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The Search for High Power in China: State Grid Corporation of China

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INTRODUCTION

In 2016, a new international non-profit NGO was established: Global Energy Interconnection Development and Cooperation Organisation (Geidco).* Its first president was the recently retired chief executive of the State Grid Corporation of China (SGCC), Liu Zhenya, and its vice president was the Nobel Laureate, Steven Chu, former US Secretary of Energy (2009–13). Though with limited acknowledgment globally, Geidco has captured the attention of the world's largest electricity transmission companies and of international organizations, such as the International Energy Agency (IEA) and International Renewable Energy Agency (IRENA).[1] Geidco aims "to promote the establishment of a global energy interconnection (GEI) system, to meet the global demand for electricity in a clean and green way, to implement the United Nations 'Sustainable Energy for All' and climate change initiatives, and to serve the sustainable development of humanity." At the core of the GEI system is "Smart Grid + UHV Grid + Clean Energy." GEI was the brainchild of Liu Zhenya and SGCC, and brought SGCC, a state-owned corporation in China, to the global stage with its control over cutting-edge ultra-high-voltage (UHV) technologies. According to IEA, global power sector investment will be about US$20 trillion in 2015–40, averaging US$760 billion per year, and electricity networks will account for 42 percent of this investment (US$8.4 trillion). SGCC wants a piece of this action and, of course, market (IEA 2015, p. 320; IEA 2016a; IEA 2016b).

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1 See the joint IEA-SGCC workshop on "Global Energy Interconnection: Smart Grids and Beyond," 21–2 July 2015.

This chapter explains *why* and *how* the State Grid Corporation of China (SGCC) engaged in technology innovation, using the development of UHV AC and UHV DC systems as examples. SGCC's successful UHV development contradicts long held arguments that weak protection of intellectual property (IP) rights and distorted incentive structures discourage Chinese firms, especially those under state ownership, from engaging in high-risk innovation (Abrami et al 2014; Cheung et al. 2016). According to such skeptics, successful Chinese innovators, for example in industries such as telecom or renewable energy technology, tend to be private companies that benefit from state backing (Lewis 2013; Gallagher 2014; Zhou et al. 2016), with the government picking winners and pouring in resources that enable them to develop key technologies, thus confirming "the state's overwhelming power to implement innovation" (Liu and Peng 2014; Shim and Shin 2015). More often than not, however, government intervention does not lead to "innovation" but rather imitation, or what some have called, the "lower-end of the imitation-innovation with 'Chinese characteristics'" (Cheung et al. 2016). Has SGCC merely imitated its counterparts in developed countries? To what extent did it indeed engage in innovation? Why did it get involved in UHV projects in the first place? How did SGCC pursue UHV projects that were both high risk and high cost?

To address these questions, why and how, this chapter first discusses types of innovation SGCC engaged in. Transmission and distribution (T&D) business has always been considered as a natural monopoly not only because of its nature of non-exclusiveness but also because it is capital-intensive, with massive fixed investment and scale economies. The physical attributes of transmission and distribution (T&D) networks and the non-storable nature of electricity require precise coordination among generation, transmission, and distribution in real time. T&D does more than transport electricity from one location to another. It involves "a complex coordination system that integrates a large number of generating facilities dispersed over wide geographical areas to provide reliable flow of electricity to dispersed demand nodes while adhering to tight physical requirements to maintain network frequency, voltage and stability" (Joskow 1997, pp. 121–2). Given these features, for a century, the electricity industry around the world was vertically and horizontally integrated until the 1990s when electricity restructuring was pushed forward not only in developed countries but also by international financial institutions in developing countries. China first introduced the reform in the mid-1980s to lower the entry barriers to generation by allowing investments from sources other than the state. As part of the general state-owned enterprise

(SOE) reform, the electricity industry was commercialized and corporatized in the late 1990s when a vertically integrated state-owned monopoly, the State Power Corporation of China (SPCC) was created out of the Ministry of Electric Power in 1999.

In December 2002, the central government "unbundled" SPCC, parcelling out its assets to five power generation companies, two grid companies and four power services companies, all remaining state-owned under the supervision of the central government.[2] For historical reasons, SGCC was given the responsibility of building, managing, and operating cross-region transmission networks in twenty-six of thirty provinces and regions. The rest is covered by a smaller transmission company, China Southern Grid Corp Ltd. SGCC inherited most transmission and distribution assets and operation in the country from SPCC and some peak generation capacities. It was also asked by the State Council to manage many units of SPCC pending clarification of their ownership structures. More importantly, all eleven companies that spun off from SPCC remained state-owned under the supervision of the central government. The 2002 electricity restructuring was much criticized by both advocates and opponents of unbundling. Further criticism came from international institutions, including IEA and the World Bank, which viewed this reform as incomplete.

Even though it is among the top-tier SOEs under direct Party-state control and supervision, SGCC, like most large corporations, is complex and diverse in terms of its management, employees and activities. Among its 1.7–1.8 million employees, less than half worked at its headquarters and direct subsidiaries; about a quarter were employed by SGCC's county-level power supply companies; and one-third were (mostly part-time) rural electricians with limited expertise. Although SGCC was often seen as a monopoly, it owned only about 75 percent of the transmission and distribution lines and 88 percent of the transformers in its service areas. The remainder, along with many distribution assets were owned by local governments and other entities. Diverse ownership of assets and jurisdictions created continuing tension among SGCC, local governments and privately owned distribution companies. From its creation, SGCC was expected to operate as a corporation, even though its senior managers were appointed by the government. SGCC's

[2] At the time, SPCC controlled slightly over half of China's generation capacity, while the bulk of the remaining capacity belonged to provincial and local governments. Independent power producers with private and foreign ownership existed but were inconsequential. See Yeh and Lewis (2004); IEA (2006); OECD (2009).

operation expanded significantly in its first decade: between 2005 and 2015, revenue nearly tripled, total assets grew by 265 percent; and profits grew by six times.

SGCC is among a very few large SOEs to receive an “A” performance ranking from the State-owned Assets Supervision and Administration Commission (SASAC). When SGCC first entered the Fortune Global 500 in 2005, it ranked 40th, with annual revenue less than one third of that of Walmart, the global leader. A decade later, SGCC is the world’s largest utility and the second largest company in the Fortune Global 500 in terms of annual revenue, just behind Walmart. Its operation has expanded to overseas markets with direct investments in transmission, construction and operation in Brazil and the Philippines and equity investments in Australia, Portugal, Italy, and other countries. Investments in hundreds of transmission and distribution projects across Asia and Africa have helped transform SGCC into a truly global company.

SGCC’s greatest achievement is perhaps its success in mastering the technology of constructing and operating high-voltage transmission lines (defined as anything above 500kv), and its deployment of this technology to connect China’s entire population, including those living in the most remote villages in the Tibetan plateau and the Gobi desert. This chapter nonetheless focuses on SGCC’s endeavor in technology innovation in constructing and operating the so-called UHV networks that deliver large electricity across long distances using high-voltage lines to reduce transmission losses.

This first section shows that SGCC’s initial pursuit of UHV projects in 2004 was motivated more by self-preservation than innovation; it was also encouraged by overseas experimentation with UHV technologies. At the time, SGCC did not plan to engage in revolutionary, disruptive research and development (R&D), but rather tried to imitate and then adopt technology developed elsewhere. In the process, it changed its strategy to engage in R&D in order to succeed “in coming up with innovations that are adaptive, incremental, and appropriate to its stage of development” (Yip and McKern 2016, p. 10). Such a “fit for purpose” and “good enough” strategy, or what some call “secondary innovation” seemed to work for SGCC – “initially based on foreign technology, it goes beyond imitation and adaptation to something unique for China” (Yip and McKern 2016, p. 14).

These early efforts created a foundation for a subsequent effort to develop path-breaking transmission technology. Building on available UHV technologies, SGCC engaged in a panoply of innovative activities, from basic research, field and laboratory experiments, to equipment development and actual instalment. Worldwide absence of commercial UHV operations compelled SGCC to pursue a broad array of novel initiatives. It is important to understand why SGCC decided to take on high-risk, high-cost technology development and how it managed these risks and costs.

The second section discusses two sets of government policies – directed toward SOE reform and innovation – which provided the incentive structure within which SGCC operated. Such policies shape but do not determine the behavior of players. Some firms are willing and able to take advantage of the policies and engage in innovation, while others fail to do so. Three decades ago, Richard Nelson argued that the broad political and economic system, "certain unique attributes" of the industry, and a proprietary technology can all shape the choices of strategies and capacities of firms. Within this broad context, "discretionary firm differences within an industry exist and do matter significantly" (Nelson 1991, p. 62).

To understand the presence or absence of innovation, it is thus imperative to examine both general policies and the firm-level response. SGCC's strategies, structures, and capacities in technology innovation were not the simple consequence of its state-ownership or its status as a national champion. Indeed, SGCC's ownership and near monopoly worked as a double-edged sword as it provided SGCC with tremendous bargaining power, but also discouraged risk-taking behavior. In the transmission industry, where new technologies involve high risks, vision, leadership, and resources are much more in need than in many other sectors. Such risk factors are greater for central SOEs as their executives are not only directly accountable to SASAC, but also occasionally could be the scapegoat in the wake of accidents, disasters, or innovative failure.

