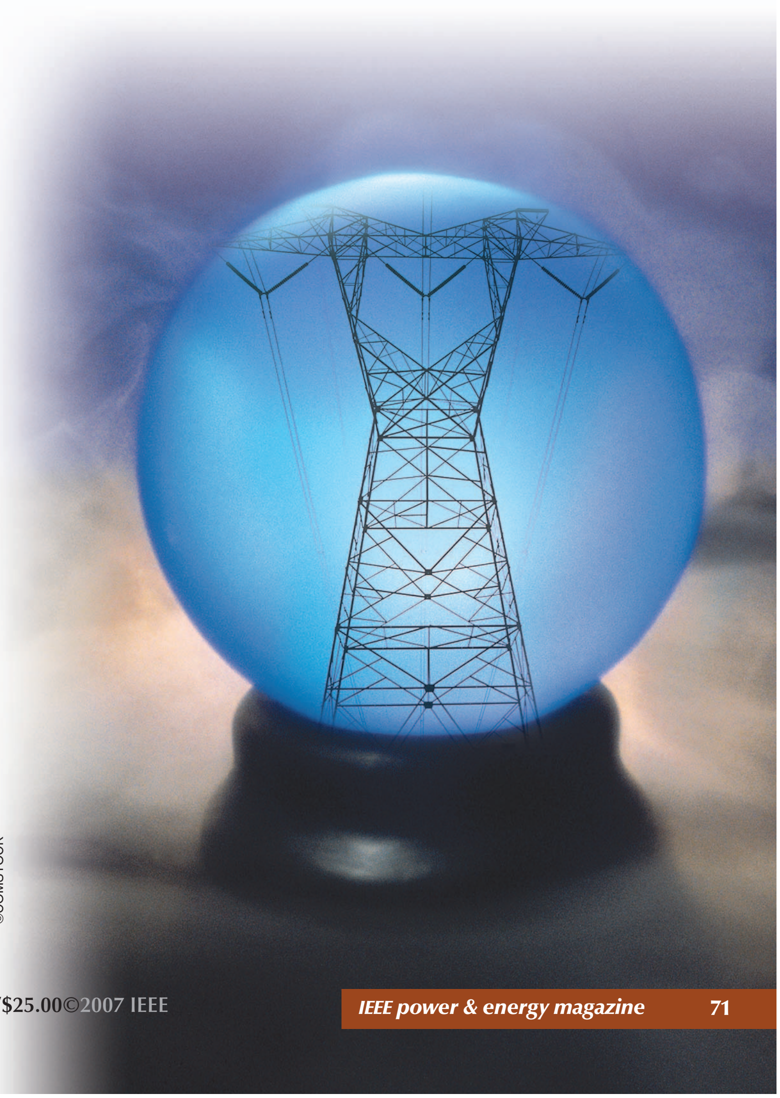
Towards Electricity for All

Transmission Planning for the Growth of India's Power System

By Subrata Mukhopadhyay

WITH HARDLY A CAPACITY OF 1,360 MW AT THE time of India's independence in 1947, the Indian power system was to serve the needs of urban centers through isolated generation. Development of river valley projects and formation of state electricity boards (SEBs) in the federal structure ushered in the addition of generation in the 1950s and 1960s through steam power plants of higher capacity along with the interconnecting network, eventually forming the state grids. The 1970s and 1980s saw the inter-state transmission development leading to five regional grids, namely, northern, western, southern, eastern, and northeastern. Almost at the same time as the central government venturing into thermal, hydro, and nuclear generation, it became a reality to have larger thermal units (initially of 200 MW and then 500 MW) in mine-mouth power stations with interconnection at the 400-kV level. Subsequent development in the 1990s and in the early part of this decade made it possible to connect even regions with HVDC systems in back-to-back mode (primarily on account of mismatch in frequency) and with trunk lines (including some intra-regional ones). Most recently it has been possible to connect four regions (excluding the southern region, which continues to be connected with the rest of the country through various HVDC connections) in synchronous mode as a step toward formation of the Indian National Grid.

