UHV Lines: Shaping the Future of China's Power Sector Landscape

Early 2016 Update

TLG has been engaged to advise on numerous wind and solar curtailment studies in Gansu, Xinjiang, Inner Mongolia, Jilin provinces, as well as curtailment and commercial viability studies of small hydro power in Sichuan, Yunnan, Fujian, and Hunan provinces. The issues in each case are complicated involving a range of technical, policy and commercial factors.

In March 2014[1], we wrote that the approval progress of State Grid Corporation of China's UHV transmission development plans has been slow not because the plans are unimportant, but because they are too important, with numerous and complex implications for China's economy. We continue to hold the view that UHV development is a priority and will have a major influence on China's evolving power sector landscape.

But where are we today? Grid-related curtailment of renewable energy is a growing concern, having worsened in many locations in recent years. Meanwhile air quality has either barely improved or worsened in many regions. As we have noted in the past, the power sector has been steadily reducing emissions, but grid curtailment of wind, solar and small hydro power has slowed the good progress. The non-power sector continues to be the primary focal point of emissions concern, but the concept of using the power sector to enable reduced emissions in the non-power sector depends on the grid. In this issue of TLG on China, we provide a recap of China's UHV plans, update their current status, and highlight important trends from recent developments.

UHV Plans

State Grid Corporation of China (SGCC) originally announced grand UHV construction targets for the eight-year period from 2013 to 2020:

- By 2015, SGCC had planned to commission "two vertical and two horizontal" UHV AC lines, the Yangtze River Delta UHV "loop", and seven UHV DC lines.
- By 2017, SGCC had planned to complete "three vertical and three horizontal" UHV AC lines and 13 UHV DC lines.
- By 2020, SGCC had planned to achieve "five vertical and five horizontal" UHV AC lines and 27 UHV DC lines totalling 89,000 kilometres.[2]

However, by the end of 2015, only three UHV AC lines (out of the four planned) and five UHV DC lines (out of the seven planned) are in operation, with a total length of 11,900 kilometres.

1 "Slow progress but momentum is building", TLG on China, March 2014.

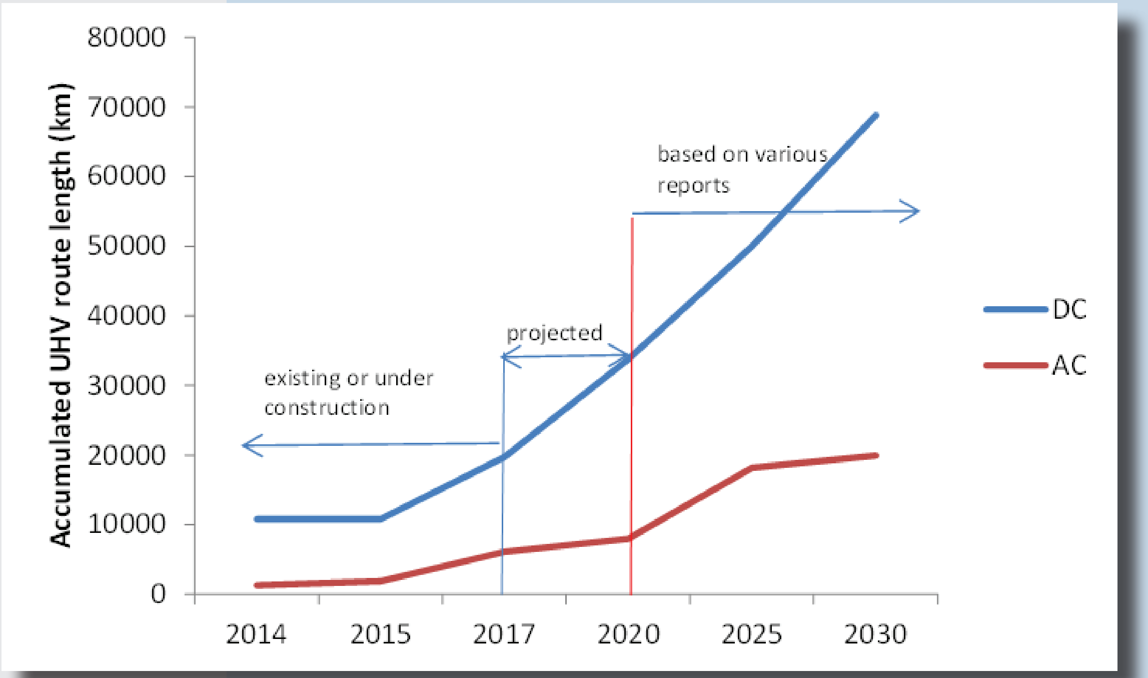
2 http://news.xinhuanet.com/politics/2015-12/16/c_128535037.htm.

