Transient over Voltages under Line Fault Conditions in Gas Insulated Substations (132KV, 220KV, 400KV)

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ABSTRACT

This Paper introduces in simulation models and equivalent circuits are planned to develop for the components of various voltages of Gas Insulated Substations (132KV, 220KV & 400KV). The fast transients over voltages are caused due to switching operations and fault with Fixed resistance and Variable arc resistance.The very fast transient over-voltage in GIS is estimated and simulated using the EMTP software in a 3-phase Gas insulated Substations (132KV, 220KV, 400KV).

Keywords —3-phase fault, EMTP Software, Gas Insulated Substations (GIS), very fast Transient over voltages, Switching operations, Control circuitry.

1. INTRODUCTION

It is a compact, multi component assembly enclosed inside a grounded metallic encapsulation that shields all energized parts from the environment. The primary insulating medium is compressed sulphurhexaflouride (SF6) gas.

Gas Insulated Substations (GIS) have found broad range of applications in power systems in many countries over the last three decades because of their high reliability, easy maintenance, small ground space requirement etc. In our country also few GIS units have been in operation and a large number of units are under various stages of installation.

GIS is based on the Principle of Operation of complete enclosure of all energized or live parts in a metallic encapsulation, which shields them from the external environment. Compressed SF6 gas, which has excellent electrical insulating properties, is employed as the insulating medium between the encapsulation and the energized parts. Gas Insulated Substations have a grounded outer sheath enclosing the high voltage inner conductor unlike conventional equipment whose closet is the earth surface. The Basic Insulation Level (BIL) required for a Gas Insulated Substations (GIS) is different from that of the conventional substation because of certain unique properties of the former Gas insulated bus has surge impedance (70 Ohm) more than that of the conventional oil filled cables, but much less than that of an overhead line (300-400 Ohms).

In addition, the GIS is totally enclosed and therefore is free from any atmospheric contamination. Hence, in general the GIS permits lower BIL rating than the conventional one. A GIS requires less number of lightning arresters than conventional one. This is mainly because of its compactness. The basic consideration for insulation co-ordination is V-t characteristic. The V-t characteristic of SF6 is considerably flat compared to that of air. Air can withstand very high voltages for very short time. On the other hand SF6 exhibits a flat characteristic. Thus the ratio of basic switching impulse level to basic lightening impulse level is close to unity for GIS, whereas for the conventional substations this ratio varies between 0.6 and 0.86.

The Very Fast Transient Over-voltage (VFTO) occurs when disconnector is operated in the GIS. In the system of the EHV and the UHV, the GIS equipments are more easily endangered by very fast transient over-voltage than eve, especially transformer. The model of transient circuit and parameter is vital factor for calculating the VFTO[1]. The VFTO is in line with the parameter of GIS apparatus. Hence, the magnitude and frequency of the VFTO can be influenced with the variety of the GIS apparatus parameter.

Their magnitude is in the range of 1.5 to 2.0 per unit of the 3 phase-to-neutral voltage crest, but they can also reach values as high as 2.5 per unit. These values are generally below the BIL of the GIS and connected equipment of lower voltage classes [2]. VFT in GIS are of greater concern at the highest voltages, for which the ratio of the BIL to the system voltage is lower[2].

The VFTO contains predominantly high frequency components range from hundreds of KHz to thousands of MHz, the transformer is regarded as lumped capacitance and lumped inductance. The SF6 bus and the cable act like transmission line with the transit time, propagation velocity and surge impedance. The values were provided by the company. Disconnector is modeled differently under open and closed conditions. When opened, it is modeled as lumped capacitances. When closed, it is replaced by the capacitance to ground. The spark is modeled as an exponentially decaying resistance in series with a small resistance. And the moving contact and fixed contact is modeled the lumped capacitance to earth [4].

The simulation depends on the quality of the model of each individual GIS component. 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. The disconnector 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 [6].

2. ESTIMATION IN GAS INSULATED SUBSTATIONS (132KV, 220KV, 400KV)

The equivalent circuits are constructed by using EMTP software. By using the circuits the transients are calculated for 10mtrs length of Gas insulated substations (132KV, 220KV, 400KV). The transients are also calculated during 3-phase fault.

