# Calculation of Very Fast Transient Overvoltages In A 2-Phase 400kv Gas Insulated Substation

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***Abstract*: -- This paper introduces very fast transient over-voltage caused by disconnecting switch operation of GIS.The VFTOs generated due to Disconnector switching can cause insulation failure at very high voltage levels. The reason of malfunction of electronic equipments is due to coupling voltages on data and control cables. The reasons of these problems are travelling waves which is generated during switching operations in a gas-insulated substation (GIS). Calculation of Very Fast Transient Overvoltage has been carried out using MATLAB7.8 for various switching conditions in a 2-phase 400kV gas insulated substation**

***Keywords*—Gas Insulated Substation (GIS), Very Fast Transient overvoltages, Switching operations, 3 phase to 2 phase, MATLAB 7.8 software and Control circuitry**



## I. Introduction

When a Disconnect Switch is opened on a floating section of switchgear, a Trapped Charge may be left on the floating section[1]. The potential caused by this charge will decay very slowly as a result of leakage through spacers. A trapped charge near 1.0 p.u (peak) can levitate particles[2].

As a result, radius, 3-phase common spacer was developed and a 3-phase common enclosure was incorporated into a more compact main bus[3][4]. This was the second generation of GIS was further reduced in size; the tank was reduced to lessthan 85% of its original size and the installation area was reduced to 46% of its originalsize. Reliability of the GIS was proven by checking both limit and practical performances [5].

Particle motion under D.C conditions is much more severe than that for A.C excitation and may lead to scattering of particles onto insulating surfaces. However, such particle motion leads to appreciable (μA) D.C currents, which will normally discharge the floating section in a relatively short time[6].

A trapped charge of 1 p.u implies that the first breakdown upon closing the disconnect switch will occur at 2 p.u across the switch contacts and may lead to conductor–to–ground over voltages of upto 2.5 p.u[7]. Thus the magnitude of trapped charge left after operation of a disconnect switch may be of some consequence to switchgear reliability[8].

During recent field tests on a 400 KV sub station, measurements were made of the trapped charge left when a DS was opened onto a floating section of switchgear. Numerous measurements led to the conclusion that for this switch, a potential of 0.1 – 0.2p.u is left on the floating section and that this result is consistent[9].

The reason for this consistent result is that the negative breakdown occurs at approximately 15% greater potential difference than the positive breakdowns for this switch. The asymmetry in breakdown voltages leads to the "falling" pattern near the end of operation which continues until the potential is low enough that breakdowns can occur during the rising portion of a power frequency cycle as shown in below figure3.

## II. Analysis of 400kv GIS System

Two such breakdowns bring the potential back to a large positive value after which the falling pattern is re-established. The end point of this process is inevitably a transition from a large negative potential to a slightly positive potential at a gap distance for which the positive breakdown potential is ≈1.1 p.u (peak) and the negative breakdown potential is ≈1.2 p. u (peak). At this point another positive and negative breakdown cannot occur, as a result 0.1 - 0.2 p. u (peak) is left on the floating switchgear.

The salient features which lead to this small trapped charge are the asymmetry in breakdown potential and relatively long arcing time. This trapped charge can be controlled through careful design of contact geometry. For the purpose of calculating transient magnitudes, a trapped charge of 1.0 p.u (peak) prior to closing of Dis-connector Switch (DS) is assumed. One of the methods suggested to suppress these over voltages is by insertion of a resistor with an appropriate value during switching.

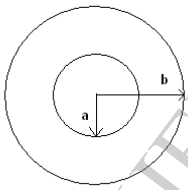
During the current operation of dis-connector switch in a GIS, re-strikes(pre-strikes) occur because of low speed of the dis-connector switch moving contact, hence Very fast Transient Over voltage are developed. These VFTO's are caused by switching operations and 2-phase fault

. Re-striking surges generated by the dis-connector switches at GIS generally possess extremely high frequencies ranging from several hundred KHz to several MHzFor the development of equivalent circuit low voltage step response measurements of the main GIS components have been made. Using MATLAB of the equivalent models is developed.

