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Modeling and Simulation of Air Insulated and Gas Insulated Substations

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Abstract

This paper presents modeling and simulation of gas insulated substation and air insulated substation. Performance analysis is carried out on the basis of obtained results and case study. Key property of AIS unit is step-up systems in connection with power stations and transformer substation in the extra high voltage transmission system. Whereas the gas insulated substation works on the principle operation of completely enclosure of all the energized parts in metallic encapsulation compressed within sulphur hexafluoride gas. Both the substations have equal merits and demerits in different aspects. In this paper equivalent circuit of substation is designed in MATLAB/Simulink software to calculate the Very Fast Transient Overvoltage. Other parameters like medium of insulation, construction/space requirement, environmental impact and maintenance are also discussed in this paper.

Keywords: Substations, AIS, GIS, Sulphur hexafluoride gas, VFTO, MATLAB Software.

I. INTRODUCTION

Providing power has become a challenge to the power companies, the power companies take care of generation, transmission as well as distribution of power through various reliable power plants. As the electricity demand is increasing day by day, the power companies are giving their active participation in fulfilling consumer demand. The design of power substation is classified as air insulated substation and gas insulated substation. An AIS unit is basically a conventional switchgear technology where air is used as primary dielectric for insulation whereas; in GIS unit sulphur hexafluoride gas is used as the primary dielectric medium for insulation. Key property of AIS unit is step up systems in connection with power stations and transformer substations in the extra high voltage transmission system. Gas insulated substation are preferred for 72.2 kV, 145 kV, 245 kV, 420 kV and above with all its equipments encapsulated in a metal enclosure compressed with SF_6 in it. [1]. As the dielectric strength of SF_6 is three times more than that of the dielectric strength of air, the overall size of complete gas insulated substation and the size of equipments can be reduced to 10% of the conventional air insulated substation [2]. As GIS substation is encapsulated in a metal enclosure free from the external environmental impacts and faults due to the natural environmental hazards, this property of GIS unit makes it more efficient and reliable as compared to the AIS unit. Although GIS has numerous advantages but if any switching operation or faults occur in GIS, high transient overvoltages get produced. These transients are called as very fast transient overvoltages (VFTO). These VFTOs are in the range of nano seconds. These VFTOs are produced due to closing and opening operations of disconnector switch. VFTOs adversely affect the system by decreasing the insulation life and also by affecting the external equipment like transformers where in-turn insulation is stressed out with a higher voltage than under chopped lightening impulse voltages [3]. Considering all the merits and demerits of both the substations a comparative analysis is made. The parameters to be compared are discussed below:

1. Very Fast Transient Overvoltage

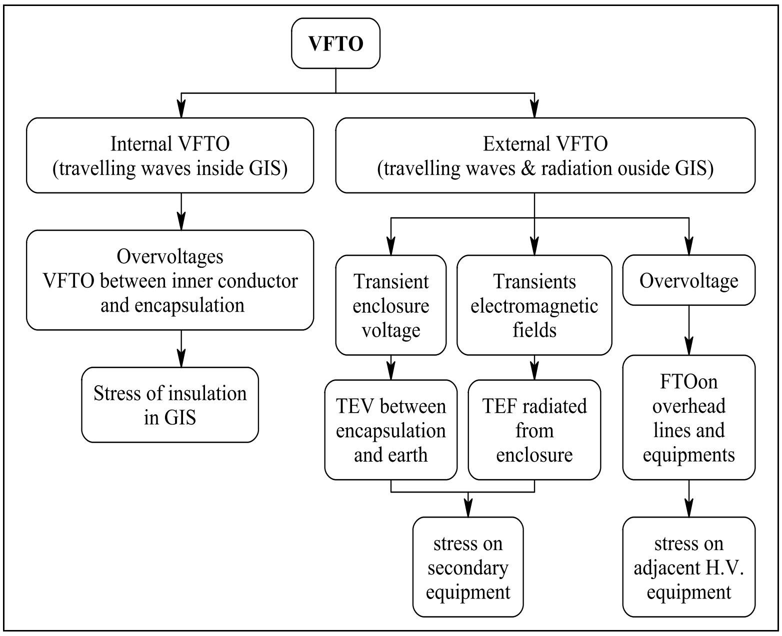

Figure 1. Classification of VFTO

Study of fast transient voltage is a very important aspect in gas insulated substation. VFTO are generated mainly due to the closing and opening operation of the disconnector switch [6]. Classification of VFTO is shown in figure 1 [7]. According to IEC 71-1, the overvoltages are classified as temporary overvoltages and transient overvoltages based on their duration [8]. Temporary overvoltages are long duration overvoltages, which are damped or slightly damped. Transient overvoltages are short duration overvoltages, which are highly damped transient overvoltage. In gas insulated substation, VFTOs can be caused by switching operation and also due to faults. Switching operation generates fast front transients and because of its travelling nature in GIS, produces internal and external transients. The internal transients are with respect to bus duct and enclosure that is; wherever it experiences impedance change in the internal bus duct which is enclosed, these fast front transients is produced. External transients are produced with respect to the enclosure discontinuities that is, between enclosure and ground at GIS to air interface. Because of these external transients enclosure voltages will be produced. So the overhead lines which are connected to the substation will be affected because of these transients. These transients also cause stresses and electromagnetic interference (EMI) in the secondary equipments. During closing and opening operation, the voltages across the breaker contacts collapse within nanoseconds and the surge interacted between two contacts, travels in either direction of bus duct. These surges when experiences an impedance change it gets reflected and refracted near the terminals. Due to these reflections, over voltages are generated, these overvoltages are known as VFTO. VFTO are developed with different magnitude at each re-strike. Maximum magnitude of VFTO appears to be 2.5 pu with very short rise time of 4-100 nano seconds.

1.1 Modeling of GIS and AIS

The equivalent circuit is constructed by using MATLAB software. By using the circuit, transients are calculated for 10 meters length of GIS (132 kV). The transients are generated not only due to switching but also by the 3- phase faults occurring on the line. The line capacitance, Inductance and the surge impedance are calculated using the following formula [9]. By calculating values of the circuit parameters, an equivalent circuit is constructed by using MATLAB software. The modeling diagram of 145kV substation is shown in figure 2. The capacitance of the GIS is calculated to be 90 pf per unit length and a line inductance is calculated to be 0.4μH per meter and a resistance of 1 ohm is connected in series with the circuit breaker. The voltage of equivalent circuit developed on MATLAB software is taken in 1.0p.u. and -1.0 p.u. Depending upon the closing time and opening time of the circuit breaker contacts the load side voltage magnitude changes. The line parameters used in the MATLAB design are mentioned in table 1.

1.1.1 Capacitance calculation

The capacitance is calculated with the assumption that the conductors are cylindrical. Capacitance is calculated using the following formulae.

$$C=\frac{2\pi\varepsilon_0\varepsilon_r l}{\ln\left(\frac{b}{a}\right)}$$

Where $\varepsilon_0 = 8.854\times10^{-12,}$ & $\varepsilon_r = 1$

b = radius of outer cylinder

a = radius of inner cylinder

l = length of the section

1.1.2 Inductance calculation

The inductance of the bus duct can be calculated by using formulae given below, where b and a are the outer radii and inner radii of the conductor respectively.

$$L = \frac{\mu_0 \ln\left(\frac{b}{a}\right)}{2\pi}$$

Where $\mu_0 = 4\pi\times10^{-7}$

Table 1. Line Parameters of AIS and GIS

Parameters	**AIS**	**GIS**
Line voltage	145 kV	145 kV
Line capacitance	101.6 pF	90 pF
Line inductance	0.43 µH	0.12 µH
Line impedance	62.7 Ω	36.5 Ω
Phase voltage	118.39 kV	118.39 kV
Phase current	2.0 A	3.243 A