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

For high-voltage transmissions, gas-insulated switchgears (GISs) are extremely advantageous and have been highly developed. One of their merits is compactness, which is advantageous in underground installation of substations, in particular, and indoor installation as well. Also, since all the high-voltage sections are housed in grounded enclosures, the GIS is a safe and highly reliable system, free of environmental hazards.

The maximum magnitude of the transient over voltage is 2.0p.u. this value is largely dependent upon the level of trapped charge on the GIS bus bar existing at the time of the re-strike. The amplitude of trapped charge is strongly influenced by the asymmetry of the inter-contact break down voltage occurring on the fixed and mobbing contacts of the dis-connector.

Under certain system configurations, the isolator switching operations could result in energizing or de-energizing a short section of GIS duct. Because of the relatively slow movement of the contacts of the isolator switches, pre-strikes or re-strikes would occur between the contacts, creating VFTO on the GIS, introducing a risk on the connected equipment, especially for transformer connected circuit. Due to its high frequency nature, the VFTO imposed on the transformers connected directly to the GIS would not be distributed evenly on all transformer windings. Some windings,

As the contacts bridge, the electric field between them will rise until spark over occurs. This first strike will almost inevitably occur at the peak of the power frequency voltage due to the slow operating speed of the contact. Thereafter, the current will flow through the spark and the charge on the capacitive loads gets changed to the source voltage V_s. During this period, the potential difference across the contacts falls and the spark will eventually extinguish. After this, the source side of the DS will continue to follow the power frequency and the voltage will fall from the peak value leaving the load charged. The potential difference across the DS will therefore rise again, but now with the opposite polarity and a second spark will occur when the source voltage is near zero.

The inter-contact breakdown voltage of a DS is always higher in one polarity that in the other due to the asymmetrical contact design and the first strike will take place when the moving contact has a negative polarity. Consequently, the second strike will take place for a greater potential difference than the first and will occur when the source voltage has crossed zero.

The main problems associated with the VFTO are:

1. Flashover to ground at the dis-connector switches contacts.
2. Failure of electronic control circuits connected to GIS, because of electromagnetic Interference of VFTO.
3. Dielectric strength is reduced under VFTO, if non-
   Uniform electric field is formed because of particle
   (mainly metallic).
4. Effect on components such as bushing and transformer.
5. Transient Enclosure voltage (TEV) on external surface
   Sheath. This may cause flashover to nearby grounded
   Objects.

For these reason, VFTO generated in GIS should he considered as an important factor in the insulation design of not only gas insulated components, but the entire substation. The VFTO generated due to switching operation, breakdown may occur if any sharp protrusion exists within the GIS. The over voltage pattern may cause the VFTO break down. This type of breakdown is known as Secondary Breakdown. This type Breakdown is also possible at the switching contacts during the current interruption. From the insulation design point of view, this new VFTO level and amplitudes of the high frequency components are also important.

For designing a substation it is essential to know the maximum value of VFTO. Hence studies are carried out on estimation of the VFTO levels. For this purpose EMTP software is used. In EMTP software a suitable equivalent circuit is necessary for each component of the substation. From the above it can be seen that the estimation of magnitudes of VFTOs is essential for design of a GIS.These VFTO's are caused by switching operations and 3-phase fault in Gas Insulated substations(132KV,220KV,400KV). Using EMTP software of the equivalent models is developed.

