Estimation of Re-striking Transient Overvoltages in a 3-Phase 132KV Gas insulated Substation

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Abstract*:* **--This paper presents the most significant results of a Very fast transient Overvoltages generated due to switching operations have been analyzed and presented. Since the contact speed of dis-connector switches is low, re-striking occurs many times before the current interruption is completed .Each re-striking generates transient overvoltage with level of magnitude. These transient have travelling wave behaviour, they travel to the external systems through enclosures, bushings, cable joints etc.. and cause damage to the outside equipment. They can lead secondary break downs in GIS and may give rise to electromagnetic interference. The Earth faults give rise to TEV which can interfere with the operation and control of secondary equipment in a 3-phase 132kv GIS. Thus it is important to develop a suitable MATLAB7.8 models for estimation of these overvoltages.**

Keywords—**Gas Insulated Substation (GIS), very fast Transient overvoltages, 3phase faults, MATLAB 7.8 software and Control circuitry**

I. INTRODUCTION

For accurate analysis of transients, it is essential to find the VFTO's and circuit parameters. Due to the travelling nature of the transients the modelling of GIS makes use of electrical equivalent circuits composed by lumped elements and especially by distributed parameter lines, surge impedances and travelling times. The simulation depends on the quality of the model of each individual GIS component [1]. In order to achieve reasonable results in GIS structures highly accurate models for each internal equipment and also for components connected to the GIS are necessary [2].

The dis-connector spark itself has to be taken into account by transient resistance according to the Toepler's equation and subsequent arc resistance of a few ohms [3][4]. The wave shape of the over voltage surge due to dis-connector switch is affected by all GIS elements. Accordingly, the simulation of transients in GIS assumes an establishment of the models for the Bus, Bushing, Elbow, Transformers, Surge Arresters, Breakers, Spacers, dis-connectors, and Enclosures and so on[5].

A GIS system comprising of an Input Cable, Spacer, Dis-connector Switch, Bus bar of 10mts length and load has been considered for modelling into electrical network and analysis [6]. The Fast Transient Over voltage waveform generated during Closing and Opening operation of Dis-connector Switch and 3-phase faults has been considered for calculations.

Spacers are simulated by lumped Capacitance. The Inductance of the bus duct is calculated from the diameters of Conductor and Enclosure. Capacitances are calculated on the basis of actual diameters of inner and outer cylinders of central conductor and outer enclosure [7]. Cone Insulators used for supporting inner conductor against outer enclosure are assumed to be disk type for approximate calculation of spacer capacitance [8].

The busduct can be modelled as a series of Pi-network or as sequence parameters. However in this model, it is considered as distributed Pi-network. The Schematic Diagram of a Typical Gas Insulated System (GIS) is shown in below figure 3.

Frequency nature, the VFTO imposed on the transformers connected directly to the GIS would not be distributed evenly on all transformer windings. Some windings, e.g. the first few turns connecting to the 132kV GIS, would be subject to a higher magnitude of overvoltage, posing a potential risk of insulation breakdown of the transformers[9][10].

II. MODELLING OF 132KV GAS INSULATED SUBSTATION:

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 3-phase fault

When a dis-connector switch is opened on a floating section of switchgear, trapped charge may be left on the floating section. In the opening operation of dis-connector switch, transients are produced and the magnitude of these

Transients and rise times depends on the circuits parameters. When there is a fault occurs, there is a short circuit in the system. Transients are also produced due to the faults in the system. Due to this VFTO's are caused by switching operation can also lead to secondary breakdown with in GIS. Re-striking surges generated by the dis-connector switches at GIS generally possess extremely high frequencies ranging from several hundred KHz to several MHz . For the development of equivalent circuit low voltage step response measurements of the main GIS components have been made. Using MATLAB 7.8 of the equivalent models is developed.

During opening of Dis- connector switch (DS), transients are produced due to internal oscillations. The magnitude of transients and rise times depends on the circuit parameters like inductance, Capacitance and connected Load. Assuming that some trapped charge is left is left during operating operation; transients can be calculated during closing operation of DS.

