Mitigation and Analysis of Very Fast Transient over Voltages (VFTOs) in 765/245kV Gas Insulated Substation (GIS) by Wavelet Transforms

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The very fast transient over voltages (VFTO) can cause the stress on insulation and may leads to damage of the insulation. If the maximum peak value of VFTOs is more than the rated lighting impulse withstand voltage then it is necessary to consider the VFTO and mitigation has to be done by employing suitable damping devices. In this paper a power transformer rating of 400MVA has been considered in 765/245kV, gas insulated substation. The parameters of the proposed system have been evaluated using very fast transient nature (VFT) for more accurate evaluation. In this work, the effect of earthing switch and Influence of grid grounding on VFTOs and TEV were reinvestigated. The wavelet transform have employed for the estimation of VFTOs and TEV since the wavelet transform is most powerfull tool for transient analysis.

Introduction

The power system is large and interconnected one in which the transformer plays an important role and thereby it is very essential to protect it against the internal and external faults as well as from the over voltages due to any reason particularly when it is used in gas insulated substation since there is always possibility continuously the likelihood of reason for fast transient over voltages. Gas insulation substations (GIS) have been utilized as a part force frameworks in the course of the most recent three decades on account of their high unwavering quality, simple support, and small ground space necessity and so on. In India likewise, a couple GIS units are under different phases of establishment.

Many authors have discussed about generation, computation, mitigation suppression [2, 12], measurementand analysis of very fast transient over voltages in different ways and many of the researchers presented their articles about mitigation and analysis of very fast transient over voltages (VFTOs) [5] in gas Insulated substations (GIS) however most of them considered low voltage low rating transformer and comparison given between the existing and proposed damping methods. This paper presents a robust wavelet technique based analysis of peak magnitude of very fast transient over voltages (VFTOs) at transformer, open end and at the disconnecting switch (DS) along with the terminal components effects on peak values of VFTOs. An exact peak value of VFTOs must be measure for proper insulation design and to protect the transformer or other...
important electrical equipments in GIS and this can be achieved by the proposed technique. The wavelet transform gives the accurate measurement [6] since the outcomes of wavelet transform is based on the time and frequency analysis, unlike individual time domain and frequency domain. The proposed 765kV/400kV, 500MVA GIS system has been designed on the basis of very fast transient (VFT) as very fast transients are travelling wave nature. The components of the proposed system are designed taking surge impedance, propagation velocity, formative time length and into account.

**Mitigation Method of VFTOs and TEV**

During switching operations or earth faults in a GIS, very fast transients occur and stress the equipment, adjacent equipment, air insulated switchgear (AIS) and secondary equipment. The VFTO’s at their origin in a GIS are characterized by a steep front having [16-17] nanoseconds rise time followed by a mono-frequent oscillation of some MHz [13]. Transient Enclosure Voltage (TEV), also known as Transient Ground Potential Rise (TGPR) is special case of VFTO. This phenomenon refer to short rise time, short duration high voltage transients which appears on external of earthed enclosure of the GIS through the coupling of initial transients to the enclosure at enclosure discontinuities [14].

**Power Transformer**

The power transform can be designed either by multi conductor model or by detailed model in general. However in gas insulated substation the very fast transit over voltages generated due to switching operations is of high frequency in the range of MHz and non stationary with very short rise time. The windings transformer at very high frequency behaves like capacitive network [8, 10] there by it should be treated as active nature, the series capacitance and shunt capacitance should be considered to evaluate an exact value of VFTOs. In the proposed system the parameters of transformer are calculated on the basis of VFT. Since the transformer coil at high frequencies behaves as capacitive network the modeling of transformer has been designed based on very fast transients (VFT) [7, 8, 9] i.e. The parameters of transformer are estimated for accurate simulation results and are given by: $R_1 = 22.8 \Omega$, $R_2 = 22.8 \Omega$, $R_3 = 300 \Omega$ and inductance of the coils $L_1 = 5 \mu H$, $L_2 = 47.5 \mu H$, $L_3 = 9.42 \mu H$ and the capacitance $C_1 = 0.84 \mu F$, $C_2 = 1.74 \mu F$, $C_3 = 35.4 \mu F$, $C_4 = 120 \mu F$ the surge impedance, velocity of propagation, formative time and length are considered as well as the series capacitance between the turn and coil and the shunt capacitance between the turn [6], coil and grounded core and transformer tank are considered for accurate results of the peak magnitude of very fast transient over voltages (VFTOs). The parameters of power transformer is estimated as per the very fast transient nature for accurate measurement of VFTOs [5, 8 1]. Figure 1 shows the equivalent circuit of power transformer in the proposed system.

