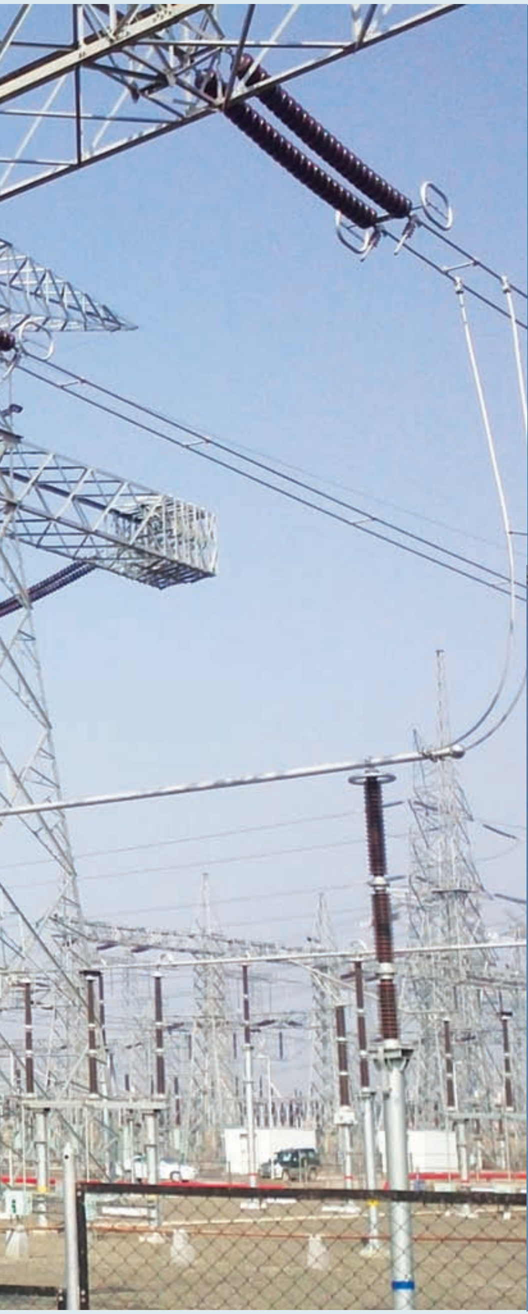
The development of India's power sector—in both qualitative and quantitative terms—will be the principal determinant of India's socioeconomic development. Power transmission and distribution have received much lesser attention as compared with power generation. In fact, power shortages have traditionally been addressed by ramping up power generation capacity. It is only over the past few years that attention is being directed to improving the technical and commercial efficiency of power generated by duly addressing critical issues in the power T&D space.

On the power transmission front, one of the means to achieve greater efficiency is the introduction of high-voltage lines. Today, commercial lines exist up to 765kV, and apart from AC (alternating current) technology, there is widespread deployment of DC (direct current) lines. In terms of high voltage direct current (HVDC) lines, India is establishing lines with ultra high voltages of even ±800kV. An outstanding aspect of India's power transmission endeavours has been the effort to set up ultra high voltage power transmission lines at 1,200kV—the highest voltage level anywhere in the world as yet.

Though India has yet to establish 1,200kV power transmission technology on a commercial scale, a

PHOTO: SUPREME & CO



India steps up to 1,200kV

PHOTO: SUPREME & CO

India is set to deploy 1,200kV power transmission lines on commercial basis, making it the highest voltage level in the world. Boosting India's prospects is the successful implementation of the 1,200kV test station at Bina in Madhya Pradesh. **VENUGOPAL PILLAI** looks into various aspects of ultra high voltage power transmission and discusses challenges that India will need to contend with before 1,200kV power transmission can become a sustainable reality.

good beginning has been made by setting up testing facilities. The Bina UHVAC test station in Madhya Pradesh is the result of the concerted effort of Central transmission utility Power Grid Corporation of India, Central Power Research Institute (CPRI) and 35 Indian suppliers. What is encouraging to note is that the UHVAC test station is based largely on indigenous technology.

