Modeling Ferroresonance Phenomena on Voltage Transformer (VT)

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Abstract

 Ferroresonance in electromagnetic voltage transformers, fed through circuit breaker grading capacitance, is studied using nonlinear dynamics methods. The magnetising charact'eristic of a typical l00VA voltage transformer is represented by a single-valued two-term polynomial of the order seven.The system exhibits three types of ferroresonance: fundamental frequency ferroresonance, subharmonic ferroresonance and chaotic fcrroresonance, similar to high capacity power transformers fed through capacitive coupling from neighbouring lines or phases. Results also show that while fundamental frequency and subharmonic ferroresonancc can occur under commonplace operating conditions, chaotic states are unlikely in practice.

Keywords: Ferroresonance, Voltage Transformer, ATP, Overvoltage,Transient Analysis

I.   INTRODUCTION

Ferroresonance is a non- linear phenomenon that can affect power network ,the main feature of this phenomenon is that one stable steady state response is possible for the network parameters that are highly depond on initial conditions and circuit parameter.

Ferroresonance is an important issue in transmission and distribution systems. It may result in equipment failure and service interruption that could be very costly and reduce system reliability .by diagnose ferroresonance we can manage our costs use to repair or change our facilities.

Ferroresonant overvoltages on distribution systems were observed early in the history of power systems (i.e., early 1900s). Many analytical and experimental work have been carried out to understand the phenomena. One of the first analytical work was presented in [1] and [2]. A more recent paper on modeling and analysis of ferroresonant phenomena was described in [4].   In this paper, the theory of ferroresonance is briefly presented (in Section II). More theoretical description can be found in many literature. Section III describes symptoms of ferroresonance and personal accounts of engineers who witnessed the phenomena. Sections IV and V present

ferroresonant modeling, and a case study of an actual ferroresonance problem with its corresponding solutions.

II .Ferroresonance

Ferroresonance is a mysterious phenomenon that seems to occur capriciously, causing much concern among utility operating personnel. It generally occurs during a system imbalance, usually during switching, that places capacitance in series with transformer magnetizing impedance. This can result in high overvoltages that can cause failures in transformers, cables, and arresters. Any system capacitance can be involved in ferroresonance, but the major concern is about underground cable capacitance.

As utilities moved cable systems into a 25-kV or 35-kV class, they found ferroresonance to be much more common than at lower voltage levels. They found they had to be more careful about how they switched the cable and how they arranged switch points to minimize the amount of cable isolated with lightly loaded transformers during switching. Ferroresonance is a greater problem at the higher voltage levels because the relative ratios of losses, magnetizing impedance and cable capacitance fall into a range more likely to produce ferroresonance. Ungrounded transformer primary connections go into ferroresonance quite easily. Therefore, many utilities no longer employ these connections and have switched to grounded-wye/grounded-wye connections for their three-phase loads fed from underground cable systems.

Grounded-wye transformers comprised of three separate units are virtually immune to the common varieties of ferroresonance.

Grounded-wye/grounded-wye three-phase pads with 4-or 5-leg cores are less susceptible to ferroresonance than delta or ungrounded-wye connections, but they are not immune. They simply require more cable length and some different transformer characteristics. The common core configuration for the three-phase padmounts provides the necessary coupling between phases to produce ferroresonance.

There are several different modes of ferroresonance possible with grounded-wye 5-leg core transformers with sustained overvoltages reaching 2,0 to 2,5 per unit for some modes. Of course, if allowed to persist, these overvoltages might cause transformer failure, cable failure, and customer appliance failure. Frequent symptoms often reported are failed arresters, customer complaints of fluctuating voltage, and bubbled or charred paint on the transformer tank when the flux gets into the tank.

The evaluation of ferroresonance ties in closely with the decision of applying arresters on the cable system. If surge arresters are not installed on the cable system, it has no protection against overvoltages. This could contribute to premature cable failure or transformer failure if allowed to persist. On the other hand, if arresters are applied, arrester duty during phase-by-phase switching operations is a concern, and there is the possibility that arresters might fail violently.

The most dangerous time is when phase-by-phase cable switching occurs during construction of a subdivision or commercial area. The transformer involved might have no load and there will be more times that the transformer is exposed to the condition with one or two open phases.

However, ferroresonance can also occur accidentally due to such things as a faulty connector or splice opening, or an overhead line feeding the cable opening due to such things as an automobile collision with a pole. The no-load condition also occurs when customers install automatic relaying to disconnect from the utility at the first sign of trouble.

