Proceedings of 30th Indian Engineering Congress, the 21st Century Engineering: The Make in India Pathway, *December 2015*, pp. 27-33

High-Power Interconnections for Future of Indian Mega Cities

Y. Nagarjun*

Karnataka Power Corporation Limited, Raichur Thermal Power Station, Raichur, India;
nagarjun.iei@gmail.com

Abstract

Data compiled by studies estimates that total electric energy requirement for the 13 of present Indian mega cities by the end of 12th Plan will be about 168 BU and by end of 13th Plan the requirement would be 233 BU. Also the ambitious plan of developing 100 smart cities by Indian government requires energy security both in decentralized and centralized manner. So in order to meet these demand future Indian cities requires a strong power link so that huge amount of power can be bought into the cities, for which Gas Insulated Transmission Lines (GIL) can be thought of as an ultimate solution for the problems caused by over-head line or under-ground cable running through cities. This paper addresses how new possibilities can mitigate power flow problems, reduce the risk of failure of electrical transmission systems and enable the installation of optimum solutions regarding technical, economical and environmental aspects.

Keywords: Future Smart Cities, Future Smart Grid, Gas Insulated Transmission Lines, High Power Interconnections

1. Introduction

Central Electricity Authority (CEA) has brought out 18th Electric Power Survey (EPS) of India, on mega cities, each with population of two million and more (as per Census 2011 data)[1]. The study contains detailed energy data of 13 mega cities, which are Greater Mumbai, Kolkata, Chennai, Hyderabad, Bengaluru, Pune, Ahmedabad, Surat, Kanpur, Lucknow, Jaipur, Nagpur and Indore. The total Electrical Energy Requirement (EER) of these 13 cities accounted for 12 per cent of total EER of all India in 2011-12, while they housed 7.5 per cent of the country's population. The compound annual growth rate (CAGR) of EER is 7 per cent during 12th Plan and 13th Plan, against around 7.4 per cent for the country. The combined T&D losses for these cities account for 14 per cent of energy produced as against 25 per cent for all-India. The loss is expected to reduce to 11.5 per cent average for mega cities against 15.3 per cent for all India by 2021-22. EER for Delhi not included in the 13 cities was estimated at 27,029 MU in 2011-12, 37,360 MU in 2016-17 and 52,696 MU in 2021-22. The pattern of utilization of electricity of the mega cities indicates slight increase in the consumption in domestic and commercial category and decreasing trend in irrigation/agriculture consumption which is due to rapid urbanization and industrial development in adjoining areas of these cities. The state utilities are to ensure matching growth of infrastructure for augmentation of T&D network and other measures are necessary to achieve the programme for reduction in T&D losses as projected in the EPS. In order to achieve this GIL can be thought of as an alternative

** Author for correspondence*

solution for the problems caused by over headline or underground cables running through cities.

It is a fact that Indian megacities are fast growing compared to the mature megacities of Tokyo, London or Paris. Though demand growth in core megacity area is low, but is high in newly developing areas. This is mainly due to additional connections and increasing penetration of appliances. In megacities electricity demand of high-end consumers who push for world class quality of supply as well as that of community services like water supply, railway traction, street lighting, hospitals etc, is high and these have no option to supply other than with electricity, thus making it an essential service. Since commercial and domestic consumers account for 60% of the demand, demand has strong correlation to weather and time of the day also. The city wise summary of total EER is given in the Table 1. The annual peak electric load (APEL) has been on the basis of EER and annual electric load factor (AELF) of each city. The summary of the APEL of mega cities is given at Table 2.

Though the transmission and distribution infrastructure in megacities is robust compared to the rural distribution system, but with the increasing demand in megacities the redundancy to cater for failures is less. In present scenario electricity supply to megacities is achieved by providing multiple routes to supply electricity to a consumer, through distribution rings at extra high voltages (132 kV and above), and high voltages (33kV or 11 kV) with remote switching facilities. Use of underground cables, which are relatively more reliable compared to overhead lines, is increasingly planned in all megacities. But many megacities face the problem of safety hazards due to proximity of overhead lines and buildings. Fatal accidents have been reported due to accidental contact with High Tension lines from the balconies and distribution poles have been found located inside houses and also laying underground cables increases fire risk and other technical problems as load on distribution links increases. The root cause for all this would be unplanned and uncoordinated growth. Short term measures to address this include insulating lines close to buildings or shifting lines, while underground cabling could be a long term solution but when looking at the cities growth rate and technical advantages of GIL it is better to suggest here for GIL in megacities as a long term solution.