Side by side with power sector reform taking place, since the early 1990s, it has been possible to add generation by the independent power producers (IPPs) in some regions, unbundling the power sector with



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generation, transmission, and distribution as separate distinct entities with private entrepreneurs taking over the distribution system and forming distribution companies. With the regulatory bodies formed, both at the central and state level, for a large number of players in the field the tariff is fixed by the former. Transmission, however, still remains a natural monopoly, though joint sector ventures have also been made. Regulation allowing open access has made it possible to do trading in power with a number of entities joining the fray, from both the public and private sectors, and also under joint ventures. In tackling the issue of congestion management, it has opened the vistas for expansion of the transmission network for adequacy.

This article describes future projections of requirements for transmission planning in the overall growth of the power sector, problems and issues specific to transmission, technology options available and needed, and what the system may look like in the future.

Current State of the Power System

As of 31 January 2007 the installed capacity in India was about 140 GW. It meets a summated peak demand of 86 GW (against a requirement of 100 GW) with the availability of inter-regional transfer capability of approximately 18 GW. The corresponding figures by 2012 (the end of 11th five-year plan) would be 210 GW, 157 GW, and 37 GW as projected in Figure 1. By 2022 installed capacity is estimated to approach 600 MW to cater to the peak demand of 450 GW utilizing the inter-regional capability of 140 GW. For this, transmission line requirements would reach 75,000 to 250,000 km at the 400-kV level, to 20,000 at the 765-kV level, and to 15,000 at the ±500-kV HVDC level. Perhaps at the ultra high voltage (UHV) level of 1,200-kV HVAC and ±800-kV HVDC, it would call for an additional 20,000 and 15,000 circuit-km of transmission lines, respectively, as shown in Figure 2. The corresponding substation capacity in MVA and for HVDC in megawatts is shown in Figure 3.

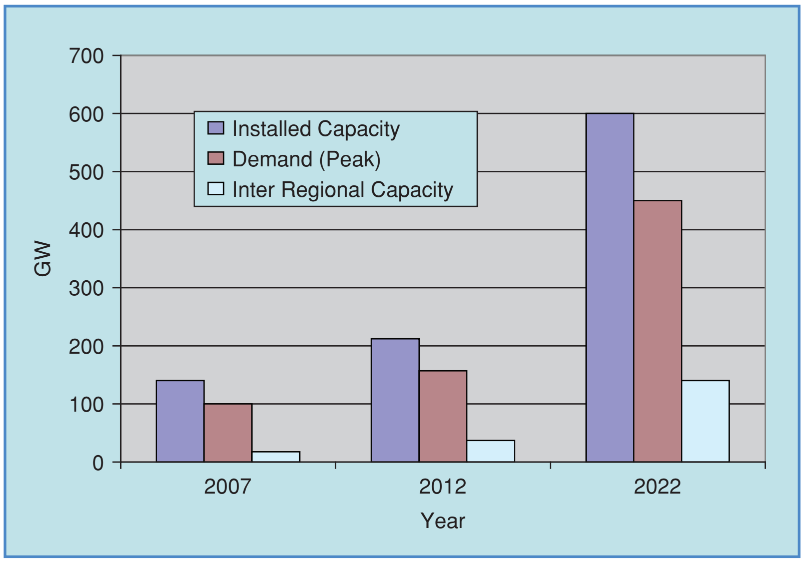

figure 1. Projected growth in installed capacity.

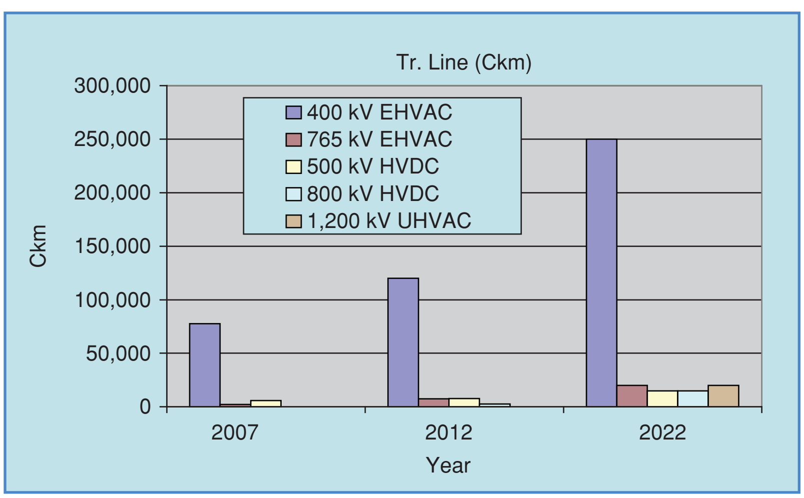

figure 2. Growth in transmission lines as envisaged.

