Review on Analysis of Very Fast Transient Overvoltage in Gas Insulated Substation

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ABSTRACT
Power systems are subjected to many forms of transient phenomena brought about essentially by sudden changes in the steady state values of voltage and current. Such changes may be the result of a lightning stroke or switching operation.GIS substation due to its wide range of functions in power system due to its high reliability and easier maintenance are considered in the distribution network.But the unique problem with GIS(Gas insulated substation) is switching transients induced at various locations,with operation of disconnecting switch. In this review paper the GIS model is considered.In GIS with opening and closing the disconnect switch, the VFTO fast transient overvoltage with few nanoseconds forehead time is studied. In this paper, these transient voltages are analyzed at the different sensitive locations of a GIS. VFTOs of the GIS can be analyzed using EMTDC/PSCAD software. The suppression of the VFTOs is also an important field of interest. The suppression techniques to reduce the VFTOs are also discussed in this paper.

Keywords- *Basic insulation level (BIL), Gas insulated substation (GIS), Restrike, Switching, Very fast transient overvoltages (VFTOs).*

I. INTRODUCTION

Compared to the common substations, GIS units are in very much use in India because of its advantages such as less maintenance[2], less fault probability. As it is enclosed, it is free from environmental problems and less space is required for installation. The lightning arresters required in GIS is less in number because of its compactness. Despite the advantages, GIS has many issues of concern. The major issue considered in GIS is very fast front transients, which are generated because of switching operation[1].
These Very Fast Transient Overvoltages are considered for voltages 420kV and above. For voltages below 350kV, no problem is observed which is related to switching operation, hence these transients are not a concern in these substations rated below 350kV.
A very detail explanation of VFTOs is done in [1][15], the VFTOs in GIS are mainly considered in systems with higher voltages,where the ratio of the LIWV to the system voltage is less, which is better discussed in [3].
The modeling of GIS is studied from [6][7][8]. Mitigation of VFTOs isdiscussedin very detail in[9-13]. The insulation coordination for the substation in [16][17][18]involves three major steps, which is discussed above.

II. INSULATION IN GIS

SF6 gas has been used in gas insulated substations due to its excellent chemical, physical and dielectric properties. down voltage (BDV) of SF6. It is also a very long-lived greenhouse gas and hence contributes to global warming[4]. The search for an alternative gas for GIS insulation has led to the choice of the gaseous mixture SF6/N2. SF6/N2 mixture is less sensitive to conducting particles under fast rise time impulse voltages such as lightning and VFTO especially at low pressures. Unfortunately, this mixture approaches the performance of pure SF6 only at SF6 percentages exceeding approximately 50%, where the cost advantage of the mixture is minimal. However, a 20 to 40% SF6 percentage offers good dielectric performance for low electrode roughness and contaminant.
To enhance the performance of GIS and to use ecofriendly gases like CO2, N2 and dry air, dielectric coating on the high voltage electrodes is preferred. The reasons for improved dielectric property of dielectric coated GIS are (i) they can reduce field emission of electrons from metallic electrodes. (ii) they can also reduce particle charging and particle levitation from the metallic surface [14]. The three different coatings tested are hard anodic-oxide coating that had been immersed in polytetrafluoroethylene (HACP), a coating comparable to cast epoxy (CCCE) and a thick cast epoxy coating (TCEC). In the case of N2, coating effectiveness decreases slightly with increasing gas pressure, and no coating effect was observed above 1.0 MP
However, conductor surface roughness can affect the break down voltage (BDV) of SF6. It is also a very long-

lived greenhouse gas and hence contributes to global warming[14][5]. The search for an alternative gas for GIS insulation has led to the choice of the gaseous mixture SF6/N2. SF6/N2 mixture is less sensitive to conducting particles under fast rise time impulse voltages such as lightning and VFTO especially at low pressures. Unfortunately, this mixture approaches the performance of pure SF6 only at SF6 percentages exceeding approximately 50%, where the cost advantage of the mixture is minimal. However, a 20 to 40% SF6 percentage offers good dielectric performance for low electrode roughness and contaminants.

