An Update on VG Integration in China

1 Background

1.1 Current development scale

China's grid-connected variable generation (VG) is mainly wind and solar power, which accounts for over 99% of the VG. In recent years, VG has continued to grow rapidly. As of the end of 2018, the cumulative installed capacity of VG was 359 GW, accounting for 19% of the national total installed capacity. The generation capacity of wind and solar power was respectively 184.3 GW and 174.6 GW, accounting for 9.7% and 9.2% of the national total installed capacity. As of the end of 2018, the installed VG capacity in 13 provinces including Qinghai, Gansu, Ningxia, Hebei and Xinjiang accounted for more than 20% of their total installed generation capacity.

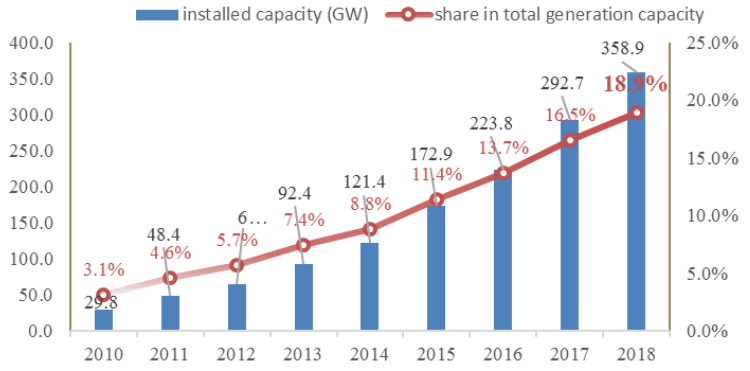

Figure 1 Installed capacities and share of VG in China from 2010 to 2018

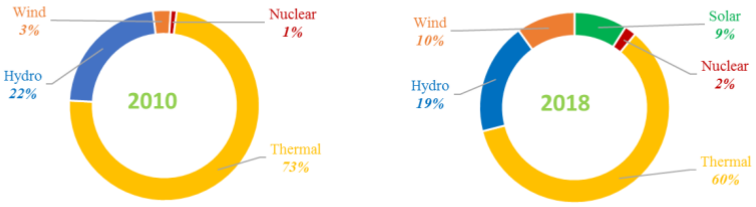

Figure 2 Comparison of China's power supply structures in 2010 and 2018

In 2018, energy from variable generation was 543.5 TWh, accounting for 7.8% of China's national total. Wind energy was 366 TWh and solar energy was 177.5 TWh. In 2018, the share of variable generation in 10 provinces was more than 10% of the total generation, as shown in Figure 3. In Inner Mongolia, Qinghai and Gansu, the share of variable generation was more than 20%.

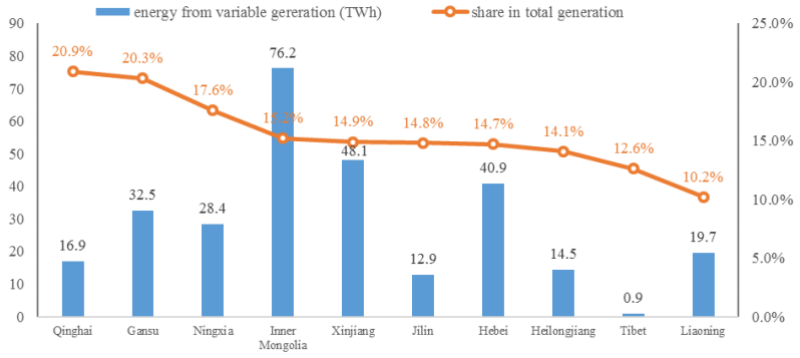

Figure 3 Provinces where the share of VG in total generation was more than 10% in 2018

