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EFFECTS OF ARC MODEL AND TRAPPED CHARGE ON VERY FAST TRANSIENT OVER VOLTAGE IN GIS

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ABSTRACT

Gas insulated substations (GIS) are hit by short rise-time transients, when a C.B, load break switch or a discount switch (isolator) is operated. These transients have very short wavefront duration (5-15) ns, considerable high frequency (from KHz to MHz) and relatively lower amplitudes (< 2p.u). Among these characteristics, their short wavefront duration is the most damaging one, that is why these transients are termed as Very Fast Transients Overvoltages (VFTO). As disconnect switch operation is the dominant source of these transients, therefore, in this paper only discount switch produced VFTO are discussed.

This paper studies he influences of variation of, the GIS system parameters on the severity of these transients. These two parameters are arc resistance and trapped charge. A typical GIS with a small number of elements has been considered. Fast Fourier Transform solution technique is applied through a specially devised computer program (Ahmad 1998), in FORTRAN language, on this GIS network to assess the patterns of voltages produced at different locations due to variations in arc resistance and trapped charge.

INTRODUCTION

In the study of influences of GIS parameters on very fast transients, parameters like spacers, arc resistance, spark collapse time trapped charges, short bus stubs, skin effect and such other parameters are usually considered. In this paper the effects of arc resistance and trapped charge are considered only. As far as the arc developed at the terminals of a disconnect switch is concerned, most of the previous work considers it sufficient to incorporates only a constant resistance at the point of arc to get the results. But as a matter of fact, arc resistance does vary with time during the process of prestriking or restriking at the disconnector. In this study both the time-invariant arc resistance models are considered.

Trapped charge (voltage left on the part of a GIS which is disconnected through a disconnector from an energized part of an electrical system) is another major parameter which directly defines the extent of magnitude of the overvoltages developed in GIS.

ARC RESISTANCE MODELS AND THEIR INCLUSION IN THE ANALYSIS

It has been observed from the previous research that its is very important to include the arc resistance in consideration while performing fast transient analysis of GIS. The problem is the selection of a proper and precise model of the arc resistance. A number of

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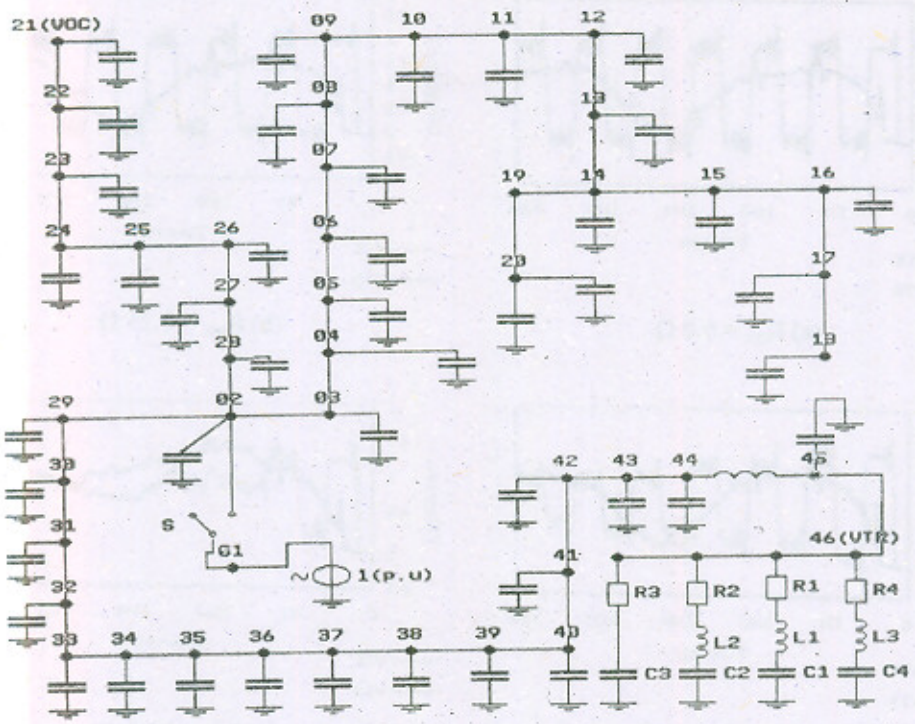
different publications have been consulted for finding out the different models/values of arc resistance considered by different scientists and researchers.