Seeds of the UHVAC enterprise were

AC & DC: A winning combination

Photo: CTC Global

The choice between alternating current (AC) and direct current (DC) has been one of the most interesting aspects in the study of electricity. Thomas Alva Edison was an active proponent of DC. On the other hand, other notable physicists of their time – Nikola Tesla and George Westinghouse – advocated the use of alternating current. AC ultimately won over DC as the generally preferred mode of electricity transmission in what was famously known as the "War of the Currents" in the 1880s. However, the world today realizes that it not a matter of "AC or DC" but "AC and DC". The use of AC or DC, whether it is for low or ultra high voltage, depends on the situation on hand. In the context of high- and ultra high voltage power transmission, India is a classic example of how it is creating a judicious mix of AC and DC power transmission infrastructure. Even as EHV and UHV transmission is taking place through the AC mode, there is a conscious effort to build high voltage direct current (HVDC) lines for voltages as high as 800kV. China too has factored the use of both AC and DC ultra high voltage lines in its national power transmission plan.

Over long-distance power transmission, both UHVAC and UHVDC offer comparable advantages. However, when it comes to equipment (e.g. transformers and circuit breakers), there is more collective expertise with AC systems than DC systems. AC transmission lines can connect loads at different points en route, while the same for DC systems is very expensive or even impracticable. Line costs for HVDC systems are said to be lower than HVAC systems, simply because DC systems need fewer number of conductors. However, there are specific applications – like subsea links – where DC enjoys distinct technical advantages.

HVDC has a solid advantage in that it allows power transmission across asynchronous AC systems (operating at different frequencies). This, experts feel, leads to grid stability. In the Indian context too, the southern grid, operating at 60Hz, was connected to the national grid using HVDC interconnectors. This was before the AC link (Sholapur-Raichur) came up in January this year.

Antonio Ardito, Chief Engineer, Consulting Division of Italy-based testing laboratory CESI, in an interaction with *Electrical Monitor* noted that competition between UHVAC and UHVDC is intensifying of late. Ardito said that technology relating to converters (used in HVDC transmission) has developed significantly over the recent years. This has resulted in lower capital costs of HVDC lines. "This makes HVDC more attractive from both a technical and economic standpoint," he felt. While ±800kV DC transmission is in commercial operation, the technology for 1,000kV DC has also been developed, he observed.

All in all, there cannot be ultra high voltage power transmission corridors using AC or DC alone. A combination of the two, depending on project conditions, is what a transmission network should deploy.

sown in 2007 when a Project Steering Committee was formed under the leadership of PGCIL and with members from Central Electricity Authority (CEA), industry body IEEMA, CPRI, and leading Indian electrical equipment manufacturers. The UHVAC Bina test station represents an interesting manifestation of the public-private partnership (PPP) philosophy. When PGCIL announced the 1,200kV venture, several equipment manufacturers came up in support. For the 35 manufacturers involved in this project of national importance, it was not merely a "contract" awarded by PGCIL, but an opportunity to contribute to a national cause. All the equipments for the station like transformers, circuit breakers, surge arrestors, insulators, etc were built indigenously. The Bina test station was dedicated to the nation on December 26, 2012. The test centre includes two test bays, one 1,200kV single-circuit line and one 1,200kV double-circuit line. The test lines are around 2 km long.

The following is a brief description of select participants in the successful commissioning of the 1,200kV Bina test station.

Bharat Heavy Electricals Ltd: Central PSU engineering company BHEL supplied a 1,200kV transformer of 333MVA rating. This single-phase auto transformer was developed with indigenous technology and manufactured at its Bhopal plant in

Madhya Pradesh. Apart from this, BHEL also supplied other key equipment like 1,200kV insulators.

Vijai Electricals Ltd: This Hyderabad-based company also supplied a 1,200kV auto transformer of 333MVA rating. Like BHEL, this single-phase transformer was developed with indigenous technology and was produced at the Rudram works near Hyderabad.

Crompton Greaves: Avantha Group company Crompton Greaves (CG) dispatched a 1,200kV capacitive voltage transformer for the Bina UHV test station. Rolling out of the Nashik plant in Maharashtra, the mammoth transformer was developed with in-house technology.

Larsen & Toubro: This private sector engineering giant was also involved in the 1,200kV power transmission regime. In late 2009, Larsen & Toubro established India's largest transmission line research centre at Kancheepuram in Tamil Nadu. The centre is equipped to test transmission towers of up to 95m height required for 1,200kV power transmission lines. This testing station, according to a statement by L&T, enables to design and validate innovative configurations without any limitations on size, shape and magnitude of loading, which is currently not possible in the industry.

