind farm, the loss of the transmission lines increases. As a result, the voltage level of the bus line decreases if the plant can not provide enough reactive power supply. Figure 8 shows the voltage variation of a bus line of a wind farm. With the increase of output power of the wind farm in the morning, the voltage reduces to a very low level, which is outside of the requirement.

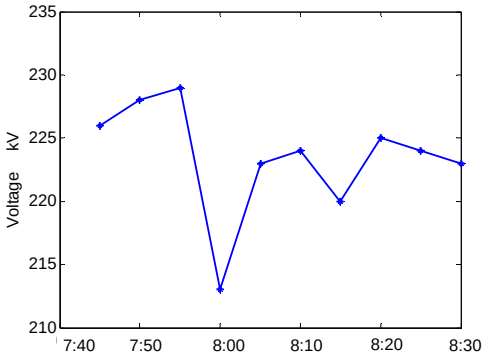

Fig. 8 Voltage variation of a bus line

D. *Frequency control*

Unlike conventional synchronous generators, the output of wind farms can not droop with the increase of system frequency automatically. For the fluctuation of wind power in the system, other power supplies have to regulate their outputs accordingly. If there is large power discrepancy in a very short time, the frequency may be unstable.

Besides, most of the wind turbines without low voltage ride through (LVRT) capability. For low voltage conditions, the wind turbines will cut out, which burdens the voltage dip of the system. By ripple effect, more wind turbines cut out. As a result, the frequency fluctuates greatly. Figure 9 shows the recorded power of Tongtao line, connecting a wind farm and the main grid. At 17:30, for low voltage condition, 350MW wind power cut out suddenly. Though the frequency is still in the tolerance for this accident, it is very dangerous for more wind power cut off.

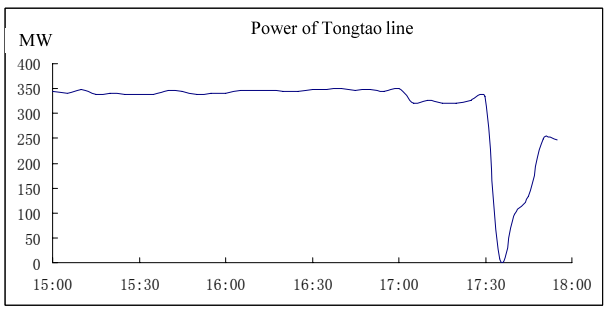

Fig. 9 Power of Tongtao line suddenly decreases

E. *Standardization and authentication*

As early as 2005, there is a technical rule to guide the integration of wind farms. However, with large-scale installation and technique development, the rules have to update accordingly to meet large scale development. Some of troubles we have met can be released by proper requirements of wind farms. The wind farms will never provide more functions if there is no requirement. Active power and reactive power control is absolutely necessary for large wind farms. Furthermore, the authentication and certification is also necessary for a wind farm connecting to the grid. Without integration measurement and certification, the conservative protection setting of some wind turbines make them cut out and cut in frequently, which affect the stability of the system.

IV. POTENTIAL SOLUTIONS OF LARGE SCALE INTERMITTENT ENERGY INTEGRATION

For the past years, we have experienced a lot for increasing wind power integration. Its intermittent characteristics brought many troubles for power system operation. Potential solutions are studied and applied in the past few years.

As mentioned before, another 60 GW wind power will be integrated in the system in the next ten years. To accommodate such amount of fluctuant power supplies in the system, continuous research effort and grid update have to be made.

A. Strengthen grid & Smart grid

After several years experience, we have known that the output of wind farms will be smoothed when they scattered in a wide geographic areas. When one area is with high wind speed and thus high wind power, other areas are not. Therefore, by strengthen the connection of provincial grids, the wind power can be balanced in a large area. For strengthened transmission lines, more wind power or other clean energy can be thus integrated in the grid. The constructed ultra-high voltage grid will definitely play big roles on interregional transmission. At that time, electricity exchange between regional grids will be more complicated under the planning economy mechanism.

The smart grid is definitely the savior for renewable energy like wind power. Under smart grid structure, the information of all participants in the system is transparent. Even with fluctuant power supplies in the system, by proper controlling of the power supplies and the loads, the system will operate at the optimal state with large safety and stability tolerance. The smart grid construction in China is currently on the pilot project stage and will be outspread after 2012.

B. R&D standard development

The old standard on wind power integration definitely needs to be updated to accommodate the large scale development. There is no requirement on active and reactive power control of wind farms. Also, the very important fault-ride-through capability is not considered previously. With significant wind power integration, the wind farms have to behavior as conventional power plants, i.e., being controllable, predictable, dispatchable, to maintain the safety and stability of the system.

The investors of wind farms will never do thing outside of the requirements. To standardize the integration and to prepare for future significant penetration of wind power, much effort is put on the formulation of various related standards. Moreover, with the development of technology, the standard may need to be updated accordingly. In China, much effort has put on the formulation of the standards. The updated national standard for wind power integration will be available at the end of this year.

C. Storage & flexible power supplies

Various energy storage methods, including pumped hydro, battery storage and electric vehicle, can also be promoted and widely used to balance the fluctuation of renewable energy.

Large scale storage system, like pumped hydro system, will smooth or reduce the fluctuation of wind power and solar power. With storage devices, the surplus power can be stored at light load. And at heavy load intervals, this power will be discharged to the grid. By this way, load

following pressures will be released. Also, with storage system, the active power of wind farms can be controlled quickly in spite of the wind.

Electrical vehicle is another important storage device. Flexible load to follow the power supply will also lessen the fluctuation of wind power.

Also, emphasis has to be put on regulating the installation structure. The rate of coal fired power plants should be reduced. Instead, fast response power supplies, like gas powered plant, will be planned as well as wind power.

To increase the flexibility of the system, in 2020, the pumped hydro and gas fired plants will be 3% and 3.1% of the total installation respectively.

V. ACKNOWLEDGMENTS

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VI. CONCLUSIONS

To meet the goal of 2020, more than 140GW hydropower, 63GW nuclear power, 64GW wind power and 10GW solar power will be newly installed in the next ten years. The clean energy will be the mainstream for newly installed plants. Based on the characteristics of clean energy, the impact of increasing of wind power will be significant, which brings big challenges to Chinese grid.

In the past years, troubles have been met for large-scale intermittent wind power integration in the system. For the inherent inflexible power supplies in the system, the load following problem has burdened the operation of the system, especially in high wind speed seasons. Also, voltage dip and mass wind turbines cutting out are occurred in the system. Transmission limitation and other challenges are faced with large-scale wind power integration.

To solve these problems, the current standard for wind power integration has to be updated. More strict requirements will be put on wind farms. In the future, the wind farms should be as controllable, predictable and dispatchable as conventional plants. Also, the grid needs to update to connect more wind power in the system. Balancing the wind power in wide area and constructing smart grid will release the operation pressure of the system. Moreover, the system should be very flexible to accommodate the quick fluctuation of wind power. Fast response power supplies, various storage technology and load management will be applied in future system to regulate the supply and demand for significant intermittent power. Still, there is much work needs to be done to design and prepare for the 2030 clean energy blueprint.

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VIII. BIOGRAPHIES

Wen-liang ZHANG was born in September 1954. He is a professorate senior engineer and Ph.D. candidate supervisor. Presently, he is the President of China Electric Power Research Institute (CEPRI) and Secretary-General of Central Enterprises Federation of Returned Overseas Chinese.

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