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Power Play: China's Ultra-High Voltage Technology and Global Standards

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About the Authors

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Executive Summary

As a matter of government policy and corporate strategy, China has been intensifying its effort to set indigenous standards for homegrown ultra-high voltage (UHV) transmission technology. The country also aims to contribute to UHV standards internationally. Indeed, this process of standard setting, influenced by both economics and politics, will have ramifications far beyond China's borders. The potential internationalization of China's domestic UHV standards will almost certainly affect the global market share for both Chinese manufacturers and dominant multinational companies.

Two factors are creating a window of opportunity for Chinese UHV technologies to gain international acceptance and become the *de facto* global standard: first, China is the only country currently deploying UHV technology on a large scale; second, no international UHV standard has yet prevailed. China's effort to internationalize its own UHV standards, then, could yield greater global market share for Chinese UHV technologies.

In fact, China has already made some modest progress in becoming the default standard-setter for UHV projects outside its borders, in part by growing its global market share. One example is the joint development of a Sino-Brazilian UHV project. Another is the successful effort to promote three indigenous Chinese UHV AC standards as international standards of the global Institute of Electrical and Electronics Engineers (IEEE).

This paper delves deeply into these developments. It explores China's UHV standardization process and the myriad challenges it faces, from a technical, economic, and political standpoint. But beyond simply detailing China's strategy in pushing out its own UHV technology to the domestic and international markets, the paper discusses how China's ambition for its indigenous technology could ultimately pose a considerable challenge to global competitors who hope to sell comparable products. The paper concludes by outlining several potential scenarios for how China's UHV standardization process, and its relationship to global standard setting, may ultimately evolve.

Key Findings:

- As a quasi-monopoly operator of transmission and distribution (T&D), the State Grid Corporation of China (hereafter "State Grid") is leading the development of UHV transmission in China. It is doing so via the assimilation and localization of low- and mid-end UHV

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technologies. The rapid deployment of UHV technology in China can be attributed, in part, to the vertical integration of both transmission utilities and electrical component manufacturers. This integration has driven a convergence of UHV standards in China.

- State Grid is investing in UHV technology to earn profits from its products rather than profiting from the standard itself or its associated intellectual property (IP). State Grid, it appears, aims to lower the cost of the IP embedded in its UHV standard in an effort to promote wider industry adoption of that standard, and thus maximize marginal profit. The low-cost IP has helped State Grid's UHV technology to prevail in the Chinese domestic market but, ultimately, it will also pose a challenge to the market share of foreign players, particularly in third country markets.

- The accelerated development of UHV transmission systems in China could strengthen State Grid's monopoly position domestically. At the same time, it may also impede innovation in UHV technology globally. The reason is this: by being the dominant player in China—a critically important global market—State Grid can use its market power to influence international standardization and allow Chinese companies to include national preferences in international UHV standards.

- This use of market power could, ironically, impede Chinese innovation over the long term because foreign markets with other preferences will resist assimilating the State Grid/Chinese product. This could leave China in an unfavorable trade position in certain overseas markets.

- The fact that State Grid and other Chinese companies display growing knowledge in high-end UHV technologies demonstrates the dramatic advancement in Chinese R&D capabilities. In this area, at least, China is not simply an imitator or late adopter of overseas technology, but is becoming a builder, within certain areas, of innovative indigenous technology. This should help to facilitate the internationalization of China's own UHV standards. And it will pose a technological challenge, not simply a competitive/market share challenge, to other countries that seek to develop UHV and to multinational companies.

- Scale matters. China is, in fact, building so much UHV technology that it threatens to crowd others out of the global market. Scale has consequences precisely because significant market share is a prerequisite for the successful internationalization of one's technical standard. So as the world's dominant developer and "deployer" of UHV technology, China is eagerly expanding it to overseas markets, which in turn has significant implications for the global standards regime.

- Brazil is the best example of this phenomenon to date. Already, China hopes to dominate the UHV market in Brazil, and State Grid maintains a good relationship with Brazilian power companies. Indeed, with State Grid's cost advantages, the company has provided more economical UHV technologies to the global market than those available from non-Chinese firms. This price advantage has been an important factor allowing State Grid to erode the global market share in UHV DC technology of its overseas competitors, such as ABB and Siemens.

- In other fields and with other technology, China has faced pressure from existing or competing international technology standards. For instance, in one prominent case, China failed to see its indigenous mobile technology, TD-SCDMA, become widely adopted internationally. Still, the path toward internationalization of the Chinese UHV standard seems more straightforward than in these other cases. That is because unlike mobile phone technology, UHV standardization is still in its infancy, and that means that China has first-mover advantage. Ultimately, the comparative lack of development of UHV technology to date means that the Chinese technology will have an opportunity to leapfrog and become accepted as a credible international standard at an earlier stage.

International UHV Development

To understand the relationship between China and international standard setting for ultra-high voltage (UHV) lines, it is important, first, to understand the nature of the technology itself. UHV power lines are typically deployed for efficient, long-distance, and bulk transmission of electricity. With a much higher rated voltage level than standard high voltage transmission, UHV transmission lines can reduce the cost of electricity transmission through the relocation of energy resources and improve power system stability.[1]

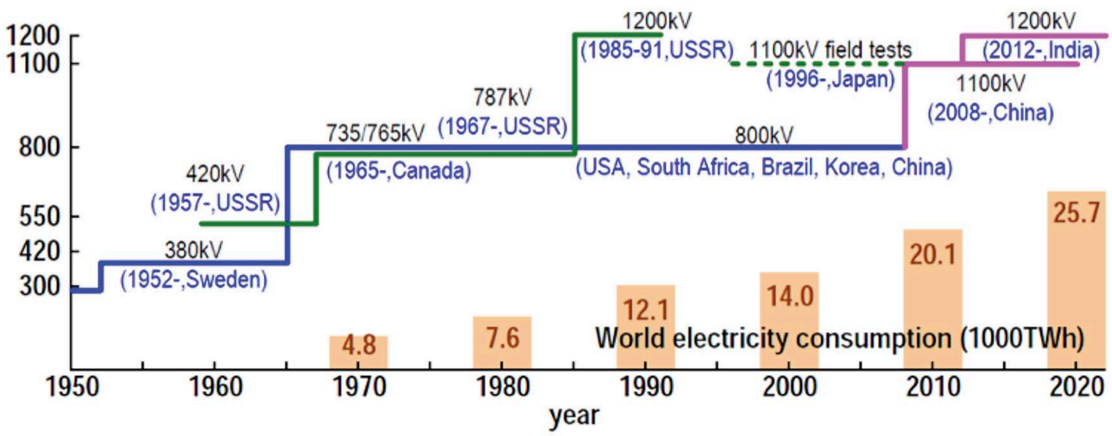
The voltage levels of transmission lines in electricity systems differ from country to country. Internationally, a high voltage (HV) AC transmission system is anywhere between 35 to 220 kilovolt (kV), while extra high voltage (EHV) ranges from 330 to 750 kV.[2] In China, the HV AC system includes both 110 kV and 220 kV transmission lines, while the EHV AC lines have various voltages at 330 kV, 500 kV, and 750 kV. According to the International Electrotechnical Commission (IEC) definition, UHV AC systems are rated at 1000 kV and above and the UHV DC system is ±800 kV.[3]

A 2,000 km, 800 kV UHV DC line transmits electricity at an extremely low line loss rate of 3.5 percent/1,000 km and up to 6.4 GW of transmission capacity. Such a line is also 30 percent more economical to build than a 500 kV EHV DC or 800 kV UHV AC line of the same length. The total transmission capacity of UHV lines through 2020 could hit 300 GW, with 60 percent being AC and 40 percent being DC. At an average construction cost of $1.05 million/mile for both UHV lines and electrical equipment, billions of dollars are needed for each UHV line. From 2011 to 2015, State Grid is investing nearly $43 billion to build 40,000 km of UHV lines.[4]

Since the 1960s, Russia, Japan, the United States,[5] Italy, and Canada have all begun research into UHV transmission technologies in overvoltage, audible noise, radio interference, and ecological effects, among other areas.[6] And a number of UHV AC circuits have been built in different parts of the world.[7] For example, 2,362 km of 1,150 kV circuits had been built in Russia by 1985,[8] and 427 km of 1,000 kV AC circuits have been developed in Japan since 1999.[9] Italy also built a short 1,050 kV experimental line in 1990. Similarly, there are many UHV DC circuits around the world,[10] such as the Itaipu ±600 kV project in Brazil.[11]

Today, and in numerous countries, there is growing interest in adopting UHV transmission technology, with China, Brazil, and India the standout cases because of each country's rapidly rising energy demand and need to connect load centers with demand centers. UHVs seem to be more appealing to countries that plan to install large amounts of renewable energy, such as wind power, that have to be transmitted over long distances.[12] China is one example: it has been developing UHV transmission lines since 2008. India, too, is planning a 1,200 kV UHV AC transmission line from Wardha to Aurangabad in collaboration with Alstom India and Power Grid Corporation of India Limited (PGCIL) (see Figure 1). And Brazil is also developing ±800 kV UHV DC projects in the Amazon.

