REDUCING WIND CURTAILMENT IN CHINA WITH SMART POWER GENERATION

A WHITE PAPER BY WÄRTSILÄ
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EXECUTIVE SUMMARY:

China is focusing strongly on the deployment of wind and solar energy to support global emission reduction targets. However, to fully optimise the output from wind and solar parks, a fundamental change is required to the country’s power system operation. With a high proportion of China’s wind power located in the north and the north-east, and load centres situated in the south and the south-east, the country recognises the need to transmit clean power through the country. To bridge the geographical divide, the Chinese government has plans to invest at least CNY 2 trillion ($315 bn) in its power grid infrastructure (Reuters 2015).

However, relocating power is only part of the solution. Upon arrival to the southern load centres, China’s power system must be capable of balancing variable renewable energy. This means thermal generators must switch from typical baseload operations to delivering a flexible and intermittent output that provides power only when wind and solar are not available. To achieve this requires generators with ultra-fast start up times that can provide accurate load-following for variable renewable energy.

While penetration of wind and solar energy is expected to increase from 6% to 20% by 2030 (Bloomberg New Energy Finance 2015a), load-following is currently unworkable in China’s nuclear and coal dominated generation mix. As a result, the only option is to curtail variable renewable energy, a practice that comes at great environmental and financial cost. During the first half of 2015, 15% of China’s wind power was curtailed, at a cost of CNY 8.9 bn ($1.4 bn) (Bloomberg New Energy Finance 2015b). Without action, this statistic will increase as more variable renewable energy comes online.

China acknowledges these cost burdens. However, tariff structure and fuel prices favouring coal and nuclear mean that the country continues to invest in inflexible capacity. In fact, such generators still have the ability to operate profitably in China, due to historic power purchase agreements that define running hour limits for each power plant.

In spite of this, China’s highest authority, the National People’s Congress, and the country’s National Energy Administration are open to change. In addition to the proposed grid expansions to transmit variable renewable energy from north to south, new policies have targeted to award clean power feed as a priority, meaning the thermal fleet must place greater emphasis on balancing wind and solar power. Furthermore, the world’s largest economy is aspiring to move towards market-based pricing, which would reward variable renewable generators and those thermal technologies that provide grid stability, thus accelerating China’s decarbonisation.

Notwithstanding these positive steps, China’s transition to a truly reliable and sustainable power system requires a new approach. In this white paper, Wärtsilä introduces Smart Power Generation (SPG); an agile generation technology based on multiple fast-reacting internal combustion engines. Due to the inherent operational flexibility of the engines, SPG power plants are capable of following the output of wind and solar power very precisely. Located in Southern China, SPG installations would help to absorb efficiently the variable wind energy transmitted from the north. The increased flexibility in the system would enable integrating larger shares of wind and solar energy. In CHP (combined heat and power) configuration, SPG power stations can also produce heat for district heating, potentially replacing combined cycle gas turbine (CCGT) or coal-based generation. The paper provides an initial assessment of the potential benefits of including SPG within China’s generation fleet, and aims to promote further debate among investors, utilities, grid companies and policy makers.
What is Smart Power Generation?

Wärtsilä’s Smart Power Generation power plants represent ultra-flexible generation, based on multiple internal combustion engines (ICEs). Common applications include baseload, peaking, wind-balancing and industrial generation.

### Energy efficiency
- High baseload efficiency, regardless of ambient conditions.
- High plant efficiency over a wide load range due to the modular ICE design.

### Fuel flexibility
- Operation on any liquid or gaseous fuels, including biofuels.
- Improved fuel security by continuous choice of the most feasible fuel.

