NEW WIND POWER INSTALLATIONS in China have doubled every year since 2004. By 2010, China’s wind generation capacity of 45 GW ranked first in the world.

Figure 1 shows how the installed wind capacity in China grew from 2000–2010. A total of 30 of 31 provinces, municipalities, and autonomous regions have wind farms. (This article does not discuss wind power development in Hong Kong, Macao, and Taiwan.) The Inner Mongolia Autonomous Region leads the other provinces with 14 GW of installed capacity, followed by Gansu, Hebei, and Liaoning.

China was also the first country outside of Europe to have offshore wind farms. By the end of 2010, total Chinese offshore wind power capacity was approximately 150 MW.

Wind capacity in China is located primarily in the north, northeast, and northwest parts of the country, which are the wind-rich areas shown in Figure 2.

Figure 3 shows the distribution of effective wind power density in China. The north, northeast, and northwest areas of China, along with Tibet, are the wind-rich areas. But they are far from the load centers (the North China Grid, Central China Grid, and East China Grid), which are also the most developed areas in China. Figuring out how
to deliver wind power from wind-rich areas to the load centers is a big challenge.

With improvements in wind power economics and interconnection requirements and aided by policy stimulus, China will continue to be the world’s leading wind power developer over the next five years. By the end of 2015, total installed wind power capacity in China will be approximately 100 GW, and annual wind energy production will reach 200–300 TWh. Chinese offshore wind power capacity will be 3–5 GW, and these facilities will produce 7.5–10 TWh annually. Of the 100 GW of wind capacity, about 46% will be consumed locally and about 54% will be delivered to load centers through long-distance transmission lines. By the end of 2020, the total installed wind power capacity in China is estimated to be 150 GW, and about 30 GW of this will come from offshore wind. Of that 150-GW total, 66 GW will be consumed locally, and 84 GW will be delivered to remote load centers.

By the end of 2020, there are projected to be eight wind plants with capacities larger than 10 GW in China, as shown in Figure 4.

**Lessons Learned**

**Wind Power Development Scale Exceeds Plans**

Actual wind power development in China has far exceeded the original plan, for the following reasons:

✔ **The wind project approval process:** Regulations state that wind power plants larger than 50 MW need to be approved by the National Development and Reform Commission, while wind plants smaller than 50 MW need to be approved by local governments. To avoid the necessity for national approval, many local governments and wind power investors divided
large projects into several smaller projects with less than 50 MW of capacity each. The result was the construction of wind power plants in some areas in the absence of a coordinated system plan. Many of the local governmental approvals for these projects were based on the benefits and stimulus the plants would bring to the local economy, but they were issued without full consideration of the coordinated transmission plan necessary to integrate the wind resources. One study showed that 90% of the wind projects approved by National Development and Reform Commission can be interconnected to the power grid, while the corresponding number for local government wind projects was only 60%.

✓ **Policy issues:** Power grid companies buy renewable energy at predetermined prices, in accordance with state policy requests. This policy promotes the return of wind power investment and encourages more money to flow to wind power projects.

**Transmission Planning and Construction Lag Far Behind Wind Power Development**
Contrary to the quick development of wind power, the planning and construction necessary for transmission system improvements are proceeding slowly.

The main reasons are:
1) **Missing incentives to build transmission to deliver the wind power:** The credits from the Interim Measures for Additional Revenue Allocation of Electricity Generated from Renewable Energy program, a Chinese government program, are not enough to pay for the construction, operation, and maintenance of most local wind interconnection projects. Yet there is no incentive tariff that defines a reasonable price for building long-distance transmission lines from large wind farms to remote load centers. And there is no compensation program for the ancillary services provided by other resources necessary for operating the wind generation, such as reserve service, load following, frequency control, and voltage regulation.

2) **The transmission projects approval process:** For high-voltage transmission projects, approval is granted by the National Development and Reform Commission. The gap between the wind power plant and transmission project approval processes exacerbates the conflicts between the wind power and power grid development.