Transmission Planning in the Overall Growth of the Power Sector

With India's Central Electricity Authority (CEA) of the Ministry of Power at the helm of affairs, the basic planning starts with a power survey. SEBs at the grass-root level do the spade work with different agencies involved through collection of data concerning new demand in commercial, industrial, domestic, public services, and irrigation areas and also the growth for the existing systems in the corresponding areas. CEA consolidates the projected figures on an all-India basis by working in close coordination with the SEBs and forecasts load and total requirement of electric energy and peak load to be met for the next few five-year plan periods based on a combination of partial end-use techniques and trend analysis and computing long-term projection by extrapolating the energy requirement at the power station bus bar. Various components, such as transmission and distribution losses (both technical and commercial), load factor, diversity factor, etc., are also taken into account state/system-wise along with growth rate. With the national grid a reality, long-term projection takes care of regional diversity factors considering significant daylight time difference across the country from east to west. Economic recession and restructuring of SEBs are the other pertinent factors that influence the overall scenario. These

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figures are, however, scrutinized by certain departments of India's government, including the Planning Commission, keeping it in mind the commensurate fund requirement compared with relative priority with respect to the other sectors of the country's infrastructure for investment under the public sector. Having made the blueprint, CEA further works out the details of generation corresponding to various scenarios of load projected for the next few 5-year plans. In all these projections, computed availability based on planned outages and forced outages (partial and complete) is taken onto account. Then, under integrated resource planning (IRP), considering all possible sources to produce electricity in conventional ways, including nuclear, the most optimum solution is attempted for meeting the load requirement. In the process of planning for the addition of generation, issues of system improvement to minimize transmission and distribution losses, raising of plant load factor, renovation and modernization of old but still running power plants, and also generation from renewable and nonconventional sources, etc., are considered to augment overall supply.

With the load points also known in the process it identifies the possible corridors of transmission of power compared with energy, though voltage level for this may be just an indicative one at this stage. As applicable for the planning of any system, the basic philosophy of configuring a transmission system is to achieve a level of operating performance with adequacy and security, which in turn requires a trade-off between cost and risk with the level of uncertainty taken care of. It is based on a combination of a deterministic as well as a probabilistic approach, with the latter being based on the most likely occurrence compared with past experience to expect ultimately an acceptable system performance. Accordingly, certain transmission planning criteria have evolved and are followed in India. With the inputs in the form of possible generation sites with capacity available and the loads in bulk, the process of transmission planning starts. In the process it configures the network for evacuation of power from new generation plants as well as determines the requirement of strengthening the existing network. It involves not only the corridors of transmission lines with voltage levels but also with finding locations of associated substations. Adequate transformation capacity in the substation with the possibility of future expansion and flexibility at the operation stage are the major guiding factors for such planning exercises.

Due to the enactment of the Electricity Act of 2003, though generation has been delicensed, the expansion of electricity grids still has good planning oversight from CEA (in perspective plans) to the Power Grid Corporation of India (in mid-term planning). With adequacy, a perennial problem as far as generation and distribution is concerned, thrust is being given to these through ultramega power projects (4,000 MW and above) as well as central government interventions through augmentation of distribution infrastructure through an accelerated power development and reform program (APDRP). Implementation of the latter is being monitored qualitatively by the time of the energized state of the 11-kV level bus, which is said to approaching an average of about 99%. This has added a new dimension to transmission system planning calling for bulk power evacuation from these projects to various load centers with lines of high loading capability and short circuit level to be dealt with at the associated substations.