Figure 1. Developing Countries Pursuing UHV Technology



Source: Ito, H. et al.[13]

Chinese UHV Technology

China has, in many ways, been the country that has invested the most in UHV technology in recent years. There are a number of reasons for this, flowing, first, from national energy policy goals and, second, from sheer technological ambition.

Aligning UHV Development with National Energy Policy Goals

In China, 80 percent of hydropower resources are located in western China and 76 percent of coal is situated in the northwestern part of the country.[14] But over 75 percent of China's energy demand is distributed along the country's east coast.[15] This geographic disjuncture—energy sources located in one part of the country while load centers are located elsewhere—has provided the rationale for building a UHV transmission network in China. The goal of China's UHV development is to meet the requirements of one of the world's largest power systems to handle growing electricity demand by transmitting power across long distances.[16]

Indeed, this is precisely why the development of a UHV transmission system has become so well integrated into China's national energy priorities. With the world's largest cumulative wind installation and a large amount of solar power generation capacity coming online, the Chinese government is trying to use UHV transmission to accommodate the country's swelling installed renewable capacity, all the while alleviating congestion in high-curtailment areas of renewable power.[17] To put this a bit differently: UHV projects are an important component of China's sweeping national industrial policy.

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Currently, China's transmission and distribution (T&D) networks are dominated by two important state-owned firms: State Grid Corporation of China ("State Grid") and China Southern Power Grid Company ("Southern Grid"),[18] which control roughly 80 percent and 20 percent, respectively, of the entire country's T&D assets.[19] As the largest electrical utilities company in the world, State Grid has outsized influence on all aspects of China's UHV transmission development, including the formulation of national plans and industrial standards, technology research and development (R&D), infrastructure investment, and the piloting and testing of new technologies.[20]

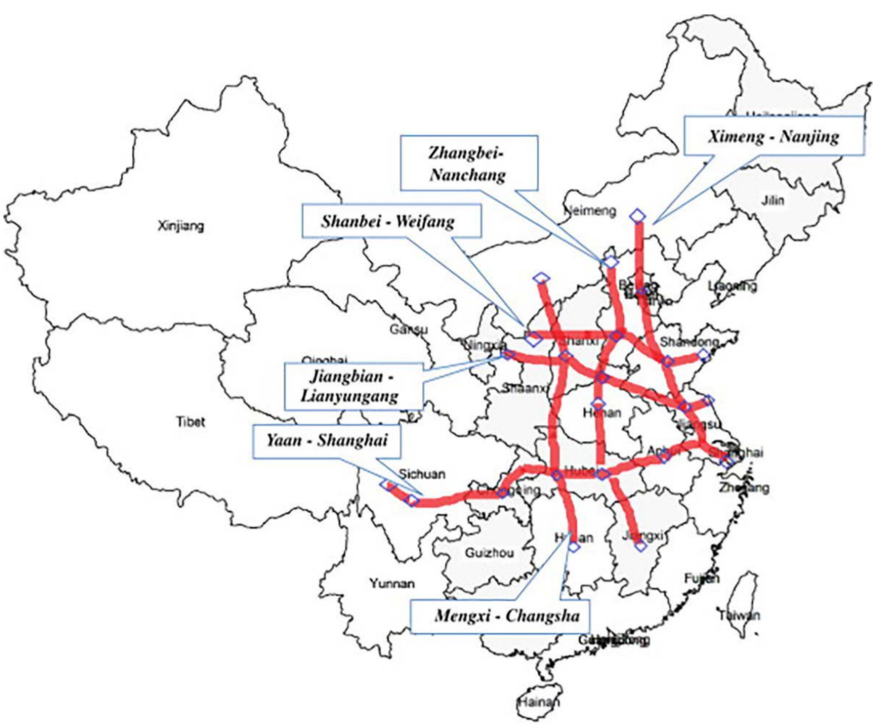
The continued advancement of UHV technologies in China would bring tremendous benefit to both State Grid and Southern Grid. For one, constructing a national UHV transmission network would help them to consolidate their dominant positions in China's electric power industry. It would also ensure a new source of income, improve the efficiency of asset utilization and operation, and allow both companies to strengthen their positions in the power industry in China and globally.[21]

In contrast to Russia and Japan, whose UHV transmission projects are limited to the construction of lines, State Grid proposed at the 2009 International Conference on UHV Power Transmission in Beijing that a "strong and smart" grid be developed.[22] And State Grid has ambitious plans for realizing that goal as early as 2020. Such a grid would be composed of numerous 1,200 kV AC and 1,100 kV DC lines.

The concept of a "strong" grid means that the UHV system would serve as the backbone of the national power grid to ensure enhanced reliability and stability of system operations. Meanwhile, China would continue to build "smart" grids by incorporating wind and solar energy, energy storage, energy transmission monitoring, intelligent substations, and smart meters.[23]

The basic goal, as State Grid has argued it, is to develop a modern power system,

Figure 2. China's National UHV Plan



Source: Innovation Norway, Korea Maritime University, Azure.[26]

centered on "strong" infrastructure and "smart" control technologies.[24]

Chinese Projects Under Development

To date, very few countries have actually built an operating UHV system, much less one on the scale that China intends. And this means that there is little prior experience anywhere in the world that can be used as a precedent to evaluate or guide China's planning.

As a general matter, building a UHV system requires tackling technical issues, such as reactive power, voltage control, and the security of large-scale AC/DC grids, among others.[25] As a result, State Grid is leading China's effort to invest in UHV pilot projects, having tabled a proposal to create a "three vertical, three horizontal" UHV grid by 2015 (see Figure 2).

One of these routes, the Jingdongnan-Nanyang-Jingmen (JNJ) UHV AC Demonstration Project, was commissioned in 2009 and is considered to be the first commercially operated 1,000 kV line in the world.[27] More than 90 percent of the equipment being used in this JNJ project is reportedly designed and manufactured domestically in China. In addition, the Huannan-Shanghai project, a separate line, is the first commercially operated UHV AC project to transmit double circuits on the same tower.

Nor is State Grid alone in this effort. For its part, Southern Grid was responsible for building China's first ±800 kV UHV DC transmission demonstration project in 2010,[28] the Yunnan-Guangdong line, which set a considerably lower 60 percent local content requirement, which means using domestically produced equipment.

To date, a total of two UHV AC and six UHV DC projects are in operation in China. State Grid runs six, Southern Grid two. Additional UHV projects are under construction (see Table 1).

State Grid and other supporters of UHV in China have seized on the current battle over air pollution and the environment, in particular, to justify the broader expansion of this nascent UHV system. Although it is not entirely clear whether UHV systems will significantly reduce air pollution, the effort aims, at least in principle, to place generation centers (where most of the pollution is generated) away from dense urban centers.[29] And the more powerful UHV transmission lines are expected to, in turn, be more capable of handling electricity demand that has been growing in China at 10 percent annually for much of the last decade.