III. VERY FAST TRANSIENT OVERVOLTAGES

According to IEC 71-1, the overvoltages are classified as temporary overvoltages and transient over voltages based on their duration.
Temporary overvoltages are long duration overvoltages, which are damped or slightly damped.
Transient overvoltages are short duration overvoltages, which are highly damped. Transient over voltages can be slow front, fast front and very fast front overvoltage.
In GIS, VFTOs can be caused by switching operation and also due to faults [1].
During switching operation, with in nanoseconds the voltage across the contacts collapse[15]. Therefore, the surge which is initiated between the contacts, travels in either direction of busduct and when it experience an impedance change it get reflected and refracted.i.e., near terminations. Sobecause of these reflections, there develops overvoltages These overvoltages are knows as very fast transient overvoltages. For every restrike, an VFTO is developed, but with different magnitudes for each, having the maximum magnitude 2.5pu with very short rise time of 4 to 100ns. The frequency of oscillation will be in the order of 50KHz to 100MHz. The rise time of the surge is given by

$$t_r=13.3.\frac{k_T}{(\frac{E}{P})_o .\square .h}$$

k_t=50kV/ns cm, by toepler spark constant
$(\frac{E}{P})_o$=860kV/cm,
Gas pressure of GIS is up to 0.5 Mp.

From the above we can that the rise time is in nanoseconds i.e.,because of higher field strength and gas pressure.

1. Disconnector Operation

In order to understand the general switching behavior of a disconnector switch, the closing of a uncharged capacitor which taken as a load, is considered as shown in Fig.1a. R_S is added as a fictional lumped element to help the comprehension of phenomenon.
During the opening operation[1][3], as the contact move away, the spark occurs when the dielectric strength between the contacts is exceeded by the voltage between the source and load side Fig 1c. Therefore, through the spark the current with high frequency will flow, charging the capacitive load to the source voltage. Now as soon the potential difference between the contacts fall, the spark gets extinguish. Another restrike occur when the voltage again exceeds the dielectric strength. The closing operation is same as opening operation, load side follows the source side voltage Fig. 1b

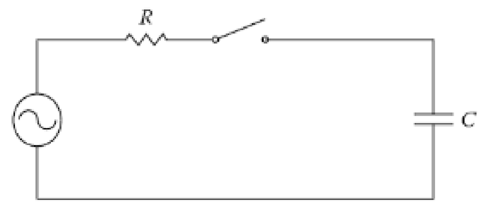
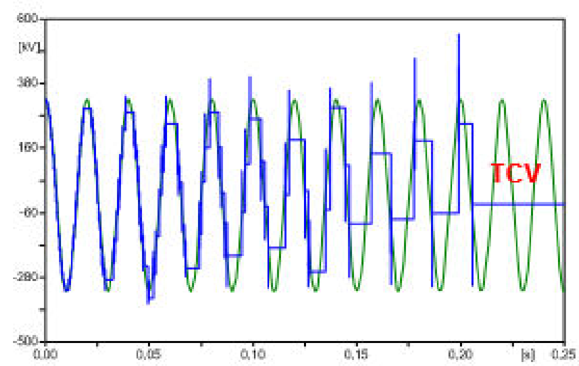
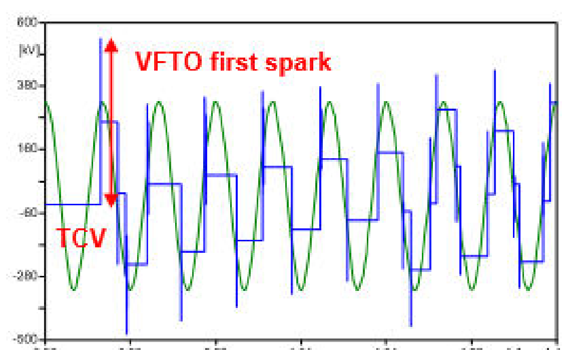


Fig1a: - Diagram of Capacitive Circuit.



2a. disconnector opening



2b. disconnector closing

Fig. 2 The voltage due to the disconnector switching in GIS

2. Importance of VFTO Analysis

The study of VFTOs is important because it is for insulation coordination.So from the past experience, a procedure for insulation coordination is done as follows, which include three major steps[16][17][18].

STEP.1 Calculation of VFTOs.

Analysis of VFTOs is done ie., the rise time and amplitude are calculated. To calculate the magnitudes of these very fast transient over voltages ATP/ EMTP/ PSCAD /MAXWELL simulation approach is used. Trapped charge is considered in simulating these transients, in worst case scenario the value is taken as -1p.u. Accurate modeling is required for analyzing both internal and external transients.

STEP.2 Comparison of calculated VFTO with Lightning impulse with stand voltage.

The VFTOs values which are calculated are now compared with LIWV by Co-ordination factor K_c, Safety factor K_s, Test conversion factor K_{tc}. Basis for the insulation co-ordination is the calculation of the required VFTO withstand voltage. The necessary safety factor to be defined is influenced by the breakdown behavior of the insulating material, the frequency of occurrence and the probability of trapped charge voltages as a basis for the simulation. Further aspects should not be disregarded, like the absolute number of occurrence and the fact, that overvoltages due to disconnector switching cannot be limited by arresters. The maximum value of the VFTO depends on the voltage drop at the DS just before striking and on the location considered. For the calculation of VFTO stresses, the trapped charges remaining on the load side of the DS must be taken into consideration. A lower trapped charge voltage gives a higher safety margin compared to the calculation based on a trapped charge voltage of 1 pu.

