

Mitigation and Analysis of Very Fast Transient over Voltages (VFTOs) of Transformer in 245KV Gas Insulated Substation (GIS) Using Wavelet Transform

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Abstract

Switching operations in a gas insulated substations generate very fast transient over voltages (VFTO) which are dangerous for the transformer and the system insulation because of their short rise time. Under special circumstances the terminal over voltages can arise close to the transformer. The suppression of VFTO is very important in GIS systems. In this a 245KV gas insulated substation has been considered and different techniques for mitigation and suppression purpose vftos at the transformer are applied and the same are analyzed by the application of wavelet transform as wavelet transform gives the better results. In this paper a 245 KV GIS considered and is designed with mat lab software simulink platform and the system is simulated to evaluate the vftos at the transformer primary side with and without ferrite ring along .The switching conditions have been created by the disconnectors at the primary side of the transformers well as at the secondary ., the VFTOs results are compared and are analyzed by using wavelet transform in ordered to determine an effective mitigation methods of VFTOs. The results show that the peak value of VFTOs can be considerably reduced by introducing ferrite ring method.

Key words: Gas-insulated substation, GIS, very fast transient overvoltage's, VFTOs, transformer. disconnector, wavelet transform, switching conditions, mitigation techniques

1. Introduction

Gas insulated substations (GIS) have been used in power systems over the last three decades because of their high reliability, easy maintenance, small ground space requirement etc. In India also, a few GIS units are under various stages of installation.

The basic insulation level (BIL) required for a gas insulated substation (GIS) is different from that of the conventional substation because of certain unique properties of the former. Gas insulated bus has a surge impedance (70Ω) more than that of the conventional oil filled cables, but much less than that of an over head line ($300\Omega - 400\Omega$). Further, the average bus run for a compact GIS is much less than that for the conventional station. In addition, the GIS are totally enclosed and therefore is free from any atmospheric contamination. Hence, in general the GIS permit lower BIL rating than the conventional one. However the life of GIS is affected by several factors such as: conductive particles, particle discharges and contamination. Conductive particles inside the enclosure are known to reduce the breakdown level of Gas insulated systems. Partial discharges can develop from conductive particles, contamination, and defects during the manufacturing process, etc.

The GIS require less number of lightning arresters than a conventional one. This is mainly because of its compactness. The basic consideration for insulation coordination is V-T characteristic. The V-T characteristic of SF₆ is considerably flat compared to that of air. Air can withstand to very high voltages for very short time. However, as the duration of voltage increases, the withstand voltage falls off considerably. On the other hand, SF₆ exhibits a flat characteristic, thus the ratio of basic lightning impulse level is close to unity for GIS, whereas for the conventional substations this ratio varies between 0.6 and 0.86. Although GIS has been in operation for several years, a lot of problems encountered in practice need further understanding. Some of the problems studied are:

- a) Switching operations generate very fast transient over voltages (VFTOS)
- b) VFTOS may cause secondary breakdowns inside a GIS and Transient Enclosure Voltages (TEV) outside the GIS
- c) Prolonged arcing may produce corrosive / toxic by products
- d) Support spacers can be weak points when arc by products and metallic particles are present
- e) From the reliability point of view, partial discharge detection is important. The methods of detection are of electric systems etc. These methods lack quality control.

For these reasons, VFTOs generated in a GIS should be considered as an important factor in the insulation design. In a GIS, Very Fast Transient Over-voltages (VFTOs) are caused by two ways:

1. Due to switching operations and
2. Line to enclosure faults.

The switching operations may be disconnector switch, circuit breaker or earth switch. Since, the contact speed of disconnector switches are low, restriking occurs many times before the interruption is completed. Each restrike generates very fast transient over voltages with different levels of magnitude. Further, disconnector switches are used primarily to isolate the operating sections of an HV installation from each other as a safety measure. Beyond this, they must also be able to perform certain switching duties, such as load transferred from one bus bar to another or disconnection of bus sections, circuit breakers etc. During switching operations, voltage collapse across the contacts take place within 3 to 20 nanoseconds depending on the system voltage, gas pressure, field intensity etc. Once this short time rise pulse starts at switching contacts, it travels along gas bus duct in either direction and gets reflected at different terminations. The superimposition of system with reflected pulse develops over voltages in GIS. These over voltages have been called as Very Fast Transient Over voltages (VFTOs), because of their very high frequency components in the range of MHz. The main problems associated with the VFTOs are as follows:

- a) Flash over to ground at the disconnector switch contacts

- b) Failure of electronic control circuits connected to GIS due to electromagnetic interference of VFTOs
- c) Di-electric strength is reduced under VFTOs, if non-uniform electric field is formed by the particles (primarily metallic)
- d) Effect on equipments such as bushing, power transformer and instrument transformers
- e) Transient Enclosure Voltage (TEV) on external surface of the sheath. This may cause flashovers to nearby grounded objects

For the above reasons, VFTOs generated in GIS should be considered as an important factor in the insulation design of not only gas-insulated components, but also for the entire substation. The levels and waveforms of VFTOS are determined by the design of the substation.