### Operational flexibility
- Fast start to full load in less than 5 minutes regardless of plant size.
- Unlimited starting and stopping with no impact on maintenance.
1. WIND CURTAILMENT IN CHINA

1.1 What is wind curtailment?

There are occasions when wind and solar energy is available, but not applied into the grid. In such a scenario, the power is ‘curtailed’ which means that it is not dispatched by grid companies to consumers and industry. A common method is to simply direct the wind turbine blades away from the wind. There are several reasons for curtailment that are unique to China, which this paper will go on to discuss. However, one common problem that is universal to the global variable renewable energy fleet is the inability of thermal power plants to come online and ramp up and down fast enough to balance variable renewable energy generation with demand. The inherent link between variable renewable energy and the weather means that changes in output can occur almost instantaneously and unpredictably. As a result, the thermal fleet must react at the same speed in order for the maximum amount of wind and solar power to be absorbed in the grid. In China, the ability of the country’s current thermal power fleet to achieve this is limited. However, as this paper will go on to discuss, significant improvements in power system balancing are possible through the use of SPG.

1.2 Current situation

While variable renewable energy currently only accounts for around 6% of total generation in China, wind curtailment is already a significant issue. As a whole, the country curtailed 15.2% of its potential wind energy in the first half of 2015, a dramatic increase on the 8.5% curtailed in 2014 (Bloomberg New Energy Finance 2015b). There are a number of reasons for this but, most importantly, wind curtailment is triggered by the geographic location of wind farms in China. As demonstrated in Figure 1.1, there is a stark divide between wind curtailment levels in the northern and southern parts of the country. Most notably, the map shows curtailment of 43% in Jilin, a province in Northern China.

Figure 1.1 Action is required to reduce the monetary and environment impact of wind energy curtailment, which is as high as 43% in some areas of Northern China. Source: Bloomberg New Energy Finance.
The high levels of wind curtailment in the north are intrinsically linked to the load centres in the south. With China’s major load centres, including Beijing, Shanghai and Guangzhou, located in the southern part of the country, it is necessary therefore for a large portion of wind energy to be transmitted to regions, where it is in greatest demand from consumers and industry.

On top of this challenge, China’s dominant two grid companies, the State Owned Grid Company of China and China Southern Power Grid Company prefer to keep all power plants operating at a lower load level rather than shutting down some plants when there’s a surplus in power supply. This becomes problematic when renewable energy generation peaks, since thermal power plants running at low load do not have any downward flexibility available. In these situations, the grid companies prefer to curtail the extra renewable output than to force baseload thermal plants to shut down beyond their already low utilisation rates.

1.3 Future prospects

Although wind curtailment is an acknowledged problem in China, this has not stopped the country from progressing the roll out of renewable energy. This is demonstrated in Figure 1.2, which shows that solar and wind generation penetration in China is expected to increase from 6% in 2015 to 20% in 2030.

![Generation penetration of intermittent renewable sources](image.png)

Figure 1.2 As China continues to deploy variable renewable energy, actions are required to absorb new generators into the power system to avoid an increase in wind curtailment costs. Source: Bloomberg New Energy Finance, New Energy Outlook 2015.
The significant rise in renewables means that the outlook for wind curtailment in 2030 and beyond is set to be extremely expensive, and will result in reduced emissions reduction in China. In order to tackle the issue, China’s power generation fleet must be able to fully absorb variable renewable energy in its power system, while simultaneously coping with variable output and ensuring reliability of power supplies.

Figure 1.3 breaks down installed capacity in China by technology, taking into account changes in the thermal and variable renewable energy fleet from 2015 and 2030. As the graph demonstrates, coal’s dominant role in the generation mix will lessen in the future, while variable renewable generation and nuclear energy will experience increases. To a lesser degree gas-fired generation capacity will also double, and will be discussed in more detail later in this paper.

