550 kV GIS VFT Simulations as a Support for Transformer Design

P. Rohrbach paula.rohrbach@ch.abb.com
M. Lacorte[1] marta.lacorte@ch.abb.com
ABB-High Voltage Technology
Switzerland

J.C. Mendes jose.mendes@br.abb
C.M. Junior camilo@eln.gov.br
ABB-Div de Transformadores
Eletronorte
Brazil

Abstract - **A standard GIS disconnector is designed to switch a small capacitive charging current. As the contact velocity is low, a large number of reignitions occurs during a switching operation. Each reignition results in overvoltages with very high frequencies and magnitudes lower than those resulting from other switching operations. These are the so called very fast transients (VFT). VFT can place a dielectric stress on the transformer windings. Therefore, the transformer should be accordingly designed to withstand this stress.**
EMTP simulations considering different modeling were performed and compared with GIS disconnector switching laboratory tests for model validation.
This modeling together with a high frequency transformer model was used to estimate the stresses resulting from the VFT at the transformer.
It should be emphasized that the VFT is function of the actual GIS layout In this way, for specific transformer applications a VFT study might be a profitable input for the transformer design.
This paper presents the results of the simulations as well as the comparison with tests.
Above procedure has been shown to be effective and helpful tool for insulation coordination analysis and evaluation of the VFT voltage stresses on the HV terminal of the transformer directly connected to the GIS. These voltage stresses may be used for the transformer winding insulation design.

Keywords: Transient Analysis, Very Fast Transient, Modeling, EMTP, Transformer.

I. INTRODUCTION

Disconnector switch operations are often associated with high frequency transients (VFT's).
In the past a lot of experience was obtained with VFT's /1 and 2/. However, up to now VFT simulations and investigations have been focussed inside the GIS. Therefore, for GIS this phenomenon is well understood and it is considered as a parameter for GIS design.
However, most of the simulations have been carried out representing power transformers as a lumped capacitor.
The present work intends to show the effect of these transients on the transformer through VFT simulations together with a transformer high frequency model. In this way, the impulse transfer is simulated as well as the high voltage impulse at the transformer winding.
The work consists of two steps:

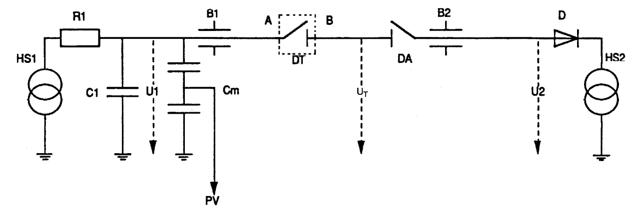
1. Validation of the GIS model for VFT simulations. The GIS model was adjusted through fitting the simulations results with test results.
2. Simulations with the validated GIS model connected to a high frequency transformer model.

The main aim of this study is to obtain a helpful tool to improve the transformer insulation design.

II. VFT MODEL ADJUSTMENT ACCORDING TO DISCONNECTOR LABORATORY TEST

In order to clarify this phenomenon, it is necessary to characterize more precisely the very fast transient overvoltage in a GIS. With this purpose and based on lab test results, a modeling for EMTP simulations was adjusted. The approach is shown and discussed in this paper.

1) Test Description: A Test Duty 1 /3/ Switching of a very short portion of bus duct – was performed in a High Voltage Laboratory by means of the test circuit in figure 1.



HS1,HS2	Transformers
C1, R1,D	Test Set
Cm	Voltage Divider 130pF
B1, B2	Bushing
DT	Disconnector under test
DA	Auxiliary Disconnector

Fig. 1. Test circuit for test duty 1 /3/

The voltage of the source side is $U1=U/\sqrt{3}=350kV$, while at the load source is U2=-494kV DC.

With the disconnector under test (DT) in the open position, the load side was charged by DC voltage for 1 minute via the closed auxiliary disconnector (DA). Before starting a closing operation, the DC voltage source was disconnected by DA.
A record of the VFT characteristic is shown in figure 2. The peak value of the transient voltage was 1.5 p.u. and the time to peak was less than 200ns.

[1]Marta Lacorte, ABB High Voltage Technologies, Brown Boveri Strasse 5, 8050 Zurich, Switzerland

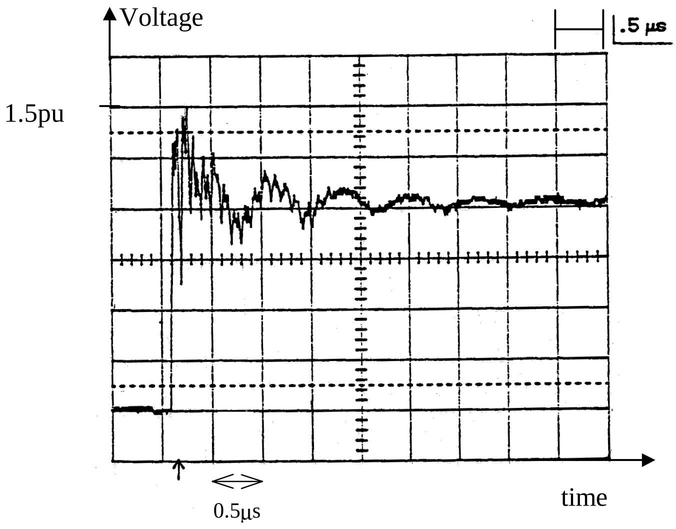


Fig. 2. Measurement of Very fast transient for test duty 1

2) EMTP Modeling: The best approach to the test measurements was achieved with the following modeling:

- **GIS busbar -** is modeled as a surge impedance of 60Ω with its associated length.
- **GIS Space Isolator -** is modeled as a capacitance of 10 pF.
- **Bushing -** On the test it was used a bushing with porcelain insulator. Therefore we modeled the grading shield as a capacitor in series with a resistor. This component leads to a reflection point side the GIS, which is taken into consideration using two different surge impedances for the bushing.
- **Capacitor and Voltage Divider** – they are modeled together according to /4/ as a series circuit of an inductor Li and a capacitor C with an ohmic part R. This connection is in parallel with the capacitance Cp.
- **Connection between capacitor and the bushing** – it is represented as a surge impedance of 500Ω with a corresponding length of 7m. The simulation equivalent circuit of the test shown in fig. 1 is presented in fig. 3.

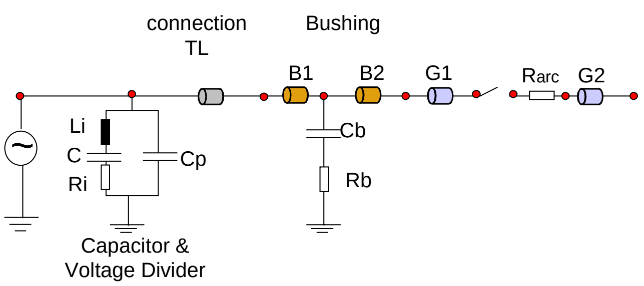


Fig. 3. Equivalent circuit for simulation

2) Comparison- Simulation x Measurement: The curve obtained by means of EMTP simulation is shown in fig. 4.a. The following evaluation shows the similarity to the test results (fig. 2):

- **Peak value –** the peak value of 1.42 pu was obtained here. In the measurements this value was up to 1.5pu.
- **End value -** The end value of the oscillations was around 1pu for test as well as for the simulation
- **Time to peak** – it was 230 ns for the simulation and 200ns for the test.

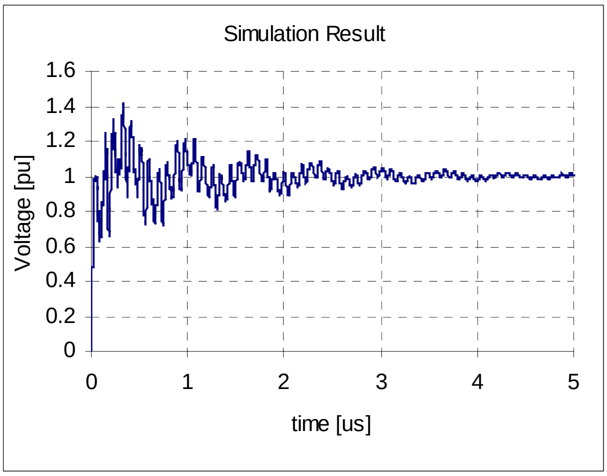
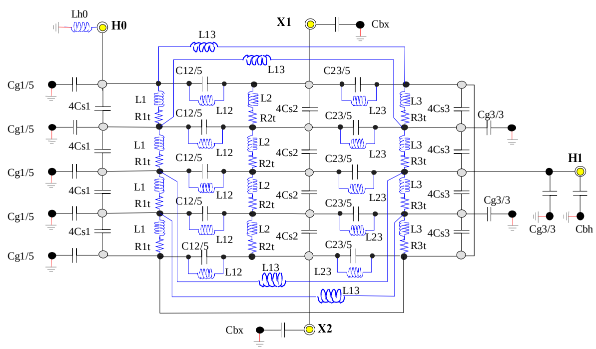


Fig. 4. VFT EMTP simulations.

III. TRANSFORMER STRESS ESTIMATION PROCEDURE

1) High frequency transformer model

The transformer is modeled in detail. The windings are represented through capacitances (series and parallel), inductances (self and mutual) and resistances (ohmic and equivalent). Fig. 5 shows schematically an example of a transformer high frequency model /5/. This model represents one phase. Therefore, for the triphase simulations, it is necessary three of this model, one for each phase. The points X1 nad X0 are the low voltage terminals and the points H1 and H0 are the high voltage terminals.



X1, X2 → low voltage side
H0, H1 → high voltage side

Fig. 5 - High frequency transformer model

2) *Procedure*

The procedure consists in performing EMTP simulations with the GIS model as presented in Item II together with transformer high frequency model (item III (1)). The GIS is connected to the point H1 and the generator to the point X1, for each phase.
The overvoltages in the transformer HV terminals, resulting from these simulations, are then used for more detailed analyzes of the transformer windings insulation design according to transformer manufacturer internal design programs. From this, local stresses in the insulation between adjacent turns and adjacent coils are evaluated and compared with local insulation withstand limits. Resonance effects are direct addressed, as frequency analysis is also included in the verification. Based on this integrated methodology, the transformer windings insulation design will be improved and also correlated to more specific stresses associated to system transients.

