

GIS Disconnecter Switching Operation

– VFTO Study

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Abstract— Very Fast Transient overvoltages (VFTO) in power systems are result of switching operations such as disconnector opening and closing inside GIS substation. The VFTO causes great threat to the insulation of the high-voltage equipment (e.g. bushings or windings of transformers). These transients are associated with very short rise times in the nanoseconds range, and are normally followed by oscillations having the frequency spectrum well above several MHz. In the present paper simulation results of the VFT overvoltages at the transformer terminals, resulting from a disconnector switching operations in a typical GIS substation are presented. In a common approach used for insulation coordination study, typically a single re- or prestrike in the disconnector is analyzed. In the presented paper an advanced model of the GIS disconnector is involved. The new model enables the analysis of multiple re- or prestrikes generated during the operation of the device. This in turn allows one to analyze the impact of the repetitive phenomenon on the HV equipment. The simulation results with use of high-frequency power network components were performed using the ATP/EMTP program.

Keywords-Gas Insulated Substation, Very Fast Transient, Disconnector switching, modelling, simulation, ATP/EMTP

I. INTRODUCTION

Gas Insulated Substations (GIS) have found a broad range of applications in power systems because of their high reliability, easy maintenance, small ground space requirements etc. It has been shown that operations of disconnector switches and breakers can cause Very Fast Transient overvoltages (VFTO), tip of which is very steep accompanied with high frequency oscillation. VFTO not only influence the operating reliability of GIS, but also causes great threat to the insulation of the high-voltage equipment, especially to windings of the transformer [1].

The VFTO in power systems cover a frequency range from 100 kHz to 100 MHz. VFT arises within GIS due to various operations, any time causing an instantaneous change in voltage. Most often this change occurs as a result of opening or closing of disconnector switch, but other events such as operation of a circuit breaker, the closing of a grounding switch or the occurrence of a fault can also cause VFT. These transients generally have a very short rise time in the range of 2 to 100 ns, and are normally followed by oscillations having the frequencies in the range of 1 to 100 MHz. Their magnitude is

in the range of 1.5 to 2.0 p.u. of the line-to-neutral voltage crest, but they can also reach values as high as 2.5 p.u. These values are generally below the BIL of the GIS and connected equipment of lower voltage classes. VFT in GIS are of greater concern at the highest voltages, for which the ratio of the BIL to the system voltage is lower.

II. GAS INSULATED SUBSTATION MODELING

For certain switching conditions where GIS disconnectors are operated following circuit breaker operation it is possible to generate VFTO, which act as travelling waves and propagate within and external to the GIS.

Due to the travelling wave nature of the VFT the GIS elements were modeled as electrical equivalent circuits composed of distributed parameter lines (defined by surge impedance and travelling times) as well as lumped elements. In order to achieve reliable simulation results the GIS was subdivided into several shorter sections.

TABLE I. EXAMPLE OF GIS COMPONENTS TO BE MODELED

GIS component		Modeling parameter
circuit breaker	closed	distributed transmission line
	open	distributed transmission line in series with grading capacitor
disconnecter	closed	distributed transmission line
	open	distributed transmission line in series with capacitor (contact gap)
earthing switch	open	lumped capacitor to earth
cone insulator, line bushing, power transformer with line bushing, voltage and current transformer		lumped capacitor to earth
busbar		distributed transmission line
overhead line		infinite line terminated by surge impedance of the line

In its simplest form and for the purpose of modeling, the GIS installation can be regarded as series of distributed

transmission lines and lumped capacitor elements. The values of each GIS section can be calculated from the standard formula of capacitance and inductance, treating the GIS as a concentric conductor.

The lumped capacitance values applicable to the insulators, busbars, line bushings etc., can be determined from first principles using the manufacturer’s drawings and technical component data for a specific type of equipment.

In order to model various switching configurations it is necessary to consider modeling disconnectors and circuit breakers in both open and closed positions. The modeling of the GIS is therefore a combination of distributed and lumped parameters, as it is summarized in Table I (also reported in e.g. [2, 3]).