2. Overview of Gas Insulated Substations

SF6 gas insulated high voltage switchgear has been in commercial operation for more than 30 years. Continuous technological and design improvements of all the components during the course of the time are characterized by appreciable savings in area and volume occupied by the substation. Gas insulated substations are in service up to the highest voltage of 800 kV, meeting almost all the requirements in urban, industrial as well as rural areas. In the initial stages, the new SF6 gas insulated substations were almost exclusively used where space limitations, site restrictions or exponential ambient conditions made it difficult to use conventional air insulated substations. However, over the last 30 years, GIS at voltage up to 800 kV in various station configurations and with various performance requirements, have been installed in increasing numbers worldwide. The modular of design of GIS offers a high degree of flexibility to meet layout requirements of both substations, as well as power station switchgear, making efficient use of available space.

In a GIS system, all energized or live parts are enclosed inside a grounded metallic encapsulation, which shields them from the environment. Compressed SF6 gas, which has

excellent dielectric properties, is used as the insulating medium between the live parts and the enclosure. Early designs of GIS followed a cautious approach and complete segregation of the three phases i.e. separate chambers were provided for each functional component such as circuit breakers, current transformers etc., of each phase. However, after gaining sufficient service experience and ability to maintain dielectric integrity three phases in one or phase integrated modules are now available. The three phase's construction has the added advantage of having only a reduced number of gas and moving parts. Gas insulated substations occupy only about ten percent of the space required by conventional substations. They also offer saving in land area and construction costs. Their modular design provides higher degree of flexibility in the substation layout and efficient use of space. These substations can be located closer to load centers thereby reducing transmission losses and expenditure in the distribution network. Since they are hermetically sealed units and hence are not affected by atmospheric contamination. As associated costs are reduced, when designing typical cases for which GIMES offers a more economic solution are following:

- a) Urban and industrial areas (space, pollution)
- b) Mountain areas (site preparation, altitude)
- c) Coastal areas (salt associated problems)
- d) Underground substations.
- e) Areas where aesthetics are of major concern.

However, a transition from air insulated to gas insulated technology should require recognition of certain aspects with respect to design. The bus scheme, for example, used for GIMES is quite different from what is used for AIS. In GIS, enclosure is the nearest earth surface with respect to the conductor. Therefore switching devices in metal enclosed systems have to fulfill their duties under conditions, which are different from those prevailing in conventional systems. More clearly, they are influenced by their close spatial neighborhood in the form of electrostatic interactions.

The switching device considered under the current study is a disconnecting switch (DS). Several of which are generally present in a GIS.

High frequency surges are generated in GIS during the operation of disconnectors. These are steep fronted oscillatory over voltages in the frequency ranges of several Mega hertz and known as Very Fast over Voltages (VFO). It is necessary to investigate the level of over voltages in order to assess their effect on the insulation characteristics of GIS. Even though the dielectric strength of a clean GIS may be adequate under clean conditions, under particle contaminated conditions, the dielectric strength for over voltages may become lower resulting in bus-bar to enclosure flashovers.

2.1 Generation of Very Fast Transient over Voltages (VFTOs) in a GIS

Fast transient over voltages in GIS are mainly due to two reasons

1. Disconnecter switch operation
2. Faults between bus bar and enclosure

Very fast transient over voltages (VFTOs) occur in Gas Insulated Substation (GIS) due to the operation of the disconnecter switch. It has very short rise time of less than 5ns, and an oscillatory component of several MHz lasting for few microseconds. There are concerns about a possibility that the VFTOS sets of a resonance in the winding of the transformer in the system, particularly if the transformer is connected to the GIS through a gas insulated bus.

The voltage oscillations in transformer winding have always been troublesome. Using the concept of 'on-resonance' or 'surge-proof' transformer, it is intended to suppress the oscillations by controlling the initial voltage distribution or capacitive voltage distribution. The device works against ordinary lightning impulses, but it may not necessarily be effective for oscillatory pulses such as VFTOs originated in GIS. It is of prime importance to investigate the underlying mechanism of VFTOs phenomena in the transformer and to provide a means to accurately predict the over voltages in the winding.