According to one of these studies, the arcing can sufficiently be simulated by a constant residual arc resistance of approximately 1 to 3 ohms (Boeck 1987). In another publication the initial collapse across the disconnector gap has been modeled by a time-varying resistance derived from Toepler law (Uglesis 1989).

According to the publication (Ogawa 1986) variations of the peak value of the surge voltage caused by the existence and the non-existence of 2Ω is appoximately 0.1 p.u. (i.e. 10%), according to the calculations. Another study suggests that simulation of the arc is an important parameter to be discussed. In a particular case examined, a simple resistor of about 1Ω are arc resistance results adequate (Pigini 1983).

After gong through different publications it is quite clear that the inclusion of arc resistance, in the calculation of fast transients developed in the GIS is important, in order to obtain realistic estimation of voltages developed in the GIS under fault conditions.

In the following networks, spacers are simulated by capacitors, and line sections and bus bars by their equivalent transmission lines. Transformer and bushing b their equivalent RLC and LC circuits respectively. Below node—46 is the transformer and above this is the bushing. Transient wave entering the GIS network due to the operation of a discount switch has been simulated by the injection of a unit-step voltage source connected at node-2. Patterns of voltages at node-21 (VOC) and at node-46 (VTR) are chosen for analysis.



Transformer

R1=20.5 (Ω), R2=29.5 (Ω), R3=22.5 (Ω), R4=300 (Ω), C1=0.77 (nF), C2=940 (pF), C3=1.25 (nF), C4=33.8 (pF), L1=4.02 (μH), L2=7.37 (μH), L3=55.5 (μH).

Values of R, L & Distances

Resistances between nodes 45-46=250 (Ω), 9-10 &10-11=70 (Ω) & between all others=110 (Ω). Inductance between nodes 44-45=0.1 (μH). Distance between nodes 45-46=1(m) while between all others=5(m). Capacitances at each node=30 (pF).

Figure 1. A typical GIS substation layout (Qureshi 1993)

ANALYSIS WITH TIME-INVARIANT ARC RESISTANCE VALUES

Inclusion of the arc resistance in the program is very simple, we insert a resistance "R_{arc}" in series with the equivalent circuit of the GIS network. The variation of the voltage (VOC & VTR) for different values of arc resistance, is shown in Fig.2.

RESULTS

From the present study it is observed the arc resistance is an important parameter, to be considered in the calculation of fast transients in GIS.