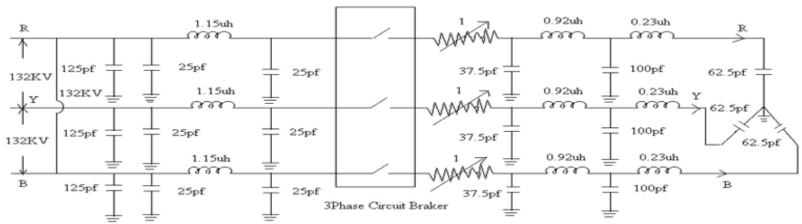

Fig1. Equivalent circuit for 10mtrs length in a 3 -phase 132KV GIS

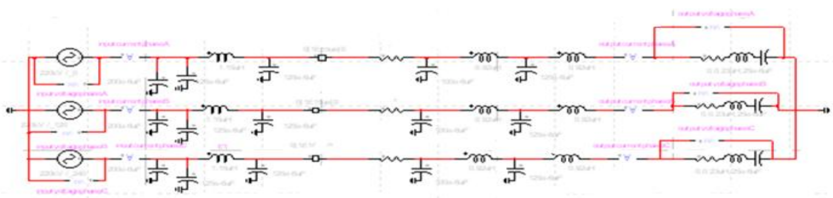

Fig2. EMTP circuit for 10mtrs length in a 3-phase of a 132KV GIS.

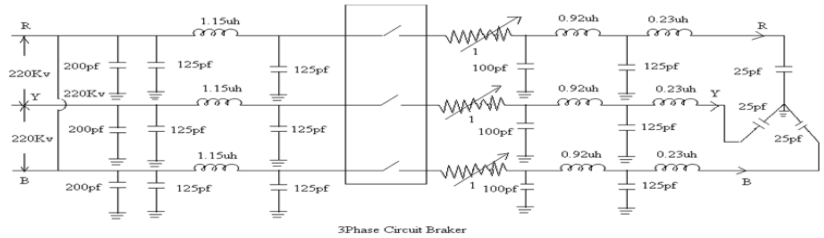

Fig3. Equivalent circuit for 10mtrs length in a 3 -phase 220KV GIS.

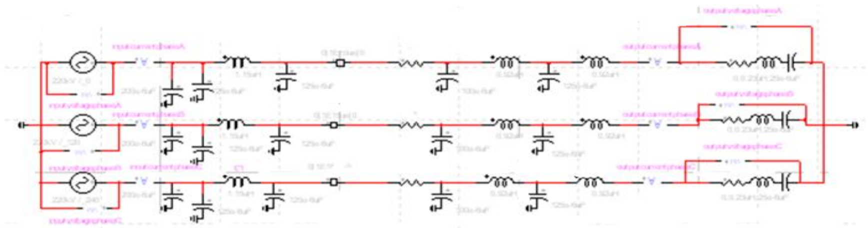

Fig 4. EMTP circuit for 10mtrs length in a 3-phase of a 220KV GIS.

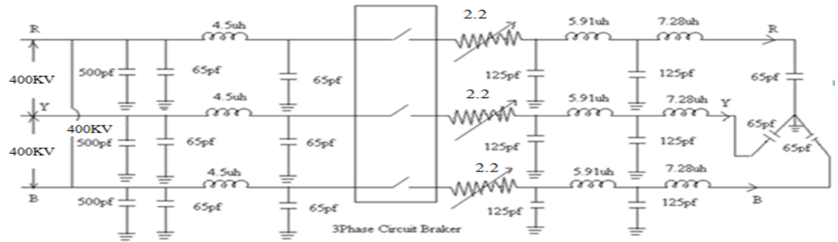

Fig.5. Equivalent circuit for 10mtrs length in a 3 -phase 400kv GIS

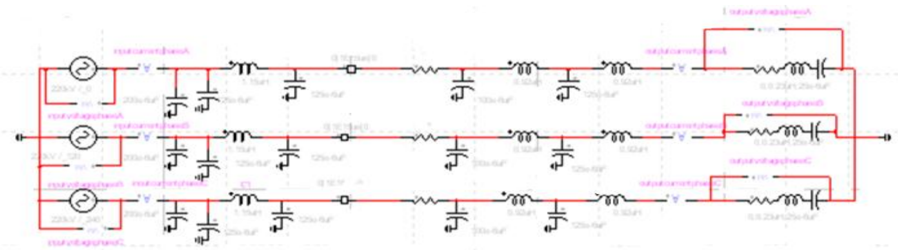

Fig 6. EMTP circuit for 10mtrs length in a 3-phase of a 400KV GIS

3. RESULTS AND DISCUSSION

The various transient voltage and current at different positions in a 3-phase Gas insulated substations (132KV,220KV,400KV) for the first switching operation presented in results. The inductance of the bus bar is found out from the diameters of enclosure and conductors. The bus capacitance is calculated using formula for concentric cylinders.This circuit is divided into three sections of 1mtrs, 4mtrs and 5mtrs respectively from load side and by the circuits shown in figure 1 & 2 are made use of. This in effect makes the transmission line of 3-phases only.