Fast transient over voltages generated during Dis-connector Switch operation are a sequence of voltage of voltage steps created by voltage collapse across the gas at re-striking specific over voltage shape is formed by multiple reflections and refractions. Operation of Dis-connector Switch (DS) can be shown by using the fig 1

Where L1 = Inductance of Source
C1 = Capacitance of Source
C2 = Capacitance of GIS Open part
U1 = Power Frequency Voltage
U2 = Power GIS Voltage

The more frequent service situation of the isolator is its use to connect or dis-connect unloaded parts of the installation as is shown in fig 1 for example apart of the of the GIS is dis-connected by an isolator from an overhead supply line. Where by the self-capacitance C2 of this part of circuit can be up to several nF, depending on its length. First re-strike across the gap occurs when voltage across the gap exceeds the breakdown voltage. The occurrence of re-strikes is described with the following Fig 2

The voltage across the gap is the difference between U1 and U2, if it is assumed that the breakdown voltage UB of the gap increases with increasing separation and therefore with time as shown in fig 2.Then the curve U2 can be constructed as follows. At the instant of mechanical contact separation, U1 and U2 have the same value, the voltage U2 continues to retain this value, while U1 changes with power frequency, the voltage (U2-U1)

Across the gap of the isolator also changes. As soon as, (U2-U1) exceeds the dielectric strength UB of the gap, a

Breakdown and thus first re-strike occurs. Both electrodes are there by electrically connected by conducting spark, whereby GIS section with initial voltage U2 is very rapidly charged to instantaneous value of U1. The transient current flowing through the spark then interrupts as soon as the GIS have been charged to U1 and spark extinguishes.

The voltage U2 now remains constant with time, while the voltage U1.on the side of supply keeps changing. This continues until the second re- strike occurs with an increased breakdown voltage UB as a consequence of larger separation. Hence U2 follows U1, until finally at the end of the switching process the gap no longer can be broken down. Transients are also produced due to faults in the system. When there is a fault, there will be short circuit in the system. Due to this, oscillations occur due to presence of inductance and capacitance on both sides of the fault section causing transients.

Dis-connector Switch (DS) operation typically involves slow moving contacts which results in numerous discharges during operation .For example, a floating section of switchgear between a disconnect switch and an open breaker (load side may be disconnected from an energized Gas insulated system (supply side).

For capacitive currents below—1 amp, are-strike occurs every time the voltage between the connects exceeds the dielectric strength of the gaseous medium between them.

Each re-strike generates a spark, which equalizes the potentials between the switch contacts. Following spark extinction, the supply and load side potentials will deviate according to the AC supply voltage variation and the discharge characteristics of the load side respectively. Another spark will result when the voltage across the electrode gap dependent breakdown voltage UB and the potential difference of the load and supply side U.

Each Dis-connector Switch (DS) operation generates a large number of ignitions between the moving contacts. The number of ignitions depends on the speed of the contacts. The largest and steepest surge voltages are generated only by those breakdowns at the largest contact gap. Therefore, only by those breakdowns (10-50) need be considered for dielectric purpose.

A. *Calculation of variable arc resistance*

The Variable arc resistance is calculated using the formula:

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

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.