The last section of this chapter explains the open-innovation strategy SGCC adopted to answer the "how" question. Instead of pursuing techno-nationalism as some have argued (Naughton and Segal 2003; Kennedy 2013), SGCC adopted what some scholars have termed "open innovation" strategy (Chesbrough 2003; Fu 2015, ch. 7), working with a range of players, universities, research institutions, suppliers and multinational corporations (MNCs), all on SGCC's terms. It was able to do so in part because of the general government policy on innovation and in part because of the entrepreneurship of its chief executive.

As the UHV projects developed, SGCC revised its objective from initial focus on self-interest and self-preservation to a more ambitious goal of reversing its position from follower to a leader in the global transmission industry by taking the commanding heights in the transition to low-carbon electricity and becoming an international standard setter. The completion of SGCC's first UHV DC project at the end of 2009 alarmed some experts and industry insiders. At the National Press Club in 2010, the then US Secretary of Energy, Steven Chu, told the audience that "China has installed the highest voltage and capacity, lowest loss HVDC (800kv) and HVAC (1000kv) lines, and plans an integrated HVDC/HVAC backbone" (Chu 2010). Secretary Chu urged the American government to "play a key role in accelerating energy innovation" to avoid the risk of losing American leadership in science and technology. The US Department of Energy listed high-voltage transmission as one of the crucial technologies where the United States must innovate to take the lead in the transition to low-carbon energy. The US National Science and Technology Council made similar suggestions.[3] Then SGCC set an even more ambitious objective – to "sell" its vision of global energy interconnection to the international community.

INNOVATION

If innovation is defined as "a process to create new knowledge in scientific development and to generate commercially sustainable breakthroughs that provide competitive economic advantage" – something new, something radical, something revolutionary and something disruptive – most Chinese firms can at best be described as partially innovative (Crooke 2012, p. 168).[4] They are known to introduce "incrementally upgraded products with unprecedented rapidity" (Steinfeld and Beltoft 2014, p. 50), by taking advantage of relatively low costs of inputs (labor as well as resources). With this cost-innovation strategy, new products may allow producers to briefly realize slightly higher margins that will quickly disappear in the absence of genuinely new knowledge (Zeng and Williamson 2007). Innovation nonetheless is not only restricted to products. It refers to a wide range of activities (processes, practices) and a wide range of result (goods, services,

[3] In June 2011, the Obama administration released "A Policy Framework for the 21st Century Grid: Enabling Our Secure Energy Future," accompanied by supporting studies produced by the National Science and Technology Council (Executive Office of the President 2013).

[4] The debate over what innovation entails is relevant in the following discussion because "innovation" as used here is less about invention or discovery, but more about a chain of activities from invention to commercial development, design, production, and supply of new or improved products and services in the market. Consequently, invention is only one small part of innovation. See Breznitz and Murphree (2011).

or practices). It includes "new" as well as "significant improvement" – a "significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations" (OECD 2005, p. 6).

The threat of climate change calls for revolutionising the production, distribution and utilization of electricity. Developing low-carbon sources of electricity is essential because electricity production and consumption currently contributes about 40 percent of the global greenhouse gas (GHG) emissions. Some firms have engaged in R&D in renewable energy technologies (solar, wind, geothermal, and others), some in electricity storage (e.g. battery systems), some on efficient usages by helping change consumer habits with better information (e.g. smart meters), while others focus on energy transport. Some of these efforts involve blue-sky R&D, designed to overcome "longstanding physical limits on energy conversion and storage" (Lester 2014). Examples of innovations with the potential to revolutionize entire energy systems include the efforts of US national laboratories to mimic plants by combining water and sunshine to generate energy and multilateral research on fusion under ITER (a thirty-five-country international nuclear fusion research and engineering project).

As a major transmission operator, SGCC avoided blue-sky R&D research. It built on the technologies that had been developed in other parts of the world but were not in use at the turn of the century. At that time, most R&D activities in the electricity industry focused on how to quickly develop renewable generation capacity at a cost which could be acceptable to consumers without government subsidies. Challenges facing the electricity networks as the result of an expansion of renewable sources of electricity generation were not widely appreciated until a decade later. In China, different pressures encouraged SGCC to focus on R&D in transmission technologies. In 2003–5, power shortages spread around the country, with the gap between available supply and user demand reaching 34 percent. They had an immediate economic impact. All concerned players jumped into action: generation companies, with the encouragement of provincial and local governments, quickly constructed hundreds of thermal power stations (about 95 percent of them were subcritical ones – small size, low-efficiency, and highly polluting) (IEA 2015); the coal industry expanded production with thousands of coal mines going into operation with little safety and environmental protection; the National Development and Reform Commission (NDRC), the central planner, freed coal price to encourage coal production, increased power tariffs to discourage consumption, speeded up project approval for power generation plants, adopted policies to encourage investment in renewable energy, and encouraged the adoption of energy efficiency measures; and hydro, nuclear, and renewable industries all embraced the opportunity to expand production as a solution to power shortages.

SGCC grabbed its opportunity and interpreted power shortages in its own terms. It attributed the problem to bottlenecks in China's transmission and distribution (T&D) infrastructure – that is, fragmented T&D networks meant surplus electricity in one province could not always be shared with a neighbor facing shortages. As in most countries, China's T&D system developed by connecting local power plants and supplying local end-users. It remained fragmented and disconnected at the end of the 1990s even though the number of separate grids had been reduced – from eighteen in the early 1980s to ten in 1997, and then down to six regional grids in 2002 (IEA 2006, pp. 40–1). In addition to weak interconnection, T&D management was decentralized, in part because of the different ownership of distribution companies and in part because of the large number of separate transmission grids. Fragmented networks encouraged and were reinforced by protectionist policies of local governments. This was one of the main reasons for the central government to restructure the industry.

For SGCC, electricity demand would continue to rise because of the initial low electricity consumption per capita, continuing economic growth and rapid urbanization. The way to support rising demand was to expand large-scale renewable sources of generation and to build large coal-fired thermal and hydropower power generation bases. These developments would necessitate expanded infrastructure to "wire" electricity to load centers. The uneven geographical allocation of natural resources – coal reserves are in north and northwest regions of China and hydro is in south and southwest parts of China – and location of end-users (more than three quarters are along the coast) meant that long-distance coal transportation had already clogged railways and roads in 2002–4. Investing in cross-province, cross-region interconnected networks would help solve several problems simultaneously: energy security and efficiency, congested railways and roads, and worsening environmental pollution, especially around coastal cities where population and power demand were concentrated.

SGCC needed to "sell" its diagnosis and solution for power shortages to the government officials who were besieged with proposals from many interested players. Even in China, there is no monopoly over the definition of problems, which depends on the "preferred solutions" of political players, and their interpretative maneuvres. As Cobb and Elder explained some time ago, "policy problems are not simply givens, nor are they matters of the facts of a situation; they are matters of interpretation and social definition" (Cobb and Elder 1983, p. 172). Instead of seeing the cause of power shortages as the lack of generation capacity or coal supplies, SGCC presented an alternative explanation – inadequate interconnected transmission networks. Government officials would not take a new definition of problems seriously without a proposed course of action. The management of SGCC suggested that its UHV projects could address multiple challenges facing NDRC: relieving power shortages, promoting energy security, and halting the deterioration of urban air quality. In so doing, SGCC steered the narrative in a new direction, echoing Aaron Wildavsky's observation that "If one can alter conceptions of what is problematical (not inevitable), an entire series of actions may be affected" (1979, p. 57).

GOVERNMENT POLICIES

Policies on SOE reform and on innovation provide the institutional matrix within which SGCC operates. The electricity restructuring in 2002 was part of the broader reform of SOEs, designed to rationalize the position and role of SOEs in the economy. Medium- and small-sized enterprises were "encouraged" and guided to find their way in the market through restructuring, merger and acquisition, even bankruptcy while large ones, especially in strategic sectors, such as defense, telecommunication, and energy, were placed under the supervision of the central government and encouraged to expand – a policy known as "grabbing the large and letting go of the small" (抓大放小) (Lin and Wilhaupt 2013; Naughton and Tsai 2015). SASAC was created in 2003 as the ultimate owner of 196 central SOEs, mandated to "manage the state assets" of these central SOEs and to maintain and expand the value of their assets. At the time about two-thirds of these central SOEs were loss-making entities. How to turn them around was left to SASAC to decide as there was no agreed reform strategy. SASAC took a proactive role in defining its mandates. Instead of selling off loss-making SOEs, SASAC decided to help restructure and build them into modern corporations. To achieve this objective, SASAC engineered a series of measures to encourage these SOEs to: separate and reorganize core and non-core functions; divest non-core businesses to build strong competitive firms around a few core functions; reduce the social burdens many of them had inherited from the planned economy; and encourage successful firms to acquire failing SOEs.

From the beginning, the minister of SASAC made it clear to the chief executives of these central SOEs: "We have only one objective – that is, to promote and strengthen our large SOEs and help build your global competitiveness" (Li 2004). He called on central SOEs to become the top three or top five companies in their sectors – either on their own, or by merging with or acquiring other firms. The evaluation systems of the SOE chief executives and of SOEs themselves were set in such a way to encourage them to become competitive in both domestic and global markets. Meanwhile, the SOEs were also encouraged to bring in technically adept managers and were provided greater clarity of ownership rights.

