IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 13, Issue 6 Ver. II (Nov. - Dec. 2016), PP 13-18
www.iosrjournals.org

Safety of Power Generation and Transmision

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Abstract: *India is a power starved country. Population explosion and unprecedented rise in socio–economic status of population has led to steep rise in demand for power while the generation capacity has been lagging. Most households now possess modern electronic gadgets. This serious mismatch of demand and supply leads to power cuts. It affects industrial production besides inconvenience to a large part of population. Modern trends in safe power generation, transmission and conservation are presented in this paper.*
Keywords: *Hydro-power, Transmission tower, IS 4091:1979, GRIHA, Tower collapse factor*

I. Introduction

Civil Engineering plays important role in safe power generation, its transmission and conservation. Firstly, all forms of power generation require extensive construction. In fact, power generation always begins with extensive feasibility study and site survey followed by construction. In the case of hydro–power, a dam and all other structures have to be erected, some of which may be underground. Then, generated power from the powerhouse has to be transmitted to the consumers. A large number of transmission towers have to be erected to complete journey of power from generation head to the consumers. Safety of generation and its transmission is of utmost importance. For example, all power generation structures must be safe against natural disasters such as earthquakes, landslides and floods. Any failure leads to loss of life and property, and can have severe economic consequences. Further, all hydro–power generation plants are located deep inside hills while consumers are mostly hundreds of miles away in the cities. Transmission towers have to be located on unstable, hostile, treacherous, un–accessible and inhabitable hilly terrains. Each collapse of tower interrupts power generation and power supply. It leads to huge loss of revenue.

Table 1 Installed power generation capacity in India

Sector	**Coal**	**Gas**	**Diesel**	**Nuclear**	**Hydro**	**RES***	**Grand Total**
Central	48130.0	7519.73	0	5780.00	11091.43	0	72521.16
State	58100.5	6974.42	602.61	0	27482.00	3803.67	96963.20
Private	58405.38	8568.00	597.14	0	2694.00	31973.29	102237.81
All India	164635.88	23062.15	1199.75	5780.00	41267.43	35776.96	271722.17
Note : All figures are in MW							
*The break up of RES is small hydro (4055.36 MW), wind power (23444.00 MW), Bio mass power & gasification (1410.20 MW), Bagasse cogeneration (3008.35 MW), Waste to power (115.08 MW) and Solar power (3743.97 MW).							

II. Indian Scenario

The total installed capacity as on Year 2015 is 271,722.17 MW. Table 1 gives sector–wise and type–wise break up. India has about 4710 completed large dams. The dams provide storages to tide over the temporal and spatial variation in rainfall for meeting the year round requirements of drinking water supply, irrigation, hydro–power and industries in the country. Dams have helped immensely in attaining self–sufficiency in food grain production besides flood control and drought mitigation. Table 2 describes the Largest Hydroelectric Dams in India in terms of Power Generation. Table 3 gives list of super thermal power plants. This data proves indegenous Indian expertise in power generation.

Table 2 Important hydroelectric power generation schemes of India

Name	Features	Details	Power Generation
Tehri Dam Bhagirathi River near Tehri in Uttarakhand **[**capacity 2400 MW]	Highest multi–purpose dam in India and tenth tallest dam in the world.	260.5 metres high rock and earth–fill embankment dam 575 metres long	Tehri Dam & Hydro Power Plant (1000 MW) Koteshwar Hydro Electric Project (400 MW) Tehri Pumped Storage Plant (PSP) (1000 MW) Tehri Pumped Storage Plant (PSP) (1000 MW)
Koyna Dam **[**capacity 1960 MW]	Second largest hydroelectric power plant of India with 4 stages of underground power generation	Concrete gravity dam	1st stage 4 x 70 MW = 280 MW 2nd stage 4 x 80 MW = 320 MW Dam foot 2 x 20 MW = 40 MW 3rd stage 4 x 80 MW = 320 MW 4th stage 4x250 MW = 1000 MW
Srisailam Dam [capacity 1670 MW]	Krishna River at Srisailam in the Kurnool district in the state of Andhra Pradesh	Concrete gravity dam	Turbines left 6 × 150MW reversible Francis–type Turbines Right 7 × 110MW Francis–type
Nathpa Jhakri Dam [capacity1500MW]	Satluj River in Himachal Pradesh	Concrete gravity dam	Turbines 6 × 250 MW Francis–type
Sardar Sarovar Dam **[**capacity1450MW]	Narmada River near Navagam, Gujarat	Concrete gravity dam	Turbines: 6 x 200 MW Francis pump–turbine
Bhakra-Nangal Dam [capacity 1325 MW]	Sutlej River in Bilaspur, Himachal Pradesh with Second largest reservoir in India	Concrete gravity dam. The “Gobind Sagar”, stores up to 9.34 billion cubic metres of water	Turbines 5 x 108 MW, 5 x 157 MW Francis–type
Indirasagar Dam [capacity 1000 MW	Madhya Pradesh on the Narmada River at Narmadanagar in the Khandwa district	Reservoir has 12,200,000,000 m^3 capacity	Turbines 8 Units of 125 MW each
Nagarjuna Sagar Dam [capacity 816 MW]	Krishna River at Nagarjuna Sagar in Guntur and Nalgonda districts of Andhra Pradesh	Masonry dam constructed between the years of 1955 and 1967	Turbines 1 x 110 MW Francis turbines, Turbines 7 x 100.8 MW reversible Francis