In the meantime, with restructuring reform taking place in the power sector since the early 1990s, some IPPs came into the arena and started feeding the state grids coming under the regional grid. At the same time, in order to improve efficiency and performance in certain states, vertically integrated state utilities were unbundled to form generation, transmission, and distribution companies. Though the transmission sector was opened up for private-sector participation in early 1998, it has

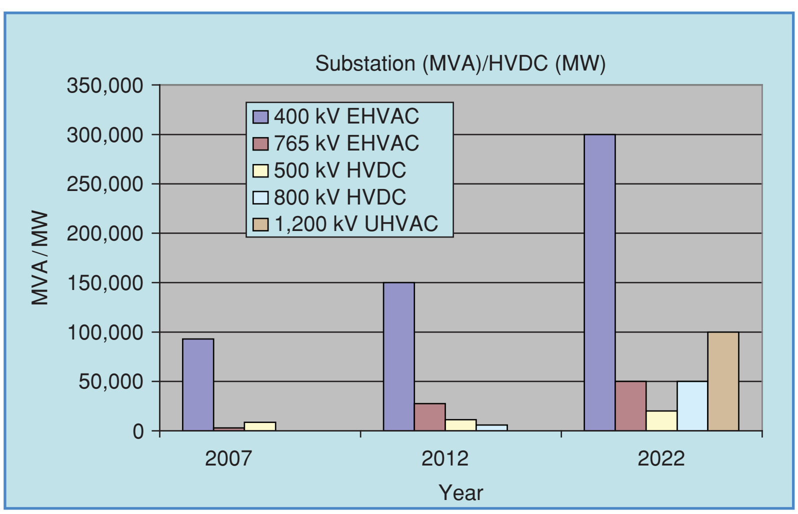

figure 3. Additions to substation capacity.

yet to pick up. As is traditional in pockets, generation and distribution activities were existing in the private sector and only these saw further expansion through setting up new generation plants and acquisition of distribution companies. Transmission as a natural monopoly remains still under government-owned companies, both at the central and state level, though right at the beginning of 1998 it had been opened to private enterprises to build, own, and operate from point to point. With the open access in inter-state transmission to any distribution company, trader, generating company, captive plant, or any permitted consumer as per an order of Central Electricity Regulatory Commission (CERC), certain changes are taking place.

Problems and Issues Specific to Transmission

Due to a large population and environmental restrictions particularly due to forest coverage, right of way (ROW) for the construction of extra high voltage (EHV) transmission lines is gradually becoming more and more difficult. In the early 1980s, due to the construction of single-circuit 400-kV lines, quite a good amount of corridors had been lost with limited amount of flow of power. In fact, subsequently with almost the same amount of corridor width, double-circuit construction in a hexagonal formation has paved the way for hauling twice the amount of power. However, as a measure of enhancement of power flow, series compensation (both static and dynamic) is being implemented to increase the loading capability of these lines. Also, with the development of loads at intermediate locations, at this time long operating lines (above 400 km) are being broken to form new substations in between, thereby improving structural stability and other operating parameters of the system in addition to enhancement of loading through these lines. Similarly, on certain corridors through forests as well as densely populated areas, high-rise multivoltage, multicircuit transmission towers have been attempted. On the other hand, some bottlenecks may still exist in the transmission system because of inadequate compensation of reactive power at lower voltages, leading to burdening EHV systems to run at lower voltages and consequently unable to deliver active power at the desired level. However, through various measures being attempted, the situation is improving.

Besides these concerns, another pertinent problem that has cropped up recently is related to EHV transmission lines passing through environmentally polluted areas due to their recurring failure in specific parts of the year. In the northern region, on account of heavy smog during the winter, frequent failure of the lines caused by flashover is being experienced in spite of insulator washing to the extent possible for the vulnerable section prior to the onset of winter. Replacement by polymer insulators for certain stretches is effective, but for the entire length it is rather impossible.

On the investment front, if one looks right from the start of independence, it may be seen that the whole power sector has been primarily nurtured with funding by the state. Very little investment has come through private sources, and that, too, has been concentrated in and around some of the large metropolitan cities only. Only since the early 1990s has the latter channel become a little more active with the opening up of the sector. For generation and distribution, some progress has been made, but for transmission it is not so. However, under the joint venture with the construction of a major synchronous link between the eastern and northern region, in future it is hoped a few more will follow.

Technology Options

In order to deal with the various problems and issues involved, there is need for application of new technologies based on the following two fundamental points:

- ✔ maximizing utilization of potential of existing system in terms of capacity and availability
- ✔ system expansion with application of new technologies on a sustainable basis.

In the first category on utilization of existing system to the maximum extent, following are some of the measures being adopted.