Many central SOEs quickly turned around from loss-making to profit-making corporations (Naughton 2015, p. 51). SASAC was criticized for steering cheap credit to central SOEs; enforcing rules selectively in favor of its SOEs; allowing them to monopolize key industries and increase political, social, and economic inequality with excessive managerial compensation; and, most importantly, promoting "state sector advance and private sector retreat" (国进民退), thus contributing to China's domestic imbalances with an overly rich and large state and a poor population (国富民穷) (McNally 2013, p. 51; Yang 2012; Eaton 2013). Justified or not, some SOEs responded to the incentive structure set up by SASAC while others did not. SGCC was among the successful ones. Its UHV projects were pursued in part to respond to the government policies – to build SGCC into China's GE or China's Siemens.

In early 2000s, the central government also began to formulate a new national innovation strategy. The economic reform started with the introduction of what Deng Xiaoping called, "four modernisations" in the late 1970s. One of them was science and technology (S&T) modernization. In the following two decades, the official policy was to allow and encourage foreign companies to bring technologies to China in exchange for market share. This policy represented a shift toward an outward-looking strategy designed to introduce, acquire, assimilate and improve mature technologies from advanced economies, repeat the process with a higher level of technology in the consolidation stage, and accumulate indigenous capacities to generate and commercialize new technologies. To implement this innovation strategy, the government introduced a series of major initiatives.

The National Science and Technology Development Plan (1978–85) focused on funding R&D to meet "urgent economic and social needs." The National High-Tech R&D Program (known as the 863 Program) adopted in 1986 aimed to develop high technology industries (e.g., biotechnology, new materials, lasers, energy, information, robotics, and space) and commercialize them. It introduced "the concept of peer review and a mixed method of project selection for the first time to technology plans in China" (Naughton and Segal 2003, p. 167). The Torch Program of high technology industry development (火炬计划) adopted in 1988 aimed to channel resources to support the establishment of fifty-three high- and new-tech industrial development zones. Like the previous innovation policies, the Torch Program emphasized "industrialisation and dissemination of technology to generate economic growth" by focusing on commercialization of proven technologies (Breznitz and Murphree 2011, p. 77). The National Basic Research Program (973 Program) was launched in March 1997, again with emphasis on commercialization.

These policies changed the government's role from "direct control of resource transfer/distribution and coordination of organizations in the innovation system" to "linking R&D through a number of measures, including setting up production centres to assist firms to implement technologies originating from state R&D institutes and creating incubator centres" (Fan 2014). Yet, only a tiny minority of enterprises took advantage of the national policies to engage in serious industrial or research innovation as economic growth could be and was achieved by depending on abundant low-cost factors of production (land, resources, and labor) and scale of the market, rather than on technology innovation. By the early 2000s, only 0.03 percent of all enterprises were able to control their own core technologies; over 99 percent of enterprises had never applied for a patent; and 66 percent of the enterprises did not even have their own logo or brand (Bai and Wang 2015). A World Bank study shows that even in 2004–6, among 300,000 Chinese firms of all sizes, 53 percent of the large enterprises, 86 percent of the medium-sized, and 96 percent of small firms had no ongoing R&D programs. More than a third of China's international patent applications came from a single firm, while "63 percent of China's new patents for innovation were held by foreign individuals or firms, the vast majority of which were concentrated in high-tech industries" (Chen 2009, p. 129).

Many attribute low innovation activity to inadequate allocation of resources to R&D. China's R&D expenditure as a proportion of Gross Domestic Product (GDP) dropped from 0.75 percent in 1991 to a low of 0.5 percent in 1996. By then, the number of people engaging in R&D per million people in China was 10.5 percent of that in the United States and merely 9 percent of that in Japan (Yusuf et al. 2009). In addition, only a minute share (5–6 percent) of total R&D spending went to basic research (Song 2008, p. 238). During the late 1990s and early 2000s, the central government introduced a series of fiscal policy changes to encourage firms to engage in applied research and innovation by shifting funding sources. Specifically, it reduced direct budgetary allocation to research institutes; offered financial incentives for research institutes to engage in applied research and "to commercialise R&D activities" (Fan 2014, p. 732), while it steadily increased the overall budget allocation on research. In 2002–4, as the central government developed a new strategy on technology and innovation, SASAC responded by including innovation in its SOE evaluation systems. These two sets of policies – on SOE reforms and innovation – provided the incentive structure within which the newly created SGCC operated.

Ever since the "war of the currents" at the end of the 19th century, alternating current (AC) technology had been used to transport electricity from power plants to end-users because of its flexibility. As the distance between power generation and end-users expanded, utilities increased carrying capacity (voltage) to compensate for line losses, which increase with distance. By the late 20th century, most countries built power transmission networks with 220kv, 350kv, and small numbers of 500kv AC lines.

In 1955, ABB successfully built its first high voltage direct current (DC) line in Sweden. DC lines can carry electrical power over long-distance with much reduced line losses. Once electricity is transported from one end to the other, complex and expensive transformer stations then must be available to convert and transport electricity to end-users via local AC networks. Even though laboratories in several countries started researching and testing high-voltage AC transmission technologies in the late 20th century, no such line was in commercial operation by the end of the century because, unlike asynchronous DC lines, high-voltage AC lines are synchronized and therefore pose technical difficulties in maintaining operational stability and reliability.

China started late in its electricity development. It had been far behind in interconnected transmission infrastructure and in its ability to design and construct high-voltage transmission networks. It constructed its first ±500kv DC transmission system, connecting the Gezhouba hydro station in western Hubei to Shanghai, only in 1989–90, more than thirty years after the technology came into widespread use in advanced economies. This was a cross-region asynchronous parallel operating system when China's highly fragmented provincial systems were predominantly connected and supported by 200kv lines. This first 500kv system was a turnkey project from the Swiss firm BBC, which soon merged with Sweden's SAEA to form what is known as ABB. BBC provided a complete package, including design, technology, and equipment. This dependence on imported technology and supply continued when China constructed its first 750kv transmission line in the late 1990s.

Having monitored worldwide R&D in transmission technology, the technology department of the Ministry of Electrical Power (MEP) suggested to the State Planning Commission in 1999 that China should develop its own technologies for high-voltage DC (±800kv) and AC (750kv) transmission systems to meet rising demand, as traditional 220kv, 350kv, and even 500kv transmission lines were both insufficient and also incapable of carrying electricity to distant end-users without excessive line losses. No one picked up the suggestion because both the risk and the price tag would be too high for the country in need of resources for everything. In addition, no single agency fully controlled the resources for transmission construction and R&D for new technologies.

Throughout the reform period, transmission and distribution always had to fight for attention and resources with generation. Generating capacity expanded quickly as provincial governments and large enterprises were keenly aware of the disruption associated with frequent power shortages. In addition, investing in generation was much less intensive than for T&D networks – a public good with widespread benefits. In 1985–95, only 20 percent of the total power sector investment went to T&D which remained the responsibility of the central government, while investment in generation came from a range of sources. Investment in distribution in the second half of the 1990s increased significantly as the central government used it to stimulate the economy following the Asian financial crisis. On average, it remained low, less than 30 percent of the total investment in the electricity industry, well below the average level of 50 percent among OECD countries (Table 6.1).

China's electrical equipment industry also lagged far behind. The grid industry depended on imports for nearly all necessary components – from switchgears, transformers, all types of circuit-breakers and surge arresters, to a multitude of specialized devices of all designs, equipment, and technologies. These imports were not from just one country or company; all major companies were competing for the market. Imports came from ABB, from Germany's Siemens, France's Schneider, Japan's Mitsubishi, and General Electric (GE). Industry specialists compared the situation to the "united army" of major powers that extracted territorial concessions from

Table 6.1 *Average Share of Investment in Generation and in Transmission & Distribution, 2001–2005*

	USA	Britain	Japan	France	China
Generation	47%	45%	46%	31%	70%
Transmission and Distribution	53%	55%	54%	69%	30%

Source: SGCC (2006, p. 22)

China in the early 20th century – 八国联军. This international mosaic made it extremely difficult and costly for China to absorb foreign technologies and develop its own.

The formation of SGCC changed all this. For the first time, T&D had a single "spokesman" and champion. It no longer had to fight for attention and resources with its colleagues in generation and other segments of the power industry. SGCC management viewed implementation of the mandate to construct and expand cross-province, cross-region interconnected T&D infrastructure as a vital corporate objective. SGCC proposed to deploy UHV technologies (both AC and DC, and synchronized AC/DC) to create a national interconnected T&D infrastructure network. With UHV projects as a platform, SGCC in turn could build its capacity and expand too.

The SGCC management, especially its chief executive, took up a critical role as policy entrepreneur, combining vision, "love for the game," and willingness "to invest resources – time, energy, reputation, money" (Kingdon 1995, p. 179). More importantly, SGCC had the institutional capacity to support T&D initiatives with financial resources, "professionals with recognised expertise and competence in a particular domain and an authoritative claim to policy-relevant knowledge within that domain or issue area" (Haas 1992, p. 3). In addition, SGCC management responded to the flow of political events, often using existing ideas to reset policy narratives with the goal of recruiting and expanding political support. This was not only a political strategy but also "the first-order economising" of firms – adaptation (Williamson 1991). In actively pursuing policy agenda setting, SGCC behaved like all corporations, state-owned or private alike, as a political, institutional, and economic entrepreneur, trying to control its destiny.