*A. Capacitance calculation*

Calculation of Capacitance is done by using the standard formulae given below.

$$C = \frac{2\pi\varepsilon_0\varepsilon_r l}{2.3 \times \ln\left(\frac{b}{a}\right)} \qquad \text{(1)}$$




Where,

$\varepsilon_0 = 8.854 \times 10^{-12}$,

$\varepsilon_r = 1$&

$\varepsilon_r = 4$( for spacers) As they are filled with Alumina filled.

Epoxy material:

b = Outer cylinder radius
a = Inner cylinder radius
l = Length of the section

*B. Spacers capacitance*

The spacer existed with finite thickness and develops some amount of capacitance in addition with existed capacitance. Spacers are used for supporting the inner conductor with reference to the outer enclosure. They are made with Alumina filled epoxy material whose relative permittivity (εr) is 4.

*C. Inductance calculation*

The inductance of the bus duct can be calculated by using the formula [8] given below, where r1, r2, r3, r4, are the radii of the conductors in the order of decreasing magnitude and 'l' is the length of the section.

$$L = 0.001 \times l \times \left( \ln\left(\frac{r1}{r3}\right) + \ln\left(\frac{r2}{r1}\right) + \ln\left(\frac{r4}{r3}\right) + 2 \times \frac{\left(\frac{r2}{r1}\right)^2}{1-\left(\frac{r2}{r1}\right)^2} \times \ln\left(\frac{r1}{r2} - 1\right) \right)$$

(2)

*D. Calculation of variable arc resistance*

The Variable arc resistance is calculated using the formula:

$$R = \frac{K_T \times l}{q_0 + \int_0^t i(t)dt} \qquad \text{(3)}$$

Where,

$K_T$ = Toepler's constant
= 0.005 volt.sec/mt for SF6 under uniform field conditions
L = spark length in meters
$q_0$ = Initial charge or charge at the instant of breakdown
T = spark collapse time in sec.

When a Circuit Breaker (C.B) is made to interrupt low inductive currents such as currents due to no load magnetizing current of a transformer, it does so even before the current actually passes through zero value, especially when the breaker exerts the same de-ionizing force for all currents within its short circuit capacity. This breaking of current before it passes through the natural zero is termed as "Current Chopping".

Now, if the breaker is called upon to break a load current which is less than the highest short circuit current, then the de-ionizing force would be sufficient enough to force the arc from its high value straight to zero before the same actually reaches to natural zero. This results a tremendous amount of over voltage as shown in the above figure 3.

The value of time varying spark resistance R(t) is calculated until it reaches a value of 1 to 3 ohms. The integral in the denominator sums up the absolute value of current 'i' through the resistance R(t) over the time beginning at breakdown inception. Thus, it corresponds to the charge conducted through the spark channel up to time 't'.