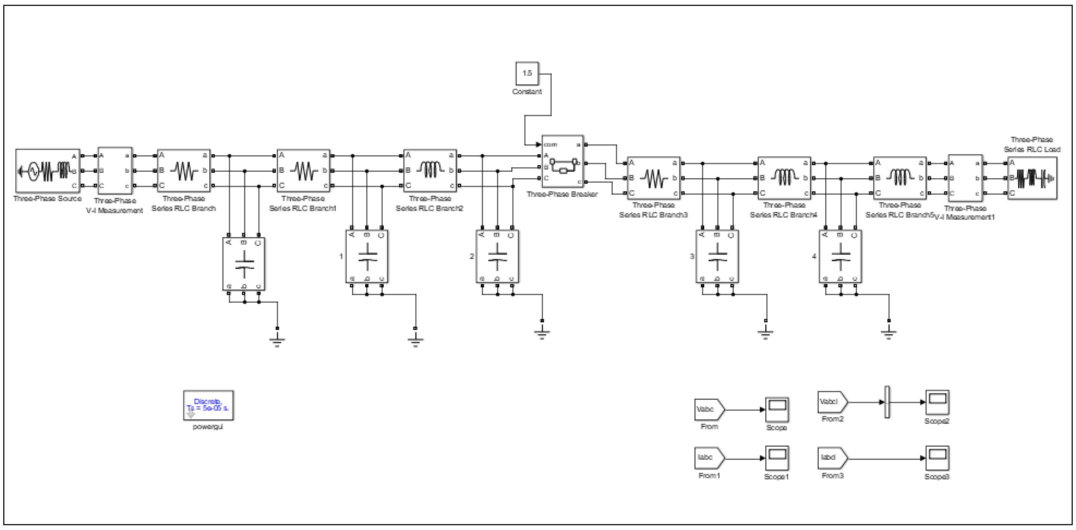

Figure 2. Simulink Model of 145 kV Substation

1.2 Simulation results

The various transient voltages at different switching operations (closing and opening) are shown in the results. The inductance of the line is calculated from the diameter of the enclosure and the conductors. The transient overvoltages and over current due the opening operation are shown in figure 3 and figure 4 respectively. From the graph the peak voltages of all the three phases are obtained as 1.2p.u., 1.2p.u. and 1.2p.u. and current of all three phases is obtained as 0.03p.u., 0.03 p.u., and 0.03 p.u.