SGCC's active policy entrepreneurship worked at a time when the central government was in the process of drafting a national innovation strategy. SGCC mobilized institutional resources to "sell" its technologies and projects to decision makers throughout 2005. It organized research teams supervised and guided by experts, including many drawn from China's prestigious academies of science and engineering, to conduct preliminary studies and report their findings to national and international conferences that SGCC organized.

To incorporate its vision, ideas, and projects into the national innovation strategy, SGCC had to compete with many demands from all corners of the society (Wessner 2011). More importantly, it had to convince key decision makers who were being lobbied by many sectors and groups, including those who opposed UHV projects.[5] The opposition came from several directions: some opposed the UHV projects on political grounds, insisting that SGCC sought to further monopolize and centralize its control over China's power sector. Some did so for economic reasons – that is, UHV projects would necessitate large increases in electricity prices, massive government subsidies, or both. Others opposed it for technical reasons, arguing that the proposed jump to frontier technology was premature for an industry that had barely finished its first 750kv line, and also that SGCC's proposed innovations in long-distance transmission could endanger the stability and reliability of China's entire electricity system.[6]

SGCC appealed for policy makers' support from two perspectives: to build SGCC into an internationally competitive technology powerhouse, and to master UHV technologies in order to take the commanding heights in global competition for the transition to low-carbon electricity. This was SGCC's key selling point – to invest in the development of UHV technologies, master them and actually utilize them would enable SGCC to reverse

[5] An increasing number of studies highlight the pluralization of decision making in China. The debate over the UHV projects was only one example. See the discussion on the pluralization of decision making in Mertha (2009) and Hammond (2013).

[6] Scale matters in transmission infrastructure: in general, as transmission voltages and capacities increase, carrying distance extends, line losses decline, greater scale economies accumulate, and costs decline. The voltage level of a transmission line is the key factor that determines its power-carrying capacity. Given its physical attributes, the higher the voltage of a transmission line, the more power it can carry. For instance, over the same distance, a 345kv line can carry approximately as much power as six 138kv lines; a 765kv line can carry as much power as five 345kv lines or thirty 138kv lines; and the natural transmission capacity of a 1000kv AC circuit is about four to five times that of a 500kv AC line, while a circuit ±800kv DC line has the capacity equivalent to 2.1 times that of a ±500kv DC line. High voltage transmission lines thus economize on land use: a 1000kv AC line saves 50–66% of the corridor area required by a 500kv AC line, while a ±800kv DC line saves 23% of the corridor required by a 500kv DC line in transmitting the same capacity. For the merits of these technologies, see Scherer, Jr. and Vassell (1985); Lings (2005); Huang et al. (2009); and MIT (2009).

its position as "second fiddle" depending on "technology transfers from multinational companies" (Williamson and Raman 2011, p. 110) and place a Chinese firm among world leaders in this major industry.

After a three-year drafting process, the State Council released the *Medium- to Long-Term Plan for the Development of Science and Technology, 2006–2020* in 2006 (the 2006 MLP). The 2006 MLP consisted of three specific provisions: firstly, to build strong Chinese enterprises, technology, and brands, and to reduce their dependence on foreign technology; secondly, to require government ministries and SOEs to procure at least 80 percent of their goods, when feasible, from domestic sources; and, thirdly, to encourage foreign firms doing business in China to transfer their latest and most advanced technology to Chinese partners. To help Chinese firms develop their capacity to compete, the 2006 MLP included some specific fiscal measures, such as exemption from tariffs or import-related VAT on equipment for firms engaging in technological renovation and product upgrading, and income or turnover tax relief for foreign firms or joint ventures engaging in technology transfer, and direct grants to R&D activities. The centerpiece of the 2006 MLP was a transition from encouraging imitation to pursuing innovation focusing on *indigenous innovation* (自主创新) to address China's weak record of firm-level innovative capacity for sustainable economic growth.[7]

The national priority list included energy-related technologies, among them SGCC's proposals for large-scale, large-capacity, long-distance DC technology, UHV AC technology and equipment, technologies for integrating intermittent generation sources into the grid, and grid safety and reliability. Even though in theory, both UHV AC and UHV DC were "relatively mature technologies" that several countries had tried to implement, no UHV DC or UHV AC line was in commercial operation at the turn of the century. Nor did an integrated system of UHV AC and UHV DC exist in any country. Since transmission networks in most countries primarily employed 220kv and a few 350kv lines, there was no commercial production of the equipment required for ±800kv DC and 1000kv AC lines.

SGCC's proposal to construct innovative long-distance UHV transmission networks required multiple technological breakthroughs. Innovation is

[7] The 2006 MLP was controversial outside China as many commentators argue it was a protectionist measure that the government put in place to assist Chinese firms in an increasingly global market. Without taking a position on the issue, this chapter highlights the point that some firms took advantage of the incentives offered by the Plan to engage in innovative activities while others failed to do so. For the debate, see Fan et al. (2009); Crooke (2012); Steinfeld and Beltoft (2014).

a quest into the unknown. It "involves uncertainty, risk taking, probing and reprobing, experimenting, and testing," and in the process, "'dry holes' and 'blind alleys' are the rule, not the exception" (Jorde and Teece 1990, p. 76). An electricity transmission system is a complex assemblage of individual elements, consisting of transmission lines, transformers, switching equipment, and a multitude of specialized devices necessary to assure the *safe* and *reliable* delivery of electric power to the consumer. Thus, UHV technologies were on the priority list of the 2016 MLP because of their spill-over effects. Their development would require technology breakthroughs in basic physics and engineering research, materials, and equipment manufacturing.

In combination with the 2006 MLP, SASAC adopted measures to encourage central SOEs to engage in R&D and develop indigenous technology. Included in the assessment criteria for central SOEs, for instance, were building global brand names, global networks, international standards and global leadership. These policies changed national narratives on technology innovation and brought a cultural shift among some large firms, public and private alike: it became well accepted that "the first class firms build standards; the second class firms build brands, and the third class firms make products" (一流企业做标准，二流企业做品牌，三流企业做产品).[8] Policies play an important role in moulding firms' strategies and actions, but they do not determine whether firms will respond, what strategies and actions they will take or how they implement their plans. "Firms have a considerable range of freedom regarding whether, or just how, they will take advantage of the opportunities the environment affords" (Nelson 1991, pp. 63–4). This is certainly the case with China's central SOEs; state ownership alone cannot explain their different strategies, organizational structures supporting such strategies and their capacities to implement their plans.

STATE GRID CORPORATION OF CHINA'S STRATEGY FOR INNOVATION

SGCC adopted a project-driven research strategy that was inclusive and collaborative, based on a technology innovation chain of education,

[8] A few central SOEs started investing heavily in R&D and technology innovation, nearly all around 2003–4. Therefore, it is more accurate to view the adoption of the 2006 MLP as a confirmation of practices than an initiative undertaken by the State Council. A six-episode documentary provides a good explanation of the motivation and the difficulties of these innovative efforts, especially how difficult it is for their new products to be accepted in China when foreign companies had already dominated the core technology markets. See CCTV-2 (2013).

research, application, and production (产，学，研，用结合的创新体系), with centralized resource allocation and centralized management of patent applications and intellectual property rights. It was an open innovation in the sense that SGCC created the Common Engineering Platform, a working group centered around its core experts, but including external specialists from a wide range of universities, research institutes, potential future customers, and equipment suppliers (both domestic and international). Meanwhile the question "who is in charge" was never in doubt. Collaboration was on the terms and conditions set by SGCC as its management controlled the agenda, provided financial support for research, and determined terms of cooperation.

Human capital is the key to firm-level innovation. Changing its position from being a "follower" to a "leader" in the grid industry would require SGCC develop the necessary "hardware, software, 'organisation-ware', 'human-ware' and other types of invisible assets" (Hagstrom and Chandler 1998, p. 2). As a grid operator, SGCC had limited capacity to engage in R&D in UHV technologies. Even at its research institutes, the core team of researchers was limited. SGCC needed research capacity at the Chinese Academy of Engineering and the Chinese Academy of Sciences, and at key universities. One of the first things the SGCC management did was to mobilize and assemble a team of internal and outside experts who shared its vision.

Three groups of people were identified and each played a different role in this effort. A group of older and established experts, including some retirees, was brought on board to provide intellectual leadership, supervise and mentor young researchers, ensure standards, serve on advisory committees, and offer legitimacy for the projects with their authoritative assessment on all aspects of UHV technologies. Many of these experts were members of the Academy of Sciences and Academy of Engineering, working in national research institutes or universities. The second group of experts were SGCC insiders who had not only technical expertise but also management capacity. They were put in leadership positions to assemble teams and to head the research institutes under SGCC or to lead specific research teams on core technologies for the UHV projects. This group included the chief executive and his deputy. These well-educated and highly intelligent specialists were willing to work in the harshest conditions possible, which was necessary for some of the most difficult tests and experiments. Many were industry insiders with decades of experience (Li 2008). The third group of researchers consisted of recent graduates who had risen to the top in their fields. These young researchers were selected from various parts of the SGCC as well as universities and other research institutes around the country and told by the management, "there are only two scales for your evaluation, 0–1; if UHV succeeds, you get one; otherwise, it is zero."