Series Compensation on 400-kV Lines

Application of series compensation is being done in many important corridors of the EHV transmission network. This has enhanced power carrying capacity of lines by 40 to 50%, depending on the degree of compensation. Moreover, in the case of transmission lines interconnecting different regional grids, series compensation along with a state-of-the-art thyristor controlled series capacitor system has been/is being implemented in damping out low-frequency inter-area oscillations besides enhancing the power transfer capacity. Intra-state/inter-state 400-kV Kanpur-Balabhgarh, Rourkela-Raipur, Purnea-Muzaffarpur, and Muzaffarpur-Gorakhpur lines are worth mentioning in this regard. Further, many fixed-series compensations on 400-kV lines have been planned and are under implementation.

Upgrading of Lower-Voltage Lines to Higher-Voltage Levels

In an effort to utilize the ROW and to enhance the power transfer capacity of the line, upgrading of lower-voltage lines to higher-voltage levels is being explored. In this direction, upgrading the 220-kV double-circuit Kishenpur-Kishtwar line in Jammu and Kashmir to a 400-kV single circuit has been done for the first time in India. This has resulted in an increase of power transfer capacity of the existing 220-kV transmission corridor line with marginal increase in ROW. Similarly, action was taken to upgrade a 66-kV line to a 110-kV level in the state grid of Kerala, replacing porcelain insulators by long-rod polymer insulators, thus utilizing existing towers to the maximum extent.

Substation Upgrades

Similar is the problem when expanding existing substations in the urban areas with the enhancement of load due to economic growth and/or geographical expansion in populated

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areas. Practically due to nonavailability of the corridor for incoming and/or outgoing feeders even at the EHV level, use of underground cable has to be resorted to for minimizing the space requirement of the substation and a compact gas insulated substation (GIS) has to be deployed.

Reconductoring of Transmission Lines

Upgrading existing transmission lines by reconductoring with high current carrying capacity conductors such as invariable resistance, aluminum conductor composite reinforced, and aluminum conductor composite core conductors with higher temperature endurance (above 200 °C) is being adopted for selected transmission corridors. It enhances the thermal capacity up to 200% over conventional aluminum conductor steel reinforced conductors. Further, while implementing the reconductoring, in order to maintain the line availability within acceptable limits, the technique of live line reconductoring is also being explored.

Multivoltage, Multicircuit Transmission Line

Utilizing the existing corridor earlier used for the 220-kV double circuit, with high-rise towers having 400-kV double circuits at the top and 220-kV double circuits below, it has been possible to use a stretch of forest for evacuating power from the Tala Hydroelectric Project in Bhutan to the Siliguri substation in India. Many more lines in similar situations are on the anvil wherever constraints in a corridor are being faced.

In order to enhance the reliability of the existing system, effort has been made to imbibe culture among power utilities in India for the condition-based maintenance on the basis of monitoring the health of the equipment rather than totally being dependent on periodic maintenance. On the substation side, transformers, circuit breakers, relays, surge attesters, etc., are under surveillance with various diagnostic tools. From time to time, based on measurements of relevant parameters, decisions are being made for complete or partial replacement for extending the life of substations under the doctrine of run-refurbish-replace.

Similarly, for the new transmission systems aimed at reducing investment on ROW per megawatts carried, less loss and overall economy, right from construction to operation and maintenance, development centers around the following aspects.

Enhancement of Conductor Maximum Temperature Limits

With the change in design philosophy the maximum temperature limit of conductors has been successively increased from 65 °C to 75 °C and then to 85 °C as currently adopted for the construction of EHV transmission lines. In fact, a few lines are being done with 95 °C also on a case-by-case basis. With this, an increase in thermal capacity of 28–50% is being achieved with marginal increase in cost but without additional ROW requirements.

High-Capacity 400-kV Multiconductor and 765-kV System

A bundle of quadruple (quad) conductors per phase is also being adopted in selected transmission corridors instead of twin-conductor bundles to enhance the power transfer capacity of the line, again without additional ROW requirements.

Keeping in view bulk power transfer requirements, 765-kV ac has been adopted as the next higher voltage. The Kishenpur-Moga, Anpara-Unnao, Tehri-Meerat 765-kV lines are already under operation at the 400-kV level. All these lines will be operated at the rated voltage of 765 kV in the near future. The 336-km transmission line being constructed between Sipat and Seoni in the western region would be India's first 765-kV line to be operated at rated voltage to evacuate power from Sipat Super Thermal Power Station.