III. SIMULATION SET-UP

For the VFT study a typical GIS substation layout has been taken into consideration. Its single line diagram is shown in Fig. 1. For that diagram, a complete ATP/EMTP model has been developed according to the description given in sec. II (Fig. 2).

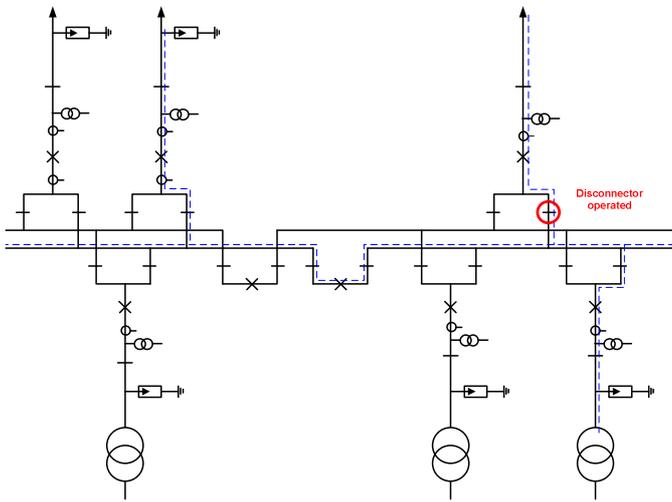


Figure 1. Single line diagram of a typical HV GIS substation with marked calculated configuration

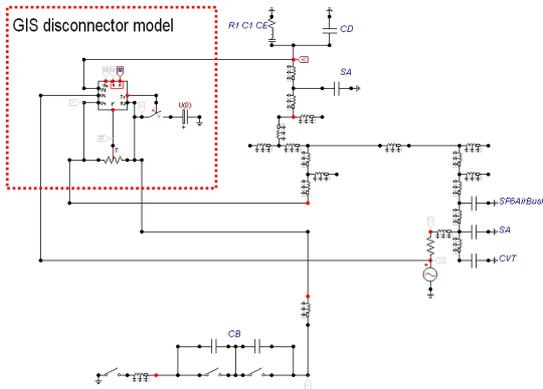


Figure 2. Complete ATP/EMTP simulation model for VFT phenomenon study – new GIS disconnector model applied (more in paragraph IV)

Due to the already stated random nature of the trapped charge at the commencement of a disconnector opening (or closing) and its direct affect on the resulting magnitude of VFTO, the studies have been carried out not only on the worst case scenario, i.e. 1.0 p.u. trapped charge, but also for other levels of trapped charge.

IV. DISCONNECTOR MODEL

A. Common approach – single spark model

The common approach which is in use for the purpose of VFT modeling due to disconnector switching involves only a single spark model, as it is widely reported in the literature (e.g. [4, 5]). In such an approach, the assumption of the so called worst-case analysis is being made, in which only the spark of maximum amplitude is taken into account (i.e. the last one for breaking and the first one for making operation). The spark resistance is modeled by the exponential formula [2]:

$$R = R_a + R_0 \cdot e^{-t/\tau}, \quad (1)$$

where: R_a – arc resistance, R_0 – resistance of the gap while disconnector is opened, τ – time constant leading to the spark duration specific for the breakdown in SF_6 .

B. New disconnector model

For the purpose of simulations presented in the paper, a new disconnector model has been developed. In the model, not only one spark, but the whole process including many re- or prestrikes has been incorporated.

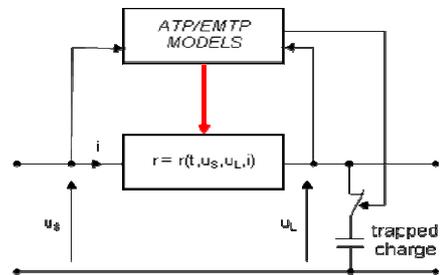


Figure 3. EMTP model of disconnector; u_s – source side voltage, u_L – load side voltage

The main idea of the model is based on the concept previously applied for modelling of Vacuum Circuit Breaker, as it is presented in e.g. [6]. The concept (Fig. 3) is to control the nonlinear resistance using the MODELS tool of the EMTP program [7]. By means of the control procedure, a decision is being made whether the spark is to be ignited or extinguished in order to produce the VFT phenomenon of interest. The decision is based on the values of potentials on source and load side of the disconnector, which are compared with the withstand voltage of the contact gap. The withstand voltage is calculated in each simulation step on the basis of moving contact velocity (obtained from mechanical characteristics of the disconnector) and the rated power frequency withstand

voltage across isolating distance. Trapped charge is modeled by additional capacitance, which is triggered by the ideal switch so that it does not influence the travelling wave phenomenon constituting VFT.