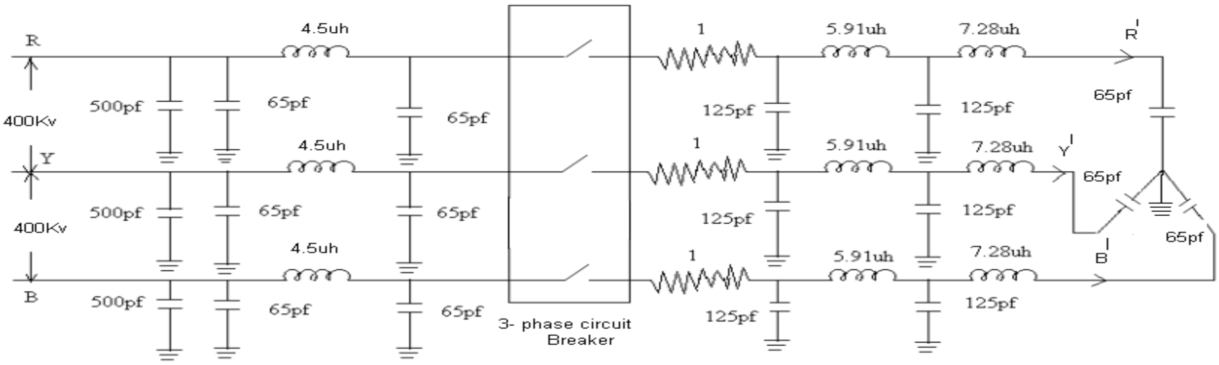



Fig. 1 Equivalent circuit for 10mtrs. Length in a 3 -phase to 2-phase 400kv GIS

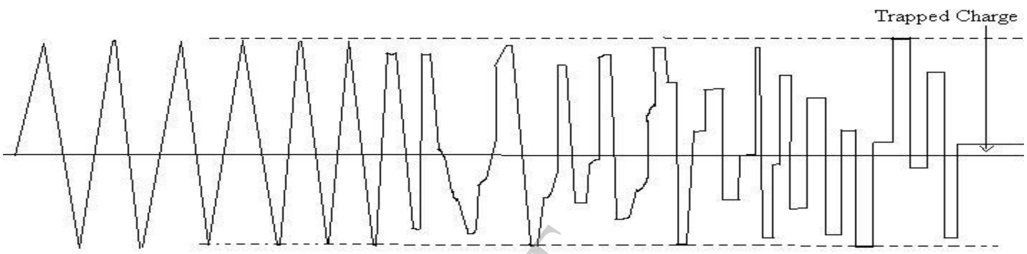



Fig 2 Load side voltage waveform during opening of disconnect switch



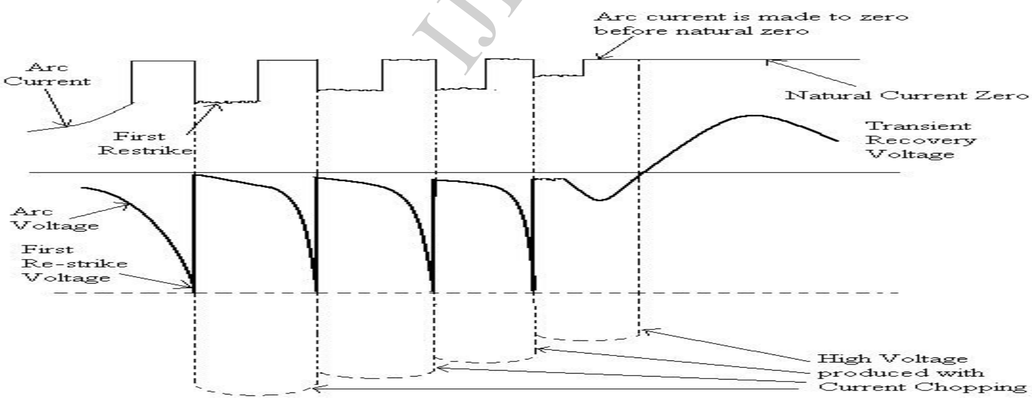



Fig 3 waveform of over voltage with current chopping

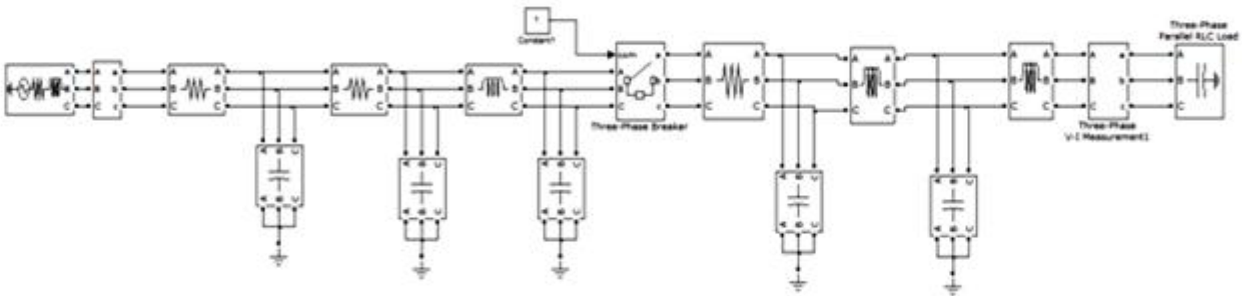



Fig. 4 MATLAB circuit for 10mtrs length in a 3-phase to 2-phase 400KV GIS

## III. 3-PHASE TO 2-PHASE EQUIVALENT CIRCUIT FOR 400KV GIS SYSTEM FOR 10MTRS LENGTH

This circuit is divided into three sections of 1mtr, 4mtrs and 5mtrs respectively from load side and by using the circuit shown below figure 3 & 4. In a 3-phase circuit one phase (say phase B) has been earthed, difference between in any two phase voltage 400Kv. This in effect makes the transmission line of 2-phases only. The equivalent circuit of the same will be as shown in Fig 4

The Fast transient over voltages are generated not only due to switching operations but also due to 3-phase to 2-phase faults .The bus duct is dividing into three sections of length from load side. The GIS bushing is represented by a capacitance of 500pf. The resistance of 2.2 ohm spark channel is connected in series with circuit breaker. MATLAB Circuit for 10 mtrs. length in a 3-phase to 2-phase 400 Kv GIS sho wn in the fig. 4.