This is why China's central government has promoted another nine UHV projects in 2014, including four UHV AC and four UHV DC lines built by State Grid, and one UHV DC built by Southern Grid. Under this so-called "Four AC, Four DC" program, the National Development and Reform Commission (NDRC), China's central economic planning and regulatory body, approved the Huainan-Nanjing-Shanghai UHV AC project in April 2014.

Table 1. Existing and Planned UHV Projects

Year	Region	Technology	Operator	Capacity (GW)	Circuit Length (km)
Nov 2006-Dec 2008	Jindongnan-Nanyang-Jingmen	1,000 kV UHV AC	SGCC	5	654
Dec 2006-Jun 2010	Yunnan-Guangdong	±800 kV UHV DC, 12-pulse bipole	CSCC	5	1,418
Dec 2007-Jul 2010	Xiangjiaba-Shanghai	±800 kV UHV DC, 12-pulse bipole	SGCC	6.4	1,907
Dec 2009-Dec 2012	Jinping-Sunan	±800 kV UHV DC, 12-pulse bipole	SGCC	7.2	2,095
Dec 2010-Jun 2013	Luozhadu-Guangdong	±800 kV UHV DC	CSCC	5	1,413
Oct 2011-Sep 2013	Huainan-Wannan-Zhebei-Shanghai	1,000 kV double circuit UHV AC	SGCC	8	2x649
May 2012-Jan 2014	Hami-Zhengzhou	±800 kV UHV DC	SGCC	8	2,192
Jul 2012-Jun 2014	Xiluodu-Zhejiang West	±800 kV UHV DC	SGCC	8	1,680

Source: Hu, Thomas, Zhang.[30]

All this has made China's UHV development plan one of the most comprehensive and capital-intensive in the world, which may bring China some distinct technological and standard setting advantages when compared to other countries with an interest in UHV technology.

For example, the wide deployment of UHV projects in China owes much to the fact that Chinese utilities are allowed to build infrastructure faster than in most places in the world today, and they have ready access to cost-competitive equipment.[31] What is more, it is feasible to impose a consistent adoption of UHV standards nationally in China because of its vertically integrated ownership of utilities and manufacturing capacity.[32]

So China is likely to achieve the development and deployment of UHV technologies at a faster pace than other countries. As a point of comparison, take the United States: it

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generally requires coordination between transmission grid owners and regional reliability coordinators to determine whether new transmission lines should be built (e.g., MISO, PJM). And other key barriers to the development of UHV transmission in the United States include uncertainty of returns on new energy investments due to the lack of unified technology standards, as well as a wide array of regulations applicable to new energy sources,[33] cost allocation, and land acquisition.[34]

Chinese Indigenous Innovation for UHV

To support the indigenous development of UHV technologies in China, the government has an 80 percent local content requirement.[35] In the Chinese UHV market, then, domestic firms are in a clearly favorable position, although foreign investors can participate in the UHV transmission segment.[36]

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Indeed, because the T&D system in China is highly vertically integrated, it is difficult for foreign players, or even Chinese private sector players, to become involved in the sector. For instance, State Grid has acquired several pioneering electric power equipment companies, including XJ Group (Henan province), Nari-Relays (Nanjing city), and Pinggao Group (Henan province), reinforcing the prevailing vertical integration model in China.

Having such a model means that such Chinese equipment manufacturers have become the primary *de facto* suppliers to China's UHV projects. As one of State Grid's subsidiaries, for instance, XJ Group is the only manufacturer that provides both protection and converter valves for national HV DC projects in China. A "bidding by invitation only" system has been used in the bidding process for supplying relay protection devices.

As a consequence, leading global T&D companies have had mixed success in trying to enter the Chinese UHV market. Global companies such as Siemens (Germany) and ABB (Switzerland) have long sought entry into state-controlled energy markets in China,[38] but have only been permitted limited market access—and that access has come only in exchange for transferring technology to Chinese UHV equipment manufacturers.

Here is one example: XJ Group has been cooperating with Siemens in research on HV DC control and protection strategies to enhance its competitive position in the Chinese market.[39] Another example: Japan's Toshiba provided 750 kV and 1,000 kV gas insulated substation (GIS) technology for the Pinggao Group, making the latter a rival in the Chinese UHV market.[40] During the construction of UHV DC projects, ABB supported State Grid on the Xiangjiaba-Shanghai

UHV DC project, while Southern Grid worked with Siemens on the Yunnan-Guangdong UHV DC project.

As a result, the participation of foreign firms has primarily served a domestic purpose for Chinese government and corporate players: the Chinese entities leveraged the technological support of these multinationals to further develop and enhance the competitiveness of their own indigenous Chinese technologies.

So in general, after a history of several cooperation projects, the trend in China seems to be that a domestic supplier receiving State Grid investment will develop a competing solution that eventually displaces the original foreign supplier of the equipment. This is precisely what is happening in the Chinese UHV transmission market, and in many market segments as well. For example, this is similar to the approach China took in its high-speed rail (HSR) program, where the transfer of foreign technologies was eventually replaced (and the foreign firms displaced) by the growing strength of domestic competitors.

By assimilating and then localizing UHV technologies in this way, more than 100 Chinese companies have participated in supplying UHV equipment to national projects, with some becoming industry leaders that have made remarkable advancements in low to mid-end UHV and HV equipment manufacturing.[41] Today, China possesses the intellectual property rights (IPR) to its own UHV technology.[42] And China can apparently produce domestically over 90 percent of its own UHV AC equipment and 70 percent of UHV DC equipment.

The Jinping-Sunan project illustrates this: this UHV transmission line was independently designed, with much of the equipment made in China, including the converter bushing, converter valves, and, for the first time, even the control software. For the two UHV DC projects commissioned in 2014, including Hami-Zhengzhou and Xiluodu-Jinhua, both have larger transmission capacities, more advanced technology, and most important,

Table 2. Key Technologies for UHV AC Systems

Equipment	Domestic Manufacturer	Foreign Manufacturer
Transformer	Tebian Electric Apparatus (TBEA) Shenyang, XD Electric, Tianwei Baobian	Trench UK, Siemens, ABB, Alstom Grid (France)
Circuit Breaker	XJ Group	Alstom Grid (France)
Current Transformer	Tianwei Baobian (TWBB) Electric	Trench Germany
Voltage Transformer	XD Electric	Trench Canada

Source: Asplund, G.[43]

Table 3. Key Technologies for UHV DC Systems

Technology	Function	Domestic Manufacturer		Foreign Manufacturer
		Company	Intellectual property	
Converter transformer	Obtain the AC voltage needed for the required DC voltage; obtain 12-pulse operation (star and delta connection); allow for series connection of 6-pulse bridges	Tebian Electric Apparatus (TBEA) Shenyang, China electric power equipment and technology (CET)	World class manufacturing, created the first UHV converter transformer of the highest voltage and largest capacity but with the same transmission constraints as a 500 kV converter transformer	BHEL (India), ABB (Switzerland), Siemens (Germany), Alstom Grid
Thyristor Valve	Perform the AC to DC conversion and vice versa	C-EPRI, XJ Group (Henan)	Researched, developed independently & made by and in China, ~20%-30% cheaper than similar types of products, but leads world in voltage, current, and capacity	AREVA (UK), Siemens, ABB
Smoothing Reactor	Connected in series to the converter terminals as a smoothing element for the DC current	TBEA (China)	World class, widely used in China and abroad	Trench (Austria)
Disconnector	Provide a safe isolation of all equipment in case of system shut-down, including during maintenance	Pinggao Group (Henan)	Researched and developed independently by, and made in, China	Siemens
Bypass Breaker	DC Yard equipment	XD Group	Researched, developed independently, and made in China	Siemens
Capacitor	Reactive power equipment used to prevent high-frequency noise from entering the DC overhead line, and to provide a connection path for the DC line-fault locator signal	Siyuan Electric (Shanghai)	Researched and developed independently, and made in China	ABB
Surge arrester	Key components for system security in case of line faults caused by lightning strikes	EPRI Toshiba Arrester (ETA)	Researched and developed jointly by China and foreign players, made in China	Toshiba (Japan), Mitsubishi Electric (Japan), ABB, Siemens
Support insulator	Use silicone casings to provide hydrophobic behavior on the surface of the insulators, which greatly reduces the risk of flashovers due to pollution	Nantong Shenma Electric (Jiangsu)	Researched and developed independently, and made in China	NGK insulators (Japan), Sediver Insulators (France)
Disconnector	Provide a safe isolation of all equipment in case of system shut-down, including during maintenance	Pinggao Group (Henan)	Researched and developed independently by, and made in China	Siemens

Source: Asplund, G.[44]

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were considered to be indigenously developed (see Tables 2 and 3).