Compact Towers

In special areas, compact towers such as the delta configuration for single circuits with reduced ROW requirements and narrow-based towers that reduce the space occupied by the tower base are being used. A 765-kV single-circuit compact tower with delta configuration has been developed and tested for the first time in the world, which has helped in reducing ROW requirement from 85 m to 64 m, resulting in forest and environmental conservation as well as reduction in forest compensation. Further, high-capacity multicircuit towers (more than two circuits per tower) are being designed to accommodate four circuits in line with the effort toward environmental conservation in specific areas. Also, the design for 220-kV and 400-kV double-circuit pole structures is being finalized for use in areas of high population density and for aesthetic aspects of transmission lines with the surrounding environment. In addition, to protect wildlife in forest areas, tall towers (with leg extension of 9–25 m) are also being constructed.

High-Capacity HVDC System

A 2,500-MW Balia-Bhiwadi HVDC system is being implemented for transfer of power from the Barh generation project located in the eastern region to the distant beneficiaries over 800 km away in the northern region. Further, for evacuation of hydro power from the northeastern region toward load centers in central India, a high-capacity ±800-kV, 6,000-MW HVDC system is being explored as an option for commercial operation.

Modern Line Route Survey Technique

Modern line route surveys with the help of the latest geographic information system/global positioning system (GPS) techniques consisting of satellite imagery and detailed survey of transmission lines using total solutions, preparation of digital profiling, computer-aided tower spotting, etc., are being used for all new lines. As a result of the updated/latest information, optimal selection of a transmission line route involving minimal environmental impact is feasible. Besides, it enhances accuracy in line routing with spotting of towers, estimation of bill of quantities, as well as reduces time requirements for such surveys drastically. Airborne laser terrain mapping is also being adopted for detailed surveys in association with the National Remote Sensing Agency (NRSA), which will result in faster surveys, accurate tower spotting, line route optimization, etc.

With these modern survey techniques, estimation of forests and river crossings are being done accurately at the project feasibility stage itself, resulting in marginal variations at the time of implementation. In this process optimization of route length along with the requirement of tower are also being achieved.

Substation Compaction, GIS, Automation, and Remote Operation

Initiatives have been taken for substation land optimization by optimizing the bay width at different voltage levels. For example, 400-kV bay width could be reduced from 27 m to 24 m, 220-kV bay width from 18 m to 16 m, etc. In addition, establishment of a state-of-the-art GIS, which requires little space compared to a conventional air insulated substation (AIS), are also being implemented at selective locations. Even with AIS, with the possibility of a transformer with switchgear mounted on it and a digital optical instrument transformer for measurement and protection, compaction has been possible in horizontal spacing to a large extent.

Further, the state-of-the-art fully automated remote-controlled 400-kV substation at Bhiwadi in Rajasthan has been implemented for improvement in operational efficiency and reduction in operational cost. Many such substations are under implementation.

Gas Insulated Line

First the time in India, in the 1,500-MW Nathpa-Jhakri hydroelectric project in the state of Himachal Pradesh from the underground cavern of transformers, the high-tension side at the 400-kV level has been connected to the pothead yard at the surface level by a gas insulated line, which is quite economical when compared to EHV cables of similar capacity. Success is leading to the exploration of many more such application where the corridor is limited.

High Surge Impedance Loading Line

A high surge impedance loading line (HSIL) to increase the surge impedance loading level in the range of 850 to 900 MW with nonsymmetric disposition of subconductors in a bundle as compared to a conventional quad conductor lines (having about 650 MW) is being explored in order to achieve the following:

- ✔ enhanced power transfer capacity over same corridor
- ✔ improved voltage regulation
- ✔ improved power system transient stability limits
- ✔ maximum utilization of existing ROW
- ✔ reduced environmental impact also in terms of corona, audible noise, and radio interference.

However, due to increased capacitance of such an HSIL line, it would call for a higher level of reactive compensation in order to regulate voltage in relation to managing reactive power.