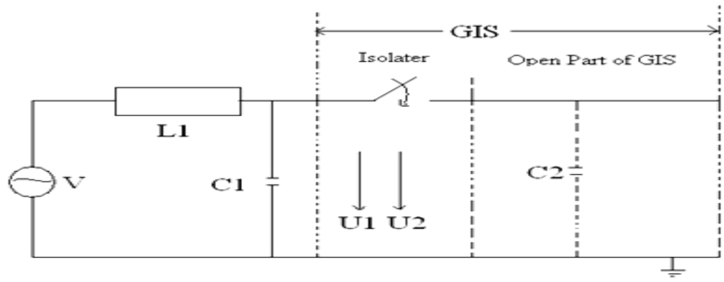

Fig. 1 Electric Circuit for explaining re-strikes

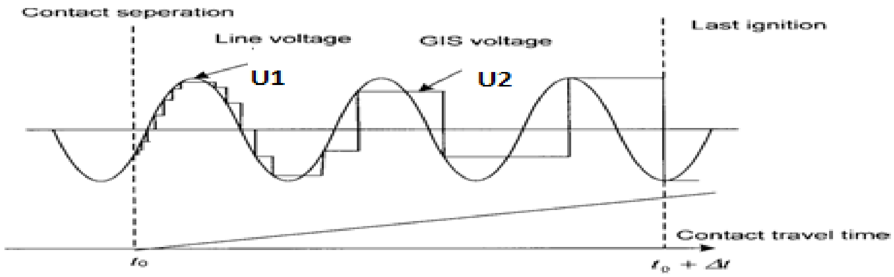

Fig 2 Voltage of the open –ended GIS side of the Isolator

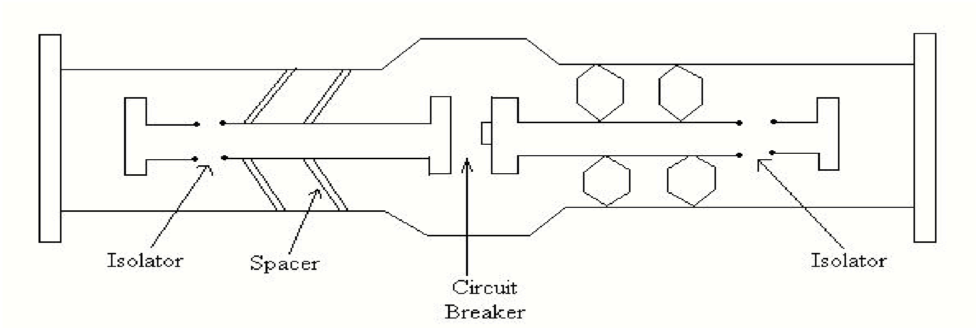

Fig. 3 Schematic diagram of a typical Gas Insulated Substation

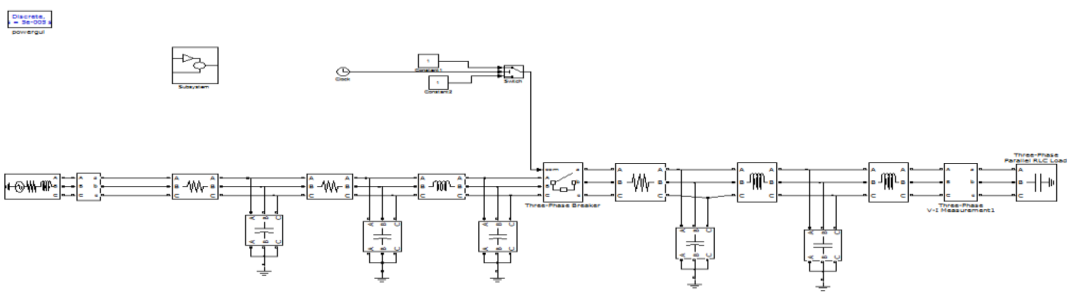

Fig. 4. 132kv GIS MATLAB implemented circuit when CB in Re-Striking Condition

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'.

The busduct can be modelled as a series of Pi-network or as sequence parameters. However in this model, it is considered as distributed Pi-network. The Schematic Diagram of a Typical Gas Insulated System (GIS) is shown in below figure 3.

Assuming that some trapped charge is left on the floating section of switchgear during opening operation of dis-connector switch, a voltage of certain value is considered during MATLAB

The apparatus as disconnected with an earthing switch, three disc type Spencer's , a load bus bar above to 10mts long width three post type spacers and a 132kv gas bushing containing stress capacitor.

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III. 3-PHASE EQUIVALENT CIRCUIT FOR 132KV GIS SYSTEM FOR 10MTS LENGTH

The bus duct is dividing into three sections of length 1mts, 4mts, and 5mts from load side. The GIS bushing is represented by a capacitance of 125pf. The resistance of 1 ohm spark channel is connected in series with circuit breaker. MATLAB Circuit for 10 mts. length in a 3-phase 132kv GIS shown in the fig. 4.

Due to trapped charge some voltage remains on the floating section which can create severe conditions because the first re-strike can occur at the peak of power frequency voltage giving a voltage of 2.0 p.u. On re-strike the voltage on each side will collapse initially zero and hence creating two 1.0pu voltage steps of opposite polarities. In this, it is assumed that re-striking is created at 1.0 p.u. respectively on either side of dis-connector switch (DS). The transients due to closing of the circuit breaker are calculated and maximum voltage obtained with a rise time.