But beyond digesting foreign technology technology, State Grid has also achieved its own technological breakthroughs in high-end UHV lines, especially in the fields of over-voltage and insulation coordination, design of transformer substations, and lines for high altitude and extremely cold regions.[45] When it comes to converter valves, considered to be the core equipment of UHV DC lines, it is a State Grid subsidiary, the China Electric Power Research Institute (C-EPRI), that owns the IP for the A5000 type of UHV DC converter valve. This valve technology has received third-party certification by DNV KEMA and has already been deployed in both the Jinping-Sunan and the Ziluodu-Zhejiang projects.

Internationalization of UHV Standards

China was a latecomer to the process of building its own UHV system. Japan, for example, began work on UHV transmission as early as the 1970s. Tokyo Electric Power Company (TEPCO) constructed two 1,100 kV UHV projects in 1999, which are now operated at 550 kV.[45] And Japan's early start gave it an edge in setting standards for these technologies. In December 2006, an international standardization committee on UHV systems was established in Japan, which has aimed to actively promote the country's 1,100 kV UHV standards through participation in international standardization activities.[46]

Photo: Flickr/Peter Nijenhuis

Nor has Japan been alone as an early adopter and promoter. European countries and the United States have also developed UHV technologies, but currently neither of them has UHV lines in operation. Over several decades, the United States, the Soviet Union, and Italy all proposed different UHV standards, and the IEC accepted the 1,200 kV (US and USSR) and 1,050 kV (Italy) standards in 1977 and 1997, respectively.

It makes sense to harmonize various standards globally because UHV systems are quite different from EHV transmission networks in terms of topology, conductors, short-circuit power through UHV transformers, line lengths, and insulation coordination.[47] Such harmonization plays a crucial role in safeguarding interoperability, eliminating technical barriers to trade, enabling information exchange among different components (e.g., transformers, switches, and breakers) of a power transmission system.[48] It can also help catalyze investment in technologies, such as hydropower and wind power.[49]

For this reason, the Council on Large Electric Systems (CIGRE) established a working group in 1988 composed of experts in UHV transmission.[50] The council agreed that, with the maturing of UHV transmission technology, a ±800 kV UHV line would be technically feasible.[51] In 1994, CIGRE detailed more specifically the main characteristics of UHV transmission lines and equipment to serve as a global reference on UHV construction and equipment manufacturing.[52]

In October 2007, the IEC and CIGRE established a joint IEC-CIGRE coordination group to create a UHV AC standards roadmap.[53] One of the main tasks of this coordination group is to evaluate existing HV AC standards and then select those that can be extended to fit the UHV range. Here is why: insulation requirements for UHV lines will mean that all equipment must be designed appropriately to be structurally sound and strengthened.[54] Some of this is still achievable with existing technologies by extrapolating from lower voltage applications.[55]

Three UHV-related international conferences were held in Beijing between mid-2007 to early 2010. These meetings successively laid out the plans necessary to support UHV technology and its potential applications.

In 2008, IEC and CIGRE recommended the 1,000 kV UHV AC line as the international standard voltage,[56] a standard that the IEC subsequently approved on May 22, 2009 as the highest voltage for equipment of its type.[57]

In April 2013, another international colloquium on UHV was held in New Delhi, India, covering various issues related to the use of manufacturing, lab and field tests for insulation coordination, and the selection of technical parameters and equipment.

China and the International Development of UHV Standards

Throughout this process, China has sought to be a significant player in developing international standards for UHV transmission. And it is currently utilizing this global coordination process to internationalize its own indigenous UHV technologies,[58] particularly by promoting UHV DC standards.[59]

Beijing's active role in this realm reflects a two-pronged strategy. First, China is attempting to become established within the UHV-specific global standards system. Second, Beijing aims at the longer-term strategic goal of internationalizing its own UHV technologies, and thus to see these accepted internationally.

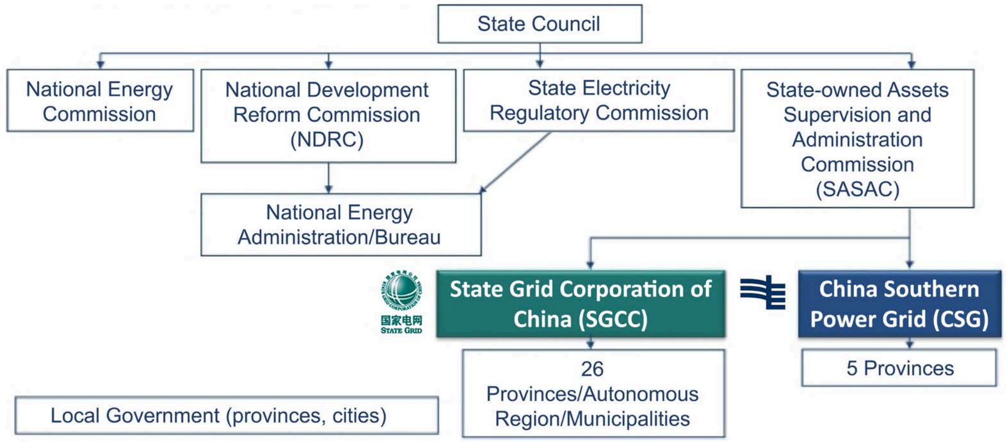
Cooperation with foreign companies has been limited thus far in China's UHV development. Still, it is part and parcel of the requirement for international standardization and commercialization of domestic standards.[60]

China's active involvement in international standardization organizations has thus allowed Chinese companies to include national preferences in international UHV standards. And the Chinese firms have sought to increase the chances of establishing a global consensus on technical specifications and market access requirements that would be favorable to their technology.[61]

Standard Setting in China

In China, standards are legally categorized into industrial, local, and enterprise standards. The national and

Figure 3. Organizations Involved in Developing China's UHV Standards



Source: Schuler, P.[64]

specific industrial standards are then, in turn, divided into mandatory and voluntary standards.[62]

The Chinese central government formulates and certifies these various standards, and the mandatory standards are often considered to be equivalent to state technical regulations.

Numerous standards development bodies are involved in setting Chinese UHV standards (see Figure 3), a process coordinated by the National Energy Administration (NEA),[63] which is a key agency under the NDRC. Ultimately, the leading player in UHV standards development is actually State Grid and its subsidiary, C-EPRI.

The State Council is not directly involved in the UHV standards development effort, but has created the Standardization Administration of China (SAC) to draft, manage, and approve most technical standards (see Box). Of course, SAC has a symbiotic relationship with Chinese industry and companies. After all, they too are heavily involved in setting standards, much as is the case in the United States.

This is especially the case for UHV technology because of the disproportionate reliance on State Grid for all aspects of the technology, from R&D to construction. The firm is one of just 113 "central" state-owned enterprises (SOEs) managed directly by the State-owned Assets Supervision and Administration Commission (SASAC), whose chairman is appointed directly by the Organization Department of the Chinese Communist Party.[65]

The central government also plays an important role in developing relations with foreign players. It helps initiate standardization in China, deal with stakeholders influenced or affected by alternative standards, and handle the international politics that might

Box 1. Other Players in China's UHV Standardization Process

As the representative of the Chinese government in international and Asian regional organizations devoted to standard setting, the SAC is responsible for harmonizing Chinese technical regulations and standards with international practices. To further develop China's UHV standardization system, several technical committees have been established with the support of SAC and the China Electricity Council, including a national standards committee for HV DC power transmission projects and a national standards committee for UHV AC power transmission technologies.

