REPORT REPORT REPORT REPORT

Status of Electric Power Transmission in India and Possible Technological Developments

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Introduction

For the effective economic growth of any country, development of energy resources is a key factor. Energy in its electrical form is the most convenient and hence most commonly used. Tapping the available resources for generating electricity, transmitting it and utilizing it is a major requirement for economic development. In so far as our country is concerned, under the constraints of financial resources, optimal usage of the available capacities becomes very necessary. This poses many challenging problems in the planning, operation and maintenance of our power systems. A look at the past history reveals that an installed capacity of 2300MW in 1950 has grown to a figure of about 9,0000 MW presently. Assuming the current rate of growth and its socio-economic impact on the energy sector, it is envisaged that by 2000 AD, the demand is likely to cross the 100GW mark, meeting which is by no means a small task. In order to meet this huge demand, emphasis is being laid in the development of thermal resources, and large super thermal power stations (which have a lower gestation period as compared to hydro power stations) are being built at coal pitheads. Since hydro power resources and pithead thermal stations are located in areas far removed from load centres, exploitation of these resources and building these power stations is essentially attendant with the requirement of long distance transmission of bulk power. It is to be emphasised that addition of generation without adequate network strengthening for evacuating bulk power and transmitting it over long distances, with minimum loss, to load centres is meaningless. For this purpose, new and effective methods of transmission have to be evolved.

Status of Transmission in India

Transmission system planning so far has been more or less on the basis of regional self-sufficiency. The strategy for transmission system development is to achieve fully integrated operation of the regional grid systems and to connect such systems through inter-regional interconnections of appropriate power transfer capabilities. Inter-regional ties are expected to improve the reliability of the connected regional grids and facilitate emergency exchanges of power and optimum utilisation of available generation facilities particularly the transfer of surplus energy available in one region to another with a deficit. In course of time, the scope of the regional plans might be required to be widened to cover the option of bulk power transfer from one region to another on economic considerations. This approach would eventually lead to integrated planning at the national level.

As in so many aspects of its culture and development, electrification in India is a study in contrast. On the one hand, in a small period of 43 years, generation capacity has grown from a scant 2300 MW to the present level of 90,000 MW. The country's power transmission system includes a 250 MW back-to-back direct current link,and a couple of long distance point-to-point HVDC transmission systems. An experimental 200 km, 200 MW DC system built almost entirely with indigenously developed and built technologies – right down to thyristors in the convertor stations – is in operation.

On the other hand, annual per-capita energy use in India is roughly 300 kWh, about 10% of global average. Furthermore, the reliability of the bulk power supply is very poor and its quality is alarmingly below the standards of the developed world. Plant availability figures – an indication of how well plants are run – are low. The average generating plant load factor (the ratio of a plant's average output to its rated maximum, capacity) is about 57%. For comparison, plant load factors in developed countries are normally higher than 70 %. Low frequency operation is routine throughout India and harms generating units and load alike.

In addition, more than two decades after regional power grids were formed, there is still no adequate tariff structure for power interchanges between Indian states. Inter-connected operation is therefore usually blocked, leaving each state system to operate in isolation. Crisis management has become the order of the day, and load shedding – both scheduled and unscheduled – has become common. Customers have also gotten used to periodic brownouts and blackouts.

Keenly aware of this serious obstruction to future development, the Government of India has made generating capacity and transmission-system additions a priority in its five-year economic plans.

Shifting the Mix

At present, India derives about 67 % of its electricity from coal, 8 % from oil, 23 % from hydro electricity, and about 2% from nuclear power. In coming years, however, this mix is likely to shift, with nuclear and renewable energy sources accounting for more of the mix and fossil fuels for less. By the end of the 10th Economic Plan in 2007, nuclear power is expected to expand to 10000 MW, or roughly 8 % of the total generation mix.

Capacity additions are of course pointless without commensurate expansion of transmission systems. Unfortunately, this idea has not always guided electrification in India, and growth in transmission systems of late has not kept pace with additions to capacity. Underlying this mismatch are several causes, including right-of-way clearance difficulties and very long waiting periods associated with the building of transmission lines, which are often more onerous than securing the environmental clearances for a large base load thermal power station.