The Fast transients over voltages are generated not only due to switching operations but also due to 3 -phase fault in 132KV GIS. The bus duct is dividing into three sections of length 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. This in effect makes the transmission line of 3-phases only. The EMTP circuit of the same will be as shown in Fig 2.

The maximum values of VFTO, the EMTP 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. During closed operation, the current through the resistance of the circuit breaker is shown in fig.7. From the graph it was found the maximum current are 32A, 35A & 36A at a rise times of 14ns, 15ns &16ns. The magnitudes and rise times of 10mts length GIS are tabulated in the table I.

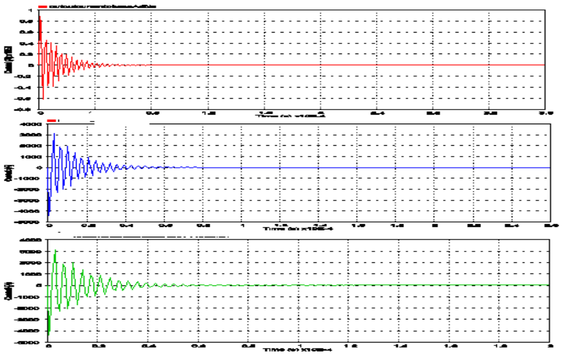

Fig7.Current waveform during as for EMTP closing operation of CB for 10mtrs length in a 3 -phase of 132KV GIS.

The transients due to closing of the circuit breaker are calculated as shown in fig 8. From this graph, the peak voltages obtained are 2.41, 2.42 and 2.43p.u at rise times of 67, 66 and 69ns respectively. The magnitudes and rise times of 10mts length GIS are tabulated in the table I.

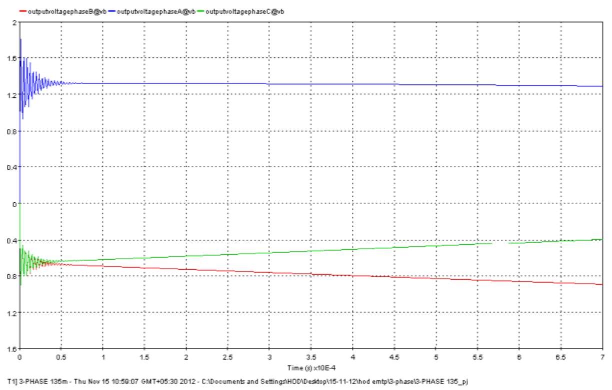

Fig 8 Transient voltage wave from during as for EMTP closing operation of CB for 10mts length in a 3 -phase of 132KV GIS

To introduce current chopping the circuit breaker is opened. The transients obtained during opening operation are shown in Fig 9. From the graph the maximum voltages obtained are 1.22, 1.23 and 1.25p.u at rise times of 60,63 and 64ns respectively. The magnitudes and rise times of 10mts length GIS are tabulated in the tableI. EMTP circuit for 10mtrs length in a 3-phase 132kv GIS shown in the fig 2.

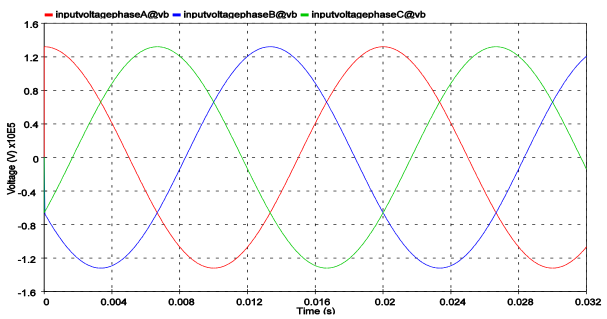

Fig9. Transient voltage waveform during as for EMTP opening operation of CB for 10mtrs length in a 3 -phase of 132KV GIS.