Other major Chinese players involved in UHV standardization efforts include the China Electronic Standardization Institute, the Instrumentation Technology and Economy Institute of China, and the China Communication Standards Association.[66]

arise from conflicts between domestic and international players and their respective technical standards.[67]

The central government also protects Chinese domestic equipment suppliers for UHV projects, such as Tebian Electric Apparatus, XD Group, XJ Group, and Tianwei Baobian Electric, among others. That protection has allowed them to incubate and test technologies domestically before they are exposed to, or pursue inclusion in, international standards arrangements and regimes.[68]

Modest Pushback

To be sure, the intimate relationship between government and State Grid does not mean that Beijing and the firm always see eye to eye on standard setting. For instance, State Grid had laid out an ambitious plan in its own corporate version of the national 12th Five-Year Plan (FYP) to build 10 UHV projects by 2015, and another five by 2020.[69] Yet Beijing had second thoughts on State Grid's plan when its first UHV AC project, running between Jindongnan and Jingmen, demonstrated subpar performance and saw cost overruns.[70]

Indeed, the price tag for what State Grid hopes to achieve is astronomical: a cost of roughly $1 million/mile of UHV lines, and each of the company's planned trunk lines would cost billions of dollars. But more than just the question of cost, the central government is also wary of State Grid's ambitions for other reasons.

First, State Grid is increasing its monopolistic position in all aspects of UHV technology, thereby limiting competition even for other Chinese firms and making market entry next to impossible.

Second, Beijing has also felt some public resistance to the speed and scope of UHV expansion. For example, conflict over land acquisition for these massive projects and possible localized environmental and health impacts due to electromagnetic radiation, may yet lead Beijing to take a more active role in managing how the UHV projects progress.

Third, as Beijing's economic and energy priorities have shifted to emphasize more renewable energy and energy storage development, it may push State Grid to focus more on the "smart" part of its grid expansion rather than devoting vast resources to the "strong" part. Already, the State Council has postponed the construction of some new UHV projects, forcing State Grid to slow its "Strong and Smart Grid Development Plan."[71]

Indigenizing UHV Standards

Broadly speaking, China's national policy on UHV standards aims not just to advance the commercial interests of the country's power industry in the short term but to also create a paradigm for developing a national innovation ecosystem over the long run. State Grid-led UHV standard setting aims to ensure the quality and security of UHV projects in (and for) China, to provide a large market share for the domestic power transmission and substation equipment manufacturing industry, to enhance the international influence of Chinese UHV technologies, and ultimately to promote the technical development of Chinese power transmission equipment.[72]

But another reason for pursuing indigenous UHV standards is China's implicit aim to reduce its dependence on foreign IP. Currently, some of the domestically developed UHV standards are admittedly local variants, or even a direct replication, of foreign technologies. And these, the government believes, do little to improve the innate innovation capacity or competitiveness of Chinese firms.

As a result, China has attempted to protect its domestic industries by setting its own national technology standards.[73] The bet is that, with such standards in place, Chinese designers can provide specifications for UHV equipment, manufacturers can conduct the design, production and testing of the equipment, utilities can carry out on-site testing and commissioning, and Chinese technologies can be improved and their costs reduced.

To bridge the gap between UHV technologies and China's UHV standards system, State Grid decided to develop its own UHV standards framework to guide the construction of new UHV projects. This firm-level standardization plan comprises three phases.[74]

The first, which ran from 2009 to 2010, aimed to achieve an initial standards framework through technical innovation and experimental projects. Out of the total investment of $77.8 billion (482.4 billion yuan) in the first stage, State Grid itself invested $12.11 billion (75 billion yuan) in UHV standards development.[75]

Table 4. UHV Pilot Projects

System	Line	Purpose
1,000 kV Single Circuit UHV AC	Jingdongnan-Nanyang-Jingmen	Test the performance of UHV system; verify the reliability of equipment; optimize research and design; realize commercial operation
1,000 kV Double Circuit UHV AC	Huainan-Wannan-Zhebei-Shanghai	
±800 kV UHV DC	Xiangjiaba-Shanghai	Point-to-point bulk energy transfer over very long distances

Source: Yu, Yang, and Chen.[76]

And that amount was further divided into $8.32 billion (51.6 billion yuan) allocated for UHV AC and $3.78 billion (23.4 billion yuan) allocated for UHV DC construction.[77] This money was targeted at R&D for essential electric devices in the establishment of a master roadmap, with several demonstration projects,[78] all of which the firm claims to have achieved (see Table 4).[79]

The second and current stage of State Grid's plan spans the 12th FYP period of 2011 to 2015, with State Grid spending $43.8 billion (272 billion yuan) out of an anticipated $283 billion (1.75 trillion yuan) allocated for the promotion of UHV.[80]

But the establishment of national standards is also supplementary to the present international UHV standardization landscape. Relatively comprehensive Chinese national standards for smart grids should also be developed by 2015, with the intent to align them closely with global smart grid standards.

In the third and final stage (2016-2020), which would span the 13th FYP period, a nationwide strong and smart grid would, State Grid hopes, finally be built.[81] By then, China would have established advanced and comprehensive standards at an international level for smart grids, with an estimated $36.5 billion (226 billion yuan) to be allocated for UHV expansion.[82]

Ultimately, the completion of a national Chinese UHV network will require hundreds of distinct standards, specifications, and requirements.[83] But at this point, eight types of UHV transmission standards are being prioritized, including UHV AC/DC planning and design, construction, equipment and operation, inspection, dispatching, among others.[84] After the completion of the first pilot UHV AC project in 2009, 15 national standards for UHV AC transmission systems were issued to guarantee the reliable and effective application of such technologies (see Appendix).[85]

Chinese Participation in International UHV Standard Setting

Since 2012, State Grid has also been active globally. It has served as a member of the Institute of Electrical and Electronics Engineers Standards Association (IEEE-SA) Corporate Advisory Group, where it is responsible for offering strategic guidance on UHV transmission to IEEE-SA corporate members, as well as to the IEEE-SA Board of Governors.[86]

State Grid is also vigorously engaged in IEC technical committee activities. At present, it serves as the secretariat for three IEC technical committees (PC 118, TC 115, and TC 85) and holds one committee chairmanship (TC 95). In 2013, the Executive Vice President of State Grid Shu Yinbiao was selected as the IEC's vice chairman.[87]

State Grid has proposed two technical committees for UHV AC systems and

Table 5. Chinese vs. International UHV Standards

International Standard	Corresponding Chinese Standard	Status
IEC 62271-100 (April 2008) "High voltage alternating current circuit-breakers"	GB/Z 24838-2009 "Specification for 1,100 kV alternating current high-voltage circuit breakers"	Chinese version is applicable for 1,100 kV while IEC's current version is not.
IEEE Std 1862-2014 "Recommended practice for overvoltage and insulation coordination of transmission systems at 1,000 kV AC and above"	GB/Z 24842-2009 "Overvoltage and insulation coordination of 1,000 kV UHV AC transmission project, standard guide technique file of China"	Proposed in June 2011, approved in May 2014
IEEE Std 1860-2014 "IEEE draft guide for voltage regulation and reactive power compensation at 1,000 kV AC and above"	GB/Z 24847-2009 "Technical guide on 1,000 kV AC system voltage and reactive power"	Proposed in June 2011, approved in March 2014
IEEE Std 1861-2014 "IEEE guide for on-site acceptance tests of electrical equipment and system commissioning of 1,000 kV AC and above"	"On-site testing standards and system commissioning procedures for 1,000 kV and higher voltage UHV AC equipment"	Proposed in June 2011, approved in June 2014

Source: IEEE.[88]

large-capacity renewable energy generation and operation. Meanwhile, State Grid has participated in CIGRE's 15 technical committees and has maintained positions on various working groups and task forces.