Use of UHV Technology

UHV is another method being considered at the 1,200-kV level and ±800-kV HVDC in parallel for hauling large power, particularly from the northeastern region to the rest of the country.

Fault Current Limiting Reactor

With the development of the transmission network and new generation projects near load centers, an increase in fault level is alarming at certain locations. This has necessitated either changing the switchgear with a higher rating or providing a suitable device to limit the fault current. Various options to limit fault current and implementation of the same at suitable locations are being explored. Besides the placement of a thyristor-controlled series reactor at appropriate locations in all pervasive synchronous systems, the option of layering the network with a back-to-back mode of an HVDC system of appropriate capacity may also find use in the transmission network in the future power scenario.

Series and Shunt Compensation

This would be required mainly for controlling power through corridors as well as managing reactive power.

Use of High-Strength Polymer Insulator

For providing the desired degree of insulation in a polluted environment as well as reducing the weight of insulator string particularly when going for higher voltages, a high-strength polymer insulator would find usage.

Adoption of New Features for System Operation

It is also worthwhile in this context to elaborate on new options and features that would be called on for system operation. With unscheduled interchange mechanisms in vogue in

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the operation of the Indian power grid, a good amount of control in grid parameters has been achieved. Further, side-by-side with new hardware installed right at the investment stage, there is a requirement of implementation of the means for the monitoring and control of the vast and complex Indian National Grid. Toward this, it is envisaged to gradually develop an intelligent grid with state-of-the-art features like wide area measurement, adoptive islanding, probabilistic assessment, dynamic stability assessment and voltage stability assessment techniques, self healing grids, etc.

The intelligent grid represents a process for dealing with the power grid as a perpetual system. Integration of information and communication technology with physical grid operation increases the value of the overall system by adding intelligence on top of the conventional infrastructure. This would result in automatic anticipations on a real-time basis and quick responses to power system disturbances while continually optimizing system performance. Therefore, an intelligent grid can predict and heal grid operational problems before they get out of hand. These features result in a flexible but smart grid that provides reliable electric power supply. For electricity consumers, the smart grid provides enhanced reliability and security, lower energy bills, and new services that can add value to electricity while controlling its cost.

Real-time assessment and control of the intelligent grid will help utilities avoid a variety of problems. The intelligent grid includes various activities such as adoptive islanding, self-healing, self-correction, demand, and generation management. All these activities are accomplished with the help of a wide area monitoring system (WAMS). The latter supports utilities in making optimal usage of the transmission grid capacity and in preventing the spreading of disturbances. The modular system allows selective implementation of hardware and software. Function packages to optimize transmission capacity and to maintain grid integrity by increasing operational and planning safety can be combined with special protection and control schemes at any moment of time. Such schemes can initiate automated preventive or remedial actions and support operators; for example, in avoiding cascading effects.

The flexible architecture with a system monitoring center gathering and processing the data from any number of