Along with this megacities face the problem of space constraint for laying distribution lines; as space is a premium in megacities, where there is expansion in buildings and roads in the existing space, with changes in floor space index rules and new construction – both planned and un-planned. It is also observed that because of such issues power cables, distribution transformers and switch boards are often constructed on footpath or common land. In addition to high cost and lack of availability of land, Distribution Companies (DISCOMs) also report problems in land acquisition. To address the space challenge, use of GIL in combination with Gas Insulated Substations (GIS) can be used compared to the conventional outdoor Air Insulated Substations (AIS), in megacities. Compared to the AIS option these GIS-GIL combinations require only 15-30% of floor space and height, it has lower maintenance cost and higher reliability. These combination could also be constructed under-ground or in tunnel. Though one time cost for such a system is higher, but the overall life time cost is only 15-30% higher and the cost advantage is higher at higher voltages and higher power.

2. Gas Insulated Transmission Lines

Gas Insulated Transmission Lines (GIL) is a means for bulk power transmission at extra high voltage

Table 1. EER at power station busbar (in MUS)

City	Terminal year of			% Total		
	11th Plan	12th Plan	13th Plan	11th Plan	12th Plan	13th Plan
Lucknow	4,840	6,796	9,074	4.4	4.3	4.2
Kanpur	3,046	4,023	5,131	2.8	2.6	2.4
Jaipur	3,905	6,743	10,683	3.5	4.3	4.9
Ahmedabad	7,862	11,133	16,097	7.1	7.1	7.4
Surat	8,029	11,053	15,225	7.3	7.0	7.0
Nagpur	2,311	3,193	4,820	2.1	2.0	2.2
Indore	2,007	3,325	5,292	1.8	2.1	2.4
Pune	7,760	12,819	21,111	7.0	8.2	9.7
Greater Mumbai	22,107	30,568	43,039	20.0	19.5	19.8
Hyderabad	13,528	20,652	29,730	12.2	13.2	13.7
Chennai	15,273	21,434	26,236	13.8	13.7	12.1
Bengaluru	12,300	16,260	21,219	11.1	10.4	9.8
Kolkata	15,528	20,006	25,588	14.0	12.8	11.8
Total	**110,635**	**156,873**	**217,147**	**100.0**	**100.0**	**100.0**

Table 2. AEPL at sub-station bus bar (in MW)

City	11th Plan	12th Plan	13th Plan
Lucknow	750	1119	1594
Kanpur	580	765	976
Jaipur	771	1329	2103
Ahmedabad	1320	1869	2827
Surat	1309	1802	2556
Nagpur	315	481	812
Indore	391	621	950
Pune	1173	2091	3544
Greater Mumbai	3605	4985	7225
Hyderabad	2134	3375	5039
Chennai	2291	3370	4334
Bengaluru	2090	2805	3717
Kolkata	2577	3512	4674

(EHV), e.g. 400kV, with rated currents up to 4000A. Similar to bus sections and the bus bar arrangements on GIS, GIL principally consists of tubular aluminium conductors surrounded with insulating gas. Figure 2 shows a cross section of a three phase GIL arrangement in a tunnel. The inner conductor is at the high voltage level. The outer casing is usually grounded and serves as encapsulation.

For insulation purposes, the pipes are filled with a mixture of Nitrogen and the Sulphur Hexafluoride

(SF_6) which has been applied in the sector of high voltage engineering very successfully for several decades. Table 3 shows the most important technical data of the Siemens GIL for 420kV and 550kV transmission networks.

Figure 2. GIL cross section (3 phases).

Table 3. Technical data for 420kV & 550kV GIL

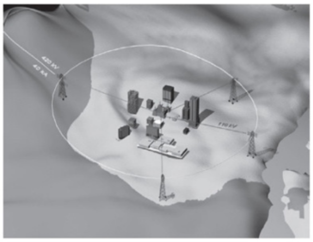
Nominal voltage	420 kV – 550 kV
Nominal current	3150 A – 4000 A
Transmission capacity	1000 MVA – 3800 MVA
Rated short-time current	63 kA/3s
Lightning impulse voltage	1425 kV-1600 kV
Switching impulse voltage	1050 kV-1200 kV
Power frequency voltage	630 kV-750 kV
Rated gas pressure	7 bar
Rated Frequency	50/60Hz
Capacitance	55pF/m
Inductance	220nH/m
Insulation gas mixture	N_2 (80%) - SF_6 (20%)
Pipe materials	Aluminium alloys