Since 2009, State Grid has presented three IEC standard proposals for international UHV AC standardization, including a specification for 1,000 kV series compensation equipment for transmission lines, a specification for a 1,000 kV controllable shunt reactor, and a guide related to a hand-over test of 1,000 kV equipment.

State Grid has also prepared five additional IEC HV DC national policy statements.[89] Among them, general guidelines for the design of ground electrodes for HV DC links was approved as IEC/TS 62344: 2007-05. Another that has received approval is an electromagnetic environment criterion for HV DC overhead transmission lines, approved as IEC/TS 62681: 2013-11.[90] In addition, State Grid has proposed three standards to the IEEE that are related to UHV AC technologies (see Table 5).[91]

In June 2011, IEEE organized a working group meeting to discuss three UHV AC related international grid standards proposed by State Grid.[92] The IEEE-SA Standards Board approved all three of these standards in 2014. Currently, the national test standard for 1,100 kV circuit breakers transient recovery voltage is not included in the IEC.

China's Position in the Global UHV Market

As China has made progress in equipment design, manufacturing, and system engineering, Chinese corporate and policy leaders clearly believe that the country is now a global pacesetter in UHV technology. Thus they now aim to increase market share internationally for Chinese designed and produced UHV technology.

Chinese manufacturers have taken modest initial steps, primarily in an effort to sell UHV-related equipment to developing countries. For example, the ability to provide low-cost infrastructure, on-time delivery, and cheap financing bundled together with equipment has given Chinese manufacturers an advantage in the Indian market, where Chinese products have taken a sizable share at the expense of Bharat Heavy Electricals Ltd. (BHEL) and other Indian companies.[93] And since they are among the few companies able to manufacture UHV equipment, the Chinese firm TBEA and XD Electric have won contracts to supply transformers and switchgear substations to India.

Chinese companies have also begun to increase their global market share in manufacturing electrical equipment, beating Japanese and South Korean competitors in the energy performance contracting (EPC) market through cost advantages. This mirrors the way Japanese and South Korean companies triumphed over European and American companies in various aspects of electronics manufacturing in recent decades.[94]

Much like Japan and South Korea before, China now seeks markets beyond its borders to sell indigenously developed UHV systems.

Indeed, much like Japan and South Korea before, China now seeks markets beyond its borders to sell indigenously developed UHV systems, particularly in emerging markets where China has strategic advantages and where Chinese vendors are able to offer competitive UHV equipment.[95] The BRICS countries (India, Brazil, Russia, and South Africa) appear to present the best opportunities for Chinese firms, as these markets seem to favor bulk power transmission to overcome the tyranny of long distances.[96]

Brazil is an example. In December 2010, State Grid acquired seven Brazilian energy companies and obtained a 30-year contract to transmit power to the southeastern region of Brazil. On February 8, 2014, a Sino-Brazilian consortium led by State Grid jointly agreed to build the Belo Monte Dam complex on the Xingu River in the Amazon.[97] At a cost estimated to be as high as $17 billion, this dam is expected to have a total power generation capacity of more than 11 GW, but will on average generate only 4 GW.[98] The planned 2,100 kilometer (1,300 mile) transmission lines will link Brazil's northern Para state to its southern state of Minas Gerais.[99] And the dam, when complete, will become the third-largest hydroelectric dam in the world, after China's Three Gorges and Brazil's Itaipu dams.

At present, Brazil is one of the largest destinations for outbound Chinese investment in the power transmission sector.[100] Because of more liberal, market-based electricity price policies that prevail in Brazil, State Grid expects a return on equity of up to 19.8 percent on the Sino-Brazilian UHV DC project, a profit about two to three times higher than in China where electricity prices are highly regulated.[101] Moreover, due to similarities in the geographical distribution of renewable energy resources and load centers, China's UHV transmission technologies can be potentially more effectively applied in Brazil.


Photo: Flickr/Ken Teegardin

These Brazilian projects provide Chinese engineers with an opportunity to play the central role in surveying, planning, design, and construction of Brazil's UHV transmission lines. As a major supplier of UHV DC devices, State Grid's subsidiary XJ Group will benefit tremendously from the Brazilian project.[102] State Grid will also gain expertise from its cooperation with Brazil in developing systems that separate power grid and power generation facilities. This, in turn, should be beneficial to China in influencing reforms of its own power sector.

The successful operation in China to date of 800 kV DC systems should lend confidence to power utilities in Brazil. State Grid has extensive experience in system construction, protection, control, and the maintenance of UHV projects under difficult conditions such as environmental pollution mitigation, stresses due to transient faults, commutation failures, and other actual system parameter variations. These experiences in operating UHV systems will almost certainly benefit State Grid in future cooperation in Latin America and elsewhere.

But China's extensive partnership with Brazil and other developing countries could also contribute to increasing divergence in global technology.[103] That is because standards specific to these countries cooperating solely with China create bilateral trade but not necessarily opportunities involving third countries (see Box).[104]

Vying for Global Market Share

Other countries may be aping China's industrial policy to push forward their own UHV development. At this point, as China has begun to export its technology, the broader global market appears yet to be fully convinced that Chinese suppliers can meet stringent quality and technical standards and third-party certification processes that have become global best practices. This has led some countries to seize a perceived window of opportunity to attempt to enter the global market and compete with China's UHVs. India is one such example. Although it has heavily relied on China's conventional voltage equipment in its own power sector, India is trying to limit overreliance on Chinese UHV technology in order to bolster its own domestic manufacturing base to develop indigenous technology, despite the Chinese inroads described above.[105]

As a global leader in the manufacturing of power products (such as circuit breakers, GIS, instrument transformers, transformer bushings, surge arresters, and disconnectors) up to 765 kV, the Indian company Crompton Greaves Ltd. launched a 1,600 kV UHV research center at its Switchgear Complex in Nashik in October 2013. And taking a chapter from China's playbook, India is likely to also target export markets in South America and Africa.[106]
Indeed, since UHV technology is still evolving and is only just becoming more widely adopted internationally, the Indian power industry has sought to enter the global marketplace by joining up 25 domestic manufacturers to build a 1,200 kV UHV national test station at Bina—the highest voltage level in the world.[107]
India's biggest transformer manufacturer BHEL has developed and tested the country's first UHV AC transformer of 333 MVA rating, which has been supplied to the central transmission utility PGCIL. For its part, Crompton Greaves has announced the development of its first indigenous 1,200 kV auto transformer. Beyond these emerging market players, many established multinational companies, especially Germany's Siemens and Switzerland's ABB, still have a significant marginal market share in the world's UHV projects. These companies have targeted the Indian market as well, since that country appears intent on developing a UHV system to rival China's. India is, it seems, collaborating with Western companies while attempting to limit China's role in its market.

In the development of India's first UHV AC project,[112] for example, Siemens developed and supplied 1,200 kV circuit breakers and surge arresters for the Bina test station. Alstom India (also known as Avera T&D) has strengthened its position in Indian UHVs through collaboration with PGCIL to supply the

1,200 kV capacitor voltage transformers. KEC International is in charge of the 1,200 kV double-circuit line in the world's highest voltage test project.

Meanwhile, a consortium of ABB and BHEL won a $250 million order to deliver an ±800 kV UHV DC transmission system from the northeast region of India to Agra, which will make India the world's second country to possess this technology.

Box 2. International Firms in China's UHV Market

As one of the two biggest suppliers in the HV DC transmission sector, Siemens has planned, designed, and erected approximately 20,000 km of high-voltage power lines up to 245 kV and 10,000 km of extra high-voltage lines above 245 kV around the world.[108] Besides the commissioning of two HV DC transmission links in southern China (Luozhadu-Guangdong and Xiluodu-Guangdong), Siemens will install the first underwater 600 kV HV DC cable to connect Scotland and England.[109]

ABB, the other major multinational HV DC supplier, also has extensive experience with such technologies.[110] It delivered the world's largest transformer in 1942 with a capacity of 220 kV/120 MVA, and the world's first 800 kV UHV DC power transformer for the 2,000 km Xiangjiaba-Shanghai transmission link in China (see Table 6). The company has been involved in the Chinese market for transmission and distribution equipment since 1974, and made a profit of some $5.2 billion on China sales in 2012. The Xiluodu-Zhejiang West project awarded ABB an order worth around $150 million to supply equipment, including converter transformers, DC filter capacitors, and converter valves.