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 10. From the graph, the maximum voltages obtained is 2.52, 2.53 and 2.55p.u at arise time of 123,124 and 126ns respectively. The magnitudes and rise times of 10mts length GIS are tabulated in the table I.

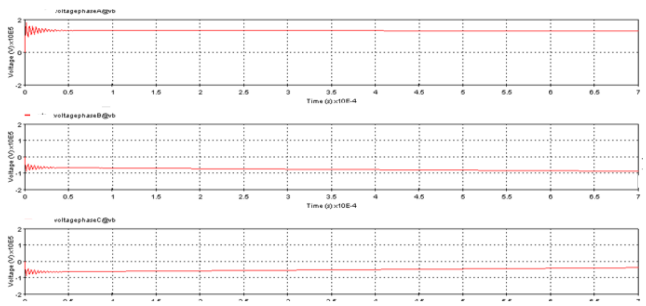

Fig10. Transient voltage waveform during as for EMTP second Re-strikes for 10mtrs length in a 3 -phase of 220kV GIS.

Mode of operation	Magnitude of voltages(p.u)			Rise time (Nano sec)		
	VR phase	VY phase	VB phase	tr	ty	tb
During closing operation	2.41	2.42	2.43	67	66	69
During opening operation	1.22	1.23	1.25	60	63	64
During second re-strike	2.52	2.53	2.55	123	124	126

Table 1 Transient due to switching operations for 10mtrs length in a3-phase 132KV

This circuit is divided into three sections of 1mtrs, 4mtrs and 5mtrs respectively from load side and by the circuits shown in figures 3 & 4 are made use of. This in effect makes the transmission line of 3-phase only. The Fast transients over voltages are generated not only due to switching operations but also due to 3-phase fault in 220Kv GIS.

The bus duct is dividing into three sections of length from load side. The GIS bushing is represented by a capacitance of 200pf. The resistance of 1 ohm spark channel is connected in series with circuit breaker. EMTP Circuit for 10mtrs length in a 3-phase 220KV GIS shown in the fig.4.

The maximum values of VFTO, the EMTP 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 220KV GIS.

During closed operation, the current through the resistance of the circuit breaker is shown in fig.11. From the graph it was found the maximum currents are 33A, 34A & 35A at a rise times of 13ns, 16ns &17ns.

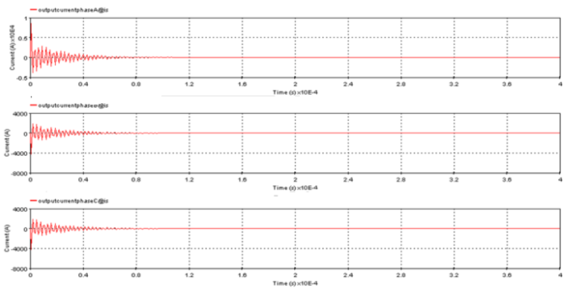

Fig. 11 Current waveform during as for EMTP closing operation of CB for 10mts length in a 3-phase of 220KV GIS.

The transients due to closing of the circuit breaker are calculated as shown in fig 12. From this graph, the peak voltages obtained are 2.41, 2.43 and 2.44p.u at rise times of 68, 66 and 71ns respectively. The magnitudes and rise times of 10mts length GIS are tabulated in the table 2.

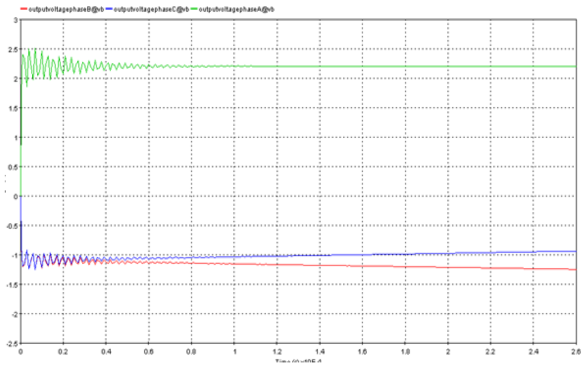

Fig 12. Transient voltage wave from during as for EMTP closing operation of CB for 10mts length in a 3 -phase of 220KV GIS.