This 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 RE-STRIKE VOLTAGE ON LODE SIDE

S.no	Load side Voltage (p.u)	Magnitude of the voltage (p.u)	Rise Time (Nanos)
1	-1.0	2.45	10
2	-0.9	2.39	13
3	-0.8	2.19	12
4	-0.7	2.15	10
5	-0.6	2.03	12
6	-0.5	1.96	11
7	-0.4	1.82	10
8	-0.3	1.77	13
9	-0.2	1.53	12
10	-0.1	1.45	9

TABLE II

TRANSIENTS DUE TO VARIATION OF RE-STRIKE VOLTAGE ON SOURCE SIDE

S.no	Source side Voltage (p.u)	Magnitude of the voltage (p.u)	Rise Time (nanos)
1	1.0	2.43	9
2	0.9	2.37	10
3	0.8	2.17	11
4	0.7	2.11	10
5	0.6	2.01	9
6	0.5	1.91	10
7	0.4	1.79	9
8	0.3	1.71	12
9	0.2	1.42	11
10	0.1	1.39	9

IV. RESULTS AND DISCUSSION

The phenomenon that occurs during the DS closing into a capacitive load is very nearly the reserve of processes that occur during its opening. Here, the first restrike occurs due to the residual voltage left behind by a previous opening on the load side. Circuit breaker or load break switch closing or openings also generate VFTO in the case of re-strikes but the number of such VFTO is much lower than those generated by DS operation. The various transient voltage and current at different positions in a 3 phase 132kv GIS for the first switching operation presented in results.

Assumed that there is a second re-strike another switch is connected in parallel to the circuit breaker for simulation in MATLAB modeling. Transients are calculated by closing this switch when voltage difference across the contacts of the circuit breaker reaches maximum value.

During Re-strike operation (source & Load) the voltage through the resistance of the circuit breaker is shown in fig.5 and fig.6. From the graph it was found the maximum current is 25A at a rise time of 13ns.

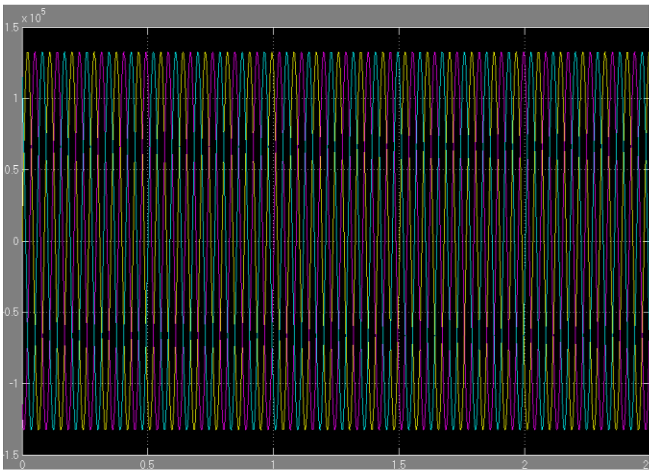

Fig. 5 Transient voltage waveform during Re-strike for 10mts from source side in a 3-phase 132kv GIS

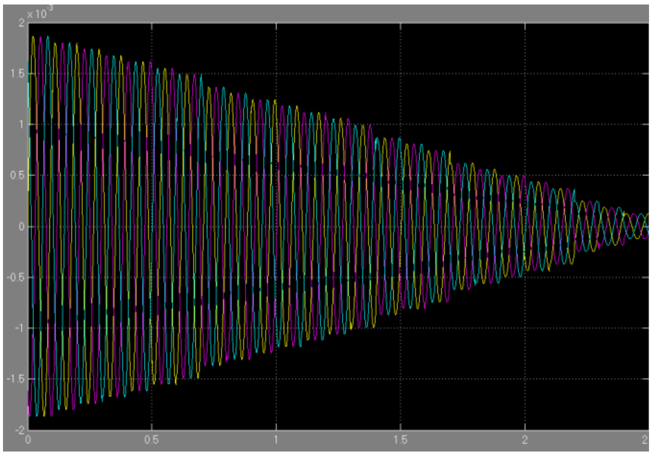

Fig 6Transient voltage waveform during Re-strike for 10mts from Load side in a 3-phase 132kv GIS

