VFTO COMPUTATION IN A 420 kV GIS

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Abstract

This paper presents the results of Very Fast Transient Overvoltage (VFTO) computations that have been carried out using EMTP for various switching conditions in a 420 kV gas insulated substation. The variation of VFTO peak along the nodes for disconnector and circuit breaker operations as well as the variation of VFTO with different trapped charges have been studied. The results indicate a distinct pattern of variation of VFTO peak along the nodes of the GIS in the case of disconnector switch operation as compared to that of circuit breaker operation. It has also been noticed that the variation of VFTO peak levels are not proportional to the increase in the trapped charge.

1 Introduction

In Gas Insulated Substations (GIS), a number of restrikes occur across the switching contacts when disconnector switch or circuit breaker is operated leading to generation of VFTO. VFTO thus generated has rise-times in the range of few ns and is followed by high frequency oscillations [1]. Even-though their magnitudes are lower than that of BIL of the system, they contribute for reduction in the life of the insulation in the system due to their frequent occurences. Also under VFTO, the dielectric strength of SF_6 in the presence of free metallic particles is reduced considerably and may lead to flashover. VFTO can also influence the insulation of other GIS components such as transformers where the interturn insulation may be stressed with a higher voltage than under chopped lightning impulse voltages [2]. Hence there is a need to estimate the magnitudes of VFTO generated during switching operations in GIS.

2 Computer Simulation

The fact that measurement of VFTO at such high frequencies is quite difficult and demands skill and utmost prudence, makes the computer simulation of the above switching operations attractive. Also, simulation enables to estimate the VFTO magnitudes, their rise-times, effect on various components etc., with ease and reasonable accuracy even before the actual commissioning of the GIS. Since the VFTO magnitude vary with the trapped charge, its value also has to be taken into consideration in the simulation.

A 420 kV GIS has been taken up for the simulation of VFTO during switching of various disconnectors and circuit breakers. A one line diagram of the 420 kV GIS is shown in figure **1** and figure **2** . This substation has **4** main generators (G1 to **G4)** and **4** Auxillary generators (GA1 to **GA4)** feeding the three buses and there are three outgoing feeder lines from the substation. For the simulation work, the whole substation has been divided into three sections, viz., the main generator lines, the auxillary generator lines and the outgoing feeder lines. Computer simulations have been done using EMTP software.

2.1 The various components of a GIS and their models

Since the VFTO contain predominantly high frequency components ranging from hundreds of kHz to tens of MHz, most of the models have their capacitances dominating the other parameters [3].

The typical lengths of a GIS bus are much smaller than an ordinary substation and also, at high frequencies in the range of few hundreds of kHz to MHz, the GIS bus acts like a transmission line with a finite transit time and propagation velocity. The value of surge impedance of GIS bus bar which is modelled as transmission line can be obtained from the relation

$$Z = 60 \ln \left(\frac{b}{a}\right) \Omega \qquad (1)$$

where a is the diameter of the HV bus and b is the inner diameter of the enclosure and is found to be 64.2 Ω.