To introduce current chopping the circuit breaker is opened. The transients obtained during opening operation are shown in Fig 13. From the graph the maximum voltages obtained are 1.23, 1.24 and 1.23p.u. at rise times of 60,61 and 63ns respectively. The magnitudes and rise times of 10mts length GIS are tabulated in the table 5.4. EMTP Circuit for 10mtrs length in a 3-phase 220kv GIS shown in the fig 2.

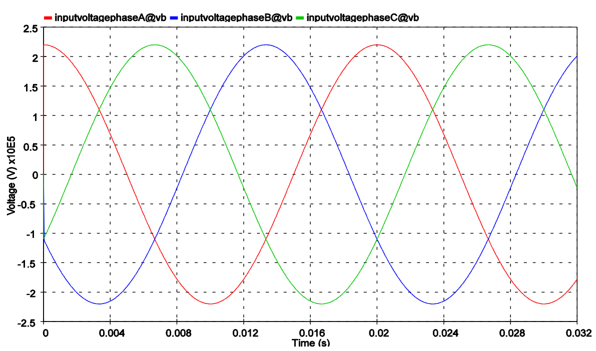

Fig.13 Transient voltage waveform during as for EMTP opening operation of CB for 10mtrs length in a 3 -phase of 220kV GIS.

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 14. From the graph, the maximum voltages obtained is 2.51, 2.53 and 2.52p.u at arise time of 123,122 and 124ns respectively. The magnitudes and rise times of 10mts length GIS are tabulated in the table 2

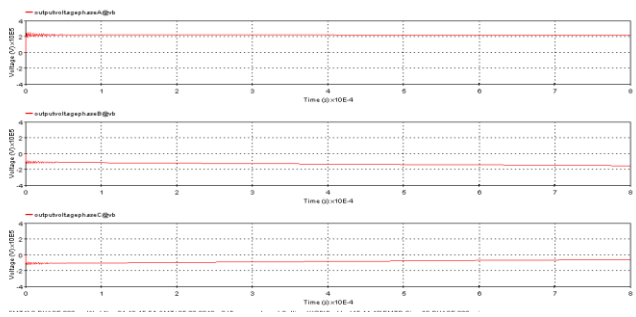

Fig 14 Transient voltage waveform during as for EMTP second Re-strikes for 10mtrs length in a 3 -phase of 220kV GIS.

Mode of operation	**Magnitude of voltages(p.u)**			**Rise time (Nano sec)**		
	VR phase	**VY phase**	**VB phase**	**tr**	**ty**	**tb**
During closing operation	2.41	2.43	2.44	68	66	71
During opening operation	1.23	1.24	1.23	60	61	63
During second re-strike	2.51	2.53	2.52	123	122	124

Table 2 Transient due to switching operations for 10mtrs length in a3-phase 220KV

The Fast transient over voltages are generated not only due to switching operations but also due to 3-phase fault in 400Kv GIS in shown figure5 .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. EMTP Circuit for 10mtrs Length in a 3-phase 400KV GIS shown in the fig. 6.

During closed operation, the current through the resistance of the circuit breaker is shown in fig.15 . From the graph it was found the maximum currents is 35A, 37A &36A at a rise times of 15ns, 14ns &16ns

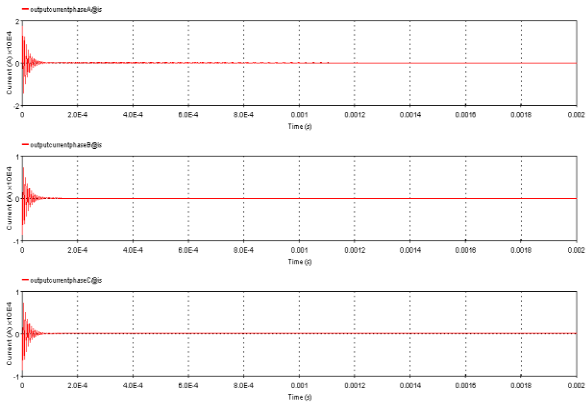

Fig. 15 Current waveform during closing operation of CB for 10mts length in a 3-phase of 400kv GIS

The transients due to closing of the circuit breaker are calculated as shown in fig 16. From this graph, the peak voltages obtained are 2.43, 2.45 and 2.42p.u at rise times of 69, 67 and 70ns respectively. The magnitudes and rise times of 10mts length GIS are tabulated in the table 3.