STEP.3 Necessary measures according to the insulation co-ordination.

If the required withstand very fast transient overvoltage is equal or lower compared to the insulation withstand strength of the equipment, no damping measures are necessary. If the required withstand VFTO is higher compared to the insulation withstand strength of the equipment, it is necessary to define measures reducing the risk of failures. Different mitigation methods are known[9-13].

3. Classification of VFTO In Gas-Insulated Substations

Switching operation generates Fast front transients and because of its travelling nature in GIS, produce internal and external transients. (see Table 1). The internal transients are with respect to busduct and enclosure i.e., whenever it experiencesa impedance change in the internal busduct which is enclosed,these fast front transients are produced [15].External transients are produce with respect the enclosure discontinuities i.e., between enclosure and ground at GIS to air interfaces.

Table.1				
Classification of VFTOs				
Origin	Switching operation in gas insulated substations			
	Very fast transients in gas-insulated substations VFTO			
Propagation	Internal transient voltages	External transient voltages		
	Travelling waves between inner conductor and enclosure	Transient enclosure voltage TEV	Transient electromagnetic fields TEMF	Travelling waves on overhead lines
Effect	Stresses in insulation	Stresses and electromagnetic interference (EMI) in secondary equipment		Stresses and electromagnetic interference (EMI) in secondary equipment

Because of these external transient enclosure voltages will be produced. So, the overhead line which are connected to this substation will be effected because of these transients. These transients also cause stresses and electromagnetic interference(EMI) in the secondary equipment.

IV. MODELING OF 420KV GIS COMPONENTS

Different components of the GIS can be modeled in to lumped elements due to the traveling nature of thetransients [5][6]. These lumped elements are defined by surge impedances, GIS sections and wave velocity.

1. GIS Bus Section:

It is Co axial in shape.Modeled by distributed parameter transmission line.Bus cross section is as shown in Fig.2

$$Z = 60\ln[\frac{b}{a}]$$

Z- characteristic Impedance
a-Diameter of inner conductor
b- Inner diameter of outer enclosure

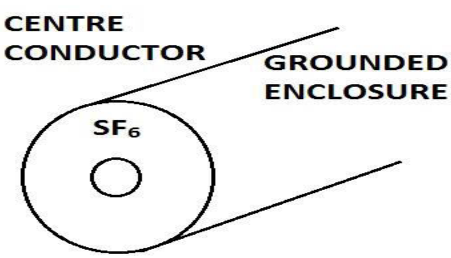


Fig.2 Cross section of bus section.

2. Disconnector:

It has three modes of operation. Open,close and arcing mode. Arcing includes dynamic arc resistance also. Open and closing mode is modelled with lumped capacitance Fig.3.

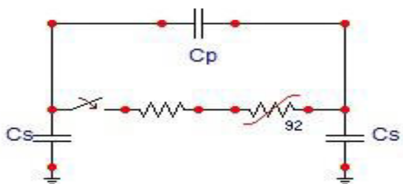


Fig. 3 Disconnector model.

3. SPARK IN DISCONNECTOR

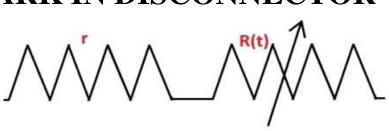


Fig.3 Dynamic arc resistance model

The arc is modeled with resistance in series with exponentially decreasing resistance Fig.3.

$$\mathbf{R = r + R_0 e^{\frac{-t}{T}}}$$

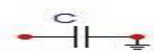
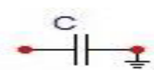
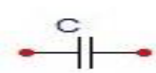
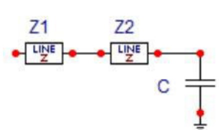
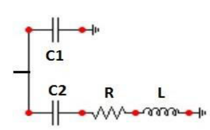
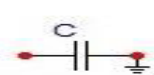
R_0 is a high initial resistance.
r is the residual series resistance

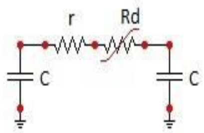
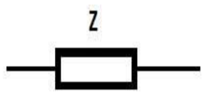
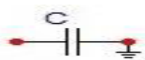
4. CIRCUIT BREAKER:

Two modes of operation open and closing operation. Open and closing mode is modelled with lumped capacitance.