Along with growth in generation and transmission capacities have come greater complexity and the need for closely interconnected and integrated operations. At present, India is divided into five independent grids, each with a Regional Electricity Board (REB) to coordinate load dispatch operations within the grid. However, the facilities available to these boards are far from adequate for controlling the interconnected operation of a complex power system. At the very minimum, modern, computer-based data acquisition systems and effective, reliable communications would be needed before the five grids could be combined into a national system.

The engineering expertise for designing such advanced systems and the trained workforce to operate them are both on hand in India. Nonetheless, serious problems are often encountered in maintaining the stability of the conventional power systems that are already in place. Peak demands on power have always exceeded the available capacity, and the gap yawns wider every year. Furthermore, transmission and distribution systems are grossly lacking in reactive compensation. Line losses are also a problem - transmission and distribution losses average about 21% of all power generated.

Not all problems are technical, however. To promote rural electrification and agriculture, power is provided to farmers at an average of only 13% of actual cost. On top of this, power losses due to pilferage exacerbate an already acute shortage of financial resources. Other problems contributing to far-from-satisfactory performance of electric utilities include an antiquated, unremunerative tariff structure and inadequacies in automated controls.

Such straits are forcing reexamination of our strategies in power development. Besides reducing transmission and distribution losses, improving plant load factors, and implementing strictly disciplined intra- and inter-regional power transfers, we must seriously consider an extensive program of energy conservation. Even marginal attempts at conservation could result in savings of at least 10% as recent studies have shown.

One of the paramount rules in interconnected operations is grid discipline with regard to voltage and frequency; but in the face of shortages and increasing demand, this discipline has been hard to maintain. Some state boards take unfair advantage of the interconnection, rather than behaving in a cooperative manner. Overdrawing of energy, especially during times of peak demand, has become common. For lack of statutory power, the regional boards cannot enforce discipline. The problem has become so severe that, in order to keep their systems in operation, some of the state boards frequently have to turn to ad-hoc measures on almost an hour-by-hour basis.

Governmental Policies

Transmission system development is an evolutionary process. Unlike generating stations that are confined to specific locations, transmission systems comprise a number of system elements covering EHV transmission, sub-transmission and distribution networks at various voltage levels, substations, switching stations, load despatch and communication facilities etc., spread over a vast area. The quality of supply to the ultimate consumers is dependent on the total effect of performance of all the system elements constituting the transmission systems. Adoption of a regional concept for power system development and multiple ownership of transmission systems call for a joint effort by the various states of the region owning the state systems and also the central agencies engaged in development of centrally owned generation projects, in maintaining the system parameters in a dynamic situation for ensuring quality of supply to the ultimate consumers.

As it is neither feasible nor economical to develop discrete transmission facilities associated with each generation project, a transmission system is planned and optimised on a regional basis without regard to ownership. The location of regional power stations at pitheads in the case of coal-based stations and at appropriate locations in the case of hydroelectric stations has necessitated bulk transfer of power over long distances, transcending state boundaries. For meeting these transmission needs, a transmission system at 400 kV has already been developed which can be further supplemented by new technological options such as HVDC transmission, higher voltage AC transmission at 800 kV etc.

For efficient management of the regional grid systems covering appropriate monitoring and control of the system parameters, requisite load despatch and communication facilities on modern lines are also being established.

Major Constraints

System development being a complex task, a number of problems are faced in its execution. The important ones among them are given below.

- Inadequacy of investment for Transmission and Distribution (T&D) works,
- Problems in obtaining forest clearance for construction of transmission lines,
- Problems in obtaining right-of-way through agricultural land,
- Problems of execution,
- Problems of multiple ownership and sharing of transmission cost,

Thrust Areas in Transmission

Action is necessary on a number of areas in order to give a further thrust to promote grid development. The most important among them are mentioned below.

The first and foremost is the simplification of the procedure for according clearance for transmission lines from the forest and environmental angles. Unless this is done, a number of critical transmission lines which are currently under implementation may get unduly delayed besides affecting the programme for further expansion of the transmission system in future.

Yet another area requiring attention is the programme for installation of capacitors. The problem is required to be tackled on a war footing as the backlog in the area is very severely endangering the security of the regional grids besides contributing to the increased system losses etc. As the resource position of the SEBs is coming in the way of speedy implementation of capacitor installation programme, it would be necessary to arrange for special financial assistance earmarked for the purpose to the SEBs.