Table 3 Important super thermal power plants in India

Power Plant	State	Operator	Capacity
Mundra Thermal Power Station	Gujarat	Adani Power Limited	4620MW
Vindhyachal Thermal Power Station	Madhya Pradesh	NTPC	4260MW
Mundra Ultra Mega Power Plant	Gujarat	Tata Power Corporation Limited	4150MW
Barh Super Thermal Power Station	Bihar	NTPC	3300MW
Tiroda Thermal Power Station	Maharastra	Adani Power Limited	3300MW
KSK Mahanadi Power Project	Chhattisgarh	KSK Energy Ventures Pvt Limited	3,600MW
Jindal Tamnar Thermal Power Plant	Chhattisgarh	Jindal Power Limited	3,400MW
Talcher Super Thermal Power Station	Odisha	NTPC	3000MW
Sipat Thermal Power Plant	Chhattisgarh	NTPC	2980MW

The transmission lines are usually charged to 400 kv. The 765 kV Bhiwani - Moga line was successfully charged recently. The introduction of 765 KV lines will strengthen the regional and national grid to enable transfer of bulk power from generating stations and surplus regions to load centers. The Wardha and Aurangabad cities in Maharashtra which are 400km apart are to be connected by transmission lines of 1200 kV capacity. This is the world’s highest capacity power transmission line. The ultra high voltage (UHV) systems have significant advantage of carrying more power. This is crucial in a country where laying new lines is a challenge because of ‘right of way’ problems. Planning and testing is underway to transmit 1600 kV power through transmission lines in future.

III. Loss And Leakage Of Power

A large part of power produced in India and supplied to consumers is lost in transmission which includes power theft. The ranking of various states as per the Planning Commission Report (Year 2013–14) is as follows. Figure in parenthesis gives power lost due to various causes. Best states are– Himachal Pradesh (11% loss), Pondichery (12%), Goa (15%), Andhra Pradesh (16%), Karela, Gujarat and Punjab (18% each). Worst states are– J&K (62%), Arunachal Pradesh (49%), Bihar (44%), Manipur (40%), Nagaland (36%). National average stands at 24%. The transmission losses in developed countries are as little as 3–4% in Germany, Korea, Japan and Isreal etc. There is a huge scope for improvement in India because power saved is also power produced.

IV. Power Deficit

The peak power deficit (shortfall in supply of power when the demand is a maximum) was 7.4% or 9,720 MW in April 2013. The demand was 41,222 MW, of which 38,163 MW was met. The deficit in the northern region was 5.1% in April last year. Western region states including Chhattisgarh, Gujarat, Madhya Pradesh and Maharashtra reported a power deficit of 2.1% or 853 MW in April 2014, as against 1.4% or 531 MW in April 2013. Southern region states of Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Pondicherry, Lakshadweep reported a drop in April's peak power deficit at 8.2% or 3,252 MW from 16.7% or 6,508 MW a year ago.

According to the latest data by the Central Electricity Authority, the total requirement in the country in year 2014 was 1,40,998 MW, as against the supply of 1,33,442 MW. Peak power deficit in the country fell to 5.4% at 7,556 megawatts (MW) in April from 7.4% a year ago due to increased capacity and lower electricity consumption by states.