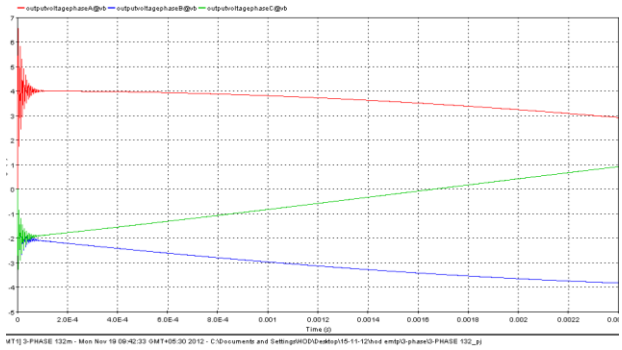

Fig 16 Transient voltage wave from during closing operation of CB for 10mts length in a 3-phase of 400kv GIS

To introduce current chopping the circuit breaker is opened. The transients obtained during opening operation are shown in Fig 6. From the graph, the maximum voltages obtained are 1.25,1.24 and 1.22p.u. at rise times of 60,62 and 62ns respectively. The magnitudes and rise times of 10mts length GIS are tabulated in the table 3. EMTP Circuit for 10mtrs length in a 3-phase 400kv GIS shown in the fig 6.

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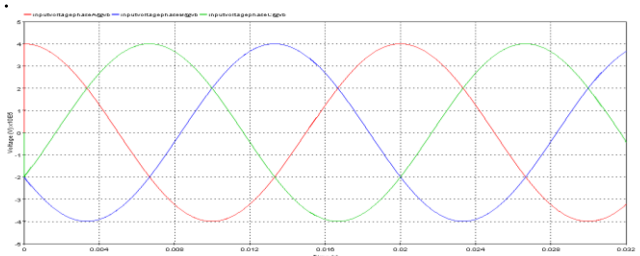

Fig. 17 Transient voltage waveform during opening operation of CB for 10mts length in a 3-phase of 400kv GIS

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 18. From the graph, the maximum voltages obtained is 2.53, 2.52 and 2.54 p.u at arise time of 124,122 and 125ns respectively. The magnitudes and rise times of 10mts length GIS are tabulated in the table 3.

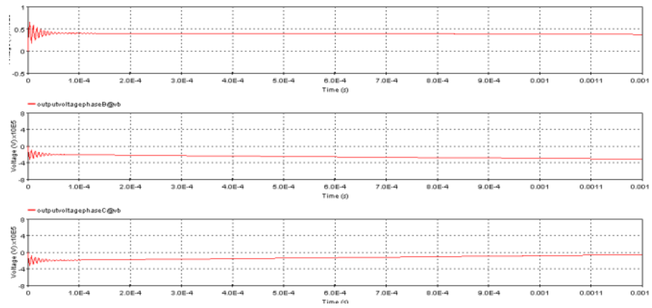

Fig.18. Transient voltage waveform during second re-strikes for 10mts length in a 3-phase of 400kv GIS

Mode of operation	Magnitude of voltages(p.u)			Rise time (Nano sec)		
	VR phase	VY phase	VB phase	tr	ty	tb
During closing operation	2.43	2.45	2.42	69	67	70
During opening operation	1.25	1.24	1.22	60	62	62
During second re-strike	2.53	2.52	2.54	124	122	125

Table 3Transient due to switching operations for 10mtrs length in a3-phase 400KV.

4. CONCLUSION

The fast transient over voltages are obtained due to switching operation of 3-phase faults are studied. The transients are calculated initially with fixed arc resistance and then variable arc resistance. The variable arc resistance is calculated by using Toepler's formulae. Transients along with load and without load are also calculated.

The peak magnitudes of fast transient currents are generated during switching event changes from one position to another in a 3-Phase Gas insulated substations(132KV,220KV,400KV) for a particular switching operation. These transients over voltages are reduced by connecting suitable resistor in an equivalent circuit during closing and opening operation.

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