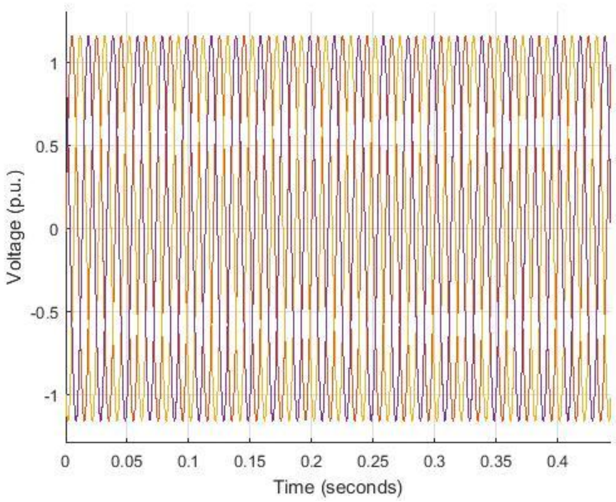

Figure 3. Transient Voltage Waveform during opening operation

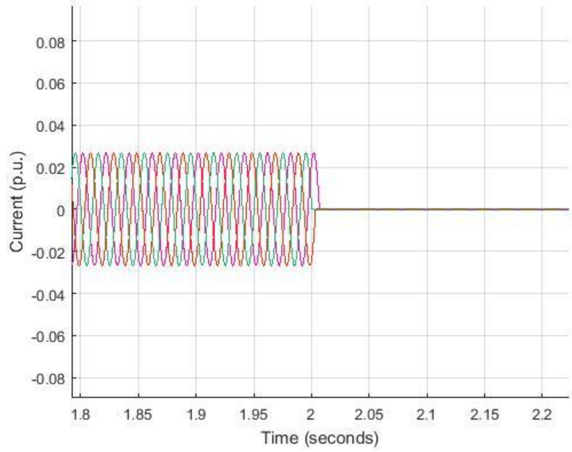

Figure 4. Transient Current Waveform during opening operation

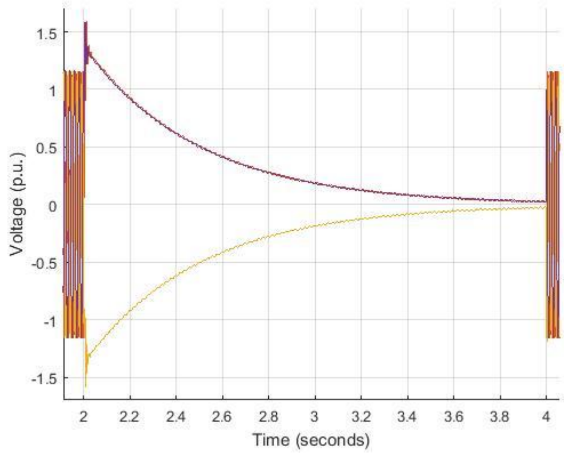

Figure 5. Transient Voltage Waveform during closing operation

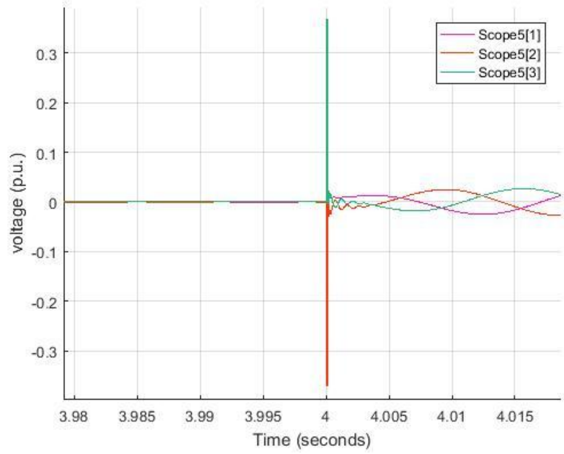

Figure 6. Transient Current Waveform during closing operation

The transient overvoltages and over current due the closing operation are shown in figure 5 and figure 6 respectively. From the graph the peak voltages of all the three phases are obtained as 1.8p.u., 1.8p.u. and 1.8p.u. and current of all three phases is obtained as 0.3p.u., 0.3 p.u., and 0.3 p.u. The magnitudes of transient overvoltages and current at closing and opening operation are tabulated in table 1.

Table 2. Transients due to switching operations

Mode of operation	**Peak magnitude of voltage (p.u.)**			**Peak magnitude of current (p.u.)**		
	V_R	**V_Y**	**V_B**	**I_R**	**I_Y**	**I_B**
Closing operation	1.8	1.8	1.8	0.3	0.3	0.3
Opening operation	1.2	1.2	1.2	0.03	0.03	0.03

2. Medium of Insulation

From years the conventional medium of insulation is preferred to air. Air is used as the primary dielectric medium for insulation in the conventional switchgear substation or air insulated substation. Whereas the advanced technique of substation i.e. the gas insulated substation utilizes a greater dielectric medium, sulphur hexafluoride gas (SF_6). The high voltage conductors, current transformers, voltage transformers, circuit breaker interrupters, and switches are placed in a metal enclosure which is compressed within SF_6 gas. Air as insulation medium is used in a conventional switchgear substation, where air is required in meters for insulation. SF_6 is an inert, colorless, nontoxic, tasteless, odorless and nonflammable gas comprising of a sulphur atom surrounded and firmly bounded to six fluorine atoms the combination of which makes an electronegative gas. SF_6 gas is about five times heavier than air [4]. When a free electron comes in collision with an unbiased gas molecule, the electron is attracted by that gas molecule and negative ion is formation takes place. As the negative ions so formed are heavy they do not attain sufficient energy to contribute to ionization of the gas. This property gives a good dielectric property [5]. Dielectric strength of SF_6 is 3 times more than that of air. Dielectric strength of air is 3 kV/mm. The metal enclosure of GIS unit is filled with SF_6 under the minimum operating pressure of 400 kPa. As the AIS unit is constructed under the open air, there is no concern of air to be filled under certain pressure. According to the IEC standards, Minimum operating pressure is 400 kPa, maximum operating pressure is 580 kPa and the burst pressure is greater than or equal to 3000 kPa.