V. Transmission Highway Congestion

In a deregulated environment, every buyer wants to buy power from the cheapest generator available, irrespective of relative geographical location of buyer and seller. As a consequence of this, the transmission corridors evacuating the power of cheaper generators would get overloaded if all such transactions are approved. Congestion is then said to have occurred when system operator finds that all the transactions can not be allowed on account of overload on the transmission network. Congestion management is a mechanism to prioritize the transactions and commit to such a schedule which would not overload the network. Despite these measures, congestion can still occur in real time following a forced outage of transmission line. Transmission highways are planned on a long–term supply agreement. Congestion blocks short–term trading between surplus regions and deficit regions. Short–term buyers are unable to forecast their demand. Power of amount 5.3 billion units was wasted due to highway congestion in year 2013–14 (shown as 6 in above Figure). This wastage rose to 9 billion units in year 2014–15.

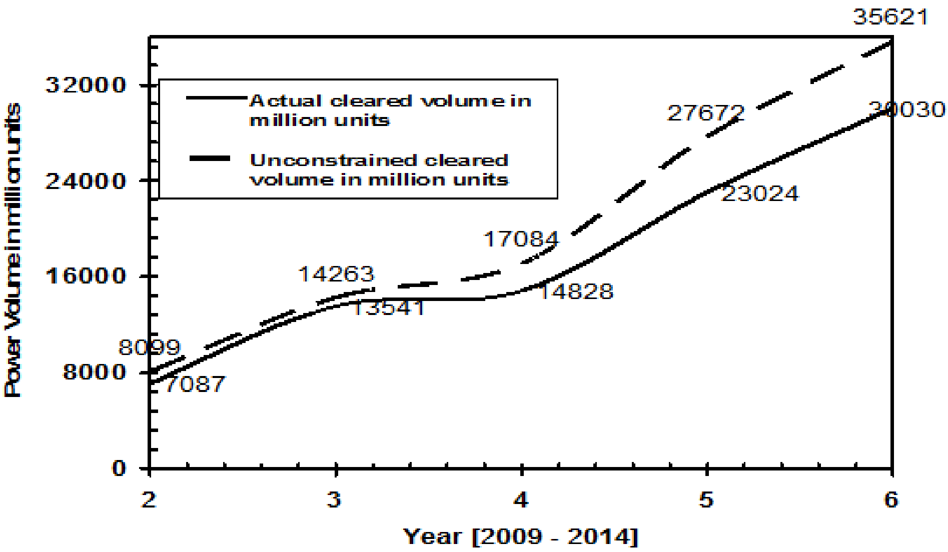

Figure shows units of power wasted due to traffic congestion on transmission highways

VI. Some Accidents Involving Transmission Lines

Five persons were killed and eight injured after a high-tension power transmission tower collapsed in Shikrawa village in Mewat, Haryana in May 2013. The incident took place in Shikrawa village near Punhana block in Mewat district, around 80km from Gurgaon around 10.30am when the work of 765kV electricity transmission from Gurgaon to Agra was on in full swing. Around 150 laborers were at work on the two towers when one of them collapsed. Three workers were crushed to death on the spot while two succumbed to their injuries in hospital. Several billion units of power were lost due to shut down.

The Power Grid Corporation planned to commission 345 km long 765 KV Gaya–Fatehpur transmission lines between Eastern and Northern Regions. The 765 KV Gaya–Fatehpur line was to be extended further by 325 km from Fatehpur to Agra and link up with the 765 KV Bina–Gwalior–Agra line of Western Grid. The 765 kV Gaya–Fatehpur line was energized on 31 March but tripped immediately on over–voltage. Thereafter, the line remained idle and a line tower at location 207 collapsed on April 12, 2012 during a storm. The tower failure of Gaya–Fatehpur line questions the design of towers which are expected to withstand the maximum storm conditions of that area as per the wind Zone.

A transmission tower collapsed in sector 148 on the supply line to NOIDA in June 2015. Wind speed on the day of collapse was normal. Although, new transmission line was obtained, yet population suffered till necessary remedial measures were affected.

Failures are unavoidable. Each failure exposes knowledge gaps and has several lessons for engineers. Failures are thoroughly investigated and documented for future consideration but without investigation and reporting, failure should not be covered. This is unhealthy practice and must be checked.

