Computer Simulation of a Ferroresonance Suppression Circuit for Digital Modeling of Coupling Capacitor Voltage Transformers

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Abstract - This paper describes development of a digital model for the coupling capacitor voltage transformer (CCVT) ferroresonance suppression circuit (FSC). A FSC may have significant influence on a CCVT transient behavior, so the circuit is of importance. This paper introduces a digital model that is based on the electro magnetic transients program (EMTP) modeling techniques.

Keywords: Computer simulation, Ferroresonance suppression circuit, EMTP

INTRODUCTION

Ferroresonance may occur in a circuit containing capacitors and iron core inductors. It is usually characterized by over voltages and distorted waveforms of current and voltage. It may endanger equipment. This phenomenon has been known for a long time, and its behavior and occurrence are fairly well understood. An investigation of the potential transformer (PT) ferroresonance instability, using field measurement and TNA analysis, is reported in the past [1]. An analytical approach to determine whether ferroresonance can occur in a system configuration containing PT has also been published [2]. A coupling capacitor voltage transformer (CCVT) may be involved with the ferroresonance oscillations too. These oscillations are mostly of a subharmonic frequencies, although harmonic and even fundamental frequencies may also be present.

A CCVT circuit diagram is shown in Figure 1. All CCVTs contain a ferroresonance suppression circuit (FSC), which is connected on the secondary side. FSC designs, accordingly to their status during the CCVT operation, can be divided into two main operational modes: active and passive.

FSCs in an active mode operation consist of capacitors and iron core inductors connected in parallel and tuned to the fundamental frequency. They are permanently connected on the secondary side and affect the CCVT transient response.

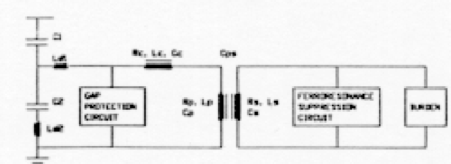


Figure 1. General CCVT Circuit Diagram

FSCs in an passive operational mode consist of a resistor connected on the secondary side. This resistor can be permanently connected. Another option is to have a gap or an electronic circuit connected in series with the resistor, which are activated whenever an over voltage occurs. These FSCs do not affect CCVT transient response unless an over voltage occurs.

Details of the CCVT designs and various FSC circuits have been studied by the authors for the purpose of CCVT modeling. Extensive results of this study have been recently published [3].

FSC DESCRIPTION

The PCA-5 CCVT type is used to illustrate FSC in an active operational mode [4]. Its circuit diagram is shown in Figure 2. The FSC design detail is shown in Figure 3. Capacitor C_f is connected in parallel with an iron core inductor L_f, tuned to the fundamental frequency. Resistor R_f is a damping resistor designed to damp ferroresonance oscillations within one cycle. The circuit is tuned with a high Q factor in order to attenuate ferroresonance oscillations at any harmonic except the fundamental.

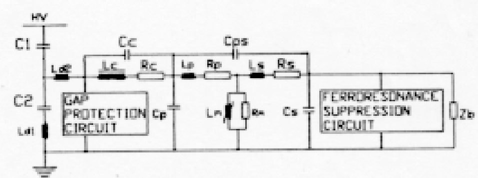


Figure 2. PCA-5 CCVT Circuit Diagram

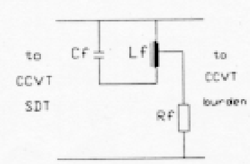


Figure 3. Circuit Diagram of a FSC in the Active Operational Mode

FSC FREQUENCY RESPONSE MEASUREMENTS

The FSC frequency response measurement is needed for model validation. This measurement is done as shown in Figure 4. The FSC impedance is calculated from the measured voltage at point "2" and current, which is calculated as a division between voltage drop on the resistor R and the value of R. The FSC frequency response is shown in Figure 5.

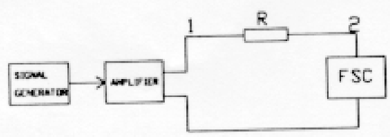


Figure 4. Measurement of FSC Frequency Response

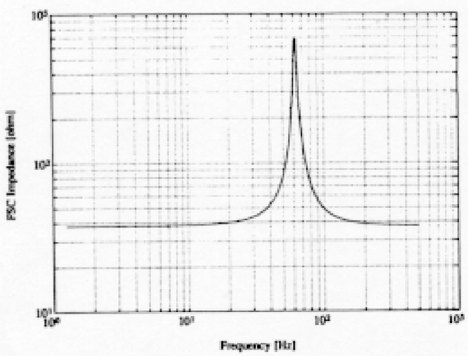


Figure 5. PCA-5 CCVT FSC Frequency Response

MODEL DEVELOPMENT

A CCVT has a complex structure as shown in Figure 2. It consists of elements such as: compensating inductor (R_c, L_c, C_c), step–down transformer (R_p, L_p, C_p, C_{ps}, R_s, L_s, C_s, L_m, R_m), ferroresonance suppression circuit (R_f, L_f, C_f), drain coils (L_{d_1}, L_{d_2}), and other circuits with L, C elements and gaps, which in many cases, are non–linear [5,6]. These elements may have mutually interactive influences and may cause resonances at different frequencies.