2.1 Comparison of other Transmission Systems

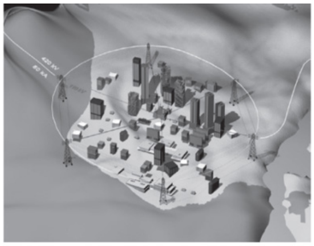
Basic requirements for power transmission are high power capacities combined with long distance application. The possible length of high voltage alternating current (HVAC) cables is strongly limited due to their high capacitance and low thermal permissible power. GIL does not have this disadvantage because its capacitance is significantly lower and its permissible power is much higher. Therefore, from a technical point of view it is the best high HVAC transmission line for long distance applications. Despite of their good electrical behaviour, overhead lines (OHL) are not applicable in the offshore environment, which reduces the options to sea cables and GIL. In case of low power transmission of up to 200 MVA and short distances of less than 100 km, the sea cables with a voltage of 110-170 kV are the most economic option. But for higher transmission capacities only GIL or high voltage direct current (HVDC) systems are appropriate for transmission. For usage under offshore conditions three-phase alternating current has some benefits to HVDC solutions, like robust and well known behaviour, simple configuration, and easier encapsulation because of smaller platforms. Furthermore compared to HVDC systems, the benefits of GIL are the higher power capacity and the robust three-phase technique, which does not demand huge converter stations. GIL does not generally compete with OHL but is applied as a means of power transmission where OHL cannot or must not be applied, such as, densely populated areas or in environmentally sensitive regions. Additionally, due to their outstanding advantages, GIL may be applied where the application of cables are not possible or where they reach their technical limits. The most important advantages GIL offer are: high transmission capacity, low transmission losses, low capacitance, high reliability, high operational safety (no fire risk, no external impact in case of internal failure), applicability of automatic reclosure, no practical ageing of components (long lifetime) and very low external magnetic fields.

2.2 High-Power Interconnections in Metro Cities

Metropolitan areas in India are growing in load density, mainly at their centres. Demand for power has grown because of the construction of huge residential and tall office buildings with air conditioning and lots of electronic equipment, leading to increase in electric loads of up to 10% per year in metropolitan areas[2]. The following short historical overview explains how the power supply of metropolitan areas has developed over the last 30 years. Figure 3 shows the principle for power supply in a metropolitan area. Power generated in remote areas is connected to a metropolitan area by either 220kV or 400 kV overhead lines with a short-circuit rating of 40 kA. Several substations are placed around the city as overhead towers using a ring structure around the metropolitan area enter the city from which 110 kV or 220 kV cables transport electrical energy into the centre of the city, where next energy is distributed at medium-voltage. Figure 3 shows that metropolitan area has grown over years, with more grown infrastructure in the centre. Most cities in India still have a 400 kV ring around the city, but the short-circuit rating has been increased to 50 kA or, in some places, to 63 kA. So, to increase the power transportation into the centre of the city, it is not possible to increase the voltage to 1000 kV because of dielectric problems. Moreover, worldwide experience with very high short-circuit ratings shows that short-circuit rating values cannot go far above 63 kA because of mechanical problems. So the only way to increase the power transportation into the city is to lay 400-kV bulk-power transmission systems right into the centre. In such cases, the GIL offers the best solution. This GIL could have a length of 30–60 km and could allow splitting of the short-circuit ratings of the ring network into two half rings and to connect directly to the existing 220kV or 400-kV transmission links.



(a) In 1970



(b) In 2000

(c) In 2010

Figure 3. Power supply of metropolitan areas during different years.

2.3 Use of Traffic Tunnels to Route GIL

In order to have a better infrastructure within cities, GILs can safely be routed through tunnels carrying traffic on rails or roads. This new application for electrical transmission systems with solid insulated cables was not possible until today because of the risk of fire or explosion. The GIL has a solid metallic enclosure and does not burn or explode. The combinations of GIL and street or railroad tunnels are shown in Figure 4.

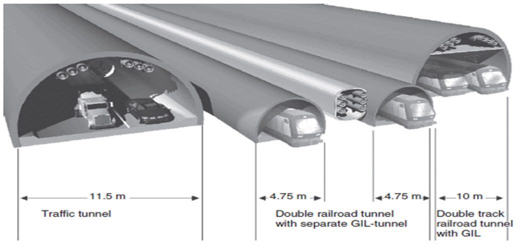


Figure 4. Different types of traffic tunnels to be used for GIL.

In Figure 4 three examples are given. The first one is a traffic tunnel with cars and a GIL mounted on top of the tunnel; the second is a double railroad tunnel system with a separate GIL tunnel; the third example is a double-track railroad tunnel with a GIL included. The use of such traffic tunnels with GIL is now under investigation in different parts of the world. In the European Alps, interconnections between Germany, Austria, Switzerland, Italy, and France are now planned to improve the traffic flow and to allow trade of electric energy. In China and Indonesia, interconnections between the mainland and islands or between outlying islands are under investigation. In the near future, GILs will become economically viable and will be widely used as high-power, long distance transmission lines.