VII. Engineering of Transmission Tower Collapse

Power over long distances is transmitted through towers. Underground transmission involves digging and requirement of huge insulation makes it economically unviable. Transmission line towers are stable and versatile semi–permanent structure. These are designed as per the extreme cyclonic and seismic loading of the region. The conductor cable spans between two adjacent towers and sags. The sag and tension in wire must be optimally adjusted to provide adequate ground clearance together with tower height and spacing. Towers may however collapse due to following factors.

(7.1) ***Structural design deficiency***

Structural design is a specialized task and must be done to religeously obey all code provisions. A slight misunderstanding or overlook of any provision can prove disasterous for safety. In addition, all calculations must be thoroughly checked by an independent authority before certifying the design. A slight over–design may be favorable.

(7.2) ***Fabrication and erection defects***

The fabricator of transmission tower is other than the designer and is not likely to be a competent engineer to understand intricacy of engineering profession. It is responsibility of the controlling agency to ensure that fabricated towers meet all the design features within the limit of fabrication tolerances. One particular feature is to ensure that all members of tower are straight. Use of initially curved members must be avoided. This necessary to ensure that fabricated tower after erection meets the assumptions of the design process.

(7.3) ***Failure of foundations***

Footings in Soils are normally designed for the following load(s) at the ground levels: a) Downward load, b) Uplift load, c) Horizontal thrust, and d) Overturning moments. Comprehensive geo–technical investigation to determine bearing capacity, variation in water table, and flooding potential of site must precede construction.

Inclined loads shall be split up into vertical and lateral loads (shear) at the top of footings. The uplift loads are assumed to be resisted by the weight if the footing plus the weight of an inverted frustum of a pyramid of earth on the footing pad with sides inclined at an angle of up to 30^o with the vertical for an average firm cohesive material. A 20^o cone shall be taken for non–cohesive materials, such as sand and gravelly soils.
Differential support settlement is a major reason for distress in towers. Perrmissible differential settlement and tilt data in isolated footings is as follows.

Table 3 IS 1904: 1986 provisions on isolated foundation for transmission towers

Structure	**Sand and hard clay**			**Plastic clay**		
	Max settlement	Differential settlement	Angular distortion	Max settlement	Differential settlement	Angular distortion
Steel structures	50mm	0.0033L	1 in 300	75mm	0.0033L	1 in 300
Water towers	50mm	0.0004L	1 in 2500	75mm	0.0015L	1 in 666
L denotes the length of deflected part of wall or centre–to–centre distance between columns						

(7.4) ***Lack of maintenance***

A transmission tower is subjected to hostile forces of nature in the form of hot sunshine, rain and cold which may alternate. The material of tower starts to corrode over a period of time unless proper care is taken. Iron oxide is more thermodynamically stable than its derivative known as steel. When opportunity arises steel tends to corrode to return to its more stable state. Corrosion process is electrochemical in nature. When two bodies of different electrical potential are electrically connected in presence of an electrolyte, electrons from anodic body move towards cathode leading to corrosion of anode. A steel member with some rust and water make a battery in which rust acts as cathode. Water and oxygen act as electrolyte and corrosion of steel member begins.

Corrosion is classified as– General Corrosion, Pitting Corrosion, Crevice Corrosion, Exfoliation Corrosion, Stress Corrosion, Galvanic Corrosion (dissimilar metal, differential aeration), Stray–Current Corrosion, Coating Damage and Deterioration, Microbial Induced Corrosion.

Concrete is of highly alkaline nature (pH >12) and normally provides a non–corrosive environment for embedded stub angle of transmission tower foundation. Stub steel above concrete footing gets submerged in water during rainy season. The chlorides, sulphates and phosphates in rain water initiates corossion process in steel. It causes rusting and compounds with a larger volume than the original material form. This leads to expansion and tensile strains develop. Each cycle of wetting and drying accelerates the process of corrosion and widening of cracks. The rain water enters into concrete through open cracks. It enhances the corrosion process resulting finally in spalling of concrete. The process continues further even to the extent of eating away of transmission tower leg starting from the coping level to the bottom level.

Corrosion of buried power line components is governed by diffusion of dissolved oxygen in the water entrapped in the soil. In marshy and swampy areas, anaerobic sulphate–reducing bacteria (SRB) enhance the corrosion rate of steel.