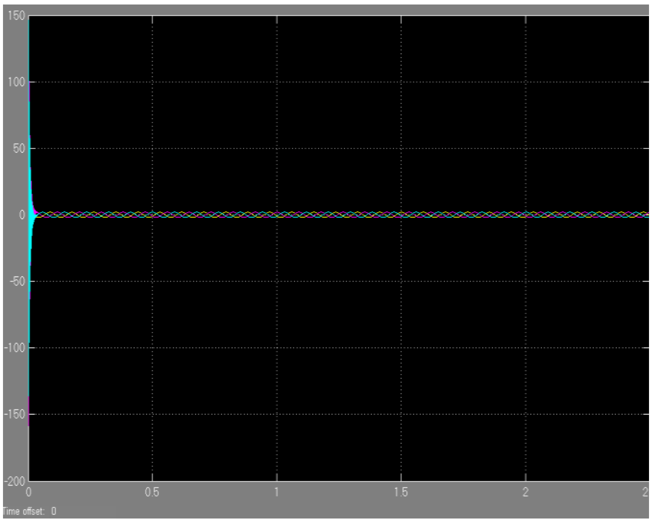

Fig 7 Current waveform during Re-strike for 10mts from source side in a 3-phase 132kv GIS

To introduce the current chopping, the circuit breaker is opened remains. Hence to calculate transients due to opening operation the CB is opened at 12ns. The transients are obtained and show in fig.7.

The transient calculated due to re-strike gives the peak voltage of 2.45p.u at a rise time of 112ns show in fig.8.

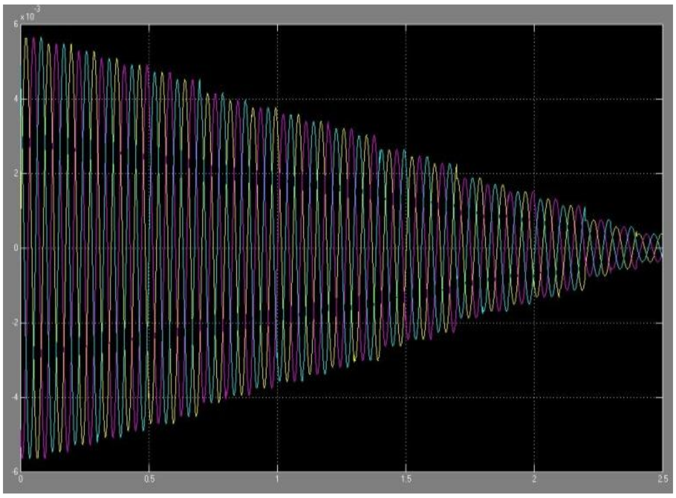

Fig.8 Current waveform during Re-strike for 10mts from Load side in a 3-phase 132kv GIS

TABLE III

THE ANALYSIS VALUES ARE TABULATED AS FOLLOWS:

Mode of operation	**Magnitude of voltage(p.u)**	**Rise time (Nano sec)**
During closing operation	2.46	69
During opening operation	1.22	56
During second re-strike	2.45	112

V. CONCLUSION

A model is Developed for the prediction of the VFTO phenomena in the circuit of voltage and current transformers in GIS. The main advantage of such model is to enable the transient analysis of GIS.A spark collapse time was correctly simulated by the variable resistor. By this spark collapse time, resistance of the VFTO is extended, and the component caused by short surge impedance discontinuities such as spacers, dis-connectors and short bus branches were damped.

A GIS system comprising of spacers, bus bar and dis-connectors has been considered for modelling into electric network. The inductance of the bus bar is calculated from diameters of conductors and enclosure using standard formulae. Cone insulators used for supporting inner conductor against outer enclosure are assumed to be disk type for approximate calculation of spacer capacitance is calculated using formulae for concentric cylinders. The entire bus length is modelled as distributed pi-network. The peak magnitude of fast transient currents generated during switching event changes from one position to another in a 132kv GIS for a particular switching operation. These transients over voltages are reduced by connecting suitable resistor in an equivalent circuit during closing and opening operation.

VI. REFERENCES

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