Siemens: Siemens developed a 1,200kV circuit breaker for the Bina test station. This apart, Siemens also supplied surge arrestors of 1,200kV rating. A Siemens official told *Electrical Monitor* that these arresters were designed and tested at Siemens' Berlin and Cologne facility in Germany.

Alstom India: Formerly known as Areva T&D, Alstom India supplied a 1,200kV capacitive voltage transformer for the Bina test station. This equipment was developed at the Hosur plant in Tamil Nadu. Alstom has also planned to make other 1,200kV gear including digital current transformers.

KEC International: RPG Group company KEC International was involved in the Bina test station as the EPC contractor for the 1,200kV double-circuit line. The line involves handling of towers each weighing more than 400 tonnes and with a height of 130m. In an exclusive interaction with *Electrical Monitor,* Ramesh Chandak, MD & CEO, KEC International Ltd expressed pride in being associated with this landmark project. *(Full interaction presented elsewhere in this story.)*

Supreme & Co: Kolkata-based Supreme was an active supplier of critical hardware for the Bina test station. In an earlier interaction with *Electrical Monitor,* the company said that it had supplied nearly 80 per cent of the hardware used in the UHVAC centre. Some key equipment included

Photo: CPRI

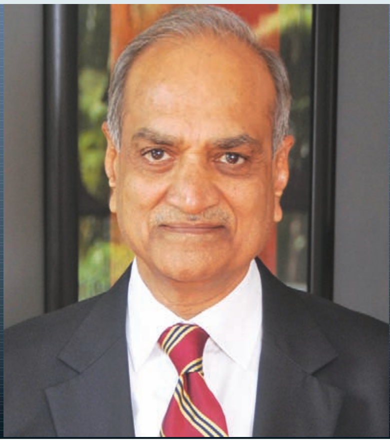
Photo: CESI, Italy

Early adopters: Russia & Japan

Several countries, since the 1970s, have been planning to develop ultra high voltage AC lines for efficient power transmission. Two countries that were successful in putting UHVAC lines in commercial operations include Russia and Japan. (Also see Box: Italy's Experience)

In 1985, Russia (erstwhile USSR) energized a 500-km section of the 900-km 1,100kV UHVAC line between Ekibastuz and Kokchetav substation. The remaining 400-km line between Kokchetva and Kustanai was energized in 1998. The line was operated at 1,100kV only for a brief period of time and today, the UHVAC line has an operational voltage of 550kV. This drop in voltage resulted from lower electricity transfer demand, among other reasons.

Japan has been working on UHV technology since the early 1970s in an attempt to find solutions to upgrade its then existing 550kV power transmission network. Bulk of the research was conducted by Tokyo-based Central Research Institute of Electric Power Industry (CRIEP), in association with power utilities. Tokyo Electric Power Company, in 1993, completed the 190-km 1,100kV North-South route linking the nuclear power station on the Sea of Japan to the metropolitan region. The 240-km East-West route connecting power plants on the Pacific Ocean was built in 1999, designed for the same nominal voltage of 1,100kV. However, for much of their commercial life, the lines have operated at 550kV voltage.



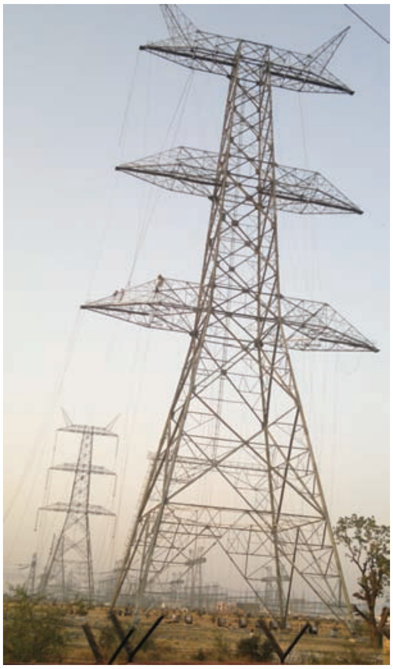
We are proud to be part of the world's first 1,200kV test project

KEC International Ltd was involved in setting up the 1,200kV double-circuit line that was a crucial component of the Bina UHVAC test station. We have Ramesh Chandak recalling the experience and sharing his elation in being part of a landmark project.