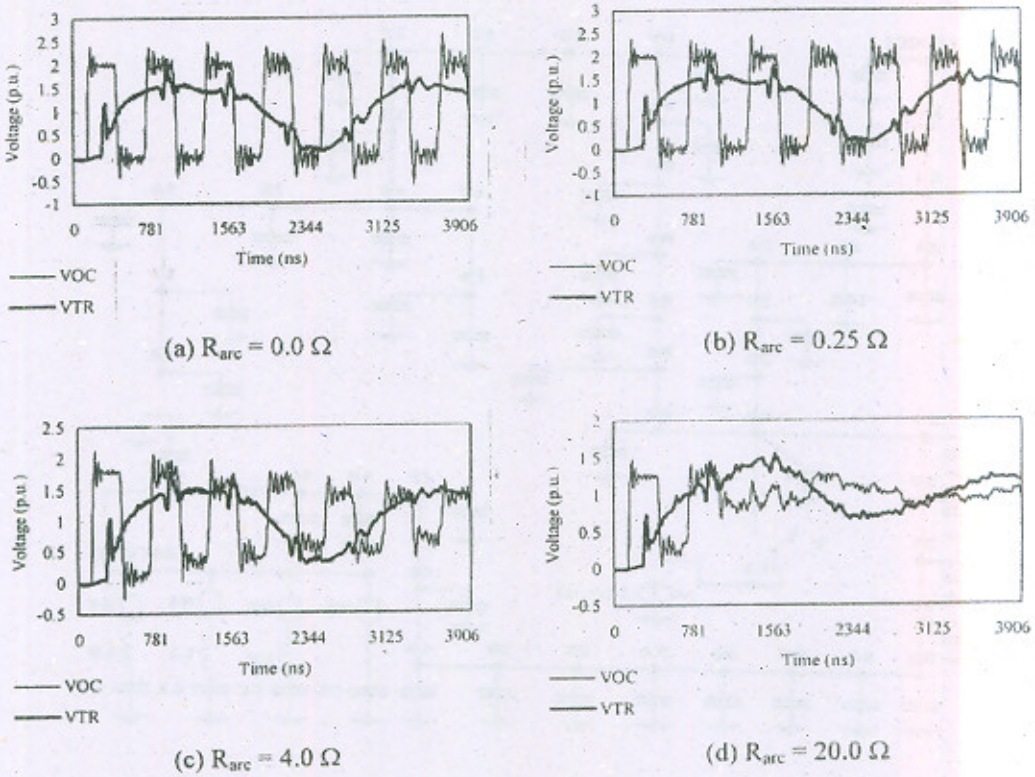


Figure 2. Variation of the voltages in GIS for different values of arc resistance, R_{arc}.

The variation in the arc resistance changes the pattern of the voltages (VOC and VTR) to a great extent if the resistance is varied from 0.0Ω to 20.0Ω. After going through the different recommendations for assigning the value of arc resistance to be included in the GIS analysis and observing the results obtained from our study, it seems that a value of 4.0Ω for the arc resistance (if time-invariant arc resistance model is considered), is good enough for reasonable approximate results.

ANALYSIS WITH TIME-VARIANT ARC RESISTANCE MODEL

Before assigning an exact time variant model of arc resistance, a relationship of variation of arc resistance with time is needed. The spark resistance on the place of breakdown was taken into account according to the Toepler law (Uglesic 1989):

$$R(t) = \lambda K_T / {}_0{}^t\!\int idt$$

Where λ = Spark length, and K_T = Toepler coefficient (0.4 * 10Vs/cm was taken in the calculations). It was observed that the spark resistance was 2.8Ω only 20 ns after the breakdown and after 7.5μs remained 0.05Ω (Uglesic 1989).

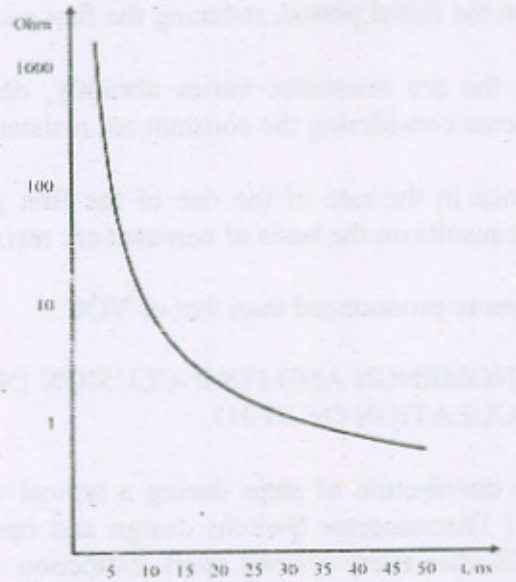


Figure 3. Proposed spark resistance curve (Uglesic 1989)

In one of the GIS fast transient studies, (Yanabo 1990) an arc resistance b etween 1Ω and 10Ω was assumed, but it was not sufficient to completely simulate the attention of measured waveform. Therefore, it was suggested that in order to have accurate results we must use time-variant arc resistance (Yanabo 1990).

A proposed model of variation of arc resistance with time is shown in Fig. 3 (Uglesic 1989).On the basis of this proposed curve, an attempt has been made to incorporate a time-variant arc resistance model for this analysis of fast transients in GIS. The wave form patterns are shown in Fig. 4.