1.2 Key adjustments and trend of national policies

At the early stage of China's variable generation development (2006-2015), the national policies focused on the promotion of the rapid development of variable generation. The Renewable Energy Law, which was enacted in 2006, is the core policy. The most effective tools stipulated in the law are the feed-in tariff (FIT) and the cost sharing system to support variable generation development. While the *Renewable Energy Law* played an important role in driving the significant growth of variable generation in the past decade, there had been a lack of guidance on the scale and layout of variable generation. There were large differences in resource conditions and economic and social development among various regions in China. Variable generation developed at a rate far higher than expected in some regions, e.g., Xinjiang, Gansu and Inner Mongolia. As a result, the curtailment issue of wind and PV arose. At the same time, the subsidy deficit, which is the difference between the subsidy needed for variable generation and the subsidy fund collected from consumers via renewable energy surcharge, was enlarging. By the end of 2018, the cumulative subsidy deficit exceeded 120 billion yuan.

To solve the above problems, the National Energy Administration (NEA), which is the chief national authority responsible for VG development, began to shift the focus of variable generation policies from scale and speed to quality in 2016. Key points of these policies follow.

I. Strengthening the management of scale and layout of newly installed VG. In 2016 and 2017, monitoring mechanisms for wind and solar power projects were established by NEA to give notice on the status of VG development in the provinces. Regions with an annual VG curtailment rate above 20% are indicated in red, which means that no new wind or solar power projects are allowed to be installed within those regions. Such measures were not applied to distributed variable generation, which has developed rapidly since 2016 and further increased the subsidy deficit. Therefore, the NEA introduced a policy in 2018 prescribing that all types of variable generation requiring government subsidies be subject to a maximum annual installed capacity limit.

II. Introducing competition in VG development to drive down variable generation

costs. In 2015, China launched the “Front Runner” program for PV to encourage the manufacturing and application of technologically advanced products. “Front Runner” projects were implemented by bidding with a price cap which is the local FIT of solar and wind generation determined by the government. Untill now, 19 PV projects were successfully procured under the “Front Runner” program, with a total capacity of 13 GW. According to the bidding results of the “Front Runner” program in 2018, the bidding price of one solar project in Qinghai was 0.31 yuan/kWh, 0.0147 yuan/kWh lower than the local coal-fired generation. In 2018, this competition mechanism was expanded to all annually procured central solar power stations, and onshore and offshore wind power plants.

III. Reducing FIT and launching grid parity pilot projects. After the implementation of the *Renewable Energy Law*, feed-in tariffs for onshore wind/solar power generation, biomass power generation, offshore wind, concentrated solar thermal generation, etc., were established. As stipulated, these feed-in tariffs would be adjusted as the variable generation costs decline. The differences between the benchmark generation prices for variable generation and benchmark generation price for coal-fired generation are subsidies for variable generation, which come from a subsidy fund established by the government. The main source of funds was the renewable energy surcharge levied on electricity users nationwide. With the rapid development of variable generation, the demand for funds from the renewable energy surcharge is increasing rapidly as well. Since 2006, the government has raised the renewable energy surcharge five times, with the most recent adjustment in 2016. The levy level was raised from the initial 0.001 yuan/kWh to 0.019/kWh. However, there is still a huge subsidy deficit. The deficit reached 52 billion yuan at the end of 2016, and more than 120 billion yuan at the end of 2018. To prevent further increases in the subsidy deficit, the central government began reducing the benchmark generation prices for wind and solar power in 2016. In 2019, the government initiated grid parity pilot projects for wind and solar, giving priority to the construction of wind and solar projects that do not need funds from the national subsidy.

IV. Exploring comprehensive approaches to promote VG integration

In March 2015, China launched a new round of power sector reform. Innovations in the variable generation integration mechanism have been carried out in regions with curtailment over 10%, including the establishment of several market mechanisms for a downward dispatch ancillary service market, direct trading between variable generation and electricity consumers, a trans-regional spot market for variable generation, and generation rights trading between variable generation and conventional generation. More diversified VG utilization portfolios have been explored, including concentrated solar thermal generation, decentralized wind power generation and offshore wind power generation. Efforts have also been made to encourage the development of energy storage technologies. In May 2019, the NEA enacted a renewable energy quota system, in which a minimum share of renewable energy is specified in the total electricity consumption of each province.