In March 2014, however, China's state approving authority for UHV projects, the National Energy Administration (NEA) increased the pace of approvals, suddenly approving nine UHV projects, including four UHV AC projects. Similarly, in 2015, NEA approved a further two UHV DC projects. Currently, four UHV AC projects and three UHV DC projects are currently under construction, with a planned total circuit length of 7,890 kilometres and transmission capacity of 56,000 MW. However, two UHV DC projects among the nine approved UHV projects have not started construction yet due to ongoing need to complete environmental impact assessments, gain additional approvals and local permits, or acquire land.

The most recent development involves the commencement on 11 January 2016 of construction of a UHV DC line from Zhundong in Xinjiang to Huainan in Anhui, a major development running 3,324 kilometres with a maximum transmission capacity of 12,000 MW. This line positions Xinjiang to become China's power and energy supply hub in the future.[3]

Figure 1 shows the estimated UHV transmission route lengths in various stages of completion over time.

Figure 1: Lengths of UHV transmission routes existing, under construction or proposed



Source: TLG Research based on various reports

By 2017 (when the lines that were approved in 2014 are most likely to be commissioned), the total length of operating UHV lines will be about 25,800 kilometres.[4] Even so, progress will be behind original targets[2] of about 89,000 kilometres for 2020. To meet this original 2020 target, China would need to more than double its UHV development efforts, which seems unlikely given the challenges.

There are a number of reasons for the slower progress than SGCC had initially planned:

- First of all, the NEA may not share the same view or vision concerning the role that UHV AC transmission projects play in the national grid system, especially with respect to the value (and risk) of synchronizing China's three largest regional power grids: North China, East China and Central China, with a combined generation capacity of 840 GW at the end of 2014.

3 This new line will be about 1000 km longer and will operate at a higher rating (±1100 kv vs ±800 kv) than the previous longest one which runs from Jiuquan to Xiangtan.

4 23,000 km of which will be operated by SGCC.

- Second, slowing demand growth has dampened the demand for UHV projects in the power importing provinces, though the exporting regions such as Northwest China, Inner Mongolia, Northeast China continue to seek UHV transmission projects in order to export massive surplus generation and reduce renewable curtailment problems.

- Third, the utilization of UHV projects commissioned to date has been lower than the rated capacities (particularly the UHV AC projects), as shown later in Table 2, which most likely reflects other complex factors such as planning delays, resource imbalances/inadequacies, and system integration challenges. Lower than expected utilisation re-enforces the concerns about the economics of the UHV AC transmission projects.

Against this backdrop, we take stock and posit three key observations related to China's on-going UHV development.

Overview of UHV Developmental Progress

SGCC's original plans reflected a strategy of interconnecting the three largest regional grids of North China, East China and Central China.[5] However, judging from the pattern of NEA's approvals, NEA does not appear to be motivated by cross-regional integration. Instead, NEA is allowing China's grid networks to strengthen within regions, with new UHV AC lines entirely within the East China and North China grids. In this light, SGCC's vision to synchronize regional power grids is almost certainly not being taken seriously. The most likely reason for the NEA's alternative approach concerns the complexity of reliably integrating China's enormous regional grids using UHV AC technology. Until it is clear that China's growing UHV AC system will not impose undue technical challenges and reliability risks on the power system, a regional approach makes sense. And it may make sense forever. The United States operates several massive regional grids, with virtually no prospect that these will ever be fully integrated (due to costs exceeding benefits) using UHV AC technology.

Two important tell-tale signs to this departure in strategy are apparent when comparing the 2014 and 2015 planning approvals by China's powerful National Development and Reform Council (NDRC), versus SGCC's original transmission infrastructure proposals.

- First, SGCC had long planned for a UHV AC line from Ximeng, via Shandong's Jinan in the North China Power Grid (NCPG), to Nanjing in the East China Power Grid (ECPG). However, NEA, approved only the segment from Ximeng to Jinan, rather than extending fully to ECPG's UHV system as SGCC had proposed.