But although Siemens and ABB have long been recognized globally for their transmission technology, Chinese companies have successfully penetrated the Brazilian UHV and Indian HV markets, and are able to compete vigorously with multinationals based on China's own technology offerings.

As the third country in the world to have mastered the thyristor technology for UHV DC systems after Sweden and Germany, China is now a leader in the UHV DC industry, which has resulted in carving into the UHV DC market share for ABB and Siemens. This trend is unlikely to change in the near term as China increasingly seeks to be an active participant in international UHV projects.

Table 6. Major UHV Players Vie for Global Markets

Country	Company	System	Project
India	ABB + BHEL + PGCIL	800 kV UHV DC	North-East Agra (2015)
	Siemens + PGCIL	1,200 kV UHV AC	UHV national test station at Bina (under construction)
Brazil	State Grid + Furnas + Electronorte	800 kV UHV DC	Northern Para state-Southern state of Minas Gerais (planned)
China	ABB + State Grid	800 kV UHV DC	Xiangjiaba-Shanghai (2010), Jinping-Sunan (2012), Hami-Zhengzhou (2014)
		1,100 kV UHV DC	Zhundong-Chengdu (2015)
	ABB + Alstom + State Grid	800 kV UHV DC	Xiluodu-Zhejiang West (2014)
	Siemens + State Grid	800 kV UHV DC	Xiangjiaba-Shanghai (2010)
	Siemens + Southern Grid	800 kV UHV DC	Yunnan-Guangdong (2010), Luozhadu-Guangdong (2013)
	Southern Grid	800 kV UHV DC	Jinping-Sunan (2012)
		1,000 kV UHV AC	Jindongnan-Nantang-Jingmen (2009), Huainan-Shanghai (2013), Zhejiang North-Fuzhou (2015)

Source: ABB.[111]

Implications of China's UHV Standardization

From the preceding analysis of the evolution of UHV technology and China's role in it, several conclusions follow about the future of the standards regime.

China's UHV Standardization Strategy Matches Past Patterns

For one, China's overarching strategy for UHV largely mirrors policy it has pursued in building an HSR network, as well as developing indigenous mobile phone technology. Ambition aside, both UHV and HSR in China have been based on a vertically integrated model, with the ultimate objective to export such technology to the global market.

China's overarching strategy for UHV largely mirrors policy it has pursued in building an HSR network, as well as developing indigenous mobile phone technology.

The difference between the two sectors is that China faces more risk with UHV because it is the first major global adopter of the technology at such a large scale. This means that as a latecomer to the global standards system, but as an early participant in international UHV standardization specifically, China's UHV standard setting functions differently from that of other major players.

In Europe, for instance, smart grid standards are prepared by the three European standards organizations, which collaborate on developing standards for the next generation of electricity networks. In the United States, smart grid standardization is an industry-led process, where manufacturers are in the leading market position for smart grid technologies.[113] But standardization of UHV technology in China is led by grid companies and driven by the central government, in large part because China's electric equipment manufacturers are vertically integrated with (and controlled by) the country's utilities.

Although China is ambitious, the country's technology standards policy for UHV is still a long way from posing a serious technological challenge to established multinational companies. That is due, in part, to bureaucratic infighting, out-of-date legal and administrative standardization systems, and heavy dependence for core technology on foreign companies.

Most important, China's crucial challenge to current UHV market participants is, at this point at least, not in the development of indigenous UHV technologies but rather in embedding inexpensive technologies into UHV standards development.

China has had mixed success in developing its own technology standards to compete with global technical standards and win market share. This was prominently illustrated in the case of the 3G mobile telecom standard TD-SCDMA. But there are some crucial differences with the UHV experience.

First, TD-SCDMA was developed amid the existence of two dominant—and reliable—international standards, WCDMA and CDMA2000. UHV standards, by contrast, are being developed without comparable existing international standards. Indeed, although TD-SCDMA was finally accepted as an international standard, it had failed to gain much market share. China's two major telecom carriers themselves ultimately decided to go with the more internationally accepted 3G standard WCDMA. In other words, there is not the same kind of competitive pressure in the UHV marketplace that occurred in the 3G telecom standards race.

Second, the Chinese government directly led TD-SCDMA through its various technology bureaucracy. The nation's grid companies, by contrast, spearhead UHV, although they are of course SOEs.

Still, it is difficult to judge whether China's indigenous UHV standardization will converge with, or diverge from, prevailing international standards, such as they are. That is because UHV technology itself continues to evolve.

To encourage domestic industries to apply national technologies, Chinese enterprises and standards organizations favor inexpensive licensing for embedded IP in UHV technology standards. And that, in turn, diverges from international organizations in terms of IP licensing.

Unlike in the United States where IP embedded in standards is regarded as a revenue stream from licensing fees, China only sees IP as a means to upgrade products.[114]

China has had mixed success in developing its own technology standards to compete with global technical standards and win market share.

The trend in China's standardization, therefore, shows that the greatest amount of effort is being made to achieve inexpensive technology breakthroughs by lowering licensing fees for embedded IP in UHV technology standards. This is viewed in China as a way to maximize the profit margin of UHV equipment producers at the expense of the IPR holders.

That is precisely why State Grid aims to become the primary producer of UHV transmission infrastructure for the global market. It hopes to do so by exporting the firm's UHV standards overseas and secure markets for its products.[115]

This strategy encourages market acceptance of Chinese UHV technologies

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by charging as little as possible. It thus incentivizes other firms to support or adopt indigenous Chinese technologies. If successful, this could pose a challenge to leading multinational companies, not least by affecting the means through which IP in standards is monetized and licensed.

Factors Affecting the Implementation and Harmonization of China's UHV Standards

China faces considerable technical, economic, and political challenges to realizing its UHV highway plan.

The frequent revision of the plan is due, in part, to the recent recognition that the existing wind power spillage problem in certain parts of China is more a problem of wind power overcapacity in regions without adequate transmission, rather than of insufficient transmission infrastructure.[116]

China will also face challenges in maintaining system security as the UHV system expands and becomes more integrated. This remains one of the strongest and most persistent technical challenges to its overall UHV network. The potential risks of extreme weather conditions affecting long transmission lines add to the expected vulnerability to blackouts, when local problems could develop into a system-wide shutdown.[117]

Expanding China's UHV network could also be delayed or impeded by the complex and cumbersome process of evaluating and approving projects. This involves coordination among project proposals and grid operators, local and central governments, and grid companies.

The weakness of private enterprises in China, and their inability to effectively participate in standardization, is also a major concern. Although private electrical equipment enterprises should, in principle, become the main forces behind the international standardization of UHV technology, only a few SOEs, such as State Grid, have the ability to participate in standardization at the national and international level. For other smaller businesses, there is no strong incentive to participate in UHV technology innovation or related standards development.

For other smaller businesses, there is no strong incentive to participate in UHV technology innovation or related standards development.

Unlike dominant multinational firms, there are few Chinese companies with sufficient clout and market power to set enterprise standards that could shape the whole industry worldwide.[118] Most of the Chinese manufacturers involved in the development of the country's UHV projects are owned by State Grid, whose monopolistic position remains a concern to regulators and is a potential impediment to future industry reforms. China's vertically integrated model

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would likely ensure market share for the equipment company (and sustain shareholders' profit through eliminating competition and bidding beyond market prices).[119] Consequently, the excluded Chinese manufacturers have inadequate financial muscle and little incentive for R&D, and thus can rarely enter into the UHV market. This combined with State Grid's strategy of lowering equipment costs will almost certainly impede innovation in the overall development of UHV technology in China.