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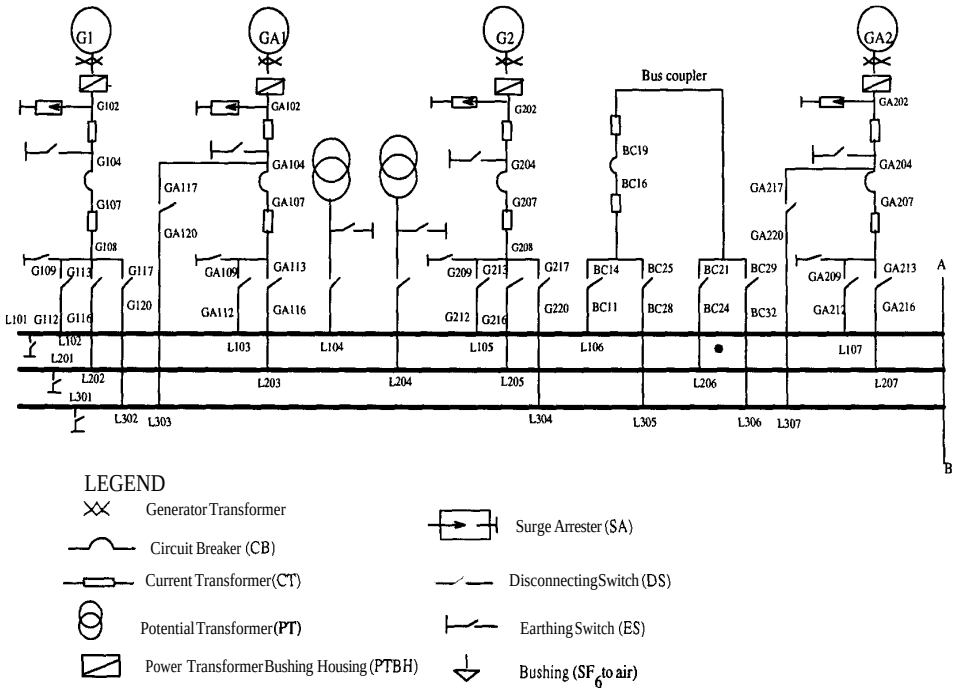

Figure 1: Single line diagram of the **420** kV substation (Co nt'd...)

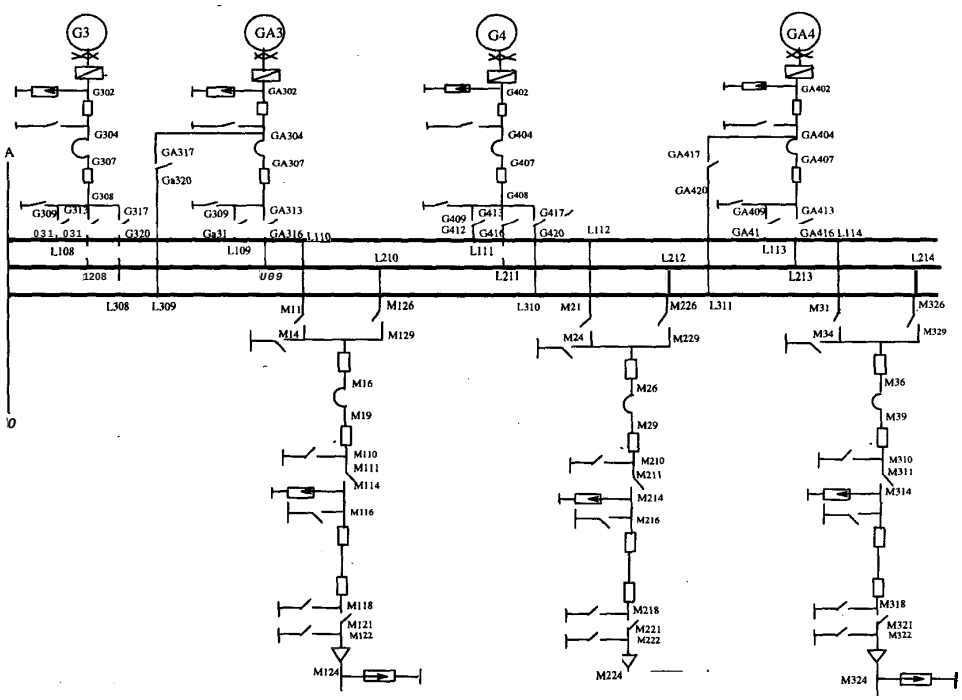

Figure **2:** Single line diagram of the **420** kV substation

Elbows, spacers and spherical shields are modelled by a lumped capacitance of 15 pF.