- Second, the UHV AC line that had been proposed from Sichuan's Ya'an to Hubei's Wuhan (both locations being in Central China Power Grid (CCPG)), was not approved. These two decisions suggest that NEA does not view full synchronization of the Northern (NCPG), Eastern (ECPG), and Central (CCPG) regional grids via UHV AC lines as important (or at least not as urgent).

Notwithstanding this, strengthening UHV AC networks within these regional grids is still important. For example, in the ECPG, the UHV AC network supports power transfers from nuclear power stations in Fujian to Zhejiang and other provinces in the region, power from coal-power generation bases in Anhui to Zhejiang, Jiangsu and Shanghai. In the NCPG, power from Inner Mongolia and Shanxi (and also from Shaanxi) can be transmitted to the load centres of Beijing, Tianjin-Hebei and Shandong.

5 China has no national grid. Instead, there are six regional grids. Five are managed by the State Grid Corporation of China (SGCC) – the North, North-East, East, Central and North-West grids. An independent grid in the south is managed by the China Southern Grid (CSG) Corporation.

More importantly, a more robust regional grid is needed to receive massive power transfers from the various UHV DC transmission lines. We consider that the regional UHV AC loop in ECPG is helpful (even necessary) for the construction of the Zhundong-Huainan ±1100 kV UHV DC project with a maximum transmission capacity of 12 GW.

Table 1: UHV projects in operation, under construction and potential candidates

Status	Type	2012	2013	2014	2015
Commissioned	AC	Jindongnan-Nanyang-Jingmen	Jindongnan-Nanyang-Jingmen	Jindongnan-Nanyang-Jingmen	Jindongnan-Nanyang-Jingmen
			Huainan-Zhebei-Shanghai	Huainan-Zhebei-Shanghai	Huainan-Zhebei-Shanghai
			Fuzhou-North Zhejiang	Fuzhou-North Zhejiang	Fuzhou-North Zhejiang
	DC	Yunnan-Guangdong	Yunnan-Guangdong	Yunnan-Guangdong	Yunnan-Guangdong
		Xiangjiaba-Shanghai	Xiangjiaba-Shanghai	Xiangjiaba-Shanghai	Xiangjiaba-Shanghai
		Jinping-Sunan	Jinping-Sunan	Jinping-Sunan	Jinping-Sunan
			Nuozhadu-Guangdong	Nuozhadu-Guangdong	Nuozhadu-Guangdong
				Southern Hami-Zhengzhou	Southern Hami-Zhengzhou
				Xiluodu-Zhejiang	Xiluodu-Zhejiang
Under construction/ approved	AC	Huainan-Zhebei-Shanghai	Fuzhou-North Zhejiang	Huainan-Nanjing-Shanghai	Huainan-Nanjing-Shanghai
					Xilingol-Jinan
					Mengxi-South Tianjin
					Jingbian-Weifang
	DC	Nuozhadu-Guangdong	Southern Hami-Zhengzhou		Jiuquan-Hunan
		Southern Hami-Zhengzhou	Xiluodu-Zhejiang		Jinbei-Nanjing
		Xiluodu-Zhejiang			Shanghaimiao-Shandong
					Ximeng-Taizhou
					Ningdong-Zhejiang
					Dianxibei-Shenzhen
					Zhundong-Huainan
Preliminary Approval	AC	Ximeng-Nanjing	Huainan-Nanjing-Shanghai	Jiuquan-Hunan	
	DC	Ningdong-Zhejiang	Jiuquan-Hunan		
Awaiting approval	AC				
	DC				Zhalute-Shandong

Source: TLG Research

Many more UHV projects are reported to be at various planning stages. For example, the recently proposed Zhalute-Shandong UHV DC line[6] to resolve the major wind power curtailment problem in the northeast region seems likely to receive approval in near term. However, it will take more time for China to optimize reliable and secure operation of already commissioned and soon to be commissioned (under construction) transmission infrastructure before NEA approves many (if any) more UHV projects without a clear or immediate material benefit.

Three Observations

The regional grids are becoming more robust, reducing the importance of a fully integrated national grid

China's investments in UHV infrastructure have largely enabled or supported the development of stronger regional networks, both via UHV AC infrastructure, as well as via long-distance, UHV DC infrastructure.