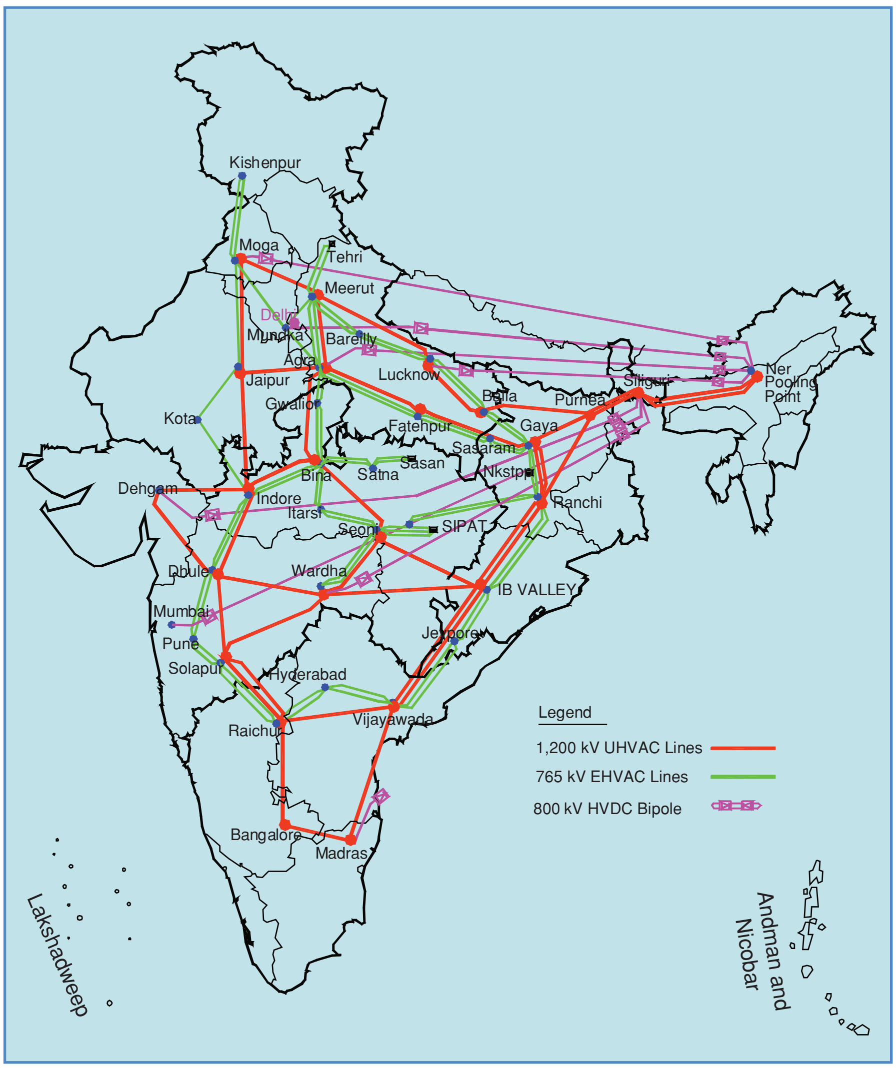

figure 4. What the transmission network of India may look like by 2025.

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GPS-synchronized phasor measurement units at important nodes (substations) allows extension with growing requirement and adaptation to changes in network topology. By providing online information on stability and safety margins for dynamic condition monitoring, it serves as early warning system in case of potential power system disturbances, and it identifies instabilities in power systems and evaluates the most effective measures against large area disturbances.

While operating a large grid, it is important that in the event of a major disturbance some part of the power system should be islanded automatically so as to help during black start. The size of the island depends upon the extent of disturbance and system conditions. The intelligent grid/WAMS enables forming of such adoptive/dynamic islands.

All the above actions are part of a self-healing/self-correcting grid and facilitate development of a smart grid.

The Future

In about 25 years and beyond, with the requisite network in position, in all probability the Indian National Grid will look like what has been depicted in Figure 4. Of course. to achieve this so rapidly, optimum utilization of existing system in relation to adoption of new technology as needed is a must.

Conclusions

The Indian power sector has grown to a large size in the last 60 years after the country's independence in 1947, and it has opened up with unbundling into distinctive entities of generation, transmission, and distribution. With both public and private participation, reliable load forecasting, planning, and system operation ensuring security to meet the demand at each instant have become the utmost necessities in the context of having electricity for all by the end of current five-year plan (March 2012). In this context adequacy as well as reliability of existing transmission systems have assumed a great significance in the entire power sector. Beyond this period, with continued growth in the economy, projection in power demand and commensurate addition in generation capacity also call for large network expansion for the Indian National Grid as a whole. Enhancement of voltage level of transmission, both with HVAC as well as HVDC, for hauling power from surplus to deficit regions poses challenges that need to be overcome through adoption of technologies.

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For Further Reading

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Biography

Subrata Mukhopadhyay was born in Asansol, India, in 1947. He graduated in electrical engineering from Jadavpur University, Calcutta, in 1968 and received his master's and doctorate degrees from the Indian Institute of Technology, Kharagpur and Roorkee, in 1970 and 1979, respectively. His employment experience of 36 years includes teaching and research in Roorkee and power system planning, design, and operation with the Central Electricity Authority of the Government of India. He has authored two books and 31 papers, won the IEEE Third Millennium Medal in 2000, the PES Delhi Chapter Outstanding Engineer Award, the PES Asia-Pacific Regional Outstanding Engineer Award for 2001, and the RAB Leadership and Achievement Awards in 2002 and 2004, respectively. He is also a fellow of the Institution of Engineers (India) and the Institution of Electronics and Telecommunication Engineers, India.