A detailed description of the model together with simulations performed for the purpose of its verification (based both on theoretical analysis and Test Duty measurements) is presented in [8].

V. SIMULATION RESULTS

A. VFT and VFTO waveforms

In Fig. 4, the VFT waveforms are shown for breaking and making operation of disconnector in the GIS under consideration. Common step-wise patterns of the load side voltage, as well as a so called falling pattern (which is due to contacts asymmetry) are visible. It can be noticed that for the breaking operation (Fig. 4a) the amplitude of VFT is very close to 1 p.u. However, for the making operation with the trapped charge -1 p.u. (Fig. 4b) it is clearly visible that not only one prestrike has significant amplitude, but at least few of them. The corresponding waveforms of VFT overvoltages appearing at transformer terminals due to disconnector operations are depicted in Fig. 5.

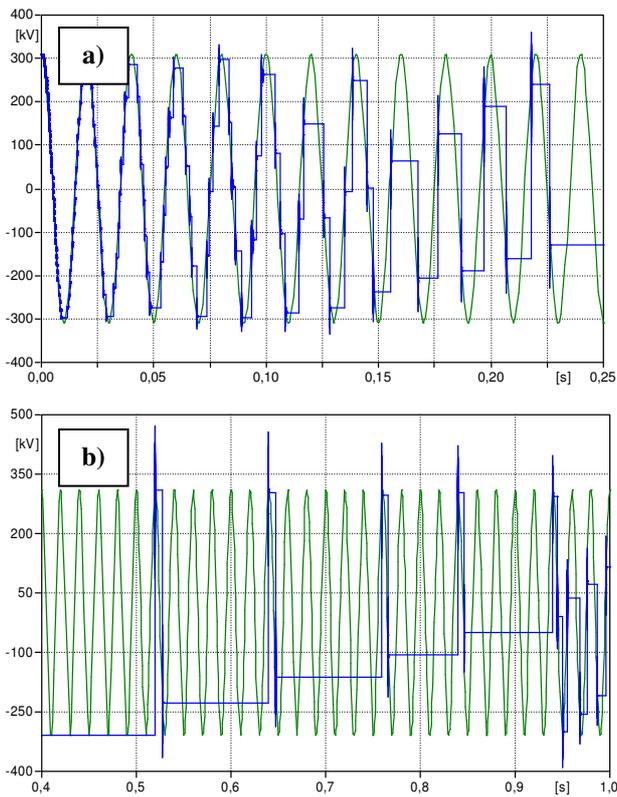


Figure 4. VFT due to disconnector switching – source side voltage (continuously alternating) and load side voltage (step wise) for: a) **breaking** (restrikes), b) **making** (prestrikes) operation at disconnector terminals

B. Quantitative measure of VFT

As it was already mentioned, the most significance of VFT phenomenon is related to the impact which is imposed on the HV adjacent equipment, such as bushings or transformers. Hence, not only the amplitude of the ‘worst-case’ VFT is of importance, but also other parameters of VFT can play an important role, especially those which are related to some cumulative aging effect on an insulation material of the adjacent equipment. This leads to the need for providing a measure by which the VFT phenomenon would be expressed quantitatively.