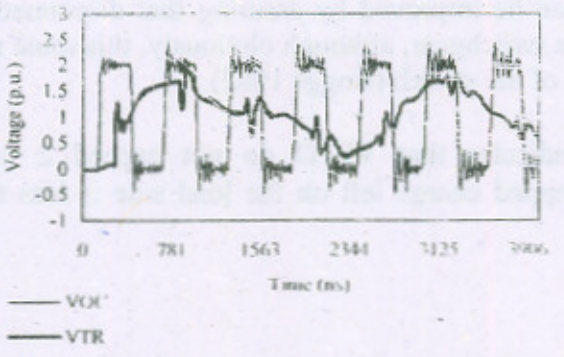


Figure 4. Plot of voltages considering time-variant spark resistance model

RESULTS

1. Arc resistance is active mainly in the initial period, reducing the first peak.

2. After the initial period, where the arc resistance varies abruptly, damping of the waveform is like that of the patterns considering the constant arc resistance.

3. There is no remarkable difference in the rate of the rise of the first peak either of VOC or VTR with respect to the results on the basis of constant arc resistance.

4. Damping, with time, in VTR is more pronounced than that of VOC.

TRAPPED CHARGE PHENOMENON AND ITS INCLUSION IN THE CALCULATION OF VFTO

The precise number and amplitude distribution of steps during a typical switching will depend firstly on the specific DS (Disconnector Switch) design and operating speed, secondly on the behavior of the GIS after every restrick spark extinction and thirdly on specific GIS functional procedures. The third case is only important in rare cases where a specific operational mode, involving the opening of a circuit breaker, can leave a floating busbar charged (Alvian 1989).

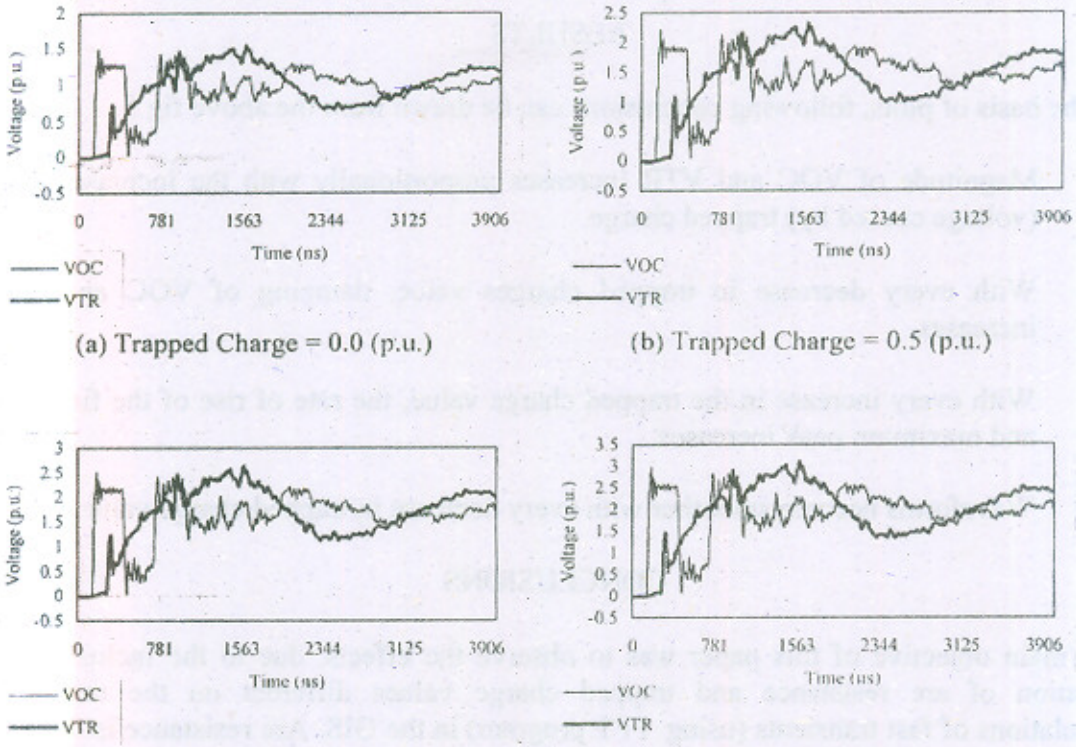
When a disconnect switch is opened on a floating section of switchgear, which is a common mode of operation, a trapped charge may be left on the floating section. The potential caused by

the trapped charge will normally decay very slowly (hour to days) as a result of leakages through (or across) spacers.