6 http://www.tj.sgcc.com.cn/html/main/col7/2015-10/19/20151019163345508435693_1.html.

As Figure 2 shows, SGCC's latest UHV AC plans generally fit within regional grids, such as the ECPG and NCPG. All provinces within the ECPG will soon be connected via the UHV AC loop when it is completed later this year. In the NCPG, a "two-horizontal and one-vertical" UHV AC configuration has been approved and is under construction. The vertical one will run from Ximeng of Inner Mongolia to Jinan of Shandong, and two horizontal UHV AC lines from Ximeng of Inner Mongolia to Tianjian and from Shaanxi to the coastal province of Shandong

Figure 2: UHV AC transmission lines

Source: TLG Research based on various sources

Figure 3 shows the UHV DC projects which are either in operation, under construction, or have been proposed (selected sample). Those in operation or under construction run from 1,100 km to 2,400 km, with capacities from 5 GW to 10 GW each. These long distances are a function of the economic and technical advantages of very long, point-to-point application of UHV DC technology compared to UHV AC. Each injection and off-take point requires infrastructure for converting AC to DC power and back again. These conversion-related costs dictate the minimum economic segment length of UHV DC technology.[7]

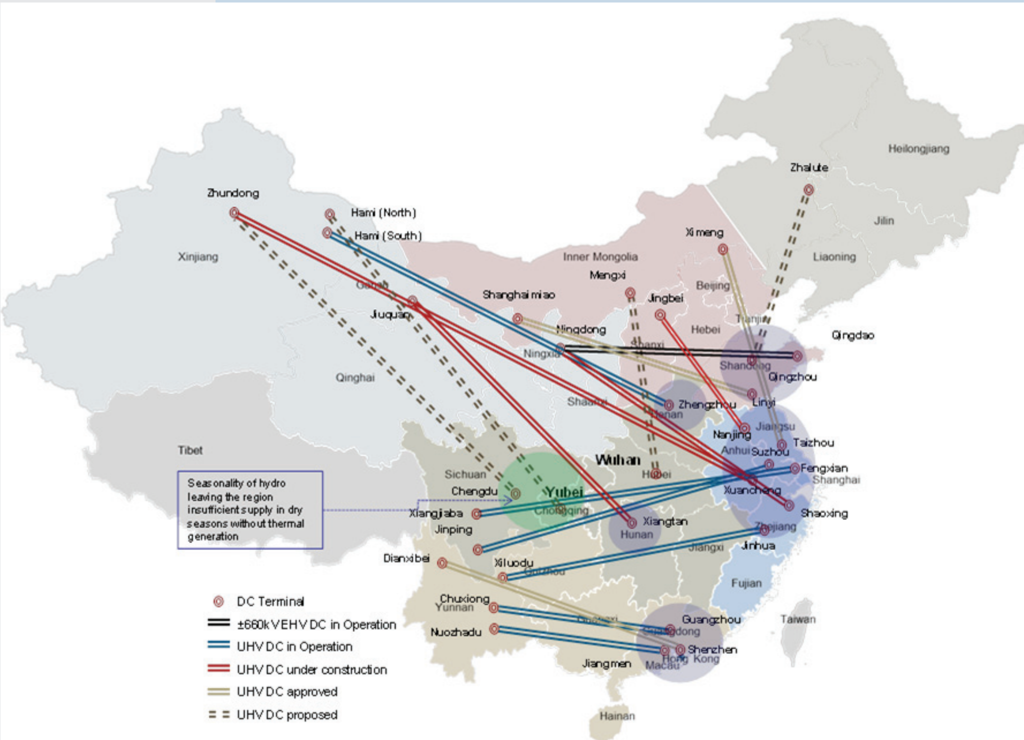
Where UHV infrastructure is or will be made available, the sending nodes are all from renewable-rich zones, primarily comprising either hydro, wind, or solar generation. In the hydro-rich provinces of Sichuan and Yunnan, UHV DC lines are typically dedicated to specific hydro power plants. For regions rich in wind and solar generation, the UHV DC lines are connected to a portfolio of resources (i.e. wind and solar farms, as well as coal-fired power plants), because an adequate supply source is a pre-requisite before power can be transmitted out cost effectively from the AC-to-DC conversion terminal via the UHV DC lines.