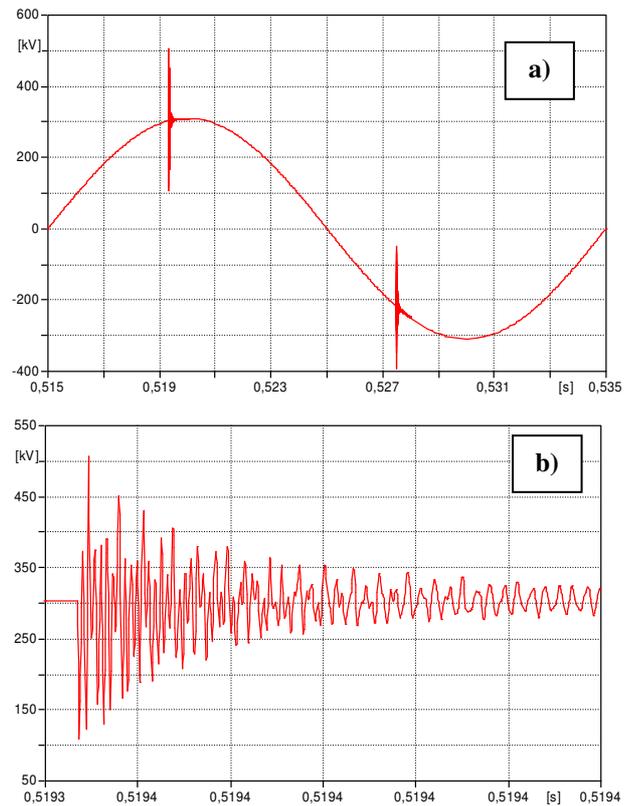


Figure 5. Very Fast Transient Overvoltages at transformer terminals: a) two selected sparks, b) view of the first spark magnified

In presented paper, such a measure has been provided. A particular VFT waveform has been characterized by a total number of sparks occurring during the whole process of contact movement of disconnector. Also, the number of sparks of certain amplitudes has been counted for each process. The ‘dot plots’ demonstrating the VFT phenomenon for breaking and making operation are depicted in Fig. 6, 7. The amplitudes of the most significant VFTO have been depicted for each operation (i.e. last 50 for breaking and first 100 for making) against the peak amplitude of the source voltage (which is assumed as 1 p.u., $1 \text{ p.u.} = V_r \cdot \sqrt{2}/\sqrt{3}$).

C. VFT analysis

Based on the “dot plots”, the two histograms of VFTO amplitudes have been obtained, as depicted in Fig. 8, 9. In Fig. 9, the total number of overvoltages is presented for breaking operation as well as for four cases of making operation characterized by different levels of trapped charge: -1 p.u., -0.5 p.u., -0.15 p.u. and zero. In Fig. 9 a number of overvoltages of certain amplitude for above mentioned cases is shown.

A total number of sparks, and hence – a total number of VFTO, depends of the type of disconnector operation, whether it is breaking of making (Fig. 8). For the making operation the total number of sparks is approximately 4 times larger than it is for the making operation, no matter how large the trapped charge is while the making operation is performed.

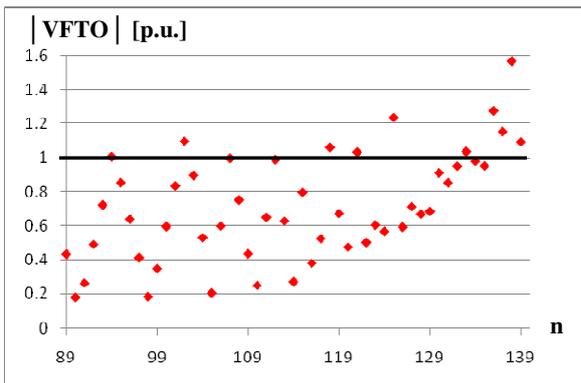


Figure 6. Very Fast Transient Overvoltages for **breaking** operation (restrikes) at transformer terminals, last $n = 50$ sparks

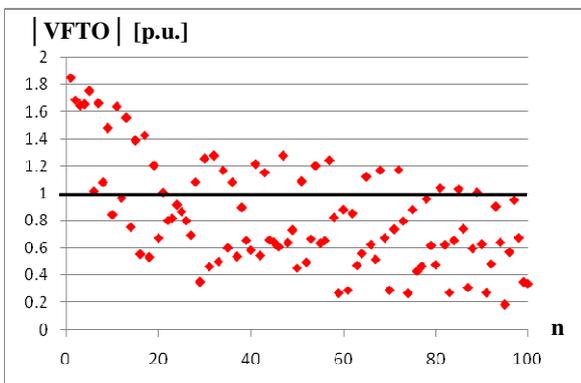


Figure 7. Very Fast Transient Overvoltages for **making** operation (prestrikes) at transformer terminals, first $n = 100$ sparks; trapped voltage = -1 p.u

As it was expected, the total number of sparks decreases with the decrease of the trapped charge while the making operation is performed. However, the reduction is not significant, namely from 421 sparks at -1 p.u. of trapped charge to 391 sparks at the common level of trapped charge equals -0.15 p.u.