The proposed method implemented on MATLAB 7.8. the voltage before and after circuit breaker is taken to be 1.0 pu and -1.0pu as the most enormous condition but depending on the time of closing of circuit breaker the magnitude of the voltage on the load side changes.

For different values of voltages on the load side the magnitudes and rise time of the voltage wave are calculated keeping source side voltages as constant as 1.0p.u the values are tabulated in table I.

Similarly by changing the magnitudes of the voltage on the source side, keeping voltage on load side constant at 1.0p.u. Then the transient due to variation of voltage on source side obtained. The values are tabulated in Table II.

TABLE I

TRANSIENT DUE TO VARIATION OF VOLTAGE ON LODE SIDE

| S.no | Load side Voltage (p.u) | Magnitude of the voltage (p.u) | | Rise Time (Nano secs) | |
|---|---|---|---|---|---|
| | | VR phase | VY phase | tr | ty |
| 1 | -1.0 | 2.42 | 2.40 | 09 | 10 |
| 2 | -0.9 | 2.32 | 2.34 | 11 | 10 |
| 3 | -0.8 | 2.12 | 2.13 | 10 | 11 |
| 4 | -0.7 | 2.11 | 2.09 | 13 | 12 |
| 5 | -0.6 | 1.94 | 1.93 | 11 | 12 |
| 6 | -0.5 | 1,86 | 1.84 | 10 | 11 |
| 7 | -0.4 | 1.72 | 1.68 | 11 | 12 |
| 8 | -0.3 | 1.61 | 1.62 | 12 | 10 |
| 9 | -0.2 | 1.44 | 1.45 | 11 | 12 |
| 10 | -0.1 | 1.35 | 1.33 | 11 | 09 |