7 UHV DC technology is only economic above transmission distances above approx. 600 kilometres.

In the resource rich Northwest region, all provinces and autonomous regions except Qinghai (which is itself short of power) have new UHV DC or AC lines in varying phases of completion:

- Xinjiang has a ±800 kV DC transmission line from Hami to Henan's Zhengzhou, in operation since January 2014.
- Gansu has China's longest UHV DC transmission line of 2,400 km from Jiuquan to Hunan's Xiangtan, which is under construction.
- Ningxia has a ±660 kV exporting DC transmission line to Shandong's Qingdao in operation since February 2011, and a ±800 kV UHV DC transmission line to Zhejiang's Shaoxin, which is under construction.
- Shaanxi is rich in coal resources, and it is relatively close to the load centres of the Beijing-Tianjin-Hebei region. Shaanxi has several dedicated coal fired power plants supplying Beijing-Tianjin-Hebei, and one UHV AC line (the south limbs of the two horizontal UHV AC lines in Figure 2) running from Yuheng (in Shaanxi) to Shandong's Weifang, which is under construction.

Figure 3: UHV DC transmission lines



Source: TLG Research based on various sources

Overall, China's UHV infrastructure developments should be viewed closely in the context of the power demand-supply balance across provinces. Of the six regional grids in China, only the northeast regional grid, covering the provinces of Heilongjiang, Jilin and Liaoning, has no UHV project that is in operation, under construction, or has been approved.

By contrast, Inner Mongolia and Shanxi are both traditional power exporters to the load centres of Beijing-Tianjin-Tangshan, Jiangsu and Central China. These two provinces have been the largest beneficiaries in the last two rounds of UHV project approvals, with Inner Mongolia securing 30 GW of exporting capacity, and Shanxi's planned exporting capacity going up to 20 GW.

In the power-receiving regions, the coastal province of Shandong has the largest number of incoming UHV lines, with two UHV DC and two UHV AC lines connecting into the province. Jiangsu province has two incoming UHV lines. Also, apart from the traditional importing regions in the east coast, Hunan in central China is another key destination for electricity exports from the northwest region (via the Gansu-Hunan UHV DC line, which is under construction).

In the ECPG, the UHV AC system may be configured to move power from mixed sources around the large electricity consuming provinces of Jiangsu, Zhejiang and Shanghai. Furthermore, power can also be supplied via the connecting UHV DC lines (six UHV DC lines with a combined capacity of 44,600 MW). These lines will be supplied by the large nuclear power generation base in Fujian (in the south), which has five units with a combined capacity of 5,445 MW in operation. When the UHV lines are fully connected, another 7,623 MW of capacity from the two existing nuclear power plants[8] and from Anhui's power generation bases will become available.

In the NCPG, three UHV AC corridors connect the supply-rich provinces of Shanxi and Inner Mongolia, with the demand-hungry provinces (and municipalities) of Hebei, Shandong, Beijing and Tianjin. The three starting nodes of the UHV AC systems have abundant coal fired generation capacity, which can be used to complement the operation of UHV systems exporting intermittent wind and solar from Inner Mongolia.

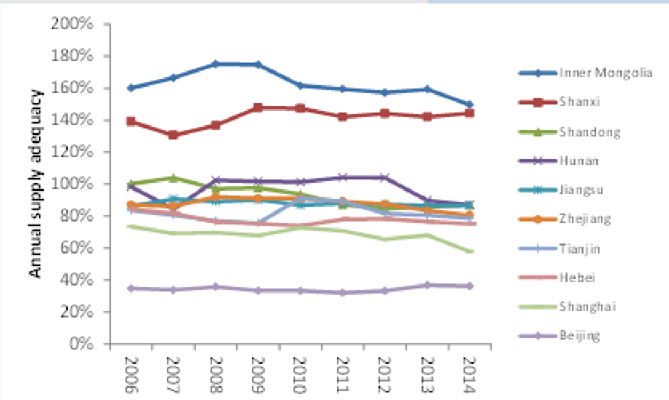
UHV developments have not kept pace with capacity additions

The chart on the left of Figure 4 shows the historical annual supply adequacy (i.e. ratio of local generation to local consumption) of key provinces and city municipalities. Supply adequacies in the main load centres of Beijing (36% in 2014), Shanghai (58%), Hebei (75%), Jiangsu (87%) and Zhejiang (80%), and Hunan (87%) have been more or less stable. In the power exporting provinces, supply in Inner Mongolia (150%) and Shanxi (140%) is in surplus.