—**Ramesh Chandak,** Managing Director & CEO, KEC International Ltd

Tell us about KEC International's role in the 1,200kV Bina test station.
As part of PGCIL's 1,200kV test station at Bina, KEC played a vital role of constructing the 1,200 kV double circuit (D/C) transmission test line. This is the first 1,200kV D/C transmission line in the world. Each tower weighed more than 400 tonnes and had a height of 130m.

What were the major challenges that KEC contended with while executing the project?
The foundation activity involved huge concreting volume—exceeding 500 cubic metres (cum) in each foundation. Erection of these mammoth towers was indeed a challenging task. We decided to use a combination of conventional and innovative mechanization techniques for this work. We deployed a central crane and a 3.5-tonne puller along with heavy-duty pullers to carry out the tower erection. To expedite the project – in view of its importance to PGCIL and to the nation – a special 150-tonne crane with an 80m boom was also mobilized at the site in February 2012. Manpower mobilization at the peak of project progress was about 400 workers at the site.



Given that the Bina UHVAC station has been a national landmark, what special treatment – so to speak – did KEC give to the project?
Yes, we gave special attention to safety in view of the enormity of the task and safety hazard it imposed. We are proud to share that we have no incident reported from site till date. This was ensured with the use of special safety equipments and communication devices.

Being a landmark project of PGCIL, the project was keenly and closely watched by the industry, government and of course PGCIL. There were regular visits of senior PGCIL officials including its CMD.

We can say proudly that we were part of the first 1,200kV test project in the world!

corona control rings, clamps, connectors, etc.

Hivelm Industries: This Chennai-based company that is a unit of Digivision Electronics Ltd designed and developed a 1,200kV isolator for the Bina test station. The isolator was shipped to Bina in August 2012.

As of now, the Bina UHVAC station is under testing. Going by industry players, the results have been satisfactory. Testing is expected to go on for another couple of years after which India can embark on setting up 1,200kV lines at the commercial level. When it comes to 1,200kV lines, India has established its competence in manufacturing equipment and hardware. The next phase—and of course the most critical one—is to study "live line" conditions, which is to investigate the working of 1,200kV lines at full load on a sustained period of time. The impact of full load is also being studied on the equipment and hardware. Depending on the results of this study, suitable modifications may need to be made for future projects.

THE NEED FOR UHVAC

India, due to its intrinsic conditions, makes a very good application area for ultra high voltage power transmission. India's current installed capacity is around 2.3 lakh mw and by 2027, installed capacity is likely to touch 7 lakh mw, necessitating the transfer of 5 lakh mw worth of power capacity.

Power transmission is very land-centric activity and land—as a subject—has always had a difficult time. Erecting power transmission lines involves obtaining the ever-elusive right of way. Securing RoW for lines passing through sensitive areas like forests or mines or through private land has been a big deterrent. Once RoW is obtained, it makes technical and commercial sense to harness it to the fullest. The difference in RoW requirement for a 400kV line and a

1,200kV is not significant. However, the benefits of being able to transmit huge quantum ultra high voltage lines cannot be overlooked. A 400kV line can typically transmit 400 mw of power. When one moves to 800kV, the quantum of power transfer is between 1,200 mw and 2,400 mw. When one graduates to 1,200kV lines, power transmission of 6,000-8,000 mw is technically possible. Ultra high voltage power transmission, despite the challenges, will be an area that India will need to keenly explore.

One more reason why UHV transmission is warranted is because of the power demand-supply situation. Power generation centres are typically in eastern and northeast regions while consumption centres are spread across rest of India – north, west and south. In general, generation hubs are limited consumers, warranting the need for carrying power across long distances. One more application for high-voltage lines stems from India's plan to import power from hydropower-rich neighbours like Bhutan and Nepal.

Thus, we see that ultra high voltage power transmission is indispensable. However, the choice of AC and DC will depend on the specific project conditions (See Box: AC or DC). In the Indian context, UHVAC has a solid advantage in that it is cheaper to build as converters used in HVDC lines are expensive. According to Antonio Ardito of Italy-based CESI, UHVAC allows easy and cheap connection of lower voltage networks. It also ensures availability of large synchronizing power during major network perturbation. Speaking to Electrical Monitor, Hitesh Mundhada, Regional Director -- India & Middle East, CTC Global, noted, "1,200kV is like a super transmission highway used for interregional connections; for example evacuating bulk power from NE region through the very narrow (Chicken's Neck) area. Through higher AC voltage levels like 1,200kV which are electrical compaction of transmission lines, unit cost of ROW per block of power is greatly reduced compared to lower AC voltage levels."