Individual researchers need an enabling institutional environment. The management team reorganized SGCC's research institutions to create such an environment supportive of ambitious and risk-laden research. In the mid-1990s MEP had ten research institutions, focusing on various aspects of the electricity industry. These research institutes were under a dual system: organizationally, they were part of the MEP and their research agenda and funding were decided by the MEP, while their research standards, professional licensing and promotion were under purview of the State Commission of Science and Technology (predecessor of the Ministry of Science and Technology, MOST). After reform started, these research institutes, like their counterparts in other fields, were burdened by social responsibilities for their retired employees and their families, but had few income sources to compensate for shrinking research budgets. The government encouraged research institutes to "adapt" to the market environment and conduct research with industrial applications. Few succeeded commercially and many suffered a serious brain drain as young and able researchers either went overseas or transferred to other industries and to multinational corporations. When the MEP was dissolved, these "loss making" research institutes were placed under SPCC. At the time of unbundling in 2002, the "best" part of the electricity industry, regarding technology, human capital or profits, was in generation, as 70 percent of the profit in the electricity industry was in the hands of generation companies, while 30 percent was in T&D. These research institutes were unwanted financial burdens (one indication is that these research institutes supported almost as many retirees as regular employees). The State Council placed them under SGCC for supervision until they could be restructured. A decade later, after SGCC managed to turn these research institutes around, the initial reasons for the arrangement were forgotten as critics attacked SGCC for monopolizing the industry's research capacities.

A few academy members and scientists in the industry, however, still remember the history:

> Fortunately, unbundling and restructuring the electricity industry did not disperse the team of scientists and engineers, and SGCC kept them. It would have been so easy to let them go, but would be extremely difficult and costly to gather talents when you need them. I don't think we could have made the UHV projects work so quickly without this group of experts.[9]

[9] Interview with Liu Qiang, Tsinghua University, Beijing, 27 July 2014.

With the core research teams in place, headed by its chosen experts, the SGCC management began reorganizing these research institutes. At the time, there were fifty-five research, design, and experiment centers, 407 laboratories, and over 20,000 employees under SGCC's big umbrella. If they all worked on what they wanted, SGCC would never be able to develop its capacity and to master the design, technology and equipment for its UHVC projects. To deal with the problem of everybody trying to do everything (麻雀虽小，五脏俱全 [although small, a sparrow has everything a vulture has]), SGCC centralized its team building and funding around five major research institutes.

A department of science and technology was created at SGCC headquarters as a center of a research network system to coordinate all activities and manage allocation of funding. The SGCC management reorganized its five main research institutes, and established a specific focus for each: Electric Power Research Institute (EPRI) in Beijing would concentrate on UHV AC; Wuhan High-Voltage Research Institute was to specialize in UHV DC; Nari (Nanjing Automation Research Institute) emphasized automation, and so forth. It also established four research test bases focused on UHV AC, UHV DC, High Altitude, and UHV engineering, as well as two specialized research centers – SGCC Simulation Centre and Centre of Metrology on Current and Frequency. Each was led by a technically-qualified expert. These institute and center directors formed part of the core team for the UHV projects and were given research funding and independence in their specific fields. The reorganization was done to create a research system with a high degree of internal coordination and concentrated resources to meet the needs of SGCC.

More importantly, SGCC increased its spending on R&D and introduced an incentive structure to reward those who could innovate and transfer those who could not. In 2006 alone, its investment in R&D rose by 34 percent from the previous year's level. SGCC promised to invest a total of 30 billion yuan in R&D in 2006–10. The change from MEP to SPCC and especially to SGCC changed the sources of funding for research institutes and consequently the focus of research. This was part of the general reform of commercializing and corporatizing SOEs that were made responsible for their own finance and development. The research institutes attached to SGCC no longer received budget allocations from the government, even though they could apply for research funding under several national competitive schemes, such as Program 973, Program 863, the Torch Program, or the 1000 Young Talents program. Their main funding source is SGCC.

Table 6.2 *State Grid Corporation of China's Research and Development Spending, 2004–2017 (billion yuan and percent)*

Year	Research and Development Spending	Change from Previous Year (%)
2004	3.79	
2005	4.82	27.2
2006	6.48	34.4
2007	10.2	57.4
2008	5.06	−50.4
2009	5.14	1.6
2010	6.13	19.3
2011	6.45	5.2
2012	7.94	23.1
2013	5.79	−27.1
2014	7.08	22.3
2015	7.38	4.2
2016	6.92	−6.2
2017	7.83	13.2

Source: SGCC, Corporate Social Responsibility Report, various years.

The research funding from SGCC HQ consists of two parts: their normal research programs, which are shaped by the demand from the various parts of SGCC; and resources allocated to specific projects. The advantage of enterprises doing R&D is that they have the money. For example, the funding for a government-funded research institute is normally in the tens of millions, but for a SGCC research institute, it is hundreds of millions of yuan. The research funding allocated by SGCC to the Electric Power Research Institute (EPRI) alone in 2005–9 exceeded the total funding EPRI had received from the central government in 1951–2004.[10] For the top researchers working on UHV technologies, management promised from the very beginning that they would not have to worry about funding. Table 6.2 shows how SGCC ramped up R&D spending – a critical ingredient in advancing high-risk research.

[10] This is not unique for research institutes under SGCC. After the corporatization of SOEs in the late 1990s, SOEs needed to support their own research activities. This development was reflected on the government spending on R&D. The country's total spending on R&D used to come from government only. By 2001, government's share reduced to 68% and down to 54% by 2005. A few large and successful companies in IT, for example, devoted a large share of their profits to R&D. SGCC significantly increased its spending on R&D in 2005–7 primarily because of its UHV projects (Gu and Huang 2009, p. 96).

COLLABORATING WITH SUPPLIERS AND MULTINATIONAL CORPORATIONS

When SGCC proposed the UHV projects to government, it promised to cover the cost of the first experimental UHV project and also to ensure that 80 percent of the technologies and equipment for this first UHV project would come from domestic sources. To achieve the objective, SGCC had to work with both multinationals and domestic equipment manufacturers.

Collaboration with multinationals was what SGCC initially wanted. Its management was conscious that it would need to work with the multinationals, especially those that not only had control of the technologies, but also had already penetrated the Chinese markets.[11] In 2006, SGCC sent its first team of senior managers to Siemens for a three-week training course. There were exchanges with Siemens, Mitsubishi, GE, and other major companies. Collaboration with the multinationals was not always easy, as SGCC wanted to gain control of core technologies; wanted to change itself from a technology buyer to a technology maker; and wanted to be in the driver's seat in collaboration, while the MNCs refused to surrender their control. The two sides had different views on "dependence"; SGCC considered that the Chinese market and UHV projects offered multinationals a valuable opportunity, especially as no other countries were developing such infrastructure. For their part, the multinationals viewed their technologies and equipment as indispensable components for attaining SGCC's UHV objectives.

In the early 21st century, several multinational giants – Siemens, ABB, Alstom, Toshiba, Mitsubishi, and GE – dominated the electric equipment industry worldwide. These corporations controlled the design, core technologies, and manufacturing capacities of primary equipment of switchgears, transformers, rally GIS, circuit breakers, and automatic switchers, and of secondary devices, such as isolation control, signal, rally, and protection devices. ABB, for example, pioneered HVDC transmission technology in 1954 when it constructed the world's first HVDC line in Gotland, Sweden. In the following years, it dominated HVDC markets. These MNCs provided turnkey transmission substations by offering "one-stop" supply of power transmission products and services. They wanted SGCC to continue the

[11] For instance, in 2004, SGCC granted ABB a US$390 million contract to build a transmission line from the Three Gorges Hydropower Station to Shanghai, hoping some technologies could be transferred and its employees could learn from the project (Tse 2005).

practice of importing turnkey projects as it had done with its first 500kv and first 750kv projects. These MNCs were confident that they could translate their superior design and technology capabilities into continued dominance in the China market as long as the Chinese equipment producers remained "far behind the leading multinationals in terms of both scale and technology" (Nolan and Wang 1998, p. 418). Even for lower voltage transmission projects, imports occupied more than half of the technologies and equipment deployed throughout China's T&D system.

SGCC's effort to turn the situation around by working with MNCs encountered unanticipated difficulties. Negotiations surrounding core technologies quickly stalled. Converter valves, for instance, are core equipment for UHV DC lines. No one was producing devices suitable for ±800kv DC lines. To develop thyristor valves – a type of converter valve for UHV DC projects – SGCC researchers approached Siemens and ABB, both of which already had large operations in China. In the prolonged negotiation held in Beijing, it became clear neither firm wanted to invest in R&D in the new product because of the high risks and uncertain returns. In the end, one firm indicated that it was willing to modify the existing 5-inch (125-mm) thyristor valves used for 500kv high-voltage DC systems for SGCC's ±800kv UHV DC projects. The other agreed to collaborate with the Chinese to develop new converter valves for UHV, but insisted on controlling all potential patent rights. The SGCC team rejected both offers. It refused to take the modified product as SGCC never intended to build only one UHV DC line; the first experimental project was just the beginning and SGCC wanted to be able to produce proper products, not modified versions of an earlier product. Researchers at SGCC took the second suggestion as an insult. If there was collaboration, the Chinese proposed to share control of any resulting patents, as one chief researcher explained later:

> Initially, we hoped to use our market to exchange for technology through research collaboration because we did not have the capacity at the time. We would have liked to have their collaboration and would have appreciated it too, but we would not be controlled on key technologies and they were not indispensable. We would do it with or without their collaboration (Wang 2014).