The last but not the least important matter requiring urgent attention is the creation of an appropriate organisation at the national level for removing the deficiencies in establishment of power transmission projects by taking up construction of inter-state and inter-regional transmission links and other trunk lines for strengthening the regional grids which might not receive the attention of the existing Central or State sector organisation.

The Central organisation could be vested also with the responsibility for construction of the National Load Despatch Centre and for coordinating the activities of the Regional Load Despatch Centres which would be in charge of regional operations. The national level organisations and the regional boards should be vested with statutory powers for exercising effective control in day-to-day grid operation. The present problems of indiscipline by the constituents in not adhering to schedules etc., of the REBs could be overcome only through implementation of this proposal.

Technological Upgradation

Side-by-side with the action taken for overcoming the difficulties in grid development, technology upgradation is being undertaken in all areas of transmission for increasing efficiency and improving the economy. Most important among them are:

- Use of Static VAR Compensation (SVC) Systems
- Application of series capacitors
- Use of Gas-insulated Substations (GIS)

- Use of Guyed-type Towers
- Use of latest technologies in substation equipment such as circuit breakers, surge arrestors, insulators, capacitors and relays.

Status of Technology Upgradation in Design and Engineering

i) Circuit breakers

The circuit breakers most commonly used untill recently at EHV substations have been of the minimum oil and air-blast types. Operating experience has shown that the minimum oil circuit breakers require frequent maintenance on account of deterioration of quality of oil and wearing out of contacts. In air-blast type also, there has been deterioration of contacts during operation in addition to mechanical problems. SF6 breakers are now being used in all EHV substations where a high degree of reliability is essential. These breakers practically do not require any frequent maintenance and are free from fire hazards. The technology for manufacture and operation of SF6 breakers for all voltage levels is available in the country.

ii) Surge Arrestors

Another technological advance is the use of metal oxide arrestors in place of conventional surge arrestors. These arrestors have much higher discharge capability and ensure better protection to the equipment, thereby making it possible to reduce switching surge overvoltages. Metal oxide arrestors are now being manufactured indigenously and thus can be used extensively for future EHV systems.

iii) Toughened Glass and Composite Long Rod Insulators

The most commonly used insulators for transmission lines at present are disc type ceramic or glass insulators. In India, generally porcelain type insulators have been used in the form of strings to support the transmission lines. Toughened glass insulators could be used on some of the 400 kV lines under construction. Toughened glass insulators are helpful in achieving more uniform distribution of voltages across insulator strings. Interest is now directed towards use of composite long rod insulators using materials like resin-bonded glass fibre cores with shed shells of organic or inorganic materials. Such insulators have been developed abroad and their field performance is under study.

iv) Gas-Insulated Substations

EHV substations in this country are generally of the open-air design. However, metal-enclosed gas-insulated substations using SF6 gas as insulating medium are now getting established in developed countries. These substations occupy considerably smaller area and volume as compared to conventional substations and require little maintenance. In India a beginning has recently been made for setting up of gas-insulated substations in Mumabi (by M/s Tata and M/s BEST) and in Delhi (by DESU). Kerala State Electricity Board is also going in for such stations at Trivandrum, Cochin and Kozhikode in Kerala State, where the pressure on land compels economy in land use for substations. The equipment required for these gas-insulated stations has to be imported. In future more such substations may find application, especially in the metropolitan cities where space is a major constraint and upgradation in distribution systems require installation of higher capacity switchgear at same locations. Indigenous development of this technology merits consideration.

Trends in Design of Transmission Towers

Design of transmission towers has undergone many improvements over the years. In India, self-supporting broad-based lattice towers are being traditionally used for EHV lines. As an alternative, guyed towers are being considered which have been extensively used in USA, Canada and Russia. These towers are light in weight, easy to construct and have simpler foundation designs. These advantages are, however, offset to some extent by greater interference in areas of intense agricultural activities, increased vulnerability to sabotage etc. In India, the use of these types of towers is to be examined for long distance transmission in appropriate locations (e.g. hilly terrain where plain land of required area for conventional towers may not be available etc.). However, guyed towers have been adopted on an experimental basis on a 10 km stretch of the Agra-Ballabgarh 400 kV line, a part of the Auraiya transmission system.