Stray current refers to the electricity flow via buildings, ground or equipment due to electrical supply system imbalances or wiring flaws. It refers to an existence of electrical potential that can be found between objects that should not be subjected to voltage. Apart from electrocution, stray current is also capable of causing damage by causing metals within the ground to corrode.

The current leaks from power conductors through insulator string to the tower in variable magnitude depending on voltage intensity, insulator surface contamination and atmospheric moisture. In addition, due to induction in ground wires from the three phases, resultant induced current flow through the loop formed by ground wire, the two towers at each end of the span member. This stray current causes corrosion at location where current leaves the structure and enters the ground through water electrolyte.

Regular inspection of towers is necessary to check for loose nut/bolts, chipping and cracking of paint, and signs of rusting (change in color). These clues identify corrosion sites. Since transmission towers are tall, a mechnaical lift must be used for proper and full inspection.

(7.5) ***Combination of above factors***

A transmission tower is supposed to be a symmetric structure so the wind load does not induce torsion. But uneven support settlement may disturb this symmetry. Similarly, excessive corrosion of some members, or missing nuts and bolts could cause eccentricity of loading leading to development of torsion. A combination of tilting at supports, corrosion and wind load may cause collapse of tower.

VIII. Energy Conservation

Buildings can be designed to meet owner's need for thermal and visual comfort at reduced levels of energy and resources consumption for heating, cooling, ventilation and lighting. This can be achieved as follows.

Promote solar passive techniques using natural energy sources and sinks e.g. solar radiation, outside air, sky, wet surfaces, vegetation, internal gains etc. Energy flows in these systems by natural radiation, conduction, convection with minimal or no use of mechanical means. Design a building in a cold climate in such a way that solar gains are maximized, but primary aim in hot climate would be to reduce solar gains and maximize natural ventilation.

Use low energy materials and methods of construction, reduce transportation energy and reduce of use of high energy building material such as glass, steel etc. Some common design elements, that directly or indirectly affect thermal comfort conditions and thereby the energy consumption in a building, are as follows.

(a) Landscaping, (b) Ratio of built form to open spaces, (c) Location of water bodies, (d) Orientation, (e) Plan form, and (f) Building envelope and fenestration.

There are certain tested and established concepts for extreme climatic conditions to satisfy the thermal comfort criteria. These are classified as advanced passive solar techniques. The two broad categories of advanced concepts are,

1. Passive heating concepts (direct gain system, indirect gain system, sunspaces, etc.)
2. Passive cooling concepts (evaporative cooling, ventilation, wind tower, earth–air tunnel, etc.).

- Landscaping creates different airflow patterns and can be used to direct or divert the wind advantageously by causing a pressure difference.
- For any given building volume, the more compact the shape is, the less wasteful it is in gaining/ losing heat. Hence, in hot, dry, regions and cold climates, buildings are compact in form with a low Surface to Volume ratio to reduce heat gain and losses respectively.
- For a cold climate, an orientation slightly east of south is favored (especially 15° east of south), as this exposes the unit to more morning than afternoon sun and enables the house to begin to heat during the day.
- The location of openings for ventilation is determined by prevalent wind direction. Openings at higher levels naturally aid in venting out hot air. The prevailing wind direction is from the south/ south-east during summer. The recommendations in IS:3362–1977 Code of practices for natural ventilation of residential buildings (first revision) should be satisfied in the design of windows for lighting and ventilation. The window size should be kept minimum in hot and dry regions
- In hot climates, insulation is placed on the outer face (facing exterior) of the wall
- The external finish of a surface determines the amount of heat absorbed or reflected by it. For example, a smooth and light color surface reflects more light and heat in comparison to a dark color surface. Lighter color surfaces have higher emissivity and should be ideally used for warm climate.

IX. Conclusions

Power generation, transmission and conservation are multi–disciplinary tasks involving, Civil, Electric and Power engineers. Civil engineering contributes to all three phases. Data presented shows that by elimination of power theft, transmission loss, highway congestion and transmission tower collapse, India can become a power surplus state even without further enhancing generation. Energy conservation in buildings must become a regular subject in secondary and graduate education in India. Paucity of space did not allow more information. The thoughts expressed in this paper are those of the authors.

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