The FSC can be modeled using two different L_f representations [7]:

a) L_f represented as an air core inductor,

b) L_f represented as a non–saturable transformer.

In case a), the FSC is modeled as shown in Figure 6. The value of the capacitor $C_f = 8\mu F$. C_f and L_f are tuned to 60 Hz and the calculated value for L_f is then 0.88 H.

Comparison between the measured frequency response and the one obtained from Electro Magnetic Transient Program (EMTP) simulation is shown in Figure 7. It can be noticed that the Q factor is much smaller in the digital model of the FSC. The factor Q could be adjusted to become high, but in that case different values for C_f and L_f should be chosen. This would change the mutual influence of FSC on other CCVT elements and modeling would not be appropriate.

In case b), the FSC is modeled as shown in Figure 8. L_f is represented as a transformer. The calculated L_f value of 0.88 H is incorporated in the transformer model as a self inductance. Primary and secondary windings are connected in such a way that parallel resonance occurs only at the fundamental frequency. At other frequencies, only the leakage inductance is involved so the damping resistor is the one which attenuates ferroresonance oscillations.

Comparison between the measured frequency response and the one obtained from EMTP simulation is shown in Figure 9. The results show that the simulated values are almost identical to the measured values.

Comparing Figures 7 and 9, it may be concluded that FSC simulation using the transformer representation of L_f is more accurate. Therefore, this model was adopted for transient behavior analysis of the CCVT [3].

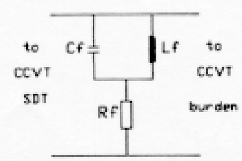
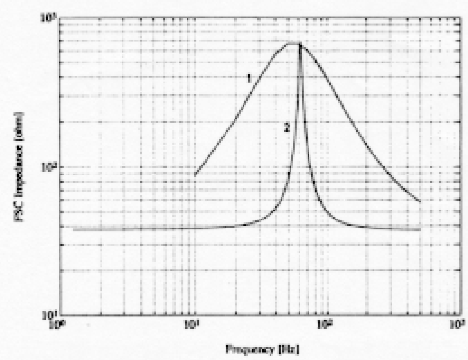


Figure 6. Digital Model of FSC for PCA-5 CCVT (L_f represented as an inductor)



1–EMTP Simulation
2–Measured by Using Signal Generator

Figure 7. FSC Frequency Response (Measured vs. EMTP Simulations)

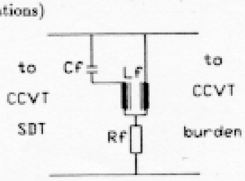
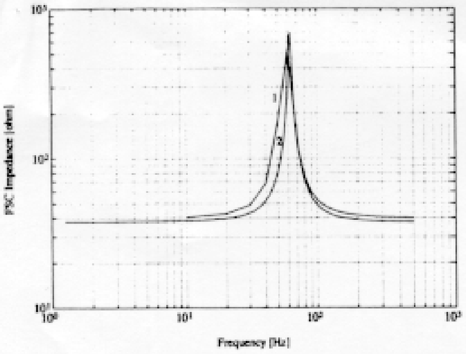


Figure 8. Digital Model of FSC for PCA-5 (L_f represented as a transformer)



1–EMTP Simulation
2–Measured by Using Signal Generator

Figure 9. FSC Frequency Response (Measured vs. EMTP Simulations)

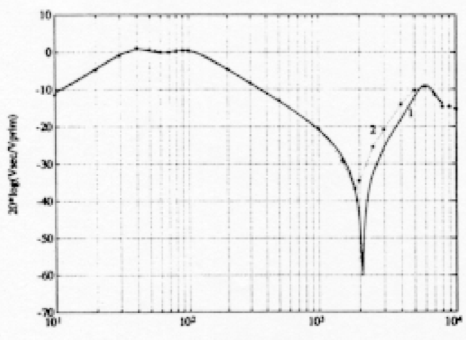
MODEL VALIDATION

The validation is based on comparison of the frequency responses obtained by means of measurements with the ones obtained by EMTP simulations.

Frequency response measured using PCA-5 CCVT vs. EMTP simulations of the same case is shown in Figure 10.

Frequency response measured using PCA-5 CCVT without FSC vs. EMTP simulations is shown in Figure 11.

The results show that the simulated values are very close to the measured values.



1–EMTP Simulation
2–Measured by Using Signal Generator

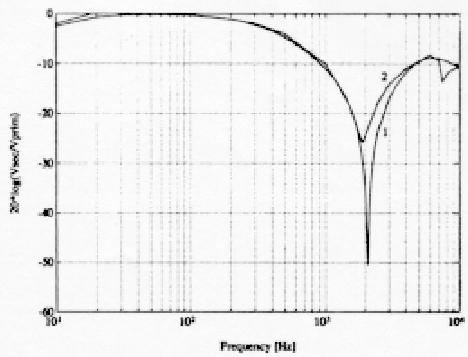
Figure 10. Frequency Response of PCA–5 CCVT Including FSC (measured vs. EMTP simulations)

COMPUTER SIMULATION OF CCVT TIME RESPONSE

Simulation of voltage collapse is selected as a typical example of FSC influence on the CCVT time response. CCVT time response is affected by energy storing components like capacitors and inductors. This CCVT has the FSC operating in an active operational mode and it makes certain influence on the frequency response.