Other developments that are gaining interest are the use of high tensile steel in the place of mild steel, upgradation of existing transmission lines etc., which are being examined. There have also been improvements in the methodologies used for the design of towers. Digital computers are now extensively used for the design calculations. Necessary software is also available to analyse the towers as space frames.

v) Use of Electronic Systems for Protection and Instrumentation

Considerable development has taken place in the field of protection and instrumentation also. Electronic instruments and equipment, capable of meeting the stringent needs of power system operation and control, are increasingly being used for this purpose. The need for special relay characteristics, which ensure better discrimination and faster response, has resulted in the phasing out of conventional electromagnetic relays and their gradual replacement by static relays. Microprocessor-based relays are likely to find application in future. Electronic systems like event loggers and disturbance recorders are also finding extensive application in the substations. Microprocessor-based technology is also promising application in energy metering.

vi) Capacitors

Mixed dielectric non-peb was hitherto being used for the manufacture of capacitors. There had been a number of failures of such capacitors. The losses in such capacitors are also high. All film non-peb liquid impregnated dielectric technology has now been introduced in the country. This technology requires special techniques for achieving proper impregnation. Capacitors using all film non-peb liquid impregnated dielectric have very low losses. There is only one manufacturer of this dielectric film in the country. It is believed that the quality of the film being manufactured is not up to the mark.

vii) Modern Communication Systems

The use of geo-stationary satellites for communication purpose is also gaining attraction, especially with the advent of low cost terminals (LCT's) for earth stations. Yet another development of interest is the use of optical fibre systems. These are completely immune to electro-magnetic interference and offer extra high capacity and reliability for data transmission. Since signals travel in the form of light rays, frequency allocation and coordination problems are completely avoided. At the national level, CEA has drawn up a communication perspective for the next few years, which envisages the coordinated use of these facilities.

New Concepts in Power Transmission

In the world scenario, unprecedented technological, environmental, social, economic and political changes are being witnessed, all of which will have a bearing on power development. The technological evolutions in power, communication and transportation systems have to exist in close proximity to each other. Increasing public sensitivity to environmental issues, often combined with the difficulty in obtaining new transmission corridors is becoming an important factor while considering transmission facilities.

Under these handicaps, coupled with severe constraints in financial resources, attention must be paid to strengthen the existing transmission networks. Ways and means to utilize them in an optimal manner have to be evolved. Losses have to be reduced to the minimum and the power transmission capacities of existing lines have to be enhanced. New technologies for adopting these have to be evolved. In this context, it becomes necessary to focus attention on the following aspects of power transmission.

i) EHV and UHV AC Transmission

ii) HVDC Transmission

iii) Very Long Distance Transmission

iv) Higher Phase Order Power Transmission

v) Compact Transmission Lines

vi) Flexible AC Transmission systems

vii) Automated Control of Reactive Power

EHV AC Transmission

Transmission systems link power generating stations with the load centres and thus provide a path for electrical energy to flow from the generating stations to the load centres. In the early stages of system development in India, the load centres were confined to urban areas, the requirements of which were met from small capacity generating stations over radial low voltage transmission links. However, with the growth of the State systems after independence, large capacity generating stations were established with corresponding expansion of the transmission network within each state. As the transmission distances increased, higher transmission voltages were adopted and generating stations within each state were interconnected over high voltage links to form state systems. With the adoption of the concept of regional planning for power development, the State systems were gradually interconnected to form regional grids in all the five regions of the country. Correspondingly, the complexity of the transmission systems grew with adoption of still higher transmission voltages for transmission of large blocks of power over long distances, cutting across state boundaries. In this manner, transmission systems at various voltages have come into existence. Till the mid seventies, the highest transmission voltage was 220 kV. For meeting the requirements of power transmission from large thermal complexes located in pitheads and remote hydro stations to the load centres, 400 kV transmission systems were introduced after the seventies. The first 400 kV transmission line was commissioned in 1977. The principal voltages for transmission are hence 220 kV and 400 kV. These lines are capable of transmitting power in the range of 150-200 MW over 100-200 km in the case of 220 kV and 400-500 MW over 300-500 km in the case of 400 kV. In certain cases the transmission distances exceed even 1000 km. These trunk transmission lines along with the underlying network at voltages of 132 kV/110 kV/66 kV serve to deliver power to the ultimate consumers. Barring heavy industries which are supplied at high voltage, other categories of consumers are served over the low voltage distribution networks which receive supply from the high voltage system.