3) **The structure of the power grid industry in China:** In China, the biggest grid company is the State

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**figure 3.** Distribution of effective wind power density in China.
Grid Corporation of China, covering 25 provinces, municipalities, and autonomous regions and part of the Inner Mongolia Autonomous Region. The China Southern Power Grid covers five provinces and autonomous regions. The western part of the Inner Mongolia Autonomous Region is operated by MengXi Power Grid Company, which is independent from State Grid and Southern Power Grid. MengXi, a wind-rich area, has the largest installed wind capacity in China. But to transport the wind power out of the area, it needs to be interconnected with State Grid’s system and depends on State Grid to build transmission lines to deliver the wind power to remote load centers in State Grid’s territory. There is no coordinated planning among these entities.

**Consequences**

Because of the fast and uncoordinated development of wind power and the lagging development of the transmission system, as of 2010 approximately 30% of Chinese installed wind power capacity has not been interconnected with the power grid. For those wind plants that are interconnected, approximately 6,000 GWh of energy is lost due to operational issues.

For example, the MengXi area, which is rich in wind and coal resources, runs its own power grid, and there are only five transmission lines interconnecting it with State Grid. Due to the limited outlet in this area, about one-third of the thermal units cannot run on full power and about 42% of the installed wind capacity is wasted.

Besides this loss of installed wind power energy production, the impact on power system operation is another challenge brought on by wind development. In China, the difference between peak and valley loads is growing gradually year after year. Load-following capability has become very tight, even without wind power additions. The situation is getting worse with the large amount of wind generation integrated into the system because the wind power peaks normally occur at system load off-peak hours.

Large-scale wind power also adversely affects the real power balance of the system. The random and intermittent characteristics of wind power lead to difficulties in achieving reliable energy balance and resource commitment. In China, coal units comprise a large percentage of the resource mix, but historically they did not provide frequency control because of their slow ramp rates. Even with these units on frequency control, the system has not adapted to quick
changes of wind output due to the large number of wind power interconnections. This has caused a serious system frequency problem under some circumstances.

Finally, large-scale wind power causes problems in reactive power and voltage control. Large-scale wind farms are normally located at the remote reaches of the power system. The wind power needs to be delivered to load centers through long-distance transmission lines. Quick and large variations of wind output cause swift changes of system voltage and tie line flows, both of which can lead to voltage stability issues and jeopardize the security of the power system.

**Strategies for Effective Wind Power Development and Management**

**Enhance the Approval Process**

Wind power development should be planned at the national level. And the local government should strictly follow the national plan in generating its own long-term development. National planning should be strategic and directional and local planning more specific and more operational. National planning and local planning need to be better coordinated to achieve the most efficient allocation of renewable and other resources nationwide. As a fix to the old wind project approval process, wind projects smaller than 50 MW are now recorded in the National Development and Reform Commission after the project receives approvals from the local government.

**Coordinate the Planning of Wind Power and Other Resources**

Planning for wind power development needs to be consistent with the objectives and basic frameworks of overall resource planning. Since wind energy and other renewable projects have different output characteristics from conventional generators, their nameplate capacities are not interchangeable.

Flexible resources are required to achieve the full integration of wind power. But in China’s wind-rich areas (the northeast, north, and northwest regions), coal is the main energy resource. For example, in the northeast, coal accounts for more than 80% of the total energy sources, and in northern China, it accounts for more than 90%. There are very limited flexibly adjustable resources in these areas. In the winter, the higher-production period of wind power overlaps with high production from thermal power plants to meet heating load and the low production of hydropower due to low water levels. With the lack of flexible support available from other resources, it is very difficult to operate the system with large amounts of wind power.

A sufficient number of peaking units is urgently needed to match the large-scale wind power development. China is not rich in oil and gas resources, but the construction of pump-storage peaking power plants is realistic. By the end of 2010, 21 pump-storage power stations had been built, with a capacity of 16.645 GW. By 2015, the pump-storage capacity in the operating territory of State Grid is projected to reach 18.4 GW. In 2020, it will exceed 40 GW. This amount of pump-storage capacity is almost sufficient to meet the load-following requirement when large amounts of clean energy, such as wind and nuclear, are integrated. The planned resource mix is expected to meet the security and stability requirements of the power system.

**Coordinate Long-Term Planning for Wind Power and the Transmission System**

The negative consequences listed above are caused by a lack of coordinated planning with respect to wind power plants and the expansion of the transmission system.