Alternative Scenarios for Chinese UHV Standardization

Still, China's experience in UHV development and operation, as well as India's, can be beneficial for power transmission around the world. China leads the world in the development of UHV technology, with heavy involvement now in both its domestic and Brazilian markets. But China is no longer alone in this endeavor: India has a 1,200 kV UHV AC test station under construction, while Japan is also planning to upgrade its existing line from 550 kV to 1,100 kV over this decade.

But as noted above, UHV standardization is still at an early stage. So all three major Asian countries—China, India, and Japan—that are pursuing UHV expansion could ultimately determine international standards in a significant way.

In the short term, UHV standardization could foster the development of related technology and create a supply chain ecosystem. Asian countries compete in the UHV market by offering more choices for electrical equipment, more value, and better services to power generation developers.

The participation of equipment suppliers in China, Japan, and India also can improve the conditions of the system by reducing the price significantly and increasing efficiencies in the UHV market.

As a result, intensifying competition thus far has promoted the development of technology. And this, in turn, has had a positive effect on the market. Over the long term, however, this may discourage technically superior innovation when a large base of equipment is built on the basis of existing standards.[120]

The possibility that national UHV standards become a barrier to trade will depend on the relative competiveness of domestic and foreign producers.[121] On the one hand, national UHV standards foster exports when consumers in the importing country trust the standardization system and the standards serve as quality signals. In the case of the Sino-Brazilian project, China's UHV standards represent no barrier because Chinese producers are much more efficient than domestic producers in Brazil.

On the other hand, national standards are unfavorable for trade when preferences in the foreign market are significantly different from the market of the original country. For example, China's UHV standards are more suited to its complex geographical environment where UHV lines are routed through high altitudes and heavily iced areas. But this may not be the case in other countries (e.g., in Japan, where earthquake resistance may be more of a priority).


Photo: Flickr/David Clarke

China has shown tremendous initiative in the development of a national grid and related UHV standards. With its enormous domestic market and diverse local conditions, China's indigenous UHV standards may well have incorporated innovations that do not appeal to advanced industrial economies, as these markets are more focused on smart grid standardization and end-user solutions.

Yet the current lack of dominant global UHV standards rooted in the market does provide Chinese UHV technologies an opportunity to gain increasing credibility and market share. And this will be especially the case if the Sino-Brazilian UHV DC project performs satisfactorily.

It remains unclear whether China's other indigenous UHV standards (besides those already approved) will gain international traction and significant overseas market support. Various factors are in play, especially now that multi-country competition in the UHV market appears to be deepening.

Accounting for uncertainties, the following are several possibilities for how UHV standardization might progress:

1. **Baseline Scenario**: If China continues more or less down its current trajectory, then it will continue to compete in some markets where specific local conditions give China an advantage. But China will nonetheless face stiff competition from other UHV technologies and suppliers.

2. **Leading Technology Scenario**: If China enhances the competitiveness of its domestic industry in UHV transmission through sustained innovation, proving that it does have world-class technology at reasonable cost and thus becomes a credible supplier, then its first-mover advantage and scale of deployment should allow it to set global standards and dominate global markets.

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3. **Race to the Bottom Scenario**: By embedding cheaper technology, China could drive down UHV equipment costs so much that others cannot compete on price and are compelled to adopt Chinese standards and equipment.

4. **Late-Comers Catch Up Scenario**: If China fails to prove high performance and credibility of its domestically designed and manufactured equipment, then after a few years of operation competitors such as Japan and India will seize the opportunity to promote their indigenous UHV standards into internationally accepted ones.

5. **Establishment Players Win**: If none of the three major Asian countries succeed in promoting their indigenous UHV standards internationally, players such as ABB and Siemens will likely become the default international UHV standard setters.

Ultimately, there are potential risks in the process of harmonizing Chinese domestic UHV standards. To mitigate the risks of Chinese standards diverging from international ones, the following principles will be important for China:

1. **Ensure an Open UHV Market**: Adopting this principle will enable China to harvest the fruits of economic globalization and international competition in the UHV market by minimizing or removing the trade-distorting influence of border and behind-the-border measures.

2. **Participate in Diverse International Standard Setting Bodies**: This principle would mean that the Chinese government proposes and drafts study reports for international organizations like IEEE-SA, IEC, and CIGRE; enhances the perspective of Chinese standards representatives; and increases the predictability and transparency of China's own regulatory environment.

3. **Harmonize Domestic UHV Standards on a Global Basis**: This principle would mean that China unifies its various UHV product standards; promotes the technical level of indigenous UHV standards up to international standards; and increases the proportion of Chinese UHV technology in key international standards.

4. **Promote Innovation of Domestic UHV Technologies**: Adopting this principle would encourage and support the independent innovation capability of local electric manufacturers (e.g., XJ Group, Pinggao Group, etc.), particularly by accelerating the development of high-tech equipment, promoting technological progress, and optimizing the power industry structure.

5. **Protect IPR**: This principle should help to increase the confidence of foreign enterprises such as ABB and Siemens to invest and trade in high-tech products, engage in localized R&D, and bring more innovative technologies to China, where there is a large UHV market and abundant resources for deployment.

6. **Use Antimonopoly Tools Carefully and with Prudence**: This principle means preventing abuses by a monopolistic player such as State Grid, but also prohibiting administrative power that restrains competition. It would also mean creating a general system for review of mergers and acquisitions.

Appendix

Classification of Chinese Standards for UHV AC Systems

Standards	Content
UHV AC design standards	Specify technologies for planning and design, including principle for over-voltage and insulation coordination, technical measures for voltage and reactive power regulation, substation design, overhead power transmission line survey and design, etc.
Standards on UHV AC System Equipment and Test	Provide specifications for power transformer equipment, including transformers, reactors, potential transformer/current transformer (PT/CT), arresters, switches, etc.; also line equipment such as fittings and insulators, protection and monitoring devices, as well as guidance for on-site test method of special equipment.
Standards on UHV AC Engineering Construction	Provide specifications for project construction techniques, equipment acceptance, construction quality inspection and evaluation, acceptance, initiation, and system commissioning, etc.
Standards on UHV AC Engineering Operation and Maintenance	Provide specifications for UHV AC system operation, maintenance, management, live working, overhaul, and technical supervision, etc.

UHV AC Systems Standards

Chinese Standard	Existing international/national standards
GB/Z 24846-2009 “preventive test standards of 1,000 kV AC electrical equipment”	No existing international standard
GB/Z 24845-2009 “specification of metal-oxide surge arresters without gaps for 1,000 kV AC system”	IEC 60099-4:2006 “metal-oxide surge arresters without gaps for AC system”

Classification of Chinese Standards for UHV DC Systems

Standards	Content
Standards on UHV DC Design	Refer to system performance, electromagnetic environment, insulation coordination, pollution categorization, test, etc., and consist of three parts of contents, i.e. synthesis, converter station, and transmission line.
Standards for UHV DC System Equipment	Illustrate equipment performance and service conditions, and at the same time provide specifications and guidance for tests and measurement methods of equipment used in UHV DC projects.
Standards on UHV DC Engineering Construction	Consist of DC transmission line and converter station construction regulation, equipment acceptance test, system commissioning regulation, etc.
Standards on UHV DC Project Operation and Maintenance	Mainly cover HV DC transmission line and converter station operation guideline, equipment reliability evaluation, live working, scheduled maintenance of protection and metering.

UHV DC Systems Standards

Chinese Standard	Existing international/national standards
DL/T 5426-2009 "system design standard for ±800 kV HVDC system"	Refer to IEC 919-3" performance of high-voltage direct current (HVDC)," IEC TS 60071-5 "insulation coordination," IEC 1803 (Ed.1)" determination of high voltage direct current (HVDC) converter station losses," CIGRE study committee 14-DC links.
GB/T 25082-2010 "specification and technical requirements of oil-immersed converter transformer for 800 kV DC applications"	Modification of GB/T 18494. 2-2007 "converter transformers-part 2: transformers for HVDC applications," IEC 60296: 2003 "fluids for electrotechnical applications-unused mineral insulating oils for transformers and switchgear."
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Source: State Grid.

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