2.4 Operating Experience

The very first Siemens 1st generation GIL (only SF_6 as insulation medium) was commissioned in 1975 in Germany at the Wehr power plant[3,4], After the Wehr project further installations of the 1st generation GIL followed. However, most of them were special applications in power plants or substations. The first installation of the 2nd generation GIL (Mixture of Nitrogen and SF_6 as insulation medium) was commissioned in January 2001 in Geneva, Switzerland[5,6]. This GIL was installed in a tunnel that replaced an existing OHL section of approximately 400m in length.

2.5 Gas Insulated Transmission Line in Combination with Highly Integrated Switchgear

Similar to Highly Integrated Switchgear (HIS), GIL of the second generation was developed to enable utilities to cope with the new challenges of the power transmission industries. The modular designs of GIL, GIS and HIS allow an arbitrary combination of these techniques[7]. These equipment types can also be connected easily to Over Head Lines (OHL) or transformers so that for each project the best arrangement can be found, both from the technical and the economic view points. In 2004, 400kV switchgear for National Grid (NG) was erected and commissioned at Elstree substation, London. It was a combination of GIS, HIS and GIL.

3. Future Perspectives

GIL is a means of bulk power transmission. Its flexibility allows installations above ground, in tunnels or directly buried. Due to the very low magnetic fields and due to the lack of a fire risk GIL enables totally new possibilities for the routing of EHV transmission lines. GIL can be routed right into or through conurbations and residential areas without violating limits for magnetic fields allowing electrical power to be transmitted right into the centre of conurbations on the EHV level which is typically 400kV in most countries. In addition, with GIL a diagonal connection of OHL rings around major cities are possible. These new possibilities can mitigate power flow problems and reduce the risk of the failure of electrical transmission systems[8].

4. Conclusion

The requirements to installations for high voltage power transmission and distribution have changed. This paper has given a thumbnail sketch of electricity issues in megacities. With high growth and high expectations on quality of electricity service, planning and operating the system is a big challenge. Issues of urban small consumers are different and need special attention. The electricity demand profile of megacities is quite different from that of the State, with peak occurring during day time and wide variation between peak and minimum demands. Megacities have severe space shortage challenge which has to be met through technology and management innovations. A facilitating role of the municipalities in improving the urban planning process by catering to the requirements of electricity service providers and institutionalizing the coordination between various service providers would improve electricity service delivery in megacities.

HIS and GIL as innovative products offer new possibilities to cope with these new requirements. Depending on each situation, by a coordinated application of the different techniques of GIS, HIS, OHL and GIL the optimum solution will be provided regarding technical, economical and environmental aspects for High power interconnections in metropolitan cities.

5. Acknowledgement

The views and opinions presented in this paper are solely of the author unless specifically quoted and not of the organisation to which the author belong.

6. References

1. CEA Report. Report on 18th Electric Power Survey of India. 2013 Mar; 2.
2. Hillers T, Koch H. Gas Insulated Transmission Lines (GIL): A Solution for the Power Supply of Metropolitan Areas. CEPSI Conference; 1998; Thailand.
3. Baer GP, Diessner A, Luxa GF. 420 kV SF_6 Insulated Tubular Bus for the Wehr Pumped-Storage Plant, Electric Tests. IEEE Transactions on Power Apparatus and Systems. 1976; PAS-95(2).
4. Baer G, Lehmann W. SF6 Insulated Metalclad 420kV Tubular Bus with Transfer Facility Connected to an Underground Hydroelectric Power Station. CIGRE Report 23-02. Paris; 1974.
5. Alter J, Ammann M, Boeck W, Degen W, Diessner A, Koch H, Renaud F, Poehler S. N_2/SF_6 Gas-Insulated Line of a New Generation in Service. CIGRE Session, No. 39. Paris; 2002. p. 21–204.
6. Koch H. Gas-Insulated Line (GIL) of the 2nd Generation. 7th International Conference on AC-DC Power Transmission; 2001; London.
7. Coventry P, Fletcher P, Bockel E, Koch H, Schoeffner G. Modernisation of Metropolitan Substations. 15th Conference on Electric Power Supply Industry CEPSI; 2004; Shanghai.
8. Schöffner G, Koch H. New Possibilities of Power Grid Modernization with Gas Insulated Line. Iasted Power Con, Special Theme “Blackout”. New York; 2003.