III.FERRORESONANCE SYMPTOMS

Disturbance due to ferroresonance is a common phenomenon in electric power distribution system operation. Depending on circuit conditions, its effect may be a random overvoltage that could be either a short transient for few cycle, a continuous overvoltage or even a jump resonance demonstrated by a sudden jump of voltage or current from one stable operating state to another one i.e., it is characterized by the possible existence of several stable states, besides the normal steady state, that induce dangerous over-currents and overvoltages. It causes both phase-to-phase and phase-to-ground high sustained oscillating overvoltages and overcurrents with sustained levels of distortion to the current and voltage waveforms, leading to transformer heating together with excessively loud noise due to magnetostriction, electrical equipment damage, thermal or insulation breakdown

and misoperation of the protective devices. In this phenomenon voltage and current relationship is dependent on:
• system voltage magnitude & frequency,
• initial magnetic flux condition of the transformer iron core i.e. extent of loading,
• capacitance of the circuit, feeding the transformer primary,
• point on wave of initial switching,
• the total losses in the ferroresonant circuit.

IV. SYSTEM DESCRIPTION AND ATP MODELLING

Current studies related to ferroresonance in electromagnetic wound voltage transformers (VT) and single-phase traction supply transformers.

A – Voltage Transformer Ferroresonance[5,6] During voltage transformer ferroresonance an oscillation occurs between the nonlinear inductance of the VT and the capacitance of any network remaining\ connected to the VT. In this case, energy is coupled to the nonlinear core of the voltage transformer via the open circuit breaker grading capacitance to sustain the resonance. The VT can be driven into saturation resulting in high currents at sub-harmonic or fundamental frequency. For the latter, very high voltage of up to 4 pu can theoretically arise in worst case conditions.

Electromagnetic voltage transformers have a relatively low thermal capacity and overheating can result in insulation failure very quickly.

Fig.1 shows the single line diagram of the most commonly encountered system arrangement that can give rise to VT

ferroresonance. Ferroresonance can occur upon opening of disconnector 3 with circuit breaker open and either disconnector 1 or 2 closed. Alternatively it can also occur upon closure of either disconnector 1 or 2 with circuit breaker and disconnector 3 open.
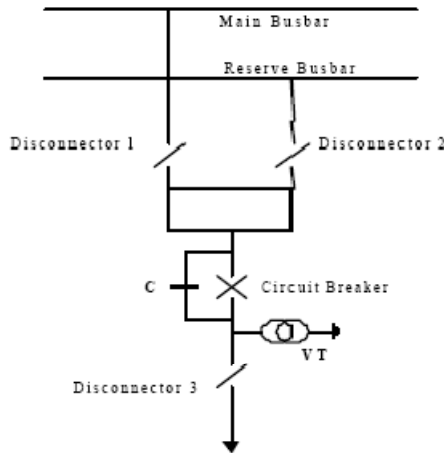

Fig. 1 System arrangement resulting to VT ferroresonance

The system arrangement shown in Fig. 1 can effectively be reduced to an equivalent circuit as shown in Fig2.
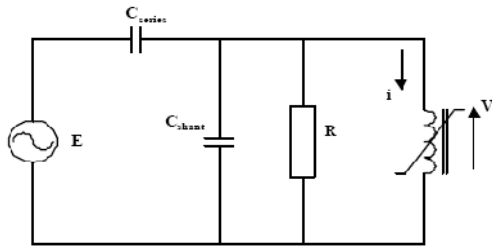

Fig. 2 Reduced equivalent ferroresonant circuit

In Fig. 2, E is the rms supply phase voltage, Cseries is the circuit breaker grading capacitance and Cshunt is the total phase-to-earth capacitance of the arrangement. The resistor R represents voltage transformer core losses that has been found to be an important factor in the initiation of ferroresonance [4,8,9].

The circuit of Fig.2 is modelled in ATP [7].

Transformer magnetisation characteristic supplied by the manufacturer was used in a type-93 true nonlinear inductor to simulate the magnetic core of the VT. The VT itself is a low thermal capacity, 400kV/110V, 100VA wound voltage transformer. Cseries and Cshunt were represented as lumped parameters. The resistance R was represented dynamically based on

$$R = \frac{R_{OS} - R_{MS}}{1 + \left(\dfrac{|B|}{B_S}\right)^a} + R_{MS} \qquad (1)$$

In (1) ROS=60W, RMS=20W, BS =1.7T and a=9.5. At every integration time-step of ATP then the value of R is recalculated depending on the value of B.

B – Traction Supply Transformer Ferroresonance Fig. 3 shows the single line diagram of a traction supply transformer arrangement. The single phase transformer is fed from two phases of the three-phase system. Ferroresonance occurs upon opening of circuit breakers 1 and 2 to de-energise the line and the transformer. Energy is coupled to the de-energised network from the adjacent live parallel circuit via the inter-circuit coupling capacitance, i.e. Cseries in the equivalent ferroresonant circuit. The equivalent Cshunt in the ferroresonant circuit is the phase-to-earth capacitance of the line and the transformer winding and bushing capacitance.