Researchers at SGCC took on the task in developing the equipment. Two years later, China became the only country able to produce this new product – 6-inch (150-mm) thyristor valves – on a commercial basis. This device now leads the world in current, voltage, and capacity. The first experimental UHV DC project from Xiangjiaba to Shanghai used over 6,000 such 6-inch (150-mm) thyristor valves. SGCC significantly reduced the cost when its own subsidiary, Xuji, was able to supply the product. The lead scientist later commented, “we could not starve just because they did not want to give us food, could we” (Wang 2014)?

Negotiations on collaborating with ABB on 1100kv gas-insulated switchgear (GIS) were equally difficult: they lasted over a month. The Chinese team laid down three principles: collaboration in designing, sharing intellectual property rights, and cooperation in production. The first principle was to ensure that Chinese researchers could develop their own new product. ABB agreed on this because, like many multinationals at the time, it did not think the Chinese could learn the core technology through such collaboration. ABB refused to share patents and intellectual property rights. “Yes, negotiation was very difficult,” explained one chief negotiator. “In the end, ABB had to agree because of the promise SGCC had made and NDRC had written in its approval of the projects – 80 percent of the technology and equipment needed to come from domestic sources. If the final product was theirs, we could not use it and we would have to do it alone” (Ni 2014). Compromises resolved the issue of cooperation in production – ABB contributed some parts, while Chinese firms supplied other components. Indeed, research on both thyristor valves and H-GIS was eventually conducted in China, Sweden, and Switzerland.

Chinese firms now make nearly all equipment for both UHV AC and UHV DC systems. Even for the few core technologies that multinationals still control, they have to work with Chinese makers because no other countries produce these devices on a commercial scale. China is the only country investing in multiple varieties of UHV projects (AC, DC and AC-DC synchronized transmission lines). This has led many MNCs to locate their research in China. According to Siemens:

In the 1990s, ‘Sold in China’ gave way to ‘Made in China’ and eventually to ‘Developed in China’. Today the new challenge is ‘Innovated in China’. An international company that aims to be successful in the world’s most populous and most dynamic country should forget the illustration of an inexpensive workbench. Today, the entire value chain – from research to development and production – has to take place in China, which is the Chinese government’s strategy. We have to speed up so that Siemens could stay ahead of growing local competition. Then as now, the main priorities of [Siemens’] 400 people, including 220 researchers and IP specialists at Corporate Technology in China, are to develop close collaboration with Chinese customers.[12]

[12] Siemens (2015). Studies have shown that advanced R&D activities of multinational corporations tend to be based in the home countries and even for those that do go global, they are often among the advanced economies with similar political systems, highly

If developing indigenous technology and innovation capacity is part of Chinese techno-nationalism, techno-globalism is also at work. Meanwhile, difficulties in collaboration with multinationals sparked episodes of techno-nationalism. For instance, laboratory managers at the US firm EPRI told visiting SGCC's delegates that "no data, no information, no camera, no recorder were allowed." "Years later when we had our own UHV technologies, we got our 'revenge' – we now tell our visitors, no data, no information, no camera, and no recorder is allowed." Hosts at TEPCO in Japan welcomed another team of SHCC visitors with warmth and politeness. The Japanese presented three huge transformers – "these are the transformers built specially for you; we are sure you would like to use our technology." The Japanese wanted to sell them as turnkey projects without technology transfer. When visiting an exhibition in Frankfurt, the Chinese team asked whether they could take pictures. It was told, "take as many as you want; you can even use video recorder if you want." Then the German host added, "you will never be able to make it anyway." The perceived arrogance or insults from MNCs seem to have created as much motivation as the incentives provided by the Chinese government (Gu and Huang 2009; CCTV-2 2013).

SUPPORTING OR DOMINATING THE TRANSMISSION AND DISTRIBUTION EQUIPMENT INDUSTRY

As a grid operator, SGCC initially had no capacity to produce equipment for its UHV projects. Under normal circumstances, SGCC would shop around until it found satisfactory equipment. To keep its promise that at least 80 percent of the equipment would come from domestic sources, SGCC intervened, first helping the electric equipment manufacturers develop the capacity to produce equipment of the required specifications and quality, and later, acquiring two of these manufacturers when opportunities emerged to reduce cost and to ensure quality. What SGCC did might be "normal" practice of firms: as Oliver Williamson and other leading economists have long argued, large corporations can lower the transaction costs associated with their multifarious activities by absorbing parts of the supply chain. That is, if firms had to contract with other firms to research, finance, manufacture, and market their products, the costs of forming, maintaining, and enforcing those relationships would far exceed

concentrated in Europe, Japan and the US. See, for example, Vernon (1966); Patel (1995); Doremus et al., eds. (1998); Boutellier et al. (1999).

the costs associated with independent ownership. By helping equipment manufacturers develop their capacity and then acquiring them as part of the supply chain, SGCC stirred up a political controversy even though all a long it had the support of SASAC. SGCC played a role as "systems integrator" or "organizing brain" at the apex of its supply chains. "As they consolidated their leading positions, the systems integrator firms, with enormous procurement expenditure, exerted intense pressure upon the supply chain in order to minimize costs and stimulate technical progress" (Nolan 2012, p. 17).

The process started when SGCC contracted with two top manufacturers in China – Tebian Electric Apparatus (Shenyang, 沈阳特变电器) and Tianwei Baobian (天威保变) – to make 1000kv transformers for its UHV project. Both products failed initial voltage tests, endangering the whole project. Opposition voices rose once again: "Why does SGCC insist on building this UHV line while even western developed countries would not do it" (Opposition 2011). Repeated test failures shook the confidence of many working on the transformer project, including some academy members. SGCC faced two options: help its domestic suppliers develop the technology or entrust the work to multinationals. Despite the risks and costs, SGCC management chose the former. In the following two months, with financial support from the corporate headquarters, the SGCC chief engineer leading the UHV project gathered experts from several manufacturers to check the design and recalculate all the data, assembled experts from research institutes to work with the manufacturers, involved academics from several universities to do the recalculation and theoretical analysis, and invited reputable international firms to help with the analysis. SGCC funded and supervised the entire effort. These were unusual measures because rival manufacturers would not normally cooperate or share information. In helping manufacturers work together by providing financial and human resources, SGCC took a huge risk. When the new product passed the test, the relationship between SGCC and the two manufacturers also changed.

In addition, SGCC management decided to bring some of these manufacturers under its own wing to internalize the cost. This meant building a strong internal supply chain, making its own specifications and standards, manufacturing equipment, and integrating the equipment into its own grids. SGCC took advantage of the policy of SASAC – to build large and internationally competitive Chinese corporations through merger and acquisition. The minister of SASAC repeatedly told chief executives of central SOEs: "there is only one objective for all of you – to build large and strong central SOEs and improve your international competitiveness" (Lu 2010). External developments also helped to make this possible. The global financial crisis in 2008 led to the large stimulus package from which SGCC benefited, the economic downturns put a lot of pressure on manufacturing industries that were looking for new ways out, and the central government's decision to provide financial resources in restructuring and revitalizing equipment industries.

In the summer of 2009, SGCC announced its decision to acquire two top, yet cash-strapped, electric equipment manufacturers – Xuji (许继) and Pinggao (平高). This move immediately triggered political controversy. Opponents criticized the acquisitions as SGCC's attempt to institute a vertical monopoly that would enable it to squeeze out competition from rival equipment manufacturers. The head of the National Energy Administration (NEA) did not conceal his opposition, telling the media, "No, I did not approve or support them." Yet, NDRC, SASAC and the Ministry of Industry and Information Technology (MIIT) all supported the acquisitions, each for different reasons. They also fitted the broader agenda of government policies aimed at revitalizing equipment manufacturing industry, including high-end electric equipment (State Council 2006).

Xuji, an important equipment producer for electrical generation, transmission, and distribution, has a long history. It relocated to Xuchang, Henan, from Heilongjiang in 1970 during the Sino–Soviet border crisis. In 1997, it listed on the Hong Kong stock market. Xuji specializes in high-voltage lightning protection systems, and high-voltage, large capacity, and flexible converter valve systems. It ranks among China's top ten electric equipment manufacturers and is a key enterprise for the country's "Torch Program for high-tech industry development." Yet, persistent quality problems gradually eroded Xuji's competitive advantage over rival domestic producers. Its domestic market share dropped to only 1.2 percent by 2005.[13]

[13] The negligible market share of both Xuji and Pinggao (1.2% and 1% respectively) in electric equipment manufacturing industry was the main reason that several government agencies did not hesitate to support SGCC's acquisitions. After the 1980s, "industrial concentration occurred in almost every sector." By the mid-1990s, over two-thirds of the global output of electrical equipment had come from three companies: Siemens, ABB and GE. This oligopolistic structure set high entry barriers and significantly pushed up prices. In responding to a global trend of industrial concentration, the Chinese government and especially SASAC encouraged a few successful large SOEs to become part of "the high value-added, high-technology and strongly branded segments of global markets" (Nolan 2012, p. 17).