Two kinds of induced voltages are reported in transformers, one is high frequency component induced electro statically and the other is lower frequency component traveling along the winding. Initially this phenomenon was analyzed using simple ladder circuit network model.

They have showed that the inter turn voltage can be explained by a simple transmission line model. They have developed a generalized analytical method applying the single transmission line model. They have successfully applied this model to the VFTOs phenomena in transformer winding. Since the analysis requires a large scale computation, they have limited the computation area by the use of a terminal admittance representing the rest of the winding. Most of the time over-voltages cause a flashover from the winding to core or between the turns. The inter turn voltage is particularly vulnerable to the high frequency oscillation and therefore the study of over voltages is of interest. The VFTOS produced by switching in GIS depend not only on connection between the GIS and transformer, but also on the transformer parameters and type of the winding.

The basic function of disconnecting switches is to isolate sections of a GIS for ensuring safety of the operations. In the process of isolations, trapped charges may be left on certain sections of the GIS on the capacitance to ground sections, resulting in large differential voltages across the disconnecting switches and also in the presence of AC-DC conditions across the poles of the switches. A switching operation such as re-energisation under such condition leads to switching charging current results in steeper oscillations which travel through the components of the system and suffer multiple reflections. These surges may cause internal flashovers to nearby grounded objects. Therefore over-voltages generated in GIS is a major parameter to be considered in insulation designs as it has bearing on many vital components of the installation such as insulating spacers, bushings, transformers etc. The electromagnetic interference (EMI) caused by over-voltages in electronic control circuitry is another problem to reckon with. For the above reasons, VFTOS generated in a GIS should be considered as an important factor in the insulation design. For designing a substation it is essential to know the maximum value of VFTOs. the presented study in this paper has been carried for the estimation of VFTOs and is analyzed by using wavelet transform for better mitigation methods of VFTOs

2.2 Wavelet Transform

A wavelet is a mathematical function used to divide a given function or continuous-time signal into different scale components. Usually one can assign a frequency range to each scale component. Each scale component can then be studied with a resolution that matches its scale. A wavelet transform is the representation of a function by wavelets. The wavelets are scaled and translated copies (known as "daughter wavelets") of a finite-length or fast-decaying oscillating waveform (known as the "mother wavelet"). Wavelet transforms have advantages over traditional Fourier transforms for representing functions that have discontinuities and sharp peaks, and for accurately deconstructing and reconstructing finite, non-periodic and/or non-stationary signals.

Wavelet transforms are classified into discrete wavelet transforms (DWTs) and continuous wavelet transforms (CWTs). Note that both DWT and CWT are continuous-time (analog) transforms. They can be used to represent continuous-time (analog) signals. CWTs operate over every possible scale and translation whereas DWTs use a specific subset of scale and translation values or representation grid.

There are a large number of wavelet transforms each suitable for different applications. For a full list see list of wavelet-related transforms but the common ones are listed below:

- Continuous wavelet transform (CWT)
- Discrete wavelet transform (DWT)
- Fast wavelet transform (FWT)
- Lifting scheme & Generalized Lifting Scheme
- Wavelet packet decomposition (WPD)
- Stationary wavelet transform (SWT)
- Fractional Fourier transform (FRFT)
- Fractional wavelet transform (FRWT)

In this thesis, predominantly continuous wavelet transform, discrete wavelet transform, Mexican wavelet transform and Coif Let wavelets have been employed for very fast transient over voltage (VFTO) analysis in GIS substations or

transformers. Here the prime cause of using wavelet transform is the robustness for analysis in time as well as frequency domain. It is clear that any non-stationary signal can be analyzed with the wavelet transforms. Wavelet Theory is the mathematics associated with building a model for a non-stationary signal, with a set of components that are small waves, called wavelets. Informally, a wavelet is a short-term duration wave. These functions have been proposed in connection with the analysis of signals, primarily transients in a wide range of applications.

2.3 Continuous Wavelet Transform (CWT)

The continuous wavelet transform (CWT) was developed as an alternative approach to short time Fourier transform (STFT). The continuous wavelet transform is defined as follows:

$$CWT(b, a) = \int f(t) \psi_{b, a}^*(t) dt$$

Where * denotes complex conjugation. This equation shows how a function $f(t)$ is decomposed into a set of basic functions $\psi_{b, a}(t)$, called the wavelet, and the variables 'a' and 'b', scale and translation, are the new dimensions after the wavelet transform.