Simulation of traction supply transformer can be carried out on a complex 3-phase network. Both the measurements and simulation results are given in figure 9. Nevertheless digital computer modelling of the traction supply transformer configuration can be simplified using the single-phase ferroresonant equivalent circuit given in Fig. 2.
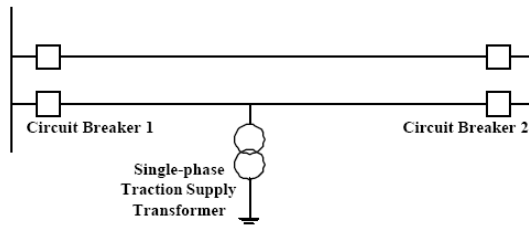
Fig. 3 Traction supply transformer ferroresonance arrangement

V. FIELD MEASUREMENTS SIMULATION RESULTS

A – Voltage Transformer Ferroresonance
Fig. 4 (a) and (b) show the measured and simulated VT secondary voltages respectively. The measured test waveform of Fig. 4 (a) was obtained after opening disconnector 3 in Fig. 1. As it can be seen from the graphs the VT did not go into ferroresonance. Although the simulated waveform does not match the measured test waveform exactly, its general appearance is a very close fit. It can be said that the ATP model employed in this study is capable of predicting possible ferroresonance modes as long as the parameters of the system are known or can be estimated. In the study Cseries was set to 514pF and Cshunt to 1137pF to give the waveform of Fig. 4 (b).
Primary current waveforms for the field measurement and the simulation study are given in Fig. 5 (a) and (b), respectively.

When the same system is tested for a second time the response is totally different to the above in that it is driven into sub-harmonic ferroresonance. Prediction of this response with digital simulation proved to be hard as the system is very sensitive to parameter changes. The measured and simulated VT secondary voltage waveforms are shown in Fig. 6 (a) and (b) and the corresponding primary current waveforms are given in Fig. 7 (a) and (b), respectively. The shape of measured and simulated waveforms in Figs. 6 & 7 (a) and (b) are of a good match.

The minute difference is believed was due to the numerical and actual saturation around the "knee" point of the magnetisation curve.

The bifurcation diagram of Fig. 10 shows the sensitivity of the model to applied voltage E. Bifurcation diagrams provide information about the dynamics of the system for range of parameter values. In the diagram of Fig. 10 all system parameters except E were constant.

Values of E from 0.8pu to 1.15pu result to a normal response while at 1.15pu and onwards a fundamental ferroresonant response is present. B – Traction Supply Transformer Ferroresonance Figs. 8 and 9 show the results of a full scale measurement and simulation of a traction supply transformer which ferroresonated at 50Hz, the fundamental system frequency. The phase voltages and current on the de-energised transformer are presented. Clearly, the two phases feeding the transformer are in sustained fundamental frequency mode ferroresonance.
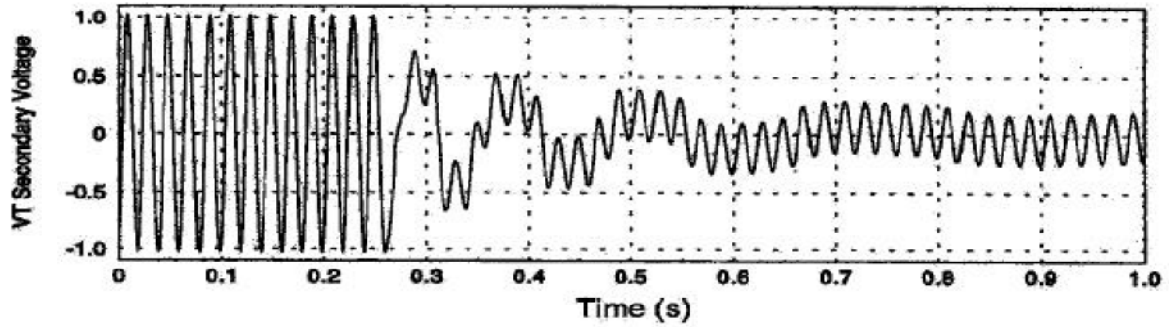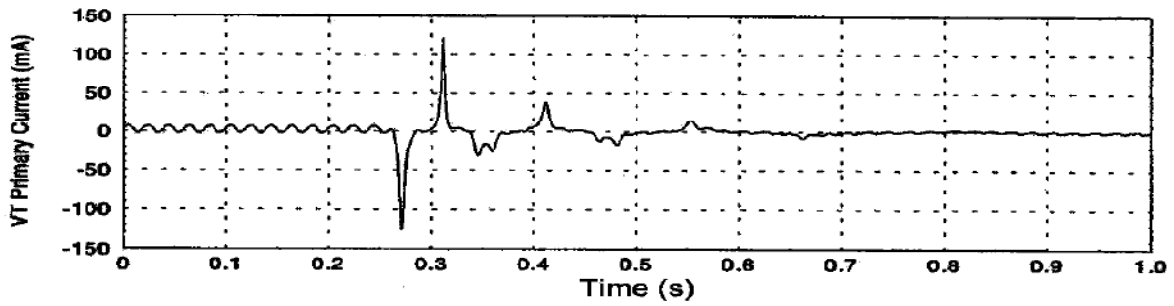