The first commercial 1,200kV line in India, by current thinking, is going to be the 400-km Wardha to Aurangabad line in Maharashtra. Currently, the line is 400kV but will be scaled up to 1,200kV over the next 2-3 years. Work on this line will of course take place when detailed tests are done at the 1,200kV Bina pilot project.

UHVAC in China

China is also pursuing ultra high voltage power transmission to carry electricity from remote generation centres. China has been adopting both AC and DC modes of transmission, much like India. As far as ultra high voltage AC transmission is concerned, China began preliminary work in 2004-05. Currently, the 1,000kV Jindongnan Nanyang-Jingmen line, which began operations in January 2009, is the highest-capacity AC line in China. Though it has a nominal voltage of 1,000kV, it has recorded its highest operational voltage of 1,100kV. Its transformational capacity stands at 6,000MVA.

The 650-km long line has two segments—a 360-km line from Jindognan in the northern province of Shaanxi to Nanyang, and a 290-km line from Nanyang to Jingmen in the central province of Hubei. The project includes a 3.7-km line crossing the Yellow river and a 2.9-km line crossing the Hanjiang River. The UHVAC line, completed in November 2008, was built by China's largest transmission utility State Grid Corporation of China, with an investment of around $1 billion.

Approved by China's National Development & Reform Commission in August 2006, construction work started at the end of the same year. It was put into commercial operations on January 6, 2009, after 168 hours of trial run. The line was built with indigenous technology and equipment.

CHALLENGES

The technical and commercial advantages of 1,200kV are significant but there are countervailing challenges. India has acquired some expertise in producing key UHVAC equipment like transformers, circuit breakers, etc. The ability to construct 1,200kV lines has also been established. The critical issue, as discussed earlier, is keeping a 1,200kV line fully charged over long periods of time. The highest-rating AC power transmission line currently operational in the world is a 1,100kV line by China. This line has been in operation only since recently; the collective global experience of fully-charged live lines is therefore relatively limited.

Electrical Monitor got in touch with some industry players to understand the challenges ahead of India in its quest of running 1,200kV lines on commercial basis. Harish Agarwal, CEO, Supreme & Co, felt that breakdown and outage management of UHVAC lines could be challenging as India has yet to acquire experience in this regard. "Sudden loss of line owing to big natural calamities, if they occur, will result in loss of huge quantum of

Italy's Experience

Corona test cage of CESI's UHV test facility at Suvereto, Italy

The experience of Italy in ultra high voltage power transmission is very interesting. The European country started development of UHVAC technology way back in the 1970s, in anticipation of bulk power transmission requirements over long distances. Interestingly enough, by 1997, Italy found no commercial application for UHVAC lines as following a systemic change in its power demand-supply situation.

Italy-based CESI, the independent global centre of expertise and provider of technical and engineering services to customers throughout the energy value chain, was closely involved in the development of 1,000kV UHVAC technology in that country. Antonio Ardito, Chief Engineer of CESI's Consulting Division, recounted Italy's UHVAC experience in an exclusive exchange with *Electrical Monitor.* His narration is summarized below.

In the early 1970s, Enel, the then Italian national electricity board, decided to develop UHVAC technology (at 1,000kV level) as a consequence to rapid and stable growth in electricity consumption, which was doubling every ten years. During this period, there was a gradual increase in capacity of power generation plants (mainly thermal), matched by increase in network voltage from 380kV to 420kV. It is interesting to note that Italy then had envisaged around four mega nuclear power generation plants, each with capacity of 5-6 GW. Italy was convinced that higher voltage lines would allow land occupied by overhead lines to be kept within acceptable limits, and that there would be significant savings in terms of both investment and technical losses.