Power transformer with bushing mounted is modelled as lumped capacitance to ground of 1250 pF whereas surge arresters are modelled as lumped capacitance to ground of 50 pF. Disconnector switches are modelled differently under open and closed condition. When opened they are modelled as two transmission lines in series with a capacitance. The surge impedance of each of the transmission line is taken as 69Ω and capacitance 20 pF. The capacitance to ground is taken as 52 pF.

When closed, the capacitance in between the two transmission lines of the open disconnector switch model is replaced by a transmission line with the same parameters as before but the capacitance to ground is taken as 88 pF.

The spark is modelled as an exponentially decaying resistance and a small resistance of 0.5 Ω in series to take care of the residual spark resistance. This is implemented using a piecewise nonlinear function in EMTP. The mathematical equation for the above is given by

$$R = R_0 e^{-(\frac{t}{\tau})} + r \qquad (2)$$

This above equation gives a resistance whose value varies from very high value (few MΩ) to a low value of 0.5 Ω within 30 ns.

Bushings are modelled with a lumped capacitance to ground of 500 pF whereas earth switches are modelled by lumped capacitance of 45 pF.

Circuit breakers are also modelled differently under open and closed condition. The open circuit breaker is modelled as two transmission lines in series with a capacitance of 2800 pF and a 17 Ω resistance in series between them. The capacitance to ground is 200 pF. The closed circuit breaker is modelled similar to the open circuit breaker with the capacitance replaced by a transmission line of surge impedance of 30 52. The capacitance to ground is also replaced by 20 pF.

The overhead line which is connected to the GIS is considered to be of infinite length. Hence it is modelled as a transmission line terminated with a resistance to ground of value equal to the surge impedance of the overhead line (350Ω), so that there is no reflection from this end.

3 Results and Discussion

3.1 Variation of VFTO along the nodes

Though simulation of 61 different switching conditions have been done for different trapped charge magnitudes of -0.3 p.u, -1.0 p.u and -1.2 p.u, only two specific cases have been presented and discussed here. The conditions considered are

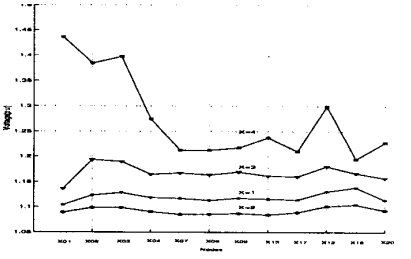

Figure 3: Variation of VFTO levels in the main generator lines (G-lines)

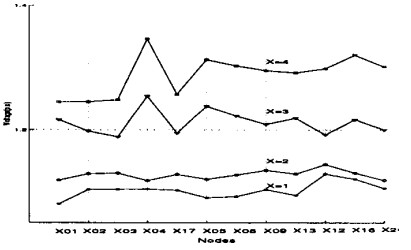

Figure 4: Variation of VFTO levels in the auxillary generator lines (GA-lines)

- All generators connected and the disconnector switch between M226 and M229 operated with circuit breaker between M26 and M29 kept open.
- All generators connected to the bus and the circuit breaker between **M36** and **M39** operated.

The results of the simulation are shown in figures 3 to 8. Figures 3 to 5 show the results for the disconnector switching condition and figures 6 to 8 show the results for the circuit breaker swithing operation. In the case of disconnector switching operation (figures 3 to 5), the VFTO peak increases in the line where the switching is done (X=2) till an open circuit breaker is encountered. Beyond this location, there is found to be a sharp reduction in the VFTO peak. The VFTO peak once again shows an increasing trend along the nodes and reaches a high value at the junction of the GIS with the overhead line.

On the contrary, in the case of circuit breaker switching operation (figures 6 to 8), the VFTO peak has a steady increasing trend till the junction of GIS with the overhead line. Also, it is found that the VFTO peak magnitudes are higher in the case of circuit breaker operation as compared to that of disconnector switching operation.