The inverse wavelet transform of the above is given as

$$f(t) = \iint CWT(b, a) \psi_{b, a}(t) db da$$

The wavelets are generated from a single basic wavelet $\psi(t)$, so-called mother wavelet, by scaling and translation:

$$\psi_{b, a}(t) = 1/\sqrt{a} \psi(t - b/a)$$

In above mentioned equation, 'a' is the scale factor, 'b' is the translation factor and the factor $1/\sqrt{a}$ is for energy normalization across the different scales.

There are some conditions that must be met for a function to qualify as a wavelet:

- Must be oscillatory
- Must decay quickly to zero (can only be non-zero for a short period of the wavelet function).

- Must integrate to zero (i. e., the dc frequency component is zero)

These conditions allow the wavelet transform to translate a time-domain function into a representation that is localized both in time (shift or translation) and in frequency (scale or dilation). The time-frequency is used to describe this type of multi resolution analysis. The selection of the mother wavelet depends on the application. Scaling implies that the mother wavelet is either dilated or compressed and translation implies shifting of the mother wavelet in the time domain. The most important properties of wavelets are the admissibility and the regularity conditions and these are properties, which gave wavelets their name. It can be shown that square integrable function $\psi(t)$ satisfying the admissibility condition,

$$\int \frac{|\psi(\omega)|^2}{|\omega|} d\omega < +\infty$$

can be used to first analyze and then reconstruct a signal without loss of information. $\psi(\omega)$ stands for the Fourier transform of $\psi(t)$. The admissibility condition implies that the Fourier transform of $\psi(t)$ vanishes at the zero frequency, i.e.

$$|\psi(\omega)|_{\omega=0}^2 = 0$$

This means that wavelets must have a band-pass like spectrum. This is a very important observation, which has been used to build efficient wavelets transform.

A zero at the frequency (ω) also means that the average value of the wavelet in the time domain must be zero,

As can be seen from the above derived mathematical expression, the wavelet transform of a one-dimensional function is two-dimensional; the wavelet of a two-dimensional function is four dimensional, the time-bandwidth product of the wavelet transform is the square of the input signal and for most practical applications this is not a desirable property. Therefore, one imposes some additional conditions on the wavelet functions in order to make the wavelet transform decrease quickly with decreasing scale 'a'. These are the reliability conditions and they state that the wavelet function should have some smoothness and concentration in both time and frequency

domains. Regularity is complex concept.

2.4 Discontinuous wavelet Transform

The wavelet transform can be accomplished in two different ways depending on what information is required out of this transformation process. The first method is a continuous wavelet transform (CWT), where one obtains a surface of wavelet Coefficients, $CWT(b,a)$, for different values of scaling 'a' and translation 'b', and the second is a Discrete Wavelet Transform (DWT), where the scale and translation are discretized, but not are independent variables of the original signal. In the CWT the variables 'a' and 'b' are continuous. DWT results in a finite number of wavelet coefficients depending upon the integer number of discretization step in scale and translation, denoted by 'm' and 'n'. If a_0 and b_0 are the segmentation step sizes for the scale and translation respectively, the scale and translation in terms of these parameters will be

$$a = a_0^m \text{ and } b = b_0 a_0^m$$

$$\psi_{b,a}(t) = 1/\sqrt{a}\psi(t - b/a)$$

The above presented equation represents the mother wavelet of continuous time wavelet series. After discretization in terms of the parameters, a_0 , b_0 , 'm' and 'n', the mother wavelet can be written as:

$$\psi_{b,a}(m,n) = 1/\sqrt{a_0}\Psi(t - \frac{nb_0 a_0^m}{a_0^m})$$

$$\psi_{b,a}(m,n) = a_0^{m/2}\psi(ta_0^{-m} - nb_0)$$

After discretization, the wavelet domain coefficients are no longer represented by a simple 'a' and 'b'. Instead they are represented in terms of 'm' and 'n'. The discrete wavelet coefficients DWT (m, n) are given by equation:

$$DWT(m,n) = a_0^{m/2} \int_{-\infty}^{+\infty} f(t)\psi(ta_0^{-m} - nb_0)dt$$

The transformation is over continuous time but the wavelets are the transformation is over continuous time but the wavelets are represented in a discrete fashion. Like the CWT, these discrete wavelet coefficients represent the correlation between the original signal and wavelet for different combinations of 'm' and 'n'.