HVDC Transmission

HVDC transmission has definite economic benefits when large blocks of power have to be transmitted over long distances. The following table gives the capability of HVDC systems for transmitting power over various distances as compared to the EHV AC system at different transmission voltages:

Distance km	Capability of + 400 kV HVDC (MW)	Capability of		EHV AC Transmission	
		400 kV MW	750 kV MW	1000 kV MW	1200 kV MW
500	2250	405	1665	3680	5790
700	1690	313	1250	2770	4340
900	1460	261	1080	2400	3770
1100	1360	210	900	1987	3125

It has to be understood that the HVDC provides a link between two AC systems. This being the case, what is essentially required for a DC system is easily seen to be a rectifier at one and an inverter at the other, with a DC transmission line in the case of a point-to-point transmission system. In the case of a back-to-back link, providing mainly an asynchronous tie between two AC systems operating at different frequencies, the DC line length is virtually zero.

A few of the advantages of HVDC power transmissions are:

1. interconnection of AC systems operating at different frequencies,
2. great flexibility in the control of magnitude and direction of power flow,
3. damping out oscillations and improvement of stability margin when embedded in weak AC systems,
4. reduction in right of way requirements,
5. reduction in structural requirements of transmissions lines,
6. reduction in line losses,
7. reduction in conductor size due to absence of reactive currents,

8. lower insulation levels,
9. reduction in corona and radio interference.

In the world scenario, HVDC transmission schemes are becoming more and more popular and as of now over 60 schemes are in operation. In the Indian scene, this is an emerging technology. Positive steps are being taken to develop indigenous know-how through R&D schemes being sponsored at the national level to look into special aspects of HVDC. The first major step in this direction is the establishment of an experimental line linking the Madhya Pradesh and the Andhra Pradesh electricity systems. The project presently uses one circuit of the existing 220 kV double-circuit AC lines between Barsoor in Madhya Pradesh and lower Sileru in Andhra Pradesh for DC power transmission. The entire scheme has been conceived with the basic idea of development of indigenous technology and indigenous manufacture of equipment. The project has less than 5% import content. The scheme is in operation now, and the transmission system is transferring power to the extent of 100 MW in the mono-polar mode. The commissioning of the project has proved that the technology can be indigenously developed and has also infused a sense of confidence amongst the HVDC personnel involved in its design, manufacture, operation and maintenance. In the second phase of the project, which is under execution, it is proposed to enhance the power transmission capacity to 200 MW at 200 kV.

The experimental line apart, a couple of commercial HVDC schemes are also in operation. One of these is the back-to-back DC tie at Vindhyachal, transferring 500 MW of power from the western to the northern region. This scheme has provided a good inter-regional balance between generation and demand. The other commercial scheme is the Rihand-Delhi point-to-point transmission system handling power of 1000 MW over a distance of 910 km. at ±500 kV. Both these commercial schemes have been executed on a turnkey basis with foreign collaboration. A few more HVDC projects like the Chandrapur-Padhke point-to-point and the Chandrapur-Ramagundam back-to-back schemes are under execution.

The experimental HVDC pilot project between Barsoor and Lower Sileru has served as a very good role model in the development of indigenous technology. In the field of HVDC power transmission, through this exercise, indigenous expertise and know-how has already been developed in our country. Despite this, it has not been possible for us to commercialize these successes. The reasons for this, need detailed analysis.

Very long Distance AC Transmission

Very long distance AC transmission schemes are not presently in operation, except may be in Russia. However, keen interest is being evoked in this area in various parts of the world. The major aspects to be considered in long distance AC transmission systems are: (a) transmission of bulk power with suitable stability margins and (b) maintaining a uniform voltage profile all along the line. The aspects to be analysed are:

i) the feasibility of half-wave length transmission,
ii) performance of series-compensated transmission system, and
iii) performance of static VAR compensated transmission system with supplementary controls.