![Figure 1. Equivalent circuit of power transformer.](image)

The surge impedance, propagation velocity and formative time can be evaluated from the equations (1), (2) and (3).

\[
Z = \frac{\tau}{\sqrt{c}} \tag{1}
\]

\[
v = \frac{1}{\sqrt{\epsilon c}} \tag{2}
\]

\[
\tau = \frac{1}{\sqrt{\epsilon c}} \tag{3}
\]
**Disconnector**

A disconnector is represented by a PI section comprised of two travelling wave models, two capacitors to ground and a capacitor across the breaking contacts as shown in figure 2 with the parameters as follows: \( Z_1 = 35 \Omega, \) \( L_1 = 640 \text{mm}, \) \( L_2 = 450 \text{mm}, \) \( C_1 = 25 \text{pF}, \) and \( C_2 = 2.5 \text{pF}. \) The spark used in disconnector re-strike cases is modeled as an exponentially decaying resistance \((R_0 e^{-t/T})\) in series with a small resistance, \( r \) of 0.5 \( \Omega \) to take care of the residual spark resistance. Disconnector is modeled in different manners for open and close positions. In the close position, it has been modeled as a distributed transmission line. Open position of the disconnector has been modeled by a series capacitor demonstrating capacitance between contacts of the disconnector and is shown in figure below. The sparking between disconnector contacts during its opening or closing operation has been modeled by a non-linear resistance in series with a fixed resistance. Value of fixed resistance \( R_s \) has been selected on the basis of the practical consideration as discussed.

![Figure 2. Equivalent circuit of disconnector.](image)

\[
L = \left(\frac{1}{1000}\right) l \left[ \ln \left( \frac{R_1}{R_3} \right) + \ln C + \ln \left( \frac{R_d}{R_3} \right) + \frac{2 \ln \left( \frac{R_2}{R_1} \right)^2}{1 - \left( \frac{R_2}{R_1} \right)} \right] \\
C = \left( \frac{2\pi \varepsilon_0 \varepsilon_r l}{2.3 \ln(\frac{R_2}{R_1})} \right) \\
R_s = R_0 e^{-t/T} + R_f
\]

Where, \( R_0 = 10^{12} \Omega, \) Fixed Resistance = 0.5 \( \Omega, \) \( T \) (spark time constant) = 1 ns, Open end section of GIS - The open ended section of GIS has been presented in the following figure where a lumped shunt capacitance has been considered. Assuming the same as a coaxial hemisphere, its capacitance has been estimated using following equation.

\[
C = 2\pi \varepsilon_0 \varepsilon_r \left( \frac{R + r}{b - r} \right)
\]

Where, \( R = \) internal radius of enclosure, \( r = \) external radius of enclosure

**Results**

In this paper the proposed system has been with an earthing witch and the simulation work has been carried for TEV at different operating speed of disconnecting switch (DS) (80ms, 125ms and 150ms). The simulation results of the proposed technique has been shown in the following section from figure 3 to 8.
Figure 3. Magnitude of TEV at a speed of 80ms.

Figure 4. Magnitude of TEV at a speed of 80ms (Db4).