1.3 Characteristics of China's VG development since 2015

I. VG becomes the main force of power supply increase with a high growth of solar

PV. The share of VG in the annual newly installed capacity increased from 34% in 2015 to 56% in 2018. Wind generation increased at a relatively steady pace, with an annual average 18 GW capacity increase and a 12.8% annual growth rate. Solar generation has seen a sharp growth rate since 2016, with an annual average 44 GW capacity increase and a 61.3% annual growth rate, while distributed solar generation has experienced explosive growth due to the influence of national policies. By the end of 2018, the cumulative grid-connected distributed solar power generation capacity in the State Grid Corporation operating area reached 47.01 GW, with an annual growth rate of 115% between 2015 and 2018. The increase of distributed solar generation capacity in 2018 alone was 18.91 GW, 9 times that in 2015. Although the installed capacity of solar generation remains smaller than wind on a national level, it has exceeded wind capacity in the State Grid Corporation operating area. By the end of 2018, the installed capacity of wind power in the State Grid Corporation was 146.1 GW, while the installed capacity of solar power was 152.83 GW.

II. The layout of newly installed capacity of VG shifts from the Northwest, North China and the Northeast to East and Central China, while the cumulative installed capacity remains concentrated in the Northwest, North China and the Northeast. In recent years, due to the variable generation curtailment issues in the Northwest, North China and the Northeast (the “three North” Regions), and the guide of the “13th Five-Year Plan on Renewable Energy”, the newly installed capacity of variable generation has shifted to Central and East China, where the load centers of China are. Between 2015 and 2018, the share of newly installed wind and solar capacity in Central and East China has increased from 15% to 40%, and 30% to 39% respectively. A large part of the newly installed wind and solar capacity in Central and East China is distributed generation. The cumulative installed capacity of wind in the “three North” Regions accounted for 71% of the national total in 2018, 7% lower than that in 2015. The cumulative installed capacity of solar power in the “three North” Regions has decreased from 72% to 54% in the same period.

III. National policies focus not only on variable generation, but more on system wide coordination to facilitate integration. The following policies were implemented since 2016. First, the power system’s capability to successfully interconnect variable generation and the cost of state financial subsidies were recognized as key issues that are now being addressed. Second, power system based measures have also been taken into account to enhance the capability of the power system to integrate VG, such as to enhance the flexibility of thermal generation, to promote market- based power exchanges, and to encourage business model innovation for variable generation utilization. Third, coordination among regions to enable variable generation integration in larger areas has been strengthened through inter-regional transmission construction and inter-provincial power transactions.

2 China's practice on facilitating variable generation integration – approaches to combat variable generation curtailment

China saw its first wind power curtailment case in 2009, and first solar curtailment case in 2013, both in Gansu province, Northwest China. In 2016, a total of 49.7 TWh of wind was

curtailed nationwide, with the curtailment rate being 17.1%. A total of 6.9 TWh of solar generation was curtailed, with the curtailment rate being 9.4%. This portion of the article presents the main measures taken to address this issue.

2.1 Basic conditions and characteristics

The large scale integration of variable generation presents challenges in China for several reasons. The first is the high concentration of variable generation in the "three North" regions, where the electric demand is low. The second is the inflexible generation structure, especially in the "three North" regions. The increasing conflict between the continuous development of all types of generation capacity and the slowdown of the economic growth with the associated slowdown of electric demand, also presents renewable integration challenges. Though a nationwide issue, the curtailment of variable generation is highly concentrated in particular regions and time periods.

