International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V72I9P127

Volume 72 Issue 9, 321-326, September 2024

Original Article

Assessment of a High Voltage Transmission Line with Gaseous Insulation

Ansari Habiburrahman[1], M. Murali[2]

[1,2]*Department of Electrical Engineering, Medi-Caps University, Indore, Madhya Pradesh, India.*

[1]*Corresponding Author : habiburrahman.ansari@gmail.com*

Received: 12 March 2024 Revised: 07 August 2024 Accepted: 12 August 2024 Published: 28 September 2024

Abstract *- Electrical Energy is generated at the generating power stations. These generating power stations may be located either near or far away from the load centers. Generally, load centers are away from the generating stations. For power transmission purposes, transmission lines are required, which may be overhead transmission lines or underground cables. In this paper, we only consider air-insulated and gas-insulated transmission systems. For the last forty-five years, another transmission technique has been working in the power system field, which is called the Gas-Induced Transmission Line (GITL). In this research paper, we summarize the results and behavior of the overhead and GITL with different parameters like the length of the transmission line, the transmission line voltage level, etc. For simulation purposes, take one simple 40 Km line with a 220 KV voltage level and show the same result next in the same transmission network with the change in line resistance, inductance, and capacitance, getting the result of a gas-insulated transmission network. Basic voltage regulation and efficiency are observed in this paper. Based on simulation results, we conclude that the most suitable design for a 40 Km short transmission line of 220 KV is GITL. Also presented is the graph of receiving and sending ends voltages for both air-insulated and gas-insulated transmission systems. Although GITL may become our future transmission line based on performance and low losses.*

Keywords *- High Voltage Gas-Insulated Transmission Line (HV-GITL), Over-Head Transmission Lines (OHTL), Voltage Regulation (VR), Ultra High Voltage Transmission Line (UHV-TL), Aluminium Conductor Steel Reinforced (ACSR), Gas-Insulated Substation (GIS).*

1. Introduction

Today, the energy demand increases with respect to population. At the same time, large-scale solar power plants and wind farms are in the planning phase or are currently being built worldwide. These large-scale windmills and solar plants may be on land and offshore power plants. Although windmills are best suited near the sea, and the sun is shining brightest in desert areas, but the loads are far away from the generating station. A transmission line is required for the transformation of power. This transmission line may be through overhead or underground cables. The transmission lines transmit the electrical power from one end to another end. Where overhead lines cannot be built, then there is another option, such as an underground cable and a new technique known as a Gas-Insulated Transmission Line (GITL). GITL provides an alternate underground cable system with all of the following capabilities: GITL will transmit the same power as the overhead line transmits. For example, in this case, 220 kV was studied, and the transmitted power was 381 MVA[1]. The low magnetic field is an important advantage of GITL whenever residential zones are very close to the high-voltage transmission line. The city, which is a highly populated area, has sensitive instruments in hospitals with their sensitive imaging systems or all kinds of sensitive electronic equipment for private or business use. Many advantages of using this new technology in high power and voltage gas-insulated power transmission lines include huge amounts of current that can easily pass through the aluminium conductor of GITL. Due to the basic formula of resistance, resistance R is directly proportional to the inverses of the area of the aluminium conductor. Therefore, the area of the conductor is large in the case of GITL, which results in very low resistance present in comparison with normal overhead transmission lines and high voltage cables used in underground systems. Also, low transmission line resistance reduces the transmission line losses[2]. The present investigation is going on to discover the optimal size of the aluminium conductor used as a bare conductor in an enclosure of GITL. This will result in better voltage regulation and reduce overall cost. Similarly, the optimal size of the aluminium enclosure and aluminium conductor used for different high voltage transmission capacities suited for GITL is going on. In this paper, parameters are distributed in the transmission network and not taking the lumped network. As in three-phase high voltage over-head transmission lines, they have double circuits for each phase [3].