Figure 1.3 Gas-fired generation capacity is expected to double by 2030. By building new gas generation capacity based on SPG instead of CCGT technology, variable renewable generation can be more effectively balanced, and wind curtailment avoided. Source: Bloomberg New Energy Finance.
2. SOLUTIONS TO WIND CURTALMENT

2.1 First step: expanding transmission network

To avoid wind curtailment due to geographical divide between variable renewable generation and load centres the Chinese government has plans to invest at least CNY 2 trillion ($315 bn) to improve its power grid infrastructure (Reuters 2015). This is definitely a desirable development, because grid expansion is an important step towards enabling an efficient power system with a high penetration of variable renewable generation. However, a strengthened grid does not solve balancing challenges, because it contains virtually no energy storage capacity. Therefore, when variable renewable energy arrives at China’s load centres the power provided must be balanced simultaneously by a highly flexible thermal power fleet.

To achieve this requires a technology with the ability to ramp up almost instantaneously at minimal cost to provide power when variable renewable energy is not available, and ramp down again at the same speed when wind and solar power are back online. A daily example of this necessity would be early evenings, when the sun goes down and solar power is no longer available, while at the same time electricity demand increases to coincide with consumers returning home from work.

2.2 Avoiding inflexible gas-fired generation

While coal and nuclear power plants dominate China’s thermal fleet, the country’s generation mix also includes some gas-fired power plants, and plans are in place to increase their total generation from 2% to 3% by 2030 (see Figure 1.3). These operate mainly in China’s cities, including Beijing, where new policies support the closure of coal power plants and the installation of new gas power plants that typically utilise CCGT technology.

Traditionally, CCGT plants have provided a degree of flexibility by ramping up over a number of hours and then quickly flexing their output to provide system balance through a process known as ‘part-loading’. While this solution may have been adequate in the past when a small amount of renewable energy was integrated into electricity systems, it is not an efficient way to provide the increased amount of flexibility needed in China as renewables increase in proliferation. This is due to the extra costs incurred by part-loading, including increased carbon costs, reduced fuel efficiency, increased numbers of generators on the grid and the cost of curtailment. Therefore, while China’s gas-fired capacity increase is welcome, close consideration must also be given to installing the right type of gas technology to bring flexibility that is proficient in enabling a high penetration of variable renewable energy.

2.3 Introducing Smart Power Generation

SPG could bring the significant benefits to China’s power system. The technology underpinning SPG is modular power based on internal combustion engines, capable of balancing variable renewable energy by starting in less than one minute and reaching full load in less than five minutes. Used in partnership with traditional coal and gas power plants, operated with their highest efficiency at baseload, SPG is not only proven to balance electricity systems with a high penetration of renewables with great reliability, but also at a cost that will realise dramatic savings to consumers.
In Figure 2.1 “Current situation” shows a business as usual situation in China, including wind, coal-fired power plants and CCGT plants. In this scenario, coal-fired power plants must continue to run in the colder north of the country in winter to provide heat for the district heating network that is responsible for warming households and industry. This results in excessive wind energy having to be transmitted to load centres in the south via an expanded network of transmission lines. However, upon arrival to the load centres, CCGTs plants are unable to ramp up and down quick enough to balance the variable output from wind farms in the north. Essentially, power transmission does not add any flexibility to the system. At the load centres in the south, CCGT plants are required to run to provide heat, but can only operate within a loading range of 50% to 100% because of the considerable time and cost associated with stops and starts. No flexible thermal generation is provided and, as a result, the only option is to get flexibility from windmills by curtailing their generation, resulting in wind curtailment costs, the loss of free energy from wind farms and reduced opportunities to limit emissions.
In contrast, “SPG scenario” proposes the replacement of CCGT plants in China’s load centres with SPG, which could stop and start almost instantaneously to follow the load from wind farms in the north. This means the SPG plants could provide speedy and flexible power when the wind is not blowing, and cease operations again when wind becomes available once more. In addition, SPG in CHP (combined heat and power) configuration can replace the heat production of CCGT plants, and in doing so, deliver heat more efficiently and flexibly. This is possible through the use of an accumulator, which is a hot water storage tank dimensioned according to the size and needs of the district heating network. Accumulators perform best in systems with a high penetration of variable renewable energy, enabling the SPG plant to run on full power when wind power is not available, while simultaneously storing heat. This heat is discharged when wind power becomes available again, promoting both the balancing of intermittent generation while also supporting the heat requirements of district heating systems. The combination of SPG and heat storage enables plants in load centres to operate a load of between 0–100% based on demand, which means the thermal fleet can provide enough flexibility to optimise wind power.