In the chart on the right of Figure 4, a huge surplus of generating capacity exists in the northwest region. Xinjiang and Gansu have the largest capacity surpluses among these provinces. Gansu's capacity margin exceeds 200% while Xinjiang's approaches 140%. Together these two provinces have over 70 GW of surplus generating capacity. More importantly, curtailment of generation is common due to shortage of transmission capacity for export. Commercial domestic and international investment in China's renewable energy resources in these regions has been hit hard by curtailment risk.

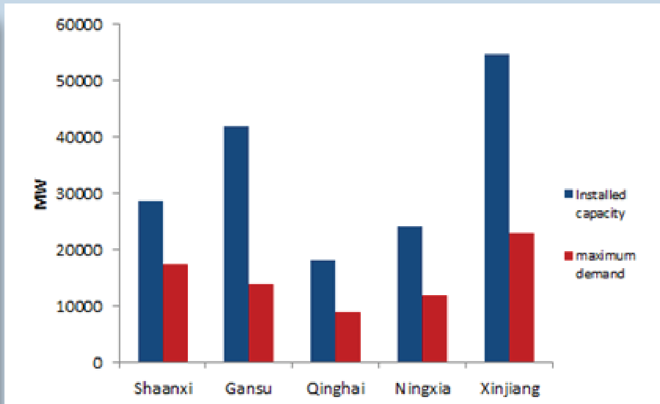
Figure 4: Supply and demand fundamentals

Historical supply adequacy of provinces



Source: Government and press releases, TLG analysis

Installed capacity verses maximum demand in Northwest provinces in 2014



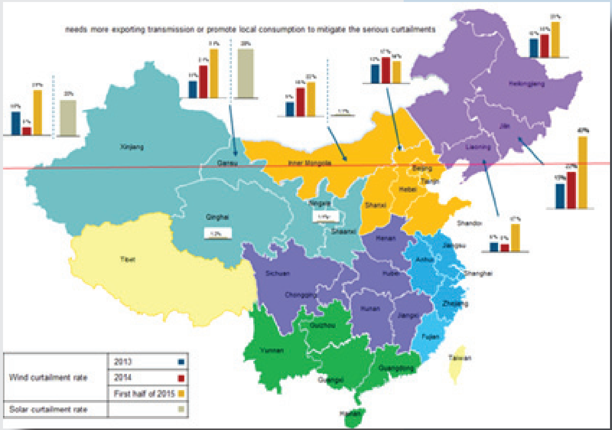
Source: TLG analysis

8 Zhejiang and Jiangsu have several nuclear power plants under construction and more units have been planned. These may complicate the power flow patterns in the region and require coordinated planning of power sources and UHV systems.

At the same time as there is surplus generating capacity in the north, northwest and northeast regions, the chart on the left of Figure 5 shows the curtailment of wind and solar power in these regions has been increasing between 2013 to the first half of 2015. This is clearly a missed opportunity to mitigate China's serious air pollution challenges, as can be seen from the chart on the right of Figure 5. In short, there is insufficient transmission capacity to channel renewable energy from areas of surplus, to displace higher emitting generation sited in demand centres.

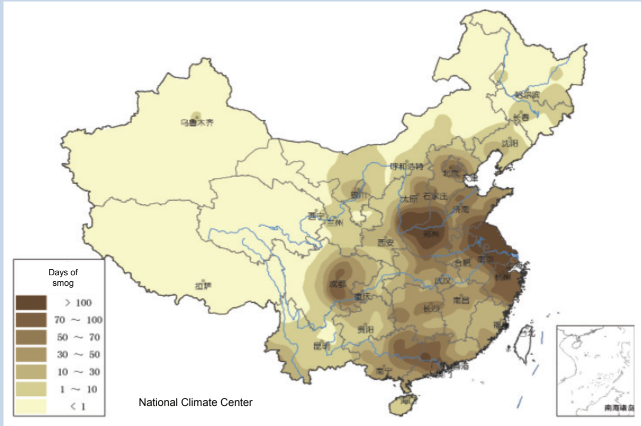
Figure 5: Wind and solar power curtailment verse air polluted cities