The voltage rating will increase with the increase in ACSR conductor diameter. In the same way, the aluminium conductor size of GITL also increases with respect to voltage level and capacity. So, these concepts are frequently adopted in Ultra-High Voltage Transmission Lines (UHV-TL) with the ultimate goal of dropping transmission line losses. Generally, large-diameter conductors in the overhead line with bulk power transmission are limited to some specific value only because it is very dangerous to build and use large-diameter conductors with various roadblocks such as public safety, right of way, and so on [4]. Recently, countries like North and South America, South Africa, Russia, China and India have been dealing with ultra-high voltage transmission levels like 735 kV, 765 kV, 1000 kV, 1100 kV and 1200 kV [5,6]. Planning is underway in Europe and North America to electrically connect non-conventional sources of energy to the electrical UHV line load centres [7,8].

2. Over-Head Short Transmission Line

An overhead short transmission line's effective length should not be less than 80 km, and the line voltage should not be less than 69 kV. Because the charging current is small on a short transmission line, the shunt capacitance may also be neglected, and additional parameters may be lumped into a short transmission line. The equivalent circuit of a short transmission line is represented in Figure 1. Based on the equivalent circuit diagram, Figure 2 illustrates the vector diagram of a short transmission line with the receiving end current Ir as a reference. Both the sending and receiving end voltages created an angle of φs and φr with the receiving end reference current Ir[1].

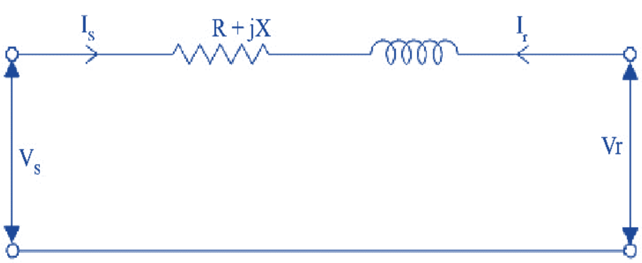

Fig. 1 Equivalent circuit of a short transmission line

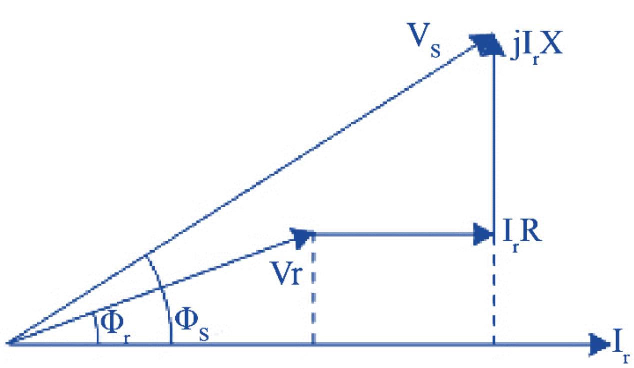

Fig. 2 Vector diagram of over-head short transmission line

2.1. Over-Head Short Transmission Line Parameters

The capacitance of the shunt branch in a short transmission line is neglected, and hence, both sending and receiving end currents are equal, i.e.

$$Is = Ir$$

Since the phasor diagram of the short transmission line, It is clear that sending end voltage Vs is roughly equivalent to

$$Vr + Ir.R.\cos\varphi r + Ir.X.\sin\varphi r$$

Therefore,

$$Vs = Vr + Ir.R.\cos\varphi r + Ir.X.\sin\varphi r$$

Since it is assumed,

$$\varphi s = \varphi r$$

During the no-load condition, zero current passes through the transmission line because there is no capacitance. Therefore, at no-load conditions, the sending end voltage is equal to the receiving end voltage. According to the definition of power transmission line percentage voltage regulation,

$$\%\text{ Voltage Regulation of transmission line} = \frac{\text{Power delivered at receiving end}}{\text{Power sent from sending end}}\ 100\%$$

$$\%\text{ VR} = \frac{Vs-Vr}{Vr}\ 100\%$$

$$= \frac{Ir.R.\cos\varphi r + Ir.X.\sin\varphi r}{Vr}\ 100\%$$

$$\%\text{ Per Unit Voltage Regulation} = \frac{Ir.R}{Vr}\cos\varphi r + \frac{Ir.X}{Vr}\sin\varphi r = Vr.\cos\varphi r + Vx.\sin\varphi r$$

Where Vx and Vr are the PU reactance and resistance of the short transmission line, respectively, the efficiency of the short transmission line can be defined as a ratio of a power receiving end to the power received at the sending end, and it is expressed by the equation below. Also, it is expressed in percentage value;

$$\%\, Efficency\ of\ transmission\ line = \frac{Power\ deliverd\ at\ receiving\ end}{Power\ sent\ from\ sending\ end}100\%$$

$$\%\,\eta = \frac{Power\ received\ at\ receiving\ end\ of\ line}{Power\ deliverd\ at\ sreceiving\ end\ of\ line + 3Ir^2R} * 100\%$$

"cosφs" is the power factor at the sending end. "cosφr" is the power factor at the receiving end. "Vs" is per phase sending end voltage. "Vr" is per phase receiving end voltage.

It is now obvious that the load current is inversely proportional to the power factor at the receiving end to transmit a certain amount of power.

2.2. Over-Head Short Transmission Line Losses

Electrical power is transmitted by several means, such as underground power transmission through power cables, overhead transmission lines through bare conductors, and gas-insulated transmission lines through aluminium pipes. Based on applications, each one has its advantages and utilizations. No matter how meticulously designed the electrical system is, losses exist and must be quantified before an effective portrayal of the system response can be computed. Because of the size of the area served by the power system, most of the system components are committed to transmission systems. The losses due to the overhead transmission line are higher than those of GITL. The Gas-Insulated transmission line uses compressed gas pipelines, which do not have any Corona effect, Ferranti effect, etc. Also, the diameter of the conductor pipe is important. The transmission line losses are a very important evaluation criterion. Because the high-power transmission lines are built for a lifetime or a long time, the losses also come along with the life of the line. Means energy losses in terms of money. MATLAB Simulink is used to simulate short overhead transmission lines. Table 1 shows the technical data of the overhead short transmission line [9-11]. As per the data given in Table 1, simulation is done on Simulink of MATLAB. The power is generated at the sending end side, and one RL load is connected to the receiving end side. Measurement blocks, displays, and scopes are used for all quantities measured. Measured quantities of overhead transmission lines are mentioned in Table 3. The standard frequency was taken as 60 Hz.

2.3. High Voltage Gas-Insulated Transmission Line

The High Voltage (HV) GITL is an alternate technique of overhead transmission and underground cables. Essentially, high voltage GITL includes four fundamental elements used in construction, like an aluminium bare conductor, aluminium enclosure pipe, and gaseous medium of insulation between the enclosure pipe and conductor. It may be pure SF6 gas or a mixture of insulating gases and physical support to the conductor by insulators made of epoxy resin to secure electrical isolation of the enclosure and conductor. The latest technologies used in GITL are robotics welding, compressed gas monitoring systems, etc. The epoxy resin insulators are used in GITL with uniform distance[6]. The insulators hold the current-carrying aluminium pipe at a very high voltage. Figure 3 shows the basic arrangement of GITL[3]. In between the enclosure and the aluminium conductor, compressed insulated gases are filled for insulation purposes. The same properties of insulating gases like sulphur hexafluoride and nitrogen are used with a defined standard ratio. Gases used for insulation may also be used in a mixture of CF3I/N2 [15]. Recently, the operating voltage or transmission voltage may be very high. In this paper, we deal with 220 KV transmission line voltage. In the latest research, the range of GITL voltage may reach up to 1500 KV[16]. Table 2 shows the line parameters of GITL. The connection between the active parts is usually only a few meters long. Because the electrical forms necessary for enclosures are frequently intricate, castings are employed widely for both active components and the flanges used for linking lines. To keep the installation light, the conductor and enclosure are often composed of aluminium [17].

Table 1. Technical data for overhead transmission line data

Overhead Line Parameters	Units
Voltage (KV)	220
Frequency (Hz)	60
Inductance L in \ kilometre Length (mH per km)	1.3263
Capacitance Cb in \ kilometre Length (nF per km)	Neglected
Resistance R in \ kilometre Length (Ω per km)	0.15
Load in (MVA)	381
Power factor	0.8 lag
Length (Km)	40

Table 2. Technical data for Gas-Insulated transmission line

GITL Parameters	Units
Voltage (KV)	220
Frequency (Hz)	60
Inductance L \ kilometer length (mH per km)	0.187
Capacitance Cb \ kilometer Length (nF per km)	Neglected
Resistance R \ km length (Ω per km)	6
Load in (MVA)	381
Power factor	0.8 lag
Length (Km)	40

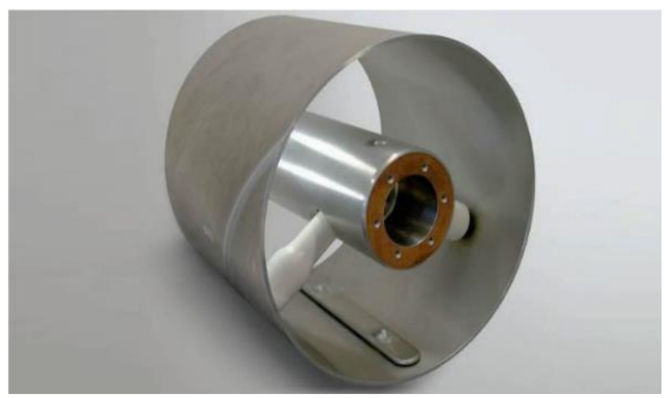

Fig. 3 GITL unit for high voltage transmission

2.4. Gases Used for Insulation

The Sulfur hexafluoride (SF6) gas is the most often used gas insulator with strong arc extinguishing as well as quenching insulating properties [18]. SF6 may be a widely utilized gas and an exceptionally predominant choice in High Voltage (HV) and Extra High Voltage (EHV) devices as an insulation medium, also in a compact circuit breaker used in Gas-Insulated Substation (GIS) and power transmission lines. It is also non-flammable compared with insulated mineral oils, making it ideal for indoor substations. In any case, having the features mentioned above and properties of SF6. Unfortunately, it has been identified as a harmful greenhouse gas by the Kyoto Protocol, with the same quantity of both gases being 22,800 times more damaging than CO2 over 100 years [19-20] as research was done in past decades on alternate insulating gas to sulfur hexafluoride SF6, covering candidates that distinguish-out including same gases like (Nitrogen, air, CO_2), perfluorocarbons, and vacuum etc. All of these gases have advantages and disadvantages.

2.5. Technologies which have recently emerged:

Conventional gases such as nitrogen, air, CO2, or their combinations have a minimal global warming potential with exceptionally restricted dielectric strength of up to roughly 40% or less when compared to pure SF6. At break even with gas pressure, 20 percent SF6 component results in 69 percent insulating capability of pure SF6. A pressure increase of roughly 45 percent is adequate to compensate for the lower dielectric strength compared to pure SF6; with this specific combination and pressure, the needed amount of SF6 may be reduced by 71 percent when compared to pure SF6 applications. At 0.7 MPa, a mixture of 20% SF6 and 80% N2 is used for 420 kV GITL. The employment of these gases as a current or an insulating interruption medium would result in significant modifications in high voltage insulator product design, i.e. whether filling pressure or device size would be raised by a factor of at least 2.5. Excessive pressure expansion would affect vessels, enclosure design, and safety. Expanding the dimension would have a direct impact on the dimension footprint and cost of the product, rendering it unsuitable as a replacement product in existing electrical substations and switchyards. Vacuum is often used as an insulating medium in the medium voltage domain. This technology is currently highly developed and has been demonstrated to be robust [21-26]. High voltage domain application at 725 kV is currently state of the art, including experimental implementation at 145 kV. However, due to the inherent characteristics of an insulating vacuum, such as its insulating material capability not being in direct proportion to the electrical insulation gap as it could be for compressed gas, there is a concentration of the insulating material capability for huge gaps in a vacuum, making the use of vacuum disrupters for higher voltage unlikely [23 - 26]. As more than just a result, the use of air at Ultra High Voltage does not appear to be economically feasible. Table 2 shows the technical data required for the simulation of the Gas-Insulated Transmission Line(GITL) model in MATLAB. Changes in the insulating gas dielectric constant will also change.

3. Simulation Results of OHTL and GITL

The simulation of MATLAB was utilized to model overhead and Gas-Induced Transmission Lines (GITL). The parameters of both lines will be different as per the data given in Tables 1 and 2. The simulation results of OHTL in MATLAB for a 40 km distributed line parameter model with 381 MVA power are summarized in Table 2. In both the MATLAB simulation of OHTL and GITL, the common load with the same fixed length were used. Figure 4 shows the transmission line model. All the blocks with the sending end and receiving end are connected with the display block, which shows the actual values of the respective block parameter.

Table 3. Simulation result

Parameters	OHTL	GITL
Sending End Voltage in KV	144.33	144.6
Receiving End Voltage in KV	127	142.4
% Voltage Regulation	14.05	2.096
Efficiency in %	94.42	99.76
Sending End Active Power in MW	322.8	383
Receiving End Active Power in MW	304.8	382.1
Sending End Reactive Power in MVAR	288.6	297.1
Receiving End Reactive Power in MVAR	228.6	288.5

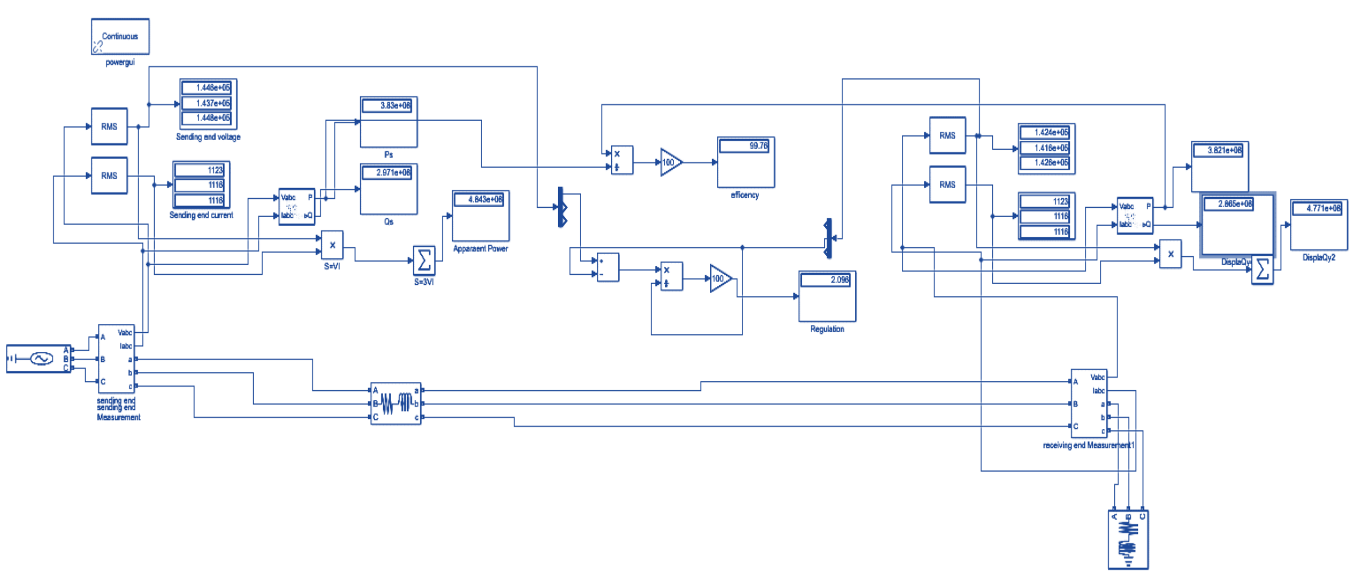

Fig. 4 MATLAB Simulink model for high voltage transmission line

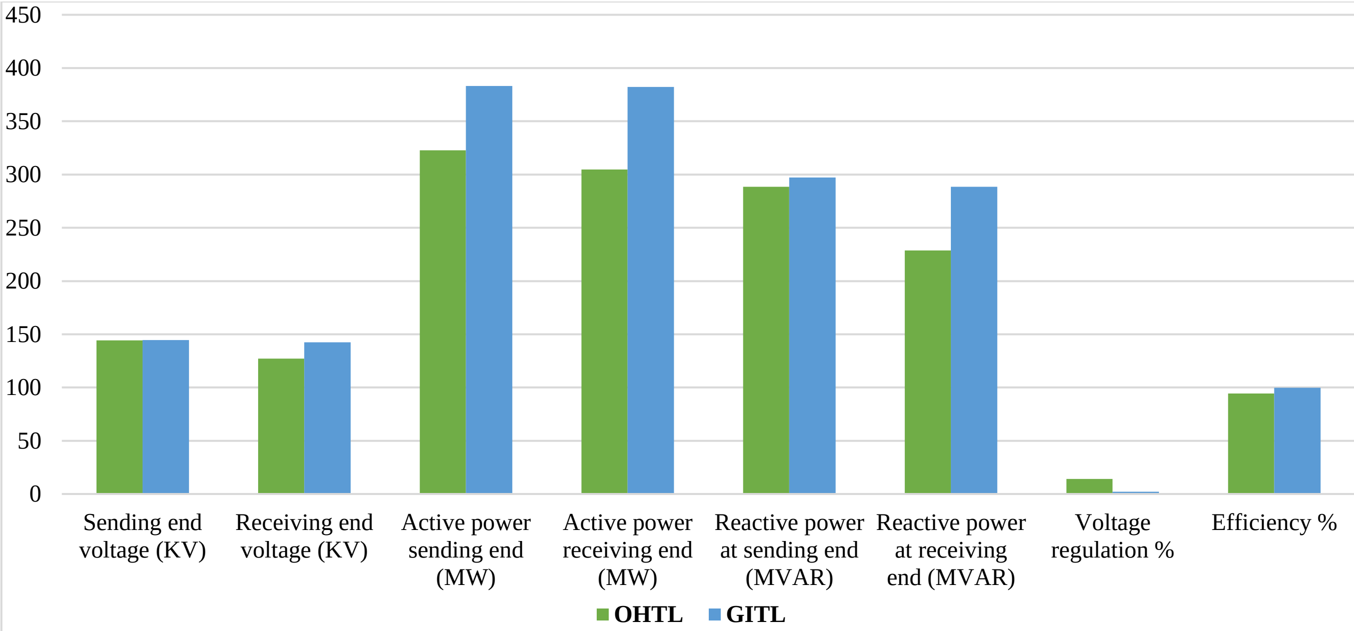

Fig. 5 Graph of comparative results obtained from MATLAB simulation

4. Conclusion

The use of high-voltage underground cables for high and ultra-high voltage transmission is quite low as compared with overhead transmission lines. But, GITL was introduced into the power sector in competition with OHTL and under-ground cables with significant advantages. The simulation result shows the percentage regulation of GITL of only 2%, whereas the overhead transmission line shows it 14%.

The difference also comes in receiving end voltages of OHTL and GITL. Similarly, the active power meet in GITL is approximately the same in transmitting and receiving ends. Meanwhile, in OHTL, the difference is 18 MW of active power. Day by day, the requirement for electrical power with low losses is increasing, and the population of the world is also increasing. So, for the new high-power transmission line, it is too tough to gain the Right of Ways (ROWs). Therefore, it is necessary to introduce an alternative to the high-voltage overhead and underground transmission lines. GITL may be an appropriate alternative for the future requirement while considering all the perspectives. As the simulation result shows, the receiving end profile has a healthy output voltage when compared to the transmitting end profile. Thus, no compensation device is required to improve the voltage profile. The GITL simulation concludes that superior voltage regulation is obtained at different loading conditions. It is also clear that the transmission line efficiency of GITL has not been disturbed significantly. Based on the simulation results, this GITL concept will be beneficial for future high-voltage transmission and interconnections.

References

[1] Abdelhay A. Sallam, and Om P. Malik, *Power Flow Analysis*, Power System Stability: Modelling, Analysis and Control, pp. 107-130, 2015, [CrossRef] [Google Scholar] [Publisher Link]

[2] Hermann J. Koch, *Gas Insulated Transmission Lines (GIL)*, Wiley, pp. 1-384, 2011. [Google Scholar] [Publisher Link]

[3] Ansari Habibur Rahman, and Kishor Bhimrao Gawale, "Optimal Sizing of Conductor and Enclosure for 400 kV Gas Insulated Line," *International Journal for Scientific Research & Development*, vol. 3, no. 5, pp. 342-344, 2015. [Publisher Link]

[4] Roberto Benato, Claudio Di Mario, and Hermann Koch, "High-Capability Applications of Long Gas-Insulated Lines in Structures," *IEEE Transactions on Power Delivery*, vol. 22, no. 1, pp. 619-626, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[5] Tomasz Magier, Andreas Dehler, and Hermann Koch, "AC Compact High Power Gas-Insulated Transmission Lines," *2018 IEEE/PES Transmission and Distribution Conference and Exposition (T&D)*, Denver, CO, USA, pp. 1-5, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[6] Michael Tenzer, Hermann Koch, and Denis Imamovic, "Compact Systems for High Voltage Direct Current Transmission," *International ETG Congress 2015; Die Energiewende - Blueprints for the New Energy Age*, Bonn, Germany, pp. 1-6, 2015. [Google Scholar] [Publisher Link]

[7] H.J. Koch, "AC Bulk Power Systems in Metropolitan Areas Application," *2005 IEEE/PES Transmission & Distribution Conference & Exposition: Asia and Pacific*, Dalian, China, pp. 1-4, 2005. [CrossRef] [Google Scholar] [Publisher Link]

[8] Danish Khan et al., “Comparison of Transmission Losses and Voltage Drops of GIL(Gas Insulated Transmission Line) and Overhead Transmission Lines,” *2014 16th International Power Electronics and Motion Control Conference and Exposition*, Antalya, Turkey, pp. 1151-1153, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[9] Ansari Habibur Rahman, and Shaikh Muhammad Moinuddin, “Comparision of Voltage Regulation of Gas Insulated Transmission Line and XLPE Cable,” *International Journal of Modern Trends in Engineering and Research*, vol. 2, no. 4, pp. 269-276, 2015. [Google Scholar]

[10] R. Benato et al., “Gas Insulated Transmission Lines in Railway Galleries,” *IEEE Transactions on Power Delivery*, vol. 20, no. 2, pp. 704-709, 2005. [CrossRef] [Google Scholar] [Publisher Link]

[11] C.G. Henningsen et al., “Electrical and Mechanical Long-Time Behavior of Gas-Insulated Transmission Lines,” *CIGRE Session*, vol. 8, 2000. [Google Scholar] [Publisher Link]

[12] Geng Chen et al., “Environment-Friendly Insulating Gases for HVDC Gas-Insulated Transmission Lines,” *CSEE Journal of Power and Energy Systems*, vol. 7, no. 3, pp. 510-529, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[13] Hermann Koch et al., “Technical Aspects of Gas Insulated Transmission Lines and Application of New Insulating Gases,” *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 25, no. 4, pp. 1448-1453, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[14] K. Elnaddab, A. Haddad, and H. Griffiths, “The Transmission Characteristics of Gas Insulated Lines (GIL) Over Long Distance,” *2012 47th International Universities Power Engineering Conference*, Uxbridge, UK, pp. 1-5, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[15] Sandeep Ushkewar, Gaurav B. Patil, and Vishal Moyal, “Wireless Charging in a Dynamic Environment for Electric Vehicles,” *2022 IEEE Bombay Section Signature Conference*, Mumbai, India, pp. 1-5, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[16] H. Shafqat Kharal et al., “Insulation Characteristic of CCl2F2 with Mixtures of CO2/N as a Possible Alternative to SF6 Substitute Gas for High Voltage Equipment’s,” *2018 International Conference on Power Generation Systems and Renewable Energy Technologies*, Islamabad, Pakistan, pp. 1-5, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[17] Mohanish Thakur, Aayush Patil, and Gaurav Patil, “The Current State of the Art for PV Grid Connected System Issues with Power Quality,” *2022 International Interdisciplinary Humanitarian Conference for Sustainability (IIHC)*, Bengaluru, India, pp. 1515-1520, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[18] Rahmat Ullah et al., “Dielectric Properties of Tetrafluoroethane (R134) Gas and its Mixtures with N_2 and Air as a Sustainable Alternative to SF6 in High Voltage Applications,” *Electric Power Systems Research*, vol. 163, pp. 532-537, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[19] Rahmat Ullah et al., “Dielectric Characteristic of Dichlorodifluoromethane (R12) Gas and Mixture with N_2/Air as an Alternative to SF_6 Gas,” *High Voltage*, vol. 2, no. 3, pp. 205-210, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[20] Gaurav B. Patil, Santosh S. Raghuwanshi, and L.D. Arya, “Effect of PV Penetration on the Steady-State Voltage on Grid-Integrated PV System,” *Proceedings of Intelligent Communication Technologies and Virtual Mobile Networks*, pp. 509-521, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[21] Kalyani Chavan, Gaurav B. Patil, and Rohini More, “Transient Stability Analysis of IEEE Test System,” *2024 IEEE International Conference for Women in Innovation, Technology & Entrepreneurship*, Bangalore, India, pp. 691-695, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[22] Sandeep Ushkewar, Nilesh Ahire, and Gaurav Patil, “Enhancing Capabilities of Wireless Transmission for Electric Vehicle,” *2022 Global Energy Conference*, Batman, Turkey, pp. 278-281, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[23] Hitoshi Okubo, and Abderrahmane Beroual, “Recent Trend and Future Perspectives in Electrical Insulation Techniques in Relation to Sulfur Hexafluoride (SF6) Substitutes for High Voltage Electric Power Equipment,” *IEEE Electrical Insulation Magazine*, vol. 27, no. 2, pp. 34-42, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[24] Gaurav B. Patil, and L.D. Arya, “Voltage Stability Assessment of Grid Connected Solar PV System,” *2021 Third International Conference on Intelligent Communication Technologies and Virtual Mobile Networks (ICICV)*, Tirunelveli, India, pp. 563-568, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[25] Amit Wani, Prathamesh Mistari, and Gaurav B. Patil, “Comparative Analysis of Power Quality Issues in Grid-Integrated Wind Energy System,” *2022 International Interdisciplinary Humanitarian Conference for Sustainability (IIHC)*, Bengaluru, India, pp. 1485-1489, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[26] H. Koch, “Optimized Pipeline for Electricity,” *IEEE Spectrum*, pp. 6-9, 2001. [Google Scholar]