In power systems with a high penetration of variable renewable energy, the 0–100% load range provided by SPG can make a significant difference to power system balance. This is demonstrated in Figure 2.2, which compares China’s typical daily dispatch with either CCGT or SPG. The graph on the left demonstrates the resulting wind curtailment, if only coal and CCGT generation is utilised, where these inflexible sources are already running at their minimum stable loads of 50% during night time and are unable to reduce output any further to integrate available wind power.

**Figure 2.2** An illustration of the impact of CCGT and SPG load ranges on wind energy curtailment. Through its ability to ramp from zero to 100% almost instantaneously, SPG can eliminate wind curtailment by following the output of wind energy in real time.

As demonstrated in the left graph, when CCGT plants are replaced with SPG, all available wind generation can be accommodated during the night by shutting down SPG. During the day when wind generation cannot meet the peak demand, SPG is started up to provide the required power.
3. HOW TO ENABLE SPG FOR INTEGRATING WIND POWER

3.1 Electricity market reform

While this paper has outlined the significant potential of SPG to prevent wind energy curtailment and its associated costs and emissions, more must be done before the technology can be installed in China. While SPG’s ability to balance the grid and prevent wind curtailment is acknowledged, questions remain over the economic viability of the solution on project level. Specifically, the lack of market-based pricing means that, unlike in Europe, US and Australia, electricity is not priced by the hour or even 5 minute intervals as a reflection of demand and variable renewable generation. Instead, for those wishing to develop a power plant in China the price of the electricity is constant and fixed when they apply for planning permission. This means that there is only one price paid for electricity during the entire lifecycle of the plant. Furthermore, grid companies dedicate running hours more or less equally to all power plants without taking into account the age, efficiency or emissions. That is not the case in the countries which have introduced the electricity markets where power plants are dispatched reflecting their real generation cost. To sustain competitiveness in the market, power plants are constantly upgraded to operate in a more efficient and environmentally friendly manner. Meanwhile the oldest power plants, which are no longer competitive on the market are decommissioned giving more space to novel and the most efficient technologies like SPG.

Similarly, the price of electricity generated by a wind farm in China is agreed when planning permission for a new site is granted. However, for wind energy there is no agreement to specify running hours. In response to this, when a wind farm is in the planning stages, developers attempt to measure how many running hours they would expect to generate based on wind speeds. However, because of wind curtailment the actual generation of a wind farm is substantially less than predicted, resulting in losses for the wind farm developers. This may deter prospective investors from placing cash into future projects. Respectively, owners of wind parks are selling their projects with the greatest curtailment rates to utilities, which, in turn, are able to meet renewable energy capacity targets specified by the government. Under this arrangement, wind curtailment is not a factor that impacts the bottom lines of utilities. This is because, in addition to responding to government goals for renewables capacity, utilities are able to compensate for curtailment by getting extra generation for coal power plants in their portfolios.

China recognises this issue and the National People’s Congress has indicated that it will pursue a market-based pricing structure to support its emerging decarbonised energy system (Chinese Communist Party’s Central Committee and the State Council 2015). In order to support such technologies as SPG, the selected electricity market design must cause sufficient price volatility to give incentives for thermal generation investment that is capable of balancing variable renewable generation. National Electricity Market (NEM) in Australia is globally probably the best example how to integrate wind and solar power effectively and reward the flexibility of thermal plants, while keeping the consumer electricity price as low as possible. Economic efficiency and grid reliability of NEM is secured by simultaneous dispatch of energy and ancillary services, 5-minute dispatch interval as well as virtually real time market gate closure (Wärtsilä 2014).
3.2 Supportive policies for RES integration