Italy did not pursue HVDC as its plan envisaged four mega nuclear power plants with load centres located at relatively short distances of around 250 km. Secondly, HVDC technology was then only evolving, in other parts of the world like North and South America, and as such was very expensive. Italy's 1,000kV UHVAC project was developed in two phases:

In the first phase, from 1970 to 1985, extensive theoretical studies and experimental investigations were performed in CESI's dedicated test facility at Suvereto and CESI's laboratories in Milano. Experimental tests were conducted on a line span with prototypes of components designed and supplied by associated manufacturers. In the second phase, from 1985 to 1990, a plant was erected with commercially-conceived components including a 3-km overhead line, a 0.5 km underground cable and all the substation apparatus and components (380/1000 kV autotransformer set, a complete SF6 switchyard and an air insulated switchyard) for a complete operational test and full feasibility demonstration.

This feasibility demonstration project was operated up to 1997 and ultimately dismantled as there was a radical change in Italy's electricity landscape. The large nuclear power plants envisaged earlier were cancelled, making way for medium-sized (400 to 800 mw) gas-fired power plants and a few coal-fired ones. Therefore the need to transmit large quantum of power over long distances simply dropped off.

power. Emergency restoration can present a challenge as such solutions today are available only up to 800kV," noted Agarwal.

Rishabh Sethi, Chief Operating Officer, SPML Infra Ltd, also pointed out some technical issues in UHVAC lines. SPML Infra is a leading multifarious EPC contractor with significant expertise in power T&D. Sethi observed, "The electrical concern in these kinds of ultra-high voltage lines is the corona effect that could lead to huge loss of power during transmission." He also pointed out India will generally have to upgrade its manufacturing and fabrication facilities to cater to the UHVAC regime.

Hitesh Mundhada, Regional Director – India & Middle East, CTC Global, was of the opinion that India should expedite the creation of testing facilities for 1,200kV otherwise it would need to import costly UHV equipment. He also expressed that due to high electromagnetic fields, there could be an impact on environment and health. Concurring broadly with this view was Harish Agarwal who felt that "Biological effect in the vicinity of UHV lines, owing to induction, may pose some challenge."

Siemens that supplied circuit breakers for the 1,200kV Bina test station expressed apprehension about testing of high-voltage equipment. A Siemens spokesperson said, "Generally the procedure for development of UHV circuit breakers is comparable to the development of those for lower voltage levels. However, one of the major challenges is the availability of suitable test fields (test equipment) to test the breakers during the development and to perform the necessary type tests at these high voltage levels."

Given that obtaining right-of-way can be very challenging in the context of India, Harish Agarwal observed that securing RoW in absolute terms may be challenging even if the ratio of RoW to power transmitted were favourably low.

CONCLUSION

India's plans for power generation capacity hinge on the setting up of large-sized plants. The ultra mega

Photo: CESI, Italy

power plant series (with each plant of around 4,000 mw) and gigawatt-sized nuclear power plants are key plans to this effect. India will continue to deal with large quantum of power that needs to be transmitted over long distances. In this reckoning, the power transmission backbone will need to incorporate ultra high voltage lines. Contentious issues like securing right-of-way will persist, once again necessitating the deployment of ultra high voltage lines. Maximum power transmission per unit right-of-way will be the key mantra. In future, India will need both AC and DC modes of ultra high voltage transmission, ensuring that the individual advantages of both technologies are exploited and a winning combination created. Experts feel that in the medium term, the bulk transmission network in India will comprise 1,200kV UHVAC and ±800kV HVDC lines. The sub-transmission network will have a combination of 756kV AC and ±500kV lines.

The 1,200kV regime is new to India, and for that matter, to the world. India thus has to build self-sufficiency in every department of UHVAC infrastructure—manufacturing, construction, testing, servicing, etc. UHVAC transmission at 1,200kV is perhaps a rare area where India will find itself without global precedents to emulate. So far, the journey has been quite satisfactory with India establishing a 1,200kV test station in less than five years, thanks to the overwhelming and enthusiastic support of Indian enterprise. However, the key challenge will be to operate commercial lines on a sustainable basis. This will need much more effort than what has been seen so far. A pilot project, especially if it is that of a world-first like 1,200kV power transmission, is bound to be a euphoric experience. What is now needed is the dedication and commitment to transmute this pilot model to commercial scale.

Creating facilities for manufacturing and especially testing of 1,200kV equipment on commercial scale will be of paramount importance. With commendable work done towards successfully building the pilot model, India now has an open field to demonstrate its prowess on building commercial 1,200kV lines. This will endorse its commitment in addressing the often-neglected cause of improving technical and commercial efficiency in the power sector.