Curtailment of wind and solar power from 2013-2015



Source: TLG Research based NEA reports and others

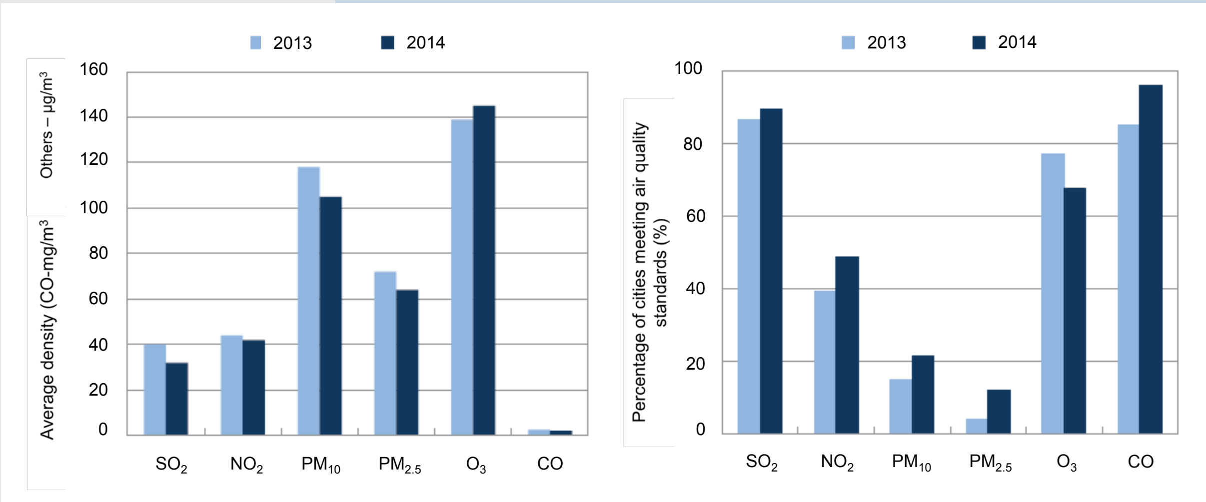
Smoggy days of 74 cities in 2013



Source: Ministry of Environmental Protection 2013 Annual Report

Figure 6: Air quality of cities: 2013 (74 cities) verses 2014 (161 cities)

Indeed, Figure 6 shows there even while there are improvements to the air quality in 2014, PM10 and PM2.5 levels remain high, and only about 20% of Chinese cities survey met the PM10 air quality standards.



Source: Ministry of Environmental Protection 2014 Report

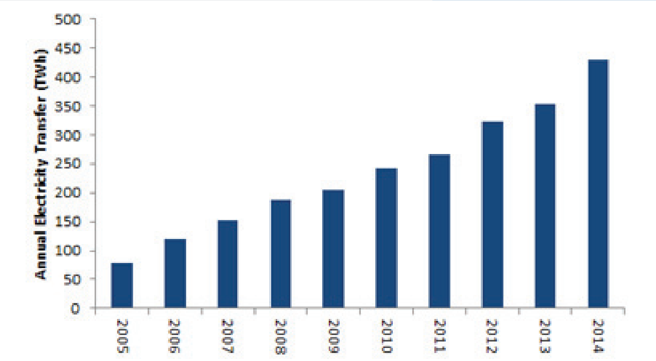
UHV line utilisation rates have been below expectation

Inter-regional power exchange within China has increased steadily from 75 TWh in 2005 to more than 400 TWh in 2014. This is a phenomenal, after five-fold growth over the short span of less than ten years. This is a direct outcome of the critical role of UHV transmission lines in supporting inter-provincial power exchange, as well as supporting major power flows within the more developed grids such as within the South China Power Grid (SCPG) and the ECPG. It is expected that future UHV lines will play similarly critical roles within the NCPG.