TABLE II

TRANSIENTS DUE TO VARIATION OF VOLTAGE ON SOURCE SIDE

| S.no | Load side Voltage (p.u) | Magnitude of the voltage (p.u) | | Rise Time (Nano secs) | |
|---|---|---|---|---|---|
| | | VR phase | VY phase | tr | ty |
| 1 | 1.0 | 2.43 | 2.41 | 11 | 10 |
| 2 | 0.9 | 2.35 | 1.34 | 10 | 11 |
| 3 | 0.8 | 2.24 | 2.21 | 11 | 09 |
| 4 | 0.7 | 2.06 | 2.04 | 12 | 11 |
| 5 | 0.6 | 2.04 | 2.02 | 11 | 10 |
| 6 | 0.5 | 1.85 | 1.83 | 12 | 10 |
| 7 | 0.4 | 1.74 | 1.73 | 10 | 11 |
| 8 | 0.3 | 1.63 | 1.62 | 11 | 10 |
| 9 | 0.2 | 1.43 | 1.45 | 09 | 10 |
| 10 | 0.1 | 1.37 | 1.35 | 10 | 09 |

## IV. RESULTS AND DISCUSSION

The various transient voltage and current at different positions in a 3 phase to 2-phase 400kv GIS for the first switching operation presented in results. The highest magnitude of transient current occurs near the disconnector switch. This is contrast to the peak magnitude for fast transient over voltages, which occurs at open ends. To understand the effect of switching configuration on peak magnitude vs transient currents at different positions, fast transient currents have been estimated for the second switching configuration as shown in below figs.

The maximum values of VFTO, the MATLAB7.8 software is used and a simulation is carried out by designing suitable equipment circuits and its models are developed. The main advantages of such models are used to enable the transient analysis in GIS.

The transients due to closing of the circuit breaker are calculated as shown in fig 6. From this graph, the peak voltages obtained are 2.45 and 2.43p.u at rise times of 72 and 71ns respectively.

During closed operation, the current through the resistance of the circuit breaker is shown in fig.5 From the graph it was found the maximum current is 30A at a rise time of 11ns.

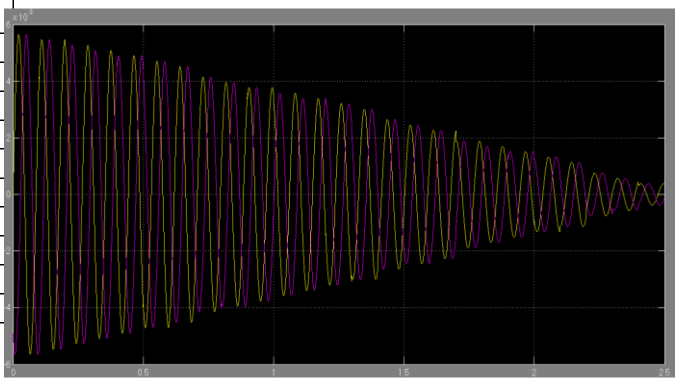


Fig. 5 Current waveform during closing operation of CB for

10mts length in a 2-phase 400kv GIS

The transients due to closing of the circuit breaker are calculated as shown in fig 6. From this graph, the peak voltages obtained are 2.45 and 2.43p.u at rise times of 72 and 71ns respectively.

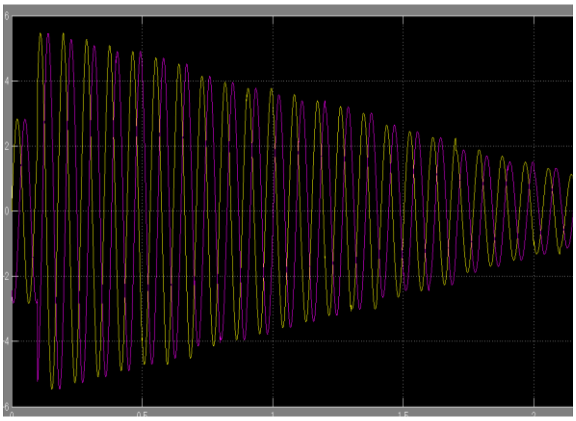


Fig 6 Transient voltage wave from during closing operation of CB for 10mts length in a 2-phase 400kv GIS

To introduce current chopping the circuit breaker is opened. The transients obtained during opening operation are shown in Fig 7. From the graph, the maximum voltages obtained are 1.23 and 1.22p.u. at rise times of 63 and 62 ns respectively. MATLAB Circuit for 10mtrs. Length in a 3-phase to 2-phase 400kv GIS shown in the fig 4.