By the end of 2008, Xuji's profit level was below the industry average, with a long chain of products, heavy dependence on borrowing and poor management. It suffered cash shortages in 2008, with its debt-asset ratio reaching 93.33 percent. In 2008, Xuji transferred all of its assets to Ping An Trust Ltd, a direct subsidiary of a central SOE, Ping An Insurance (平安保险), hoping to get a cash injection. In early 2009, SGCC's subsidiary, EPRI, approached Ping An Trust to acquire Xuji. It wanted to use Xuji as a platform for its high-end electric equipment R&D. In the end, Ping An Trust transferred a 60 percent stake in Xuji to EPRI, with a promise from EPRI that it would buy the remainder of Xuji at a later date. Xuji accepted the arrangement because it needed a capital injection (Zhang Zirui 2010).

Pinggao Group emerged from the Pingdingshan High Voltage Switchgear Factory, founded in 1970. It was state-owned, under the Henan branch of SASAC. In the 1980s, supported by the central government, Pinggao imported French technology, helping it to become one of China's top producers of electric equipment. In 1989, for the first time, it exported its PG brand switchgears to Bangladesh. In 2000, it formed a joint venture with Mitsubishi, which then floated on the Shanghai Stock Exchange in 2001, raising 740 million yuan. In the following years, Pinggao achieved several technical breakthroughs, developing China's first enclosed gas-insulated switchgear for UHV ±800 DC lines and for UHV 1000kv AC lines in 2007. The Chinese Academy of Sciences, Chinese Academy of Engineering and MOST certified these PG-brand technologies and products, which provided core equipment for UHV projects. In 2009, SGCC promised Pinggao and the local government that it would invest one billion yuan in PG that year and an additional 5 billion yuan over the following three years to build a strong electric equipment-manufacturing base – not only for domestic grid construction but also for overseas expansion. The deal was too good to reject: the local branch of SASAC at Pingdingshan in Henan province agreed to transfer its entire stake in the Pinggao Group to SGCC at zero cost. The group was formally integrated into SGCC in early 2010 (SGCC Acquisitions 2014).

Meanwhile, that both Xuji and Pinggao are located in Henan province made it easier for SGCC to obtain support from the provincial government. In addition to helping two cash-poor local companies, SGCC promised to invest 35 billion yuan in Henan's T&D infrastructure, an attractive prospect at a time when GDP growth rates figured prominently in the evaluation of provincial leaders' performance. Large investment in T&D projects meant jobs and better infrastructure in the province. Pinggao and Xuji were happy to be absorbed by the largest buyer of their products. The two manufacturers received immediate cash injections from SGCC, and its UHV projects provided them with a market and opportunity to improve their products. In the following five years, 2009–13, with SGCC's injected capital, the debt–asset ratio quickly dropped from 93 percent to a manageable level of 64 percent at Xuji, and from 65.45 percent to 46.88 percent at Pinggao. In addition, SGCC injected 2.84 billion yuan into their R&D in 2009–13. Leveraging SGCC's financial support, Xuji and Pinggao were able to raise capital for their development (9.69 billion yuan for Xuji and 7.49 billion yuan for Pinggao in 2013 alone – see SGCC Acquisitions 2014).

With the UHV projects as platforms and with SGCC financial support, Xuji and Pinggao developed their own high-end products that could dominate the Chinese market. One of the senior managers at Pinggao explained in 2010:

> Before, we could produce only circuit breakers for systems below 500kv, and switchgears and GIS for ≥200kv systems. GIS for ≤500kv was completely dominated by Foreign companies – ABB, Areva, Mitsubishi, and Toshiba. In less than three years, with the support in R&D, we have developed 23 new products, obtained over 30 patents, and led or participated in national standard setting for nine products. All this has given us a seat at the table and a voice in the industry, and it has become our advantage in competition (Zhang 2010, p. 10).

Xuji and Pinggao were able to transform themselves into effective international competitors when SGCC itself ventured overseas. By 2013, they were able to win international contracts independently from SGCC's projects. Pinggao won an order worth 200 million yuan from an Indian monopoly, the Power Grid Corporation of India (PGCIL), to supply equipment to its Kanpur and Guraon 765/400kv substation project in Uttar Pradesh in 2013. In 2014, Pinggao signed a contract with the Polish grid company to supply equipment for the construction and expansion of the Kozienice 400/220/110kv substation. The value of Xuji's overseas orders in 2013 was 744 percent of that in 2009 (Lu 2015; Wang 2015).

With UHV projects as a platform, SGCC became "a system integrator," helping the electric equipment manufacturing industry consolidate and build its capacity. By 2010, China's electric equipment industry had developed an oligopolistic structure dominated by five or six players competing but also supplementing each other. They include Xuji, Pinggao, Nanjing Automation Research Institute (NARI), Tianwei, Tebian Electric Apparatus Co (TBEA), and Xidian Group

(XD). Taking transformers as an example, by 2015 the market was split among TBEA (40 percent), XD (30 percent), and Tianbao (30 percent); Pinggao, XD and Northeast Electric dominated the GIS market; and Xuji and XD controlled the converter valve market, each commanding a 40 percent market share (Wang 2015). A few of these manufacturers were able to take their products overseas and even invest in overseas production.

In sum, the combination of corporate strategy and government support transformed the electric equipment industry, where a few "able" players emerged to dominate domestic markets, and, as international competitors, working side-by-side with the key MNCs, threatening "to crowd others out of the global markets" (Paulson Institute 2015, p. 2).

FROM "GOOD ENOUGH" TO "TAKING THE LEAD"

By the time when the first UHV DC project (Jindongnan-Jinmen, 640km) went into operation in January 2009, SGCC had already adjusted its initial objective of self-preservation to becoming a world leader. UHV projects that began as a platform to build SGCC into a modern corporation now became a launchpad for SGCC to "go global" and to become an international pacesetter. After its first overseas investment – the 2009 acquisition of a fifty-year license to operate the Philippines' national transmission grid, SGCC moved into Brazil, bringing its UHV projects in 2011. Meanwhile, it actively participated in IEC to ensure acceptance of its technologies as international standards.

In 2009–12, SGCC submitted fourteen standards to IEC; eleven have been adopted as international standards. In 2013, SGCC provided the secretariat for seven committees and chaired one. Its current chief executive, Yinbiao Shu, was elected as the vice president of IEC. In 2014, SGCC became a member of the Corporate Advisory Group of IEEE-Standard Association, joining 10 other global companies: Microsoft, AT&T, Qualcomm, Bright House Networks, Alcatel-Lucent, ATMicroelectronics, Ericsson, SanDisk, Cisco and Synopsys. SGCC takes all these positions seriously, as it is determined to lead the industry. As one of its senior scientists explained:

> In the late 1990s and early 2000s, we were also attending international conferences organised by CIGRE and IEEE. The only thing we could do then was to sit there and listen. We could not participate in discussion and had no right to speak up simply because we had nothing to say. The field was dominated by the developed countries. Now, it is different, when we speak up, especially about our UHV AC

and UHV DC technologies, people listen and they pay attention to what we have to say (Zhao 2013).

In 2011, once again, SGCC management restructured its research teams and redirected their focus toward a new objective: "strong and smart grids." This organizational shift included three key components:

- SGCC created a Smart Grid Research Institute by merging its department of science and technology with an existing research institute on smart grids under one of its subsidiaries – SG China Electric Power Equipment and Technology Co. Ltd (SGCET).[14]
- It relocated all basic research, blue-sky research, and research on its core technologies to EPRI, which would no longer engage in projects.
- It regrouped its projects and operations in the two subsidiaries – Nanjing Automation Research Institute and SGCET – and SGCET in particular focuses its work on overseas engineering, procurement, and construction projects.

The core idea was to separate basic from applied research. Headquarters would provide funding for the basic research at EPRI, and the rest would focus on applied research serving corporate objectives. Meanwhile, the two "new" organizations received additional resources to expand. The Smart Grid Research Institute pursues research on key technology and equipment for the smart grid, information and communication, new electric materials, computation and application, HVDC transmission, power electronic devices and application, intelliSense and measurement, and flexible AC transmission systems (FACTs). The Institute has about 600 employees; all its researchers are university graduates, among them over 100 with PhDs and 350 with master's degrees. SGCC sees the Smart Grid Research Institute as a "knowledge-intensive institution." Soon after its establishment, the Smart Grid Research Institute opened a North American branch at Santa Clara, California, close to many IT start-up companies, and, six months later,

[14] In 1983, the newly reconstituted Ministry of Hydro Resources and Electric Power (MHREP) created a company under its wing – China Electric Technology Import and Export Company – to help introduce foreign capital and technology into the electricity industry. In the following two decades, it did exactly that under MHREP, Ministry of Energy, and then MEP. The company was then passed on to SPCC after MEP was abolished, during which it started taking on overseas EPC (engineering, procurement and construction) projects such as the second stage of the Jili Long Hydro project in Cambodia. SGCC inherited this company. In 2010, the management changed the name of this subsidiary to China Electric Power Equipment and Technology Co. Ltd (SGCET).

a European branch in Berlin. The Institute looks for opportunities to conduct collaborative research for and with foreign researchers and research institutes. It is too early to tell what it can achieve.