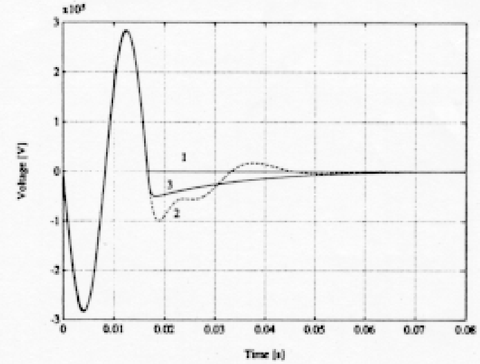
The simulation of voltage collapse has been done using EMTP for a resistive and inductive burden of 100Ω. Fault initiations were at the voltage zero and maximum value.

The influence of the FSC on the time response of the CCVT, for fault initialization at voltage zero, and for a resistive burden of 100Ω, is shown in Figure 12.



1–EMTP Simulation
2–Measured by Using Signal Generator

Figure 11. Frequency Response of PCA–5 CCVT without FSC (Measured vs. EMTP Simulations)



1–Primary Voltage
2–Secondary Voltage with FSC Referred to Primary
3–Secondary Voltage without FSC Referred to Primary

Figure 12. EMTP Simulations of the PCA–5 CCVT Time Response for Resistive Burden (Fault Initialization at Voltage Zero)

The influence of the FSC on the time response of the CCVT, for fault initialization at voltage maximum value, and for a resistive burden of 100Ω, is shown in Figure 13.

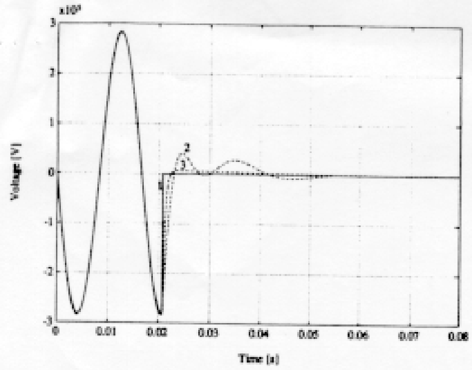


Figure 13. EMTP Simulations of the PCA-5 CCVT Time Response for Resistive Burden (Fault Initialization at Voltage Maximum Value)

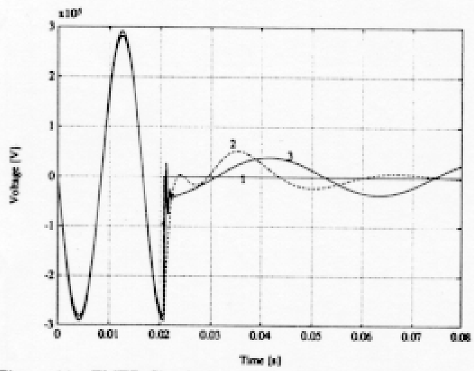


Figure 14. EMTP Simulations of the PCA-5 CCVT Time Response for Inductive Burden (Fault Initialization at Voltage Zero)

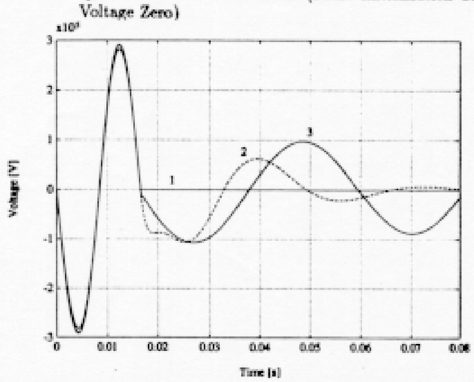


Figure 15. EMTP Simulations of the PCA-5 CCVT Time Response for Inductive Burden (Fault Initialization at Voltage Maximum Value)

Note: 1–Primary Voltage
2–Secondary Voltage with FSC Referred to Primary
3–Secondary Voltage without FSC Referred to Primary

The simulations of voltage collapse with an inductive burden of 100Ω were also carried out. The influence of the FSC on the time response of the CCVT are shown in Figures 14 and 15 for fault initialization at voltage zero and maximum value, respectively.

The EMTP simulation results given in Figures 12 to 15 demonstrate that presence of FSC causes major differences in the time response of the PCA-5 CCVT under different voltage collapse and burden conditions.

CONCLUSIONS

The FSC affects transient response of a CCVT. For modeling purposes its influence is observed both in frequency and in the time domain.

The digital model of an FSC with an iron core inductance, which is represented as a nonsaturable transformer, gives very good results.

Acknowledgments

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