Figure 5. Magnitude of TEV at a speed of 120ms.
From the outcomes of the proposed system with proposed techniques the magnitude of TEV has been estimated directly and the same has been explored to wavelet transform for extraction of high frequency transient components and the estimated
results has been tabulated in table 1.

| Table 1. Magnitude of TEV in p.u (Influence of Earthing switch for different time of operation 80ms, 120ms and 150ms). |
|---------------------------------|--------------|--------------|--------------|
|                                | t= 80ms      | t = 120ms    | t = 150ms    |
| Direct                         | 2.05         | 1.82         | 1.09         |
| D84                            | 1.98         | 1.79         | 1.04         |

From the outcomes it can be observed that by using high speed disconnecting switches the magnitude as well as the steepness of the wave an be considerably reduced and by employing wavelet transform an exact values of peak can be achieved.

In the next stage, the effect of grounding parameters on TEV and VFTOs has been investigated. In the proposed system the grounding grid resistance, grounding strip resistance and grounding strip inductance are estimated as per the following equations.

Grounding strip resistance:

\[ R = \frac{\rho L}{A} \]  \hspace{1cm} (8)

From the above equation (8) it is very clear that grounding strip resistance depends on \( \rho \), \( L \) and by changing the R we can reduce the effect of VFTOs and TEV in GIS. The specific resistivity used in this paper is 75Ω-m and 200Ω-m

Grounding grid resistance:

\[ R = \int_{r_1}^{r_2} \frac{\rho dx}{2\pi x^2} = \frac{\rho}{2\pi} \left( \frac{1}{r_1} - \frac{1}{r_2} \right) \]  \hspace{1cm} (9)

Where

Where R resistance of the strip in ohm, \( \rho \)- specific resistivity in \( \Omega \cdot m \), L- Length of the road in m, and A- cross sectional area of the road in \( m^2 \). The specific resistivity used in this paper is 75Ω-m and 200Ω-m.

Grounding grid inductance:

\[ L = 2 \times 10^{-3} \left[ \frac{21}{a+b} + 0.5 - \log_e \right] \]  \hspace{1cm} (10)

In this paper the effect of grounding resistance has been considered and the simulation work has been carried for different values of resistance. In the proposed system the transient enclosure over voltage in GIS due to disconnect switch (DS) operation was studied. In this case the total impedance of grounding strip and grounding grid has been considered as grounding impedance. The simulation results of TEV for different impedances (10Ω and 20Ω) are shown in the following section from figure 9 to figure 19 and the outcomes has been tabulated in table 2.
Figure 10. Magnitude of TEV for R = 10Ω with D84.

Figure 11. Magnitude of VFTO at Transformer (Vtr).

Figure 12. Magnitude of VFTO at Transformer (Vtr) (D84).
Figure 13. Magnitude of VFTO at open end (Voc).

Figure 14. Magnitude of VFTO at open end (Voc) (Db4).

Figure 15. Magnitude of TEV for R = 20Ω.
Figure 16. Magnitude of TEV for $R = 20\Omega$ Db4.

Figure 17. Magnitude of VFTO at Transformer ($V_{tr}$).

Figure 18. Magnitude of VFTO at Transformer ($V_{tr}$) (Db4).
Discussions

From the simulation work and outcomes it has been concluded that by providing proper and enough strength in ground resistance both the magnitude of VFTOs and TEV can be considerably reduced and the power devices can be protected against VFTOs as well as TEV. It has observed from the test results that for $R = 10\Omega$ the maximum VFTO is 1.84p.u at open end and 1.48p.u at transformer. And for $R = 20\Omega$ it has been found that 1.25p.u at transformer and at open end it is 1.51p.u. and the maximum TEV at $R = 10\Omega$ is 1.48p.u and for $R = 20\Omega$ it is 1.37p.u. Which means if ground has enough and sufficient resistance the magnitude of VFTOs and TEV can be reduced.
Conclusions

This research work concludes that the grounding of gas insulated substation (GIS) is very important and some special care has to be taken while grounding the GIS system and by employing the wavelet transform technique an exact values of peak values of VFTOs and TEV can be achieved since wavelet is a powerful tool for high frequency transient non stationary signals.

References