IV. APPLICATION TO AN ACTUAL GIS, NAMELY TUCURUÍ, BRAZIL

The procedure was applied to the transformer for the TUCURUÍ substation, ELETRONORTE, Brazil /5/. A schematic diagram of the substation is presented in fig. 6.

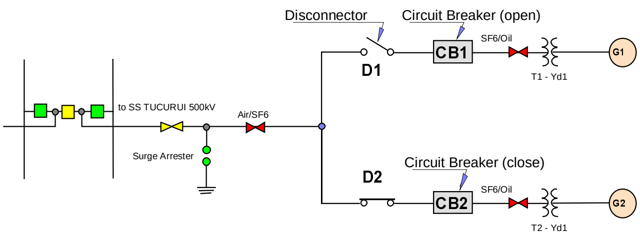


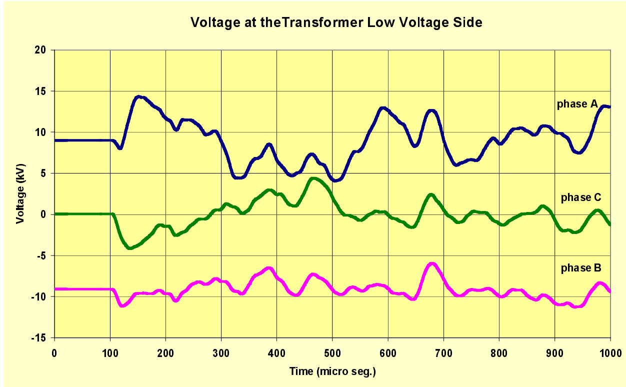
Fig. 6. Simplified Diagram for study

The disconnector D1 in fig. 6 is switched. The circuit breaker CB1 is open, therefore it is represented by its equalization capacitors. The voltage under investigation is the voltage at the transformer T2. This permitted us to model the transformer T1 as an equivalent capacitor, while for the transformer T2 the high frequency model (fig. 5) was applied.
The schmatic model shown in Fig. 6 is mono-phase, but the the simulations were performed considering a three-phase system. In this way the high voltage side and low voltage side connections were also simulated.
They are:

- High voltage side connections: Y
- Low voltage side connections: delta

The GIS was to the high voltage side connected, point H1 in Fig. 5. The generator is connected to the low voltage side, poit X1 in Fig. 5.
The resulted voltages at high and low transformer sides are shown in figs. 7 and 8 respectively.

Fig. 7. VFT Overvoltage at the high voltage side of the



transformer T2

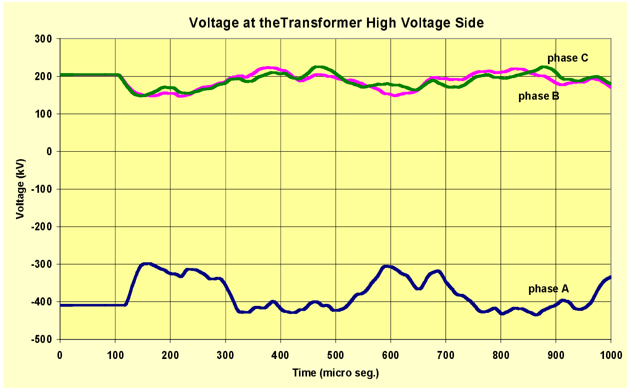


Fig. 8. VFT Overvoltage at the low voltage side of the transformer T2

The insulation level of the transformer is analyzed, improved and adjusted for Tucuruí project through manufacturer internal design programs using the overvoltage simulation results as input data.
The analysis of the simulated stresses showed that the safety margin of the transformer insulation level is adequate for the considered case.

VI. CONCLUSIONS

The proposed procedure is an effective and helpful tool for evaluation of VFT voltage stresses on the HV terminal as well as on the winding of a transformer directly connected to a GIS.
The analysis of these voltage stresses is recommended to improve and adjust to specific case the transformer insulation design.

VII. REFERENCES

/1/ J.Meppelink, K. Diederich, "Very Fast Transients in GIS", *IEEE PES, New York, 1988.*

/2/ Cigré SC 15 , "Recent research activity on the dielectric performance of SF6, with special reference to VFT's", *Cigré Paris-Session, 1988.*

/3/ IEC 1259, "Requirements for switching of bus-charging currents by disconnectors", *First edition, 1994-04*.

/4/ Zwicky, Zaengl, Knoth, "Transiente Vorgänge in Hochspannungskondesatoren", *Sonderdruck, SEV/VSE, Bd. 74*, 1983, Nr. 3, pp.442-447, September 3-7, Lisbon.

/5/ Mendes, Lacorte "ELETRONORTE - UHE Tucuruí PA Transformador Elevador - Unid Reserva - Análise e Verificação da Coordenação de Isolamento", *ABB Brasil-Report, R 1ZBR99-0210*, 1999-12-15