The issue of wind curtailment has been recognised on a government level through the introduction of supportive policies aimed at curbing wind curtailment rates. This is evidenced through a string of supportive policies issued by China’s National Energy Administration in 2015. These include the Notice on Enhancement of Wind Power Grid Connection Absorption (March 2015), followed by the Notice on promotion of wind to heat (June 2015), which will investigate new methods of local wind energy absorption by converting the excessive wind energy to heat or nitrogen. Wärtsilä maintains that SPG is a superior solution to minimising wind curtailment and investment in flexible balancing power should be respectively enabled by supportive policy. This should be a short-term solution, before an electricity market with proper price signals has been established.

While these policies are a good starting point in terms of curbing wind energy curtailment, more could be done to encourage the deployment of flexible system-balancing technologies, which would in turn see suspended wind farm projects become viable again. For example, current policies in cities such as Beijing that encourage the replacement of coal with CCGT could be amended to support ultra-flexible generation, based on the rationale highlighted earlier in this paper. By investing in flexible technologies, significant system-level savings could be achieved through renewables optimisation and reduced curtailment costs.

Figure 3.1 Wärtsilä’s fast-reacting Smart Power Generation power plants have an extensive track record of balancing the output of wind farms in the United States. This 104 MW installation in Kansas has received a Top Plant award by POWER magazine. “The engines’ part-load efficiency and low overall heat rate rival those of a modern combustion turbine combined-cycle plant, and the multiple-unit configuration gives load dispatchers much more operating flexibility than a combined-cycle plant for meeting system demand,” the magazine wrote.
4. CONCLUSION

As China continues to increase its variable renewable energy capacity, ‘business as usual’ can no longer continue in the country’s power system. Currently, transmission lines are being built to transmit wind energy from the wind farms of Northern China to the south where electricity demand is higher. However, transmission lines do not solve the challenge that is at the heart of power system decarbonisation. The challenge is to balance the intermittent output from wind and solar on the grid, enabling the maximum utilisation of clean power when it is available, by varying the load of the thermal fleet. For China, the current cost of wind curtailment, of not being able to fully absorb the potential wind energy, was CNY 8.9 bn ($1.4 bn) in the first half of 2015.

Gas-fired CCGTs, which have been introduced to replace coal power plants in major load centres, have been traditionally used to integrate a small amount of variable renewable energy into power systems while solving local emission issues. However, with wind and solar penetration set to reach 20% by 2030, such technology is no longer suitable. Instead, in the future planned CCGT capacity should be replaced with SPG, which ramps up almost instantaneously to balance renewables, simultaneously storing heat that can be used to support district heating requirements. Should heat not be required when SPG plants are online to balance renewables, the heat can be stored in an accumulator and used at a later time.

Despite these benefits, and the initiatives already taken by the National People’s Congress, a further step change in China’s power industry is required to incentive investment in flexible generation. A move towards market-based pricing, which rewards generator with the ability to balance renewables is desirable, and could be instigated swiftly with supportive policies that discourage wind – and in the future probably also solar – curtailment by utilising any suitable technology on fair basis. Furthermore, supportive policy for agile thermal generation technology would cement the case for new flexible capacity investment. Although China has made significant progress in decarbonising its power supply, the country cannot afford to continue curtailting its wind assets and should proceed now to optimise its current and future power system.
REFERENCES


Wärtsilä Energy Solutions is a leading global supplier of flexible baseload power plants of up to 600 MW operating on various gaseous and liquid fuels. Our portfolio includes unique solutions for peaking, reserve and load-following power generation, as well as for balancing intermittent power production. Wärtsilä Energy Solutions also provides LNG terminals and distribution systems. As of 2015, Wärtsilä has 58 GW of installed power plant capacity in 175 countries around the world.

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