The main factor impeding the implementation of the long distance AC transmission lines is the high cost of the compensating equipment. Instability precludes the transmission of power from a remote generating source if the angle between the generator terminal voltage and the receiving end bus voltages is between 90 and 180 electrical degrees. To provide a sufficiently stable margin of safety, a criterion used for preliminary studies is 30 electrical degrees of phase shift over the line. At 50 Hz, a 400 kV line of 500 km length at surge impedance loading (SIL) has an angle of approximately 30 degrees.

To maintain an angle of 30 degrees of Extra Long Distance (ELD) lines at SIL, 100% compensation is required for all lengths in excess of 500 km. Hence, as the line length increases, the cost per unit length (including compensation) also increases. Apart from high capital investment, ELD lines present operational problems such as surplus VAR during light load conditions, Ferranti effect and generator self-excitation. Instead of shortening, if the line is electrically lengthened so that its effective electrical length is between 180 and 270 degrees, an interesting phenomenon occurs. The system is stable as one operating in the first quadrant (0-90 degrees). For example, if the generator terminal voltage is 190 degrees leading, with respect to the load voltage, the stability margin of the system is the same as if the generator were operating at 10 degrees from the load. The salient features of an exact half-wave line are:

i) the general line constants are such that a 3000 km. lossless line will represent zero series impedance and zero shunt admittance,

ii) the voltages at both ends are extremely stable,

iii) the line will not act as either a sink or a source of reactive power,

iv) there is no Ferranti effect when the line is opened at the far end,

v) surplus reactive power and possibility of self-excitation are absent under light and no load conditions,

vi) the mid-point voltage and current are proportional to the current and voltage respectively at the receiving end of the line.

It may be worthwhile taking up a project on very long distance AC transmission for transmission of power from the power-rich eastern region down to the southern region along the eastern coast – a distance of about 2000 km. If implemented successfully, the transmission losses would be reduced to a minimum and the voltage profile along the line will be flat.

Higher Phase Order Transmission

Recently, High Phase Order transmission (HPO) systems are being considered as a viable alternative to UHV 3-phase transmission to achieve efficient utilization of Right-of-Way (ROW) and increased transmission capability to meet the growing demand for electric power. However, it is necessary to establish the basic feasibility before adopting HPO transmission systems depending on several steady-state performance indices such as SIL, thermal loading, electric fields and the related noise levels. On the other hand, obtaining completely new designs for multiphase transmission lines offer significant advantages in addition to increased power transmission capability such as:

- efficient utilisation of ROW,
- reduced electrical gradients and noise levels,
- compact structures,
- reduced insulation requirements,
- reduced overall cost.

As a result, a multiphase line with smaller dimensions can transmit a large amount of power covering the entire range of transmission voltages.

It would be worthwhile taking up the conversion of some existing 3-phase 220 kV lines in operation to 6-phase systems.

Compact Transmission Lines

Environmental and economic pressures have encouraged utilities to seek improved design approaches to make transmission lines more environmentally acceptable and cost-effective. The need for most efficient use of the ROW is being felt more keenly than ever. Compaction of a transmission line means reduction in the dimensions of the line, both in the horizontal and vertical directions. By horizontal compaction, power density over available corridors is increased by more efficient use of the land and ROW. Vertical compaction reduces the height of the support structures, making them smaller, lighter and less expensive. In general, compaction reduces the total profile of the line. Other means of optimally utilising the existing transmission lines without the need for increasing ROW requirements lie in the upgradation of the operating voltage to the next higher level by suitably changing the conductors, towers, cross-arms, insulators etc., and by adopting multi-circuits on the same towers.

It is necessary to take up some projects for compaction and upgradation of voltage levels of some existing HV power transmission lines.

Flexible AC Transmission

The most recent advance in transmission technology and one ideally suited to Indian conditions is the Flexible AC transmission, popularly known as FACTS. The way in which FACTS is to be realized is through the application of thyristor-controlled series devices which are capable of rapid adjustment of network impedance. FACTS can be used to control power flow in parallel lines in such a way that the network losses are minimised under steady-state conditions.

Under transient conditions, FACTS can substantially enhance emergency power carrying capacity of the line. FACTS concept involves the use of the following thyristor-based controllers, which also form the part of planning tools for FACTS.