Variable generation curtailment is mainly concentrated in Xinjiang and Gansu. For example, in 2016, when curtailment was the most serious, there was no curtailment of wind in 21 provinces. 72% of the wind curtailment occurred in the Northwest and the Northeast. Wind curtailment in Xinjiang and Gansu accounted for 48.5% of the total curtailment nationwide. No solar energy was curtailed in 29 provinces. The curtailed solar energy in Xinjiang and Gansu accounted for 80% of the total nationwide.

Wind power curtailment mainly happened during the heating season and off-peak hours after midnight, while solar curtailment mainly happened during the midday hours throughout the year. Take the State Grid Corporation operating area as an example. Between 2013 and 2015, about 70% of the wind curtailment happened during the heating season (October to April). This is especially the case in North China and the Northeast, where more than 80% of the curtailed wind occurred during the heating period. Moreover, wind curtailment during off-peak hours accounted for 80% of the total wind curtailment during the heating period. The solar power curtailment mostly happened during the midday hours (12:00pm-2:00pm) throughout the year when solar generation was at its peak.

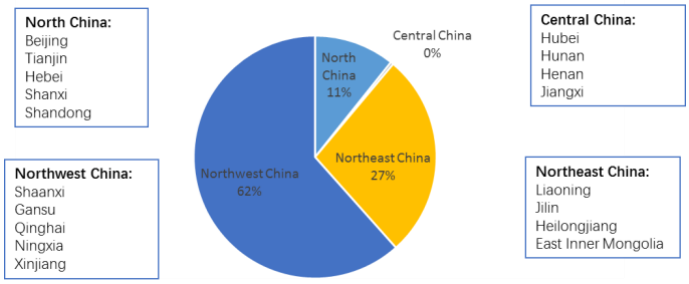

Figure 4 Distribution of wind curtailment in the State Grid operating areas in 2016

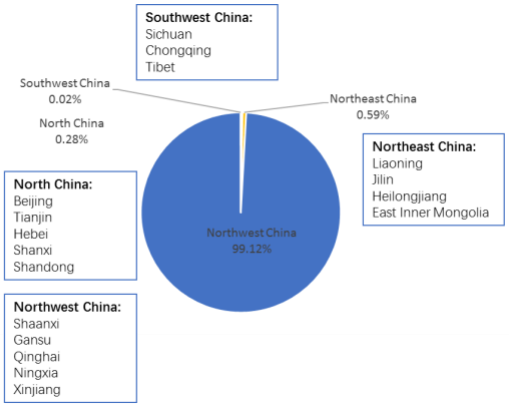

Figure 5 Distribution of solar power curtailment in the State Grid operating areas in 2016

2.2 Main strategies for addressing variable generation curtailment

The national and local governments and the power companies have implemented several measures to address the variable generation curtailment problem. These measures include technical means to improve power system flexibility as well as policies that facilitate renewable development, including changes to electric markets.

Coal-fired generators have been retrofitted to increase the flexibility of conventional generation. In addition, variable generation power plants have been equipped with high voltage and low voltage ride-through capability that improves their ability to support power grids. The construction of inter-provincial and inter-regional transmission lines and generation dispatch over larger balancing areas has been completed to make use of diverse resource locations and production. On the demand side, electrification of energy use, such as EVs and electric heating, also increase the capability of the power grid to interconnect more VG.

The main policies and market mechanisms encourage the shift of newly installed variable generation capacity to Central and East China from the “three North” regions, and foster the participation of variable generation in various types of market trading. The main market solutions include inter-regional spot markets for variable generation, downward dispatch ancillary service markets to incentivize downward dispatch of conventional generation, and generation rights trading between variable generation and consumer's self-supply coal-fired power plants.