SGCC significantly strengthened SGCET's manufacturing capacities and access to overseas markets by taking on EPC (engineering, procurement, construction) projects. It injected nine times its initial capital, from 150 million yuan to over 1.5 billion yuan, and more importantly, expanded its initial business scope to include acquisition of electric equipment manufacturers, and investment in overseas EPC projects that can absorb products from these equipment makers. According to one report, SGCET bought as many as sixteen equipment manufacturers, including Changzhou Toshiba Transformer Company Ltd that became SGCET Toshiba (Changzhou) Transformer Company Ltd in July 2011, and Shanghai Zhi Xin Electric Co. Ltd (Guo 2011). The reorganization sought to build NARI and SGCET into a chain that would ensure the development of core technology, test systems equipment manufacturing capacity, project construction, and standard setting. As each subsidiary expanded, top-down management became more difficult and complex. Yet the SGCC management continues to set expectations for these institutes: in addition to financial performance, they were required to improve their own research capacities, build brand name products, and set standards.

Less than a decade after it proposed UHV projects, SGCC turned its eye to the global market. This was in part because rapid expansion of renewable power generation increased the pressures on transmission systems in many countries. Integrating large amounts of renewables into the grid will require new and more flexible transmission networks. SGCC proposed the idea of global energy interconnection to the United Nations and other international forums. This initiative arose in part to counter domestic opponents' continued efforts to dismantle SGCC and in part to use its UHV technology to establish a leadership role in the coming global energy transition. Domestically, the interconnection proposal gained support from the government, which was struggling to curtail air pollution and establish its green credentials. SGCC's program of "replacing coal with electricity, replacing oil with electricity, and using electricity from afar" (以电代煤，以电代油，电从远方来) would help the country achieve its ambitious renewable targets. Globally, all major players in the field, from established players such as GE, Siemens, ABB, and Toshiba, to newcomers such as Tesla Motors, supported by government policies and resources, are racing to create technologies for the transition to low-carbon electricity production and consumption. As US President Barack Obama said in his 2014 State of the Union speech: “the nation that goes all-in on innovation today will own the global economy tomorrow.” SGCC made its ambition clear: it will not “stand on the sidelines” in this round of international competition. Its *Global Energy Interconnection* would allow SGCC to expand worldwide.

By now, SGCC has achieved worldwide recognition as a major competitor for global market share. The ideas of global energy interconnection may be too bold for some. Many green energy advocates focus on micro-production by rooftop solar panels and small-scale wind turbines, and micro-grids for self-sustained production and consumption as seen in military bases in the United States and some university campuses, such as UC San Diego. While large-scale connections may be out of fashion because of political difficulties in winning public acceptance of rights-of-way for large transmission projects, SGCC’s proposal for global energy interconnection has its supporters who argue it may offer a realistic global alternative for developing low-carbon electricity production and consumption.

CONCLUSION

In a decade, emerging from an old-style, inefficient, centrally controlled and yet decentralized and fragmented government agency, SGCC managed to transform itself into a global technology leader in long-distance, high-voltage electricity transmission. Encouraged by the broader political environment and favorable policies, SGCC acted as a policy entrepreneur and an aggressive initiator in strategies and deployed its immense financial resources in supporting an ambitious and audacious project

SGCC is now the world’s largest utility; it ranks second behind Walmart in the Global Fortune 500 for 2016; its 2015 revenue of US$329 billion surpassed the GDP of most countries. Its transmission networks absorb the world’s largest amount of both renewable and conventional electricity. Its UHV transmission lines, based largely on its own design and on Chinese-made equipment, span longer distances, operate at higher voltage, and experience lower power loss than any competitor has achieved. These advances provide China with an infrastructure framework that has long-term lock-in effects on future development. In so doing, SGCC has built a global brand and helped some Chinese electric equipment manufacturers to move from import dependence to a new status as globally competitive exporters. By mastering the UHV technologies and accumulating experience in constructing and operating UHV infrastructure, SGCC has become a major global player in this demanding field.

These developments contradict the common vision of centrally directed state enterprises as sluggish, debt-ridden, inefficient behemoths that act as a drag on China's economy. Instead, the spirit of entrepreneurship propelled a bold and ambitious vision that enabled SGCC to move from depending on imports for designs, technologies and equipment to a new position of world leadership in long distance electricity transmission. To accomplish this transformation, SGCC followed a conventional strategy common to innovative efforts in many large corporations: building an internal R&D hierarchy, centralizing the allocation of resources, and expanding horizontally and vertically in related industries.

Research and innovation on UHV projects and technologies became a collective exercise, carefully orchestrated by the management with its chief executive as its conductor, well-qualified senior executives leading individual sections, and external consultants providing essential technical expertise. The broader policy space also encouraged the management to, firstly, turn perceived negative and burdensome institutes into a contributing force by reorganizing them and injecting resources, and, secondly, building a broader coalition for R&D involving research academies, university specialists and domestic and international competitors yet with itself firmly sitting in the driver's seat. State Grid's innovation success rested on the creation of broad R&D coalitions involving research academies, university specialists and even business rivals – a signal achievement in an economy renowned for excessive vertical integration and narrow pursuit of corporate self-interest. Along the way, State Grid's leaders succeeded in welding unwanted and seemingly burdensome research institutes, whose initial function was to generate budget-draining pension obligations, into major cogs in what entrepreneurial leaders developed into a formidable research combine that can claim to have beaten proud multinationals at their own game. As one of China's elite state enterprises, State Grid, administered and supervised by the central government, is widely perceived as a mere instrument of the party-state. Yet, none of the specific efforts and strategies that vaulted this company into global leadership in UHV transmission came from top Communist Party or government leaders. Initiative rested first with SGCC's entrepreneurial executives. Government policies are important as in all countries for technology innovation, as "the state has a central place in the national system of innovation . . . government organisations, government-funded university laboratories, government procurement, government regulations, and publicly provided infrastructure have been essential to technological change and to the organisational development of firms" (Hart 2007, p. 170). Official actions shape but do not determine enterprise response. The success or failure of corporate entities, including China's centrally administered state firms, depends crucially on the vision, drive, and entrepreneurial capacity (or their absence) of their leaders.

This being said, firms, private or state-owned, are subject to government policies, which in China have not offered a stable environment. SGCC's scale and market power created envy and resentment on the part of local governments, local distribution companies, and some economic analysts. Long-standing calls for the break-up of SGCC contributed to the central government's 2014 issuance of the "Directives on Further Deepening Electric Power Institution Reforms" along with nine supporting documents, covering T&D pricing, cross-region and cross-province energy exchanges, power market construction, retail segment reform, and integration of renewable power generation. This new wave of reforms, discussed further in Chapters 4 and 8 of this book, empowers government auditors to set the grid's transmission charges, expands the scope for direct electricity sales from generation companies to large end users, and strips the grid of its monopoly over retail sales by allowing new firms to enter this segment of the electricity market.

The reform plan faces a serious challenge: by fixing uniform grid charges, the new system eliminates any commercial incentive to build grid connections to link new and often remotely located sources of wind and solar power with distant urban centers of electricity demand. Local governments, focused chiefly on short-term growth, continue pushing investment in generation (renewables included) leading to serious problems of curtailment as grid connections lag behind the expansion of power generation capacity (Feng 2016).

Recent reforms threaten to erode the incentives needed to motivate grid firms to mobilize their technical and economic capacity to hasten the interconnections required to achieve official promises regarding the growth of renewables in China's electricity mix. In China, both wind and solar generation capacity clusters in sparsely populated places far away from China's eastern coastal load centers. Rapid investment in renewable capacities without closing down dirty-thermal power generation plants exacerbated competition to get on grids. Meanwhile, debates continue as whether SGCC should continue investing heavily in interconnected T&D networks, especially UHV ones. This challenge is not unique to China: due to the "collective good" characteristics of T&D systems, private markets often fail to deliver sufficient investment this segment of electricity systems.

Internationally, SGCC's *Global Energy Interconnection* – a plan to combine interregional and even intercontinental UHV transmission grids with smart grid technologies to address a series of energy and environmental challenges – has received serious attention from the industry and even won the endorsement of the International Energy Agency (IEA 2016a). A global energy interconnection can potentially address issues surrounding energy security, energy poverty, and climate change, by transmitting clean energy, connecting large clean energy bases with distant distribution networks, and delivering clean energy to different types of end-users (Liu 2015). It creates the promise of a widespread, highly deployable, safe, reliable, green and low-carbon global energy distribution platform. This may be self-serving, but the successful operations of the UHV projects in China allow SGCC to propose an alternative to the international community, which is struggling to provide universal access to electricity while simultaneously making electricity clean, affordable, and sustainable. This proposal reflects what Richard R. Nelson emphasized: "it is organisational differences, especially differences in ability to generate and gain from innovation, rather than differences in command over particular technologies that are the source of durable, not easily imitable, differences among firms" (Nelson 1991, p. 72).

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