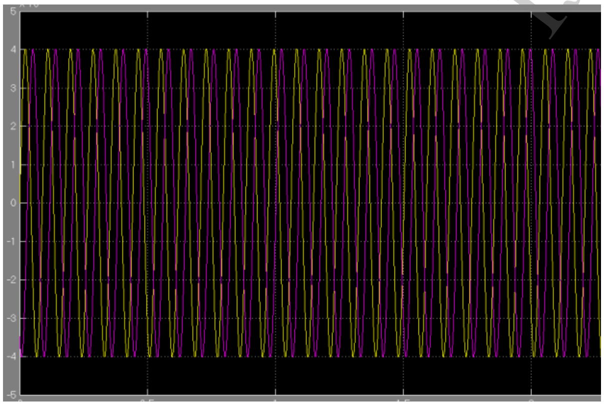


Fig. 7 Transient voltage waveform during opening operation
of CB for 10mts length in a 2-phase 400kv GIS

Assuming a second re-strike occurs the transients are calculated by closing another switch at the time maximum voltage difference occurs across the circuit breaker. The transients obtained due to second re-strike are shown in Fig 8. From the graph, the maximum voltages obtained is 2.52 and 2.53 p.u at arise time of 122 and 123ns respectively. The magnitudes and rise times of 10mts length GIS are tabulated in the table III.

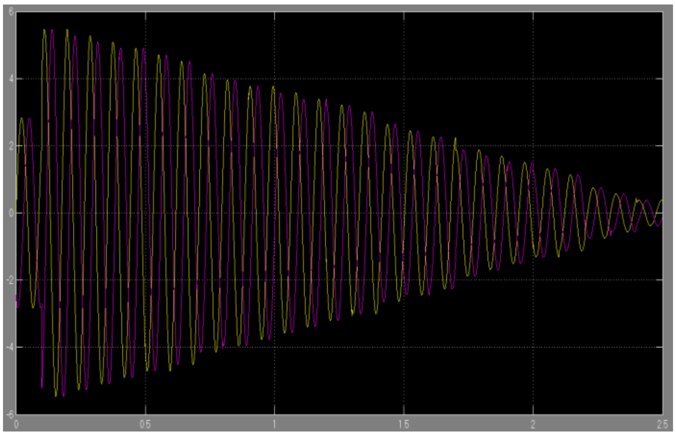


Fig.8 Transient voltage waveform during second re-strikes for 10mts length in a 2-phase 400kv GIS

TABLE III

THE ANALYSIS VALUES ARE TABULATED AS FOLLOWS:

| Mode of operation | Magnitude of voltages(p.u) | | Rise time (Nano sec) | |
|---|---|---|---|---|
| | VR phase | VY phase | tr | ty |
| During closing operation | 2.45 | 2.43 | 72 | 71 |
| During opening operation | 1.23 | 1.22 | 63 | 62 |
| During second re-strike | 2.52 | 2.53 | 122 | 123 |



## V. CONCLUSION

Switching operations in a Gas Insulated Switchgear lead to very fast transient phenomena. These VFT's stress the equipment in GIS as well as the secondary equipment. Switchgear reliability can be improved by assuring that dis-connectors minimize the trapped charge left on the switchgear. Reduced trapped charge carries two benefits. Firstly, the magnitude of dis-connector operation induced transients is reduced and secondly, the tendency for free conducting particles to be scattered onto spacers is reduced. The rise times of the initial steps of the VFTO are in the range of about 5 to20 nanoseconds and they do not have the same shape and same amplitude at all points in the GIS.

The VFTO magnitudes generally lie in the range of 1.5 p.u. to 2 p.u. in certain cases the trapped charge is 1 p.u. the VFTO magnitudes may reach values as high as 2.5 p.u.

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