With the above measures being implemented, as well as the higher than expected electric demand growth in recent years, VG curtailment has been alleviated significantly since 2017. Both the amount of curtailed energy and the curtailment rate have been reduced while the amount of variable generation and its share in the total energy supply increased. In 2017, the installed capacity of variable generation increased by 31%, and the curtailed variable generation decreased by 7.4 TWh. The curtailment rate of variable generation was reduced to 10.4%, which is 5.2% lower than 2016. In 2018, the installed capacity of variable generation increased 22% above 2017 levels, and the curtailed variable generation decreased by 33.2 TWh, which was 5.8% below 2017 levels. The goal for 2019 is to reduce

the curtailment rate of variable generation to under 5% of total potential production.

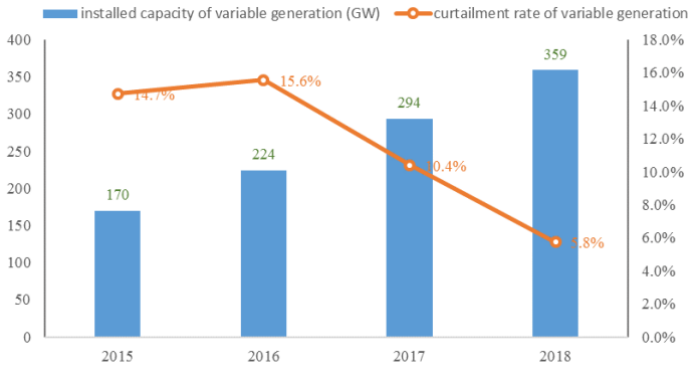

Figure 6 Installed capacity and curtailment rate of variable generation in China in 2015-2018

2.3 Key measures and their effectiveness

(1) Retrofit of coal-fired generators to unlock flexibility on the generation side-practice of Northeast China

For a system dominated by coal-fired generators, improving their flexibility is the primary technical measure required to enhance the system's capability to integrate variable generation. The NEA issued a list of coal-fired generation retrofit pilot projects nationwide to enhance the flexibility on the generation side in 2016. Northeast China is a typical case, as it was the first region to implement the retrofits, and the pilot projects are mostly located in this region. Northeast China's power grid is a single AC power grid with a maximum load of approximately 60 GW. For nearly a decade, the primary generation supply of the Northeast China Grid was wind power, thermal power and nuclear power. More recently, the region is experiencing an increase in variable power supply with a lack of flexible generation. By the end of 2018, 24 power plants in Northeast China had completed the retrofit, creating a regulating capacity of 3.95 GW.

The retrofit technologies adopted by coal-fired power plants consist primarily of two categories. One improves the boiler and turbine systems to reduce minimum power generation output by reducing steam output. This applies to both non-CHP and CHP generators. The other measure uses electric boilers to decouple the power and heat generation of conventional CHP generators, so as to increase the flexibility of their power output. The addition of electric boilers in the system also increases electricity demand, which facilitates VG integration. This measure is especially important and effective to the "three North" Regions, as CHP generators account for a large part of the coal-fired generation. In Jilin, which is in Northeast China, over 80% of coal-fired generators are CHP.

To encourage the retrofit, market mechanisms to incentivize downward regulation from coal-fired generation were introduced in 2014 in Northeast China. Downward regulation in China is a unique concept as compared with countries that have electricity markets. In typical electricity markets, power plants are dispatched up and down for load following based on market prices. In China, where a mature electricity market is developing,

conventional generators are operated based on annually allocated full load hours, and downward regulation has historically been classified as a type of ancillary service and compensated at government-set prices. There is a defined benchmark level for downward regulation service, which differs region by region and generally is about 50% of the maximum generation capacity of a generator. If the generator is called upon to provide downward regulation service when it is operating above the benchmark, the generator is not compensated for its decreased generation. If the generator is called upon to provide downward regulation service when it is operating below the benchmark, however, then its decreased generation will be compensated. In the so-called downward regulation ancillary service market in Northeast China, thermal generators can bid for their capabilities to be dispatched down and they will be compensated based on the clearing price, not on fixed tariffs. The government sets floor tariffs and cap tariffs for the bids.