In the case of disconnector switching operation, VFTO peak is found to be highest when the disconnector switch between G320 and G317 is operated with the circuit breaker between G307 and G304 kept open and all the generators except G3

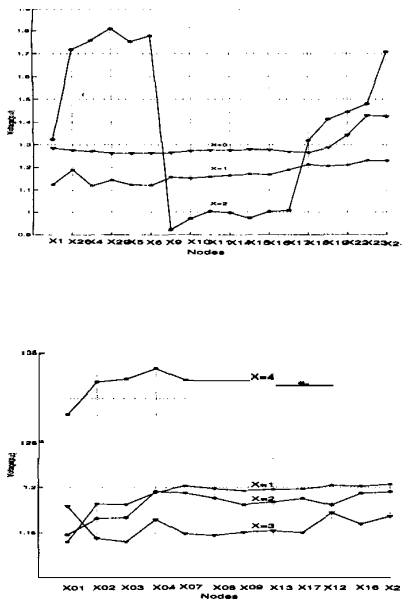

Figure *6:* Variation of VFTO levels in the main generator lines (G-lines)

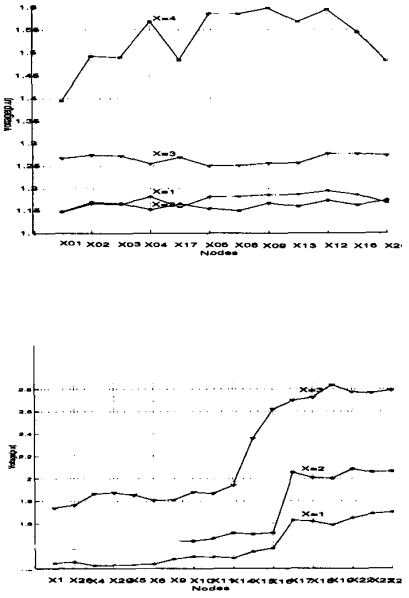

Figure 8: Variation of VFTO levels in the outgoing feeder lines (M-lines)

energized. A trapped charge of -1.2 p.u is assumed. Its value is 2.25 p . (node G305). In the case of circuit breaker operation, the VFTO peak magnitude is found to be maximum for circuit breaker between GA204 and GA207 operated and only GA2 line is connected and energized with a trapped charge of -1.2 p.u. Its value is 2.87 p.u at the node M324 on the outgoing feeder X=3. It can also be observed that there is a distinct signature pattern of the peak VFTO magnitude variation for the circuit breaker switching operation as opposed to the disconnector switching operation along the outgoing feeder lines as seen from figures 3 to 8.

4 Effect of trapped charge on the VFTO levels

Inorder to understand the exact influence of the trapped charge on the VFTO levels, the variation of the VFTO magnitudes for the same switching case but for trapped charges of -1.2 p.u, -1.0 p.u and -0.3 p.u were computed.

It is found that the influence of trapped charge on VFTO magnitudes are more at the nodes where the VFTO magnitudes are higher and in the line where the switching is done. In the case of variation of trapped charge from -1.2 p.u to -0.3 p.u, the range of difference of VFTO levels are between 0.14 p.u to 0.82 p.u. It is also observed that the increase in VFTO levels are not proportional to the increase in the trapped charges.

5 Conclusion

There is a distinct pattern of variation of VFTO peak along the nodes of the GIS in the case of disconnector switch operation as compared to that of circuit breaker operation. The circuit breaker operation results in the highest VFTO level amongst all the switching operations done. The VFTO at the overhead transmission line end is always found to have the highest value for a circuit breaker operation. Variation of VFTO levels are not proportional to the increase in the trapped charge.

References

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[3] J. Lewis, B. M. Pryor, C. J. Jones, T. Irwin, "Disconnector Operations in Gas Insulated Substations Overvoltage Studies and Tests Associated with a 420 kV Installation", CIGRE, Vol. II, 1988, paper 33.09, pages 1-8.