In China, most of the wind resources are far from the load centers. This increases the importance of developing a robust transmission plan. The absorption of large-scale wind power production needs to occur in the grids linking the various regions and even in the nationwide power grid. Large power grids can easily compensate for variability in wind power outputs among the regions and act to smooth the overall volatility resulting from wind power output. This is because the large grid provides access to a diversity of wind resource locations and to more resources that can provide regulation. The larger the power grid, the less impact wind power will have on it.

Because of the volatility of wind power, building long-distance transmission lines exclusively to deliver wind power can create risks and difficulties for the operation of the system. Load following, frequency control, voltage regulation, and system stability are among the issues that must be addressed.

A higher wind power landing price (the total price of the wind generation plus the transmission cost) at the receiving end of the long-distance transmission lines will occur for transmission capacity with low usage. The landing price will likely be twice the price of local coal-generated electricity.

The wind-rich areas in China are also rich in coal. Therefore, bundling the delivery of wind and thermal power to remote load centers becomes a viable option by coordinating the development of wind power, thermal power, and the power grid. This coordinated development means that 100% of the wind power can be delivered to remote load centers, and the capacity factor of the transmission lines can be well over 68%. Under a bundled delivery scenario, the wind power landing price at the receiving end can at times be lower than the price of local coal-generated electricity.

System security will also improve, because the bundled delivery of wind and thermal power can smooth the volatility of the wind output seen by the rest of the system. This helps relieve the operational difficulties at the receiving end of the power system.

In April 2011, to meet the long-term wind development plan in China, State Grid Corporation of China issued a white paper that proposed associated transmission expansion...
plans to absorb the wind power (or wind power bundled with coal power) output at eight wind power plant bases of more than 10 GW.

In JiLin, HuBei, ShanDong, and JiangSu, the wind power bases are located in or very close to load centers. As a result, their wind output will be consumed locally or delivered to the regional grid through 500-kV ac lines, according to the white paper. The white paper specifies the following:

- The wind power in XinJiang will be collected locally through 765-kV systems and delivered (bundled with thermal power) to the North China Grid through two 1,100-kV dc lines and to the Central China Grid through one 800-kV dc line.
- The wind powers in GanSu will be collected locally through 330-kV and 765-kV systems and delivered (bundled with thermal power) to Northwest China Grid through a 750-kV ac system and to the Central China Grid through one 800-kV dc line.
- The wind power in MengXi will be collected locally through 500-kV systems and delivered (bundled with thermal power) to three main load centers (North China Grid, Central China Grid, and East China Grid) through four 1,000-kV ac and two 800-kV dc lines.
- The wind power in MengDong will be collected locally through 500-kV systems, and delivered (bundled with thermal power) to three main load centers through three 800-kV dc lines.

Figures 5 and 6 show the wind integration plans for the XinJiang, GanSu, MengXi, and MengDong wind power bases.

**Coordinate the Construction Plans**

It takes longer to build a transmission project than a wind power plant. The construction of peaking units takes even longer than the construction of a transmission project. If the three are not coordinated, it will likely lead to curtailment of wind power production due to transmission or operation issues.

To achieve this coordination, the approval of wind, transmission, and other generator projects needs to be controlled under one umbrella, such as the National Development and Reform Commission. To match the current transmission and peaking unit construction plans, an annual wind capacity increase of 10–20% is a reasonable range, one study shows.

**Establish a Coordination Mechanism**

The ultimate goal of planning and building a wind power plant is to fully utilize the plant’s potential production. To
succeed in this while keeping the power system secure and stable, establishing good coordination between wind power plant operation and power system operation is extremely critical.

A fully functional wind power forecasting system and improved wind power forecasting technology are crucial. For a wind plant, a local wind power forecasting system is needed. For grid companies, forecasting coverage and accuracy should be improved. As the accuracy of the wind power forecasting increases, so does the amount of output from the wind plant that can be used. With greater accuracy there also comes a decrease in adverse effects on power system operation.

In addition, a valid monitoring system for the wind farm will strengthen operational control, improve the setting coordination of the relay protections and automatic control devices in the power plant, and ensure that the requirements for reactive power and voltage support are met.

Finally, the system’s load-following capability should be improved by making full use of conventional resources. Industry codes and standards should then be developed to guide the integration of wind power into the system. To meet this requirement, the China National Energy Administration has just released 18 standards, including Design Regulations for Large-Scale Wind Power Connecting to the System.

For Further Reading


Biographies
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