- SSR damping
- Series reactance
- Static VAR Compensator
- Fault Current Limiter
- Series Capacitor (Fixed & Controlled)
- Load Tap Changer
- Phase Angle Regulator
- Ferro-Resonance Damper
- Static Condenser
- Dynamic Load Brake
- Dynamic Voltage Limiter

The power flow over an AC line is a function of the phase angle, and voltage at the two ends of the line and the line impedance. In order to control the power flow, any one of these three parameters has to be controlled. With presently employed mechanical controls on the power system, phase angle control is by means of slow mechanical phase shifters; the voltage control is by means of transformer tap changers, reactors and capacitors which are mechanically switched and slow acting; there is essentially no control over line impedance. Hence, with mechanical controllers, there is very little scope for high speed control over any of the three parameters and control cannot be exercised frequently because mechanical devices tend to wear out quickly.

So, with present day mechanical devices, power system operators arrive at the required steady-state power flow through generation scheduling, transformer tap changing and switching of shunt reactors and capacitors. This is done to maintain voltage and phase angles within safe operating limits. The flexibility of an AC line or any part of an AC system can be improved, if the control over one or more of the base parameters, namely, voltage, current phase angle and line impedance is improved. This can be achieved by employing the concept of FACTS.

Advanced Static VAR Compensation (STATCOM)

The shunt-connected static VAR compensator, using conventional thryristor switches, is already a firmly established device for transmission line compensation. The static VAR compensator (SVC) is usually composed of thyristor-switched capacitors and thyristor-controlled reactors. With proper coordination of the capacitor switching and reactor control, the var output can be varied continuously and rapidly between the capacitive and inductive rating of the equipment. The compensator is normally operated to regulate the voltage of the transmission system at a selected terminal, often with a priority option to provide damping if power oscillation is detected. A totally different, advanced static VAR compensator using a particular type of solid-state switching converter, called voltage-sourced inverter, is feasible.

Unified Power Flow Controller

It has long been realized that an all solid-state or advanced static VAR compensator, which is the true equivalent of an ideal synchronous condenser, is technically feasible and, with the use of Gate-Turn-Off (GTO) thyristors, is also economically viable. The Unified Power Flow Controller (UPFC) was proposed for real-time control and dynamic compensation of AC transmission systems, providing the necessary functional flexibility required to solve many of the problems facing the utility industry. The UPFC consists of two switching converters, which are voltage-sourced inverters using gate turn-off thyristor valves. These inverters are operated from a common DC link provided by a DC storage capacitor. This arrangement functions as an ideal AC to AC power converter in which the real power can freely flow in either direction between the AC terminals of the two inverters and each inverter can independently generate (or absorb) reactive power at its own AC output terminal.

Viewing the operation of the UPFC from the standpoint of conventional power transmission based on reactive shunt compensation, series compensation and phase shifting, the UPFC can fulfill all these functions and thereby meet multiple control objectives by adding the injected voltage with appropriate amplitude and phase angle to the terminal voltage.

Conclusion

The paper briefly describes the most recent advances in electric power transmission, and traces the history of power development in the country. Most of the advances have taken place keeping pace with the developments that have emerged in advanced countries. The historical development has been mainly due to the changing environment and technical requirements for more and more efficient power transmission. Considering all the factors, it can be concluded that, under the prevailing power situation in our country, the best option available is FACTS.

Under the existing shortages and generation not being able to meet the growing demand, coupled with the lack of financial resources to add to the generating capacity or to build more transmission lines, employment of FACTS devices in our systems appears to be the best immediate solution. It is imperative that a pilot project be taken up on the development of this technology on the lines of the HVDC transmission pilot project.

It is also essential that prototype pilot projects on all modern transmission technologies be taken up at the earliest.

Mr. S. Parameswaran was Director of the Central Power Research Institute at Bangalore, and is presently Chairman of IEEE Bangalore Section. He is a graduate in Electrical Engineering from the College of Engineering, Guindy, Chennai and holds a post-graduate diploma in Water Resources Development Engineering from the University of Roorkhee, Uttar Pradesh. He is a Fellow of Institution of Engineers (India). His main areas of expertise include testing and evaluation of electrical insulation materials and systems, computer analysis of power systems, quality assurance in testing and power system grounding.

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