During 4 years of operation of the downward regulation ancillary service market in Northeast China, nearly 40 TWh of variable generation that would otherwise have been curtailed, was able to serve load. In 2018, while variable generation accounted for 14.28% of the total generation, the curtailment rate of variable generation dropped to 3.9%, the lowest level on record since 2011 in Northeast China.

(2) Limited but effective market-oriented effort on VG trading

In March 2015, the State Council issued *Several Opinions on Further Deepening the Reform of the Electricity System*, marking the start of a new round of market reforms in China. The country has explored a series of market trading steps to promote variable generation integration. Since a mature electricity market has not yet been established, there is still a gap between these practices and the electricity market measures of countries with a mature market. The main practices are presented as follows:

- **Bilateral trading between VG and electricity users**

Bilateral trading between VG and electricity users allows for the purchase and sale of electricity between VG enterprises and some industrial and commercial power users and companies. Power grid enterprises provide power transmission and distribution services, and only charge the transmission and distribution tariffs. This reduces the electricity purchase cost of end users, which was traditionally set by the government, and facilitates variable generation integration. In 2018, 2.7 TWh of inter-provincial variable generation direct trading and 27.7 TWh of provincial variable generation direct trading were accomplished within the operating region of State Grid Corporation of China (SGCC).

- **Trans-regional trading of VG**

Trans-regional trading of variable generation refers to market-oriented trading conducted between variable generation companies from regions with surplus power generation and power grid enterprises in other regions. Trans-regional variable generation trading includes medium / long-term trading, day-ahead, and intra-day trading. Day-ahead and intra-day trading, i.e. spot trading, may better deal with the volatile characteristics of wind and solar generation and thus become a crucial supplement to medium / long-term trading. On August 18, 2017, SGCC launched the pilot of trans-regional spot trading of variable

generation, effectively promoting trans-regional integration of variable generation. In 2018, there was 71.8 TWh of trans-regional trading of variable generation in the operation areas of SGCC, increasing by 45.8% compared to that in 2017.

- **Power generation rights trading between VG and coal-fired generation**

The power generation rights trading between variable generation and conventional thermal power refers to the transfer of generation contracts from conventional thermal power enterprises to variable generation enterprises. In 2018, 2 TWh of inter-provincial power generation rights trading was conducted between variable generation enterprises in the Northwest and thermal power enterprises in Central and East China.

(3) Enlarging balancing areas- increasing trans-provincial and trans-regional transmission capacity

As mentioned earlier, wind and solar power generation is mostly concentrated in the “three North” regions. Long-distance transmission is needed to integrate the variable generation with the load centers in Central and East China. In recent years, UHV transmission technology has improved trans-regional transmission capacity and enlarged balancing areas.

In 2007, China commissioned its first Ultra High Voltage DC (UHVDC) project connecting Xiangjiaba hydro power plant in Yunnan province to Shanghai. It operates at 800kV with a design capacity of 8 GW, spanning a distance of nearly 2000 km. Two years later, in 2009, the first Ultra High Voltage AC (UHVAC) project operating at 1000 kV, a distance of over 600 km from Jindongnan in the southeast of Shanxi province to Nanyang in Hubei province, was commissioned. Since then, both UHVAC and UHVDC transmission projects have experienced an accelerated pace of development. By the end of 2018, a total of 17 UHVDC and 11 UHAVC transmission lines have been built. Figure 7 shows the current situation of UHVAC and UHVDC transmission systems.

Figure 7 UHV Transmission System in China (2018)

In recent years, the trans-regional transmission lines have played an important role in

facilitating variable generation integration. From 2010 to 2018, the amount of trans-provincial trading of variable generation increased year by year, with an average annual growth rate of 123%. The proportion of variable generation delivered by some lines reached more than 50%. Taking the year of 2017 as an example, the share of variable generation in the total energy moved from Xinjiang to Henan through the Tianzhong UHVDC line was nearly 50%. 9.04 TWh of variable generation was traded between Gansu and Hunan province through the Qishao UHVDC line, accounting for 51% of the total electricity delivered.