A trapped caused by 1 p.u. implies that the first breakdown upon the closing the disconnect switch will occur at 2 p.u. across the switch contacts and may lead to conductor-to-ground overvoltages of up to 2.5 p.u.

Switch gear reliability can be improved by assuring that disconnect switches minimize the trapped charge on the switchgear, although obviously, this must not be at the expense of the dielectric integrity of the switch (Boggs 1982).

Direct measurements indicates that VFTO do not exceed 2 p.u. at the point of measurement and the trapped charge left on the load side is less than 0.3 p.u. (Boggs 1982). In practice, a



(a) Trapped Charge = 0.0 (p.u.)

(b) Trapped Charge = 0.5 (p.u.)

(c) Trapped Charge = 0.7 (p.u.)

(d) Trapped Charge = 1.0 (p.u.)

Figure 5. Variation of the voltages in GIS for different values of trapped charge

Quick estimate is possible by assuming that a typical worst-case magnitude for the transient granted by the disconnector is 0.8 p.u. (relative to the peak ac voltage) which corresponds to DS inter contact breakdown voltages of 1.6 p.u. (trapped charge of 0.6 p.u., which is approximately the "worst case" for a typical DS and assumes equal impedance on either sides of the switch (Fujimoto 1987).

The estimate maximum FTO (Fast Transient Overvoltages) level resulting from measurement was 2.7 p.u., and an FTO of more than 2.0 p.u. appeared only at the open end of the busbar. On the contrary, FOT levels near the disconnectors operated were below 1.7 p.u.(Yanabo 1990). Under trapped charged conditions the amplitudes related to crest value of the a.c. operating voltage, phase-to-ground ranges normally up to 1.7 p.u. Only in rare cases this value exceeded and maximum amplitudes of 2.5 p.u. had been found (Boeck 1989).

Fortunately, however, for low speed DS of conventional design, the trapped charge left when opening a pure capacities load (busbar) gives remaining voltages ranging from 0.1 to 0.5 p.u. peaked around 0.3 p.u . This produces values of $\Delta\mu$ at first strike of 1.1 to 1.5 p.u. once again peaked around 1.3 p.u. Fast operating DS on the other hand can leave

trapped charge levels corresponding to 1.o p.u. in a non-negligible number of cases, giving rise to $\Delta\mu$ values up to 2.0 p.u (Alvian 1989). In this light of above references, the variation of the voltage in the GIS for different values of trapped charge conditions is observed in the following section.

RESULTS

On the basis of plots, following conclusions can be drawn from the above fig.5.

1. Magnitude of VOC and VTR increases proportionally with the increase in the (voltage caused by) trapped charge.

2. With every decrease in trapped charges value, damping of VOC and VTR increases.

3. With every increase in the trapped charge value, the rate of rise of the first peak and maximum peak increases.

4. Waveforms become smoother with every decrease in trapped charge value.

CONCLUSIONS

The main objective of this paper was to observe the effects, due to the inclusion and variation of arc resistance and trapped charge values different on the results of calculations of fast transients (using FFT program) in the GIS. Arc resistance is found to be an important parameter to be included in, the calculations of fast transients in GIS. Different models of arc resistance have been considered and the results are summarized as follows :

1. Variation in the arc resistance varies the peak values, of the voltages developed in different parts of GIS, quite apparently. These voltage peaks are found decreasing with increase in the arc resistance value.

2. Damping out of these voltages are found increasing with increase in the value of the arc resistance.

3. Rate of rise of voltages (dv/dt) decreases with increase in the value of arc resistance.

4. To simulate arc as a constant resistance was found insufficient to completely simulate the attenuation of the measured waveform. Therefore, it was suggested that in order to have accurate results we must use time-variant arc resistance (Yanabo 1990).

Another important parameter is trapped charge; which can be simulated by considering a

corresponding electric potential on the floating section of the busbar., The result in this regard are summarized as follows :

1. Magnitude of either VOC or VTR increases proportionately with the increase in the trapped charge, on the floating section of busbar and waveforms become smoother with every decrease in trapped charge value.

2. With every increase in the trapped charge value, the rate of rise of the first peak increase but the damping of VOC and VTR decreases.

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