The number of sparks of certain amplitude (i.e. those of 1.0÷1.5 p.u. vs. those 1.5÷2.0 p.u.) depends on the type of disconnector operation in a very similar way as the total number of sparks does (Fig. 9). It is also larger for the making than for the breaking operation and decreases with reduction of the trapped charge for the making operation. However, the number of overvoltages of significant amplitude notably decreases when the trapped charge is small.

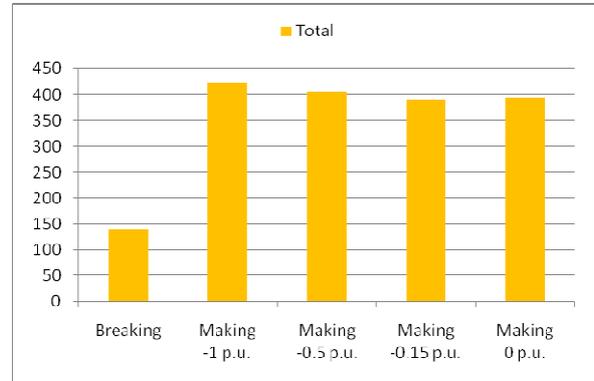


Figure 8. Total number of sparks for breaking and making operations; with different levels of trapped charge for making operation

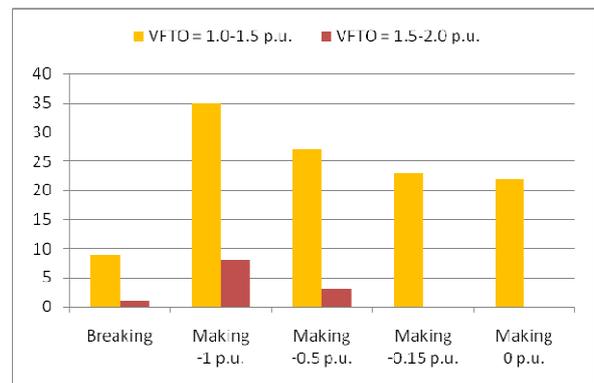


Figure 9. Number of sparks of a certain amplitude for breaking and making operations; with different levels of trapped charge for making operation

VI. SUMMARY AND CONCLUSIONS

Very Fast Transient overvoltages study has been presented in the paper, based on a typical High Voltage Gas Insulation Substation. The study has been performed with use of the newly developed model of disconnector, in which not only the worst case, but the whole process of VFT has been modeled.

It was confirmed that the Very Fast Transients exceed neither BIL (Basic Lightning Impulse Insulation Level) nor BSL (Basic Switching Impulse Insulation level), hence the existing protection system of GIS, such as surge arresters, is completely transparent for this phenomenon. Therefore, VFT can stress high voltage equipment (such as bushings and/or transformers). Therefore, the following parameters of the phenomenon are of importance: amplitude of the worst case overvoltage, total number of sparks during the whole process,

number of sparks that lead to overvoltages of significant amplitude, frequency of sparks occurrence (since it can match the resonant frequency of bushings or transformers).

The study presented in the paper concentrates on VFT parameters related to the numbers: the total number of sparks and the number of sparks that lead to overvoltages of significant amplitude. Simulations have been performed with use of the model of a very typical GIS substation, based on the state of art of GIS modelling.

Not only one spark, but the whole VFT phenomenon is of importance due to the above mentioned features of VFT impact on high voltage equipment. One of a possible measure of VFT has been presented in the paper.

The new approach based on the analysis of the entire switching operation process allows one to assess quantitatively the overall impact of the switching process on the adjacent equipment.

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