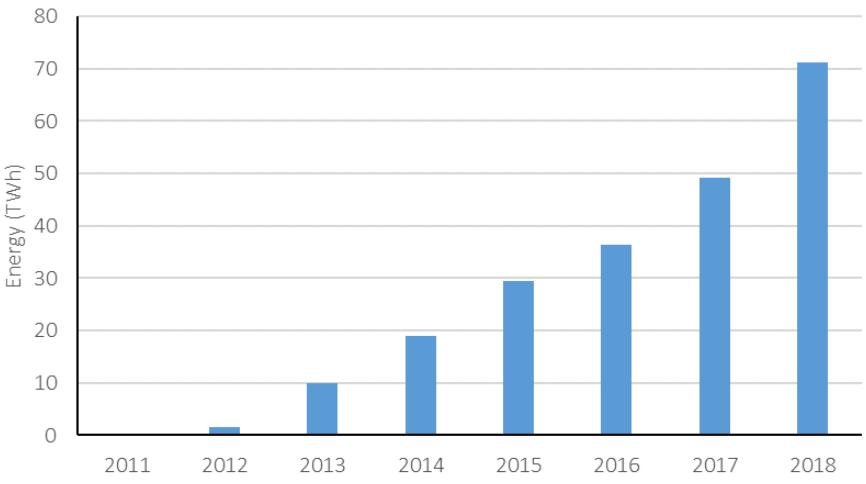

Figure 8 Trans-regional variable energy exchange in SGCC

3 Key issues of China's power systems with high penetration of VG

3.1 Challenges faced by the power system

In 2017, China issued the *Energy Production and Consumption Revolution Strategy* (2016-2030), setting strategic targets for medium and long-term energy development. According to the strategy, non-fossil energy will account for 20% of the total primary energy consumption by 2030. The target increases the proportion of non-fossil generation capacity in China from the current 41% to over 60% by 2035, with most of the growth consisting of variable generation. Large-scale integration of variable generation into the power grid will have profound impacts on the planning and operation of the power system.

The concepts of power system planning need to be updated. At present, VG is incorporated into power system planning with approaches only suitable for low amounts of VG penetration, in which variable generation is only viewed as a supplementary power source. In future power systems with high VG penetration, the planning concepts need to be updated. Flexibility will be the core criterion, in addition to economics and security. Power system planning should not only consider the economics of various types of power sources such as wind power, solar power, coal-fired power and nuclear power, but also reevaluate the functional role of these resources in ensuring the safety, reliability and flexibility of the power supply. In addition, the rapid development of distributed power generation and energy storage technologies must be considered in transmission and

distribution network planning. The planning issue is especially important to China, where the electric demand in 2035 is forecasted to double its level from 2015.

The balancing and stability of the power system need to be revisited. Forecasts for the capacity of VG in China reach 1.3-1.4 TW in 2035. According to an analysis of VG variation characteristics, the daily maximum power fluctuation would then reach 600 GW. This is equivalent to twice the current maximum load of East China, which is the system load center. This will pose huge challenges to the power grid's daily balancing. In August 2018, SGCC encountered a situation with the minimum output of wind and solar generation of only 10.99 GW, accounting for only 3.9% of the total wind and solar generation capacity. Alternatively, the large scale replacement of conventional generators by variable generation power plants would lead to a significant reduction of the inertia level in the power systems, which could result in the deterioration of the power grid's capability to reliably respond to disturbances.

The development of distributed generation and energy storage calls for a smarter distribution network. With a large number of distributed variable generators, micro-grids, electric vehicles, and energy storage devices being connected to the grid, the traditional passive electric users would need to become prosumers. The distribution network would need to be upgraded to satisfy the needs of flexible access, "plug and play" capability, and friendly interaction of these facilities on the users' side with the power system.