By the modeling approach mentioned earlier, all components in the substation are modeled and tabulated in Table 2 below

Table 2
Modeling of components

COMPONENTS	EQUIVALENT CIRCUIT
Circuit breaker (closed)	
Circuit breaker (opened)	
Disconnector (closed)	
Disconnector (opened)	
SF6-Oil bushing	
Transformer	
Shunt reactor	

Disconnector during arcing	
GIS bus section	
VT	

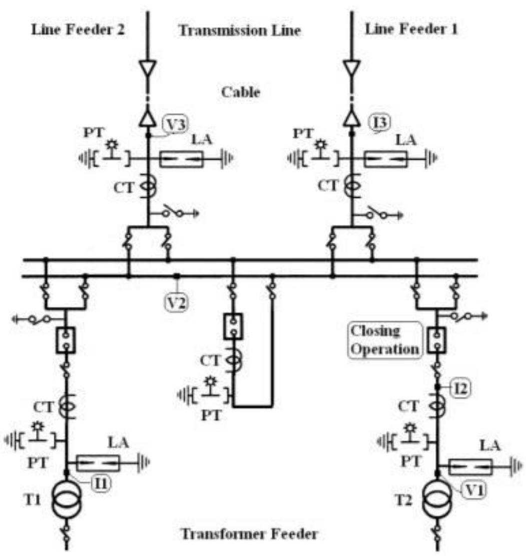


Fig.4 Single line diagram of 420kV GIS.

V. MITIGATION TECHNIQUES

These fast front transients which are produced because of switching operation are to be suppressed because they cause insulation failure and stresses in internal and secondary equipment. The methods used to mitigate these transients are using the ferrite rings,shunt resistors and RC filters. There is still much more research going on in mitigating these transients which are produced in gas insulated substation.

1. Shunt Resistor

This resistor is connected aside with disconnector switch Fig.5 and its suppress the VFTOs occurred during opening and closing operation of the switch[13].During opening operation, when the moving contact isopened a residual charge will be remained on fixed contact and as said above the magnitude of VFTOs depends on this residual charge. So, this charge leaks through the resistor which is connected with disconnector switch. During closing operation of disconnector switch the current flows through this resistor and the contact closes.The decaying of transient is initiated bythis shunt resistors.

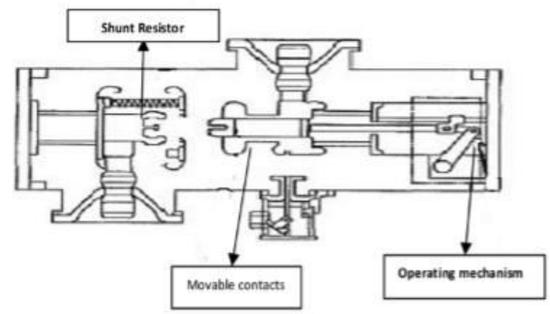


Fig.5 Disconnector with shunt resistor.

2. RC filters

As said above the VFTOs have the rise time in nanoseconds and oscillations of frequency in range 0.3MHz to100MHz.The oscillation frequency is decreased with capacitance and the resistance is placed as the energy can be attenuated. The transformers are preserved from VFTOs by placing these RC filters across the transformer.The resistance can be 50 to 400 ohms and C in the range of 0.01 to 0.2.These filters can only be used along transformers i.e., these filters can only preserve the transformers from VFTOs.

3. Ferrite rings

These ferrite rings are of magnetic material and are placed along the conductors and they are nonlinear. During closing and opening of disconnector switch restrikes and prestrikes occur. These prestrikes and restrikes generates transients and this transient energy is suppressed by ring which is placed along conductor[9-12]. These rings are connected in series with conductor, and they are represented by nonlinear resistor and inductor as shown in Fig.6,7. The ferrite ring as it is of magnetic material, because of high rise time and oscillation frequency, they may be saturated.

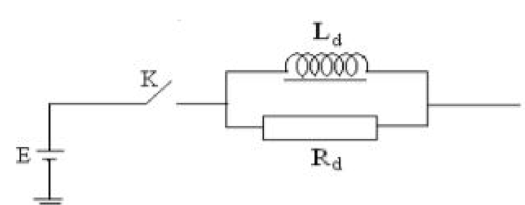


Fig.6Equivalent circuit of ferrite ring.

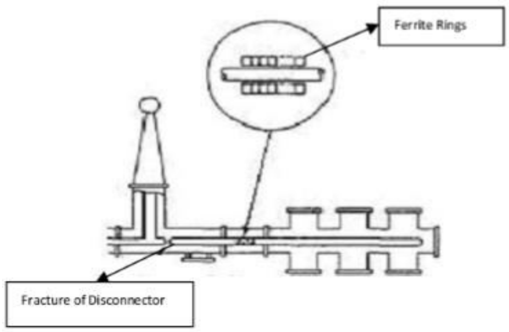


Fig.7 Ferrite rings used in disconnector switch.

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