Table1. Voltage peak without Ferrite Ring in P.u

Transformer	Conventional V- Peak (P.u)	With wavelet Transform V -Peak (P.u)
At Primary	1.34	1.466
At Secondary	1.36	1.4759

Table2. Voltage peak with Ferrite Ring in P.u

Transformer	Conventional V -Peak (P.u)	With wavelet Transform V- Peak (P.u)
At Primary	1.12	1.223
At Secondary	1.09	1.156

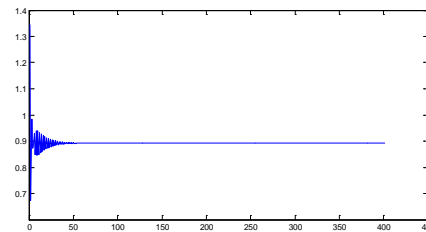


Figure 3.1.Voltage peak at Primary of Transformer without ferrite ring.

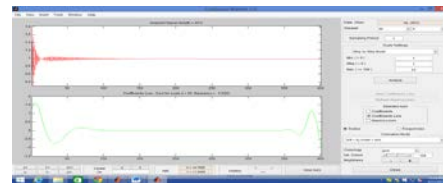


Figure 3.2.Voltage peak at Primary of Transformer without ferrite ring with wavelet Transform

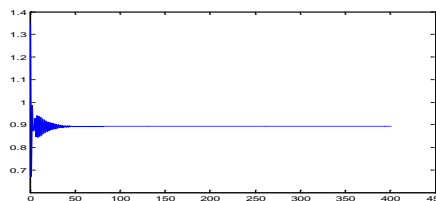


Figure 3.3.Voltage peak at secondary of Transformer without ferrite ring

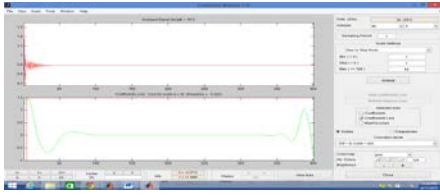


Figure 3.4. Voltage peak at secondary of Transformer without ferrite ring with wavelet transform

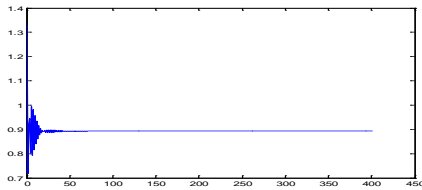


Figure 3.5. Voltage peak at Primary of Transformer with ferrite ring

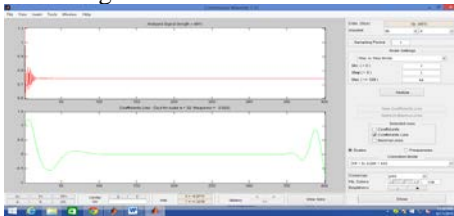


Figure 3.6. Voltage peak at Primary of Transformer with ferrite ring with wavelet Transform.

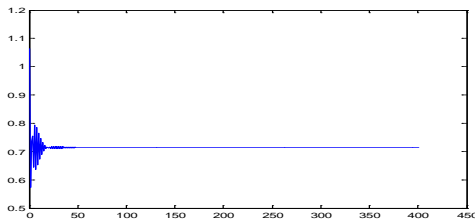


Figure 3.7. Voltage peak at secondary of Transformer with ferrite ring

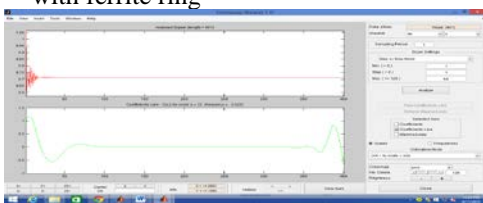


Figure 3.8. Voltage peak at secondary of Transformer with ferrite ring with wavelet transform.

4. Conclusions

In This paper the power transformer has been designed by using Mat Lab software simulink platform for accurate results of Very Fast Transient

over Voltages VFTOs. In the mitigation and analysis process, the disconnecter and ferrite ring were introduced along with the power transformer. This system has been simulated for the very Fast Transient over Voltages VFTOs generated with and without ferrite ring and is compared. This system has been simulated for VFTOs and the result is analyzed with continuous wavelet transform (CWT) with the family of Debauchee at level 4 (Db4). The simulated results with and without ferrite ring as well as with and without wavelet transform are shown in figure from 3.1 to 3.8. The voltage peak at the primary and secondary of the transformer with and without wavelet transform are analyzed and is tabulated in table 1. By the implementation of ferrite ring it is observed that the peak value of the very fast transient over voltages have been considerably reduced. The peak values are again analyzed with wavelet transform and is compared with conventional. By the implementation of wavelet transform it is again proved that wavelet transform gives an accurate value compared to convention and is shown in table 1 and 2 respectively. Although ferrite ring damping the VFTOs to a considerable level of peak it has its disadvantage that at very high frequencies the ferrite ring may saturate.

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