The emerging new market players and their various interests bring new requirements to the power market design. The large-scale integration of variable generation poses higher requirements for the flexibility of the power system, but the ever-decreasing electricity market price poses challenges to the survivability of thermal power generators that can provide needed ancillary services. The market framework and market products need to be redesigned to ensure the operational flexibility and reliability of the power system to accommodate the rapid development of distributed variable generation and energy storage, as well as electric prosumers. At present, China is exploring mechanisms for distributed generation and battery storage to participate in market trading.

3.2 Key issues of a growing power system with high penetration of VG

Efforts should be made to establish a planning methodology and update planning and operation concepts for variable generation dominated power systems. The following aspects of system planning and operation should be taken into account: 1) Identify the typical operation modes of the system. In power systems dominated by variable generation, typical operation modes will be more diverse. It is necessary to study how the power system operation will be affected, and what typical operation modes should be considered in power system planning, and generation scheduling. 2) Introduce new planning guidelines, which should be oriented around sources of flexibility. 3) Take into account the need for new stability behavior of power systems with high variable generation penetration, including such concerns as frequency instability caused by insufficient inertia, and power system power angle voltage instability caused by power electronic devices.

Looking toward the high penetration of VG, a three-dimensional framework of

policy-market-regulation is needed to support power system transformation. For the policy part, a clearly defined long-term vision for the energy supply transformation, such as minimum VG energy target or maximum carbon emission target, is needed to promote long term action from government agencies, stakeholders, and the general public. Polices to cultivate and guide public awareness toward a low carbon future are also needed. In the design of the electricity market, it is necessary to establish a market with various products that can reflect the value of the different services provided, and satisfy power supply and policy goals at a higher efficiency or lower cost. Regulations to promote fair competition among market players are indispensable. In a future with more diverse players in the power sector, the role of regulation is increasingly important. The market and regulation elements have long been the weakness in China's energy transformation. The country is currently working to establish a variable generation quota system, a green certificate market, and carbon markets. The ongoing power sector reform regards the promotion of variable generation consumption as an important part of the market design. How to smoothly transform from a highly administrated environment to a competitive market, and define a clear boundary between policy and regulation, is something China should work on in the near future.

Efforts should be made to strengthen technology innovation to support secure operation of the power system. Advanced technology should be developed to include power grid friendly variable generation technologies, long distance and flexible transmission technologies, active distribution networks, source-network-load-storage coordination and interaction technologies, and variable generation control and protection technologies. For example, in June 2016, a pilot of a source-network-load-storage interaction project was completed in Jiangsu. A total of 1370 enterprises were included in the project, with an interruptible load control of 3.5 GW per second. In this way, the balancing capacity of the bulk power system is greatly improved.

Efforts should be made to enhance energy system integration to improve power system flexibility. The "thermal-electricity decoupling" in Northeast China to unlock flexibility on the generation side is an example of thermal and power system integration. It effectively coordinated operation of thermal and power systems, and created a win-win situation by facilitating VG integration and improving reliability of heat supply at the same time. However, it should also be noted that it is not economical due to the high capital cost of VG and the low value of the thermal energy. In the future, efforts should be made to further integrate power, transportation, oil and gas and other energy systems in an economical fashion so as to enhance power system flexibility to a larger extent.

4 Summary

A dozen years of rapid VG development has posed challenges, but allowed China to accumulate a great deal of experience and lessons learned. Going forward, China will pay more attention to "quality" instead of "speed and scale" in VG development. In the future, a policy-market-regulatory framework, supported by technology innovation, is needed to enhance power system and overall energy transformation. This framework will need to accommodate VG on a large scale, the interests of emerging new parties, and the

digitalization of power systems. This framework should be continually updated based on the stage of social and economic development, as well as challenges of different stages of energy transformation in different countries.

For Further Reading:

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