3. Construction/ Space requirement

Air insulated substation are the conventional substations which are constructed over a large area mostly in the outskirts of the city. Whereas a GIS unit being compact in size can be constructed in the city as well for the voltage rating of 72.2kV, 145kV, 245kV, 420kV. Considering space as one of the parameters to be compared, again there exist merits and demerits of both the substations. Taking into the consideration of substation layout and its working operation the air insulated substation has advantageous key features. In an air insulated substation the primary choice for selection of space/area can be made as per the requirement. This system is possible with a quality design due to its low cost of switchgear and low cost of construction. Also it takes less time for construction. In contrast, GIS uses less space as there is reduced distance between active and non active switchgear parts of the system. From figure 7 the overall space required by the substations can be estimated. The dimensions of substations are mentioned in meters (see figure 7). If total area of the respective substations is calculated, it is observed the area occupied by an AIS unit is 1359 m^2 and area occupied by a GIS unit is 22.81 m^2, through which one can conclude that area occupied by GIS unit is much lesser than the area occupied by that of an AIS unit.

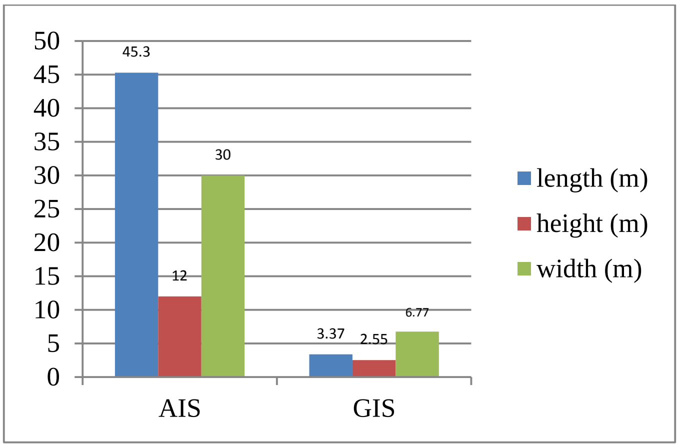

Figure 7. Dimensions of AIS and GIS unit in meters

4. Environmental Impact

The impact of environment in the field of transmission substation has become more essential for the study of both, the increase in world energy demand and also the considerable effect of human action on the nature. Transmission system presently should be more reliable, smart, efficient and furthermore environment friendly. An environmental comparison of GIS and AIS are studied so as to conclude which substation is having more environmental impact. The AIS unit considered is a particular 220 kV substation in Aurangabad region in Maharashtra state. And the GIS unit considered is a particular 132 kV substation in Aurangabad region in Maharashtra state. The analysis is based on the fault occurring frequency in the past one year due to the environmental disturbances. As the GIS substation includes a building that holds 145 kV installations does not come in direct contact of the environmental disturbances whereas an AIS unit faces a huge loss of equipments when any environmental disturbances such as lightening strokes, heavy wind strokes or transients come in contact with the live parts of the substation. In such conditions major breakdown of AIS unit happens. Two major breakdowns occurred in past one year in the AIS unit shown in table 3. According to the study no such breakdown has occurred in the GIS unit from the past 10 years. But GIS unit is supposed to trip if any external line faults occur in the system.