Figure 7: Inter-region power exchange trend and power flow in 2014

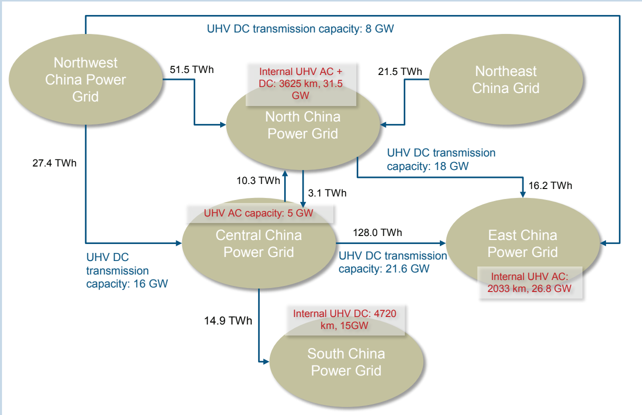
The right-hand side diagram of Figure 7 shows the UHV capacities (existing and under construction) between regions, as well as within regional grids.

Inter-region power exchange trends



Source: SGCC 2014 Power Exchange Annual Report

Power flow between regions in 2014



Source: SGCC 2014 Power Exchange Annual Report and TLG analysis (transmission capacities)

Table 2: Utilization rates of SGCC UHV lines

However, utilization of the UHV lines remains below expectations, especially in the years immediately following commissioning, as shown in Table 2. For example, the UHV DC project from Xinjiang's Hami to Henan's Zhengzhou has a rated transmission capacity of 50 TWh a year,[9] but a total of only 13.2 TWh was transmitted in 2014, and less than 20 TWh in the first 8 months of 2015.

	Commission Date	2014	2013	2012	2011	2010
Shanxi-Hubei (AC)	Jan-09	31%	28%	30%	16%	27%
Huainan-Shanghai (AC)	Sep-13	21%	6%	NA	NA	NA
Sichuan-Shanghai (DC)	Jul-10	56%	57%	26%	10%	11%
Sichuan-Jiangsu (DC)	Dec-12	56%	36%	7%	NA	NA
Xinjiang-Henan (DC)	Jan-14	19%	NA	NA	NA	NA
Sichuan-Zhejiang (DC)	Jul-14	36%	NA	NA	NA	NA

Source: Calculation based on data from SGCC Power Exchange Annual Reports

Many factors affect the utilization and operation of the UHV systems such as the performance of connected generation plants, constraints in the local power grids (at both the sending and receiving ends), hydrological conditions, as well as demand conditions. As such, efficiently coordinated planning of grid and generation, under changing economic and regulatory conditions, will become even more important to ensure better utilization of fuel, environmental and capital resources. As lower-than expected grid performance becomes more evident and better understood, we expect these issues will rise in prominence.

9 http://www.sgcc.com.cn/

Summary

China's UHV transformation started ten years ago with the construction in August 2006 of China's first UHV project Jindongnan-Nanyang-Jingmen from Shanxi to Hubei. Although the development of UHV systems is well behind SGCC's original targets, UHV infrastructure remains crucial to the development of China's power system.

Existing or approved UHV AC lines are forming regionally well connected networks, complemented by UHV DC lines that connect generation resources with demand centres. Inter-regional power transfers are becoming more complex, whilst becoming increasing important to the grid stability and management in both power-receiving and power-transmitting regions. Curtailment of renewable energy generation is growing concern, but more than that, it is also a missed opportunity to solve, or at least mitigate, China's environmental challenges.

With these in mind, it is also clear that improving the performance of a complex integrated grid presents a demanding challenge. Merely building new UHV lines is not enough. Increased focus on robust economic treatment of dispatch optimisation, resource allocation, and infrastructure development and operation can add so much more value to China's power sector.

About the Author

Dr Xinmin Hu

Principal

xhu@lantaugroup.com

+852 9381 6938

With special thanks to Mike Thomas and Zhen-Hui Eng

Xinmin is an expert in the Chinese power sector and energy economics having advised clients on generation, transmission and energy supply issues as well as regulatory developments and cost trends. He is a former lecturer at Jilin University in Changchun and at Zhongshan University in Guangzhou. He combines his knowledge of China's power sector with over a decade of experience as a consultant in the Australian and other power markets and as an associate director of RepuTex (AU) focusing on environmental and greenhouse gas emission issues. He is a regular reviewer for several international energy, operations research and optimization journals. He holds a PhD in operations research with a minor in economics from the University of Melbourne and an MSc in Applied Mathematics from Jilin University of Technology, China.

For more information, please contact Dr Xinmin Hu at
TLGonChina@lantaugroup.com

For more information about The Lantau Group, please visit **www.lantaugroup.com**