Table 3. Major Breakdown in an AIS unit occurred due to environmental disturbances

Sr. no.	Month	Duration	Reason of Breakdown
1	August	43 minutes	‘R’ phase CT burst due to heavy lightening stroke.
2	October	4 Hours 26 minutes	Single phase (R) to earth fault due to transients occurred by heavy winds.

Table 3 shows the major breakdown occurred in the AIS unit in the past one year. One of the major breakdowns which lasted for 43 minutes occurred due to the heavy lightening stroke and current transformer of the ‘R’ phase burst out. In the month of June to October these faults occur frequently due to the rainy season. Another major breakdown which lasted for 4 hours and 26 minutes occurred due to a line to ground fault. Here it was an ‘R’ phase to ground fault in which some transient came in contact with the earthting and the fault occurred. This breakdown was again in one of the months of rainy season. From the comparison it can be concluded that AIS is more prone to breakdown due to environmental disturbances.

5. Maintenance

In concern with the maintenance of GIS and AIS, maintenance is classified as routine maintenance, preventive maintenance and breakdown maintenance. As seen in the previous section no serious breakdown occurs in GIS unit in the past 10 years.

Table 4. Routine maintenance in AIS in the year 2017

Sr. no.	Month	Routine Maintenance
1	March	CT tan-delta and relay testing
2	June	Replacement of R- Phase PT due to high tan-delta value
3	August	CT and PT tan-delta measurement

GIS is less prone to faults which occur due to environmental disturbances. Also the GIS unit is a completely metal clad enclosure where it uses fixed mounted circuit breakers, whereas in AIS unit Circuit breaker can be removed for maintenance and troubleshooting. AIS unit is inspected every year to two year in which all the equipments are checked. Table 4 shows the maintenance carried out on 220kV AIS and 132kV. The maintenance is based on the equipment of AIS. A quarterly maintenance is carried out which mostly consists of relay testing. Whereas in GIS no such maintenance are done.

II. PERFORMANCE ANALYSIS

Sr. No.	Parameters	AIS	GIS
1	Design Standards	IEC 62271	IEC 62271
2	Medium used for insulation	Air	SF_6
3	Medium used for switching	Air, oil, SF_6 or vacuum	SF_6
4	Dimensions	Length: 45.3 m Height: 12.0 m Width: 30.0 m	Length: 3.37 m Height: 2.55 m Width: 6.77 m
5	Area of installation	1359 m^2	23.81 m^2
6	Sensitivity to environment	Moderate, pollution and humidity can have some effects on insulation that is exposed to air.	Excellent gas tank with high protection with very little sensitivity to environment, humidity, even altitude
7	Maintenance requirement	Moderate	Minimal, because the busbar and switching units both are completely sealed.
8	Need for gas pressure monitoring	Might be required only for switching devices incorporating SF_6	Might be required only for busbar.
9	Type of execution with switching devices	Fixed but can be drawn out according to need.	Fixed and sealed

III. CONCLUSION

The study based on air insulated substation and gas insulated substations shows that basic working operation of both the substations are same, though they differs in some aspects. A MATLAB SIMULINK model is developed for the prediction of VFTO phenomenon in the substation. The inductance and capacitance of the bus bar are calculated from the diameters of conductor. Performance analysis on the basis of insulation medium, space requirement, environmental impact and maintenance is carried out. It is concluded that GIS is significantly more advantageous than AIS. Insulation medium of GIS has dielectric strength 3 times more than that of insulation medium of AIS. Space required by GIS is almost $1/4^{th}$ of the space required by AIS. GIS is significantly very less prone to the environmental impacts as all the components are mounted fix in metal clad, whereas in AIS unit lot of faults occurs due to environmental disturbances. Also maintenance required for the GIS is less as compared to AIS. Frequency of routine maintenance is more in AIS as compared to GIS. As the frequency of fault occurrence and maintenance in GIS is less as compared to AIS, the frequency of switching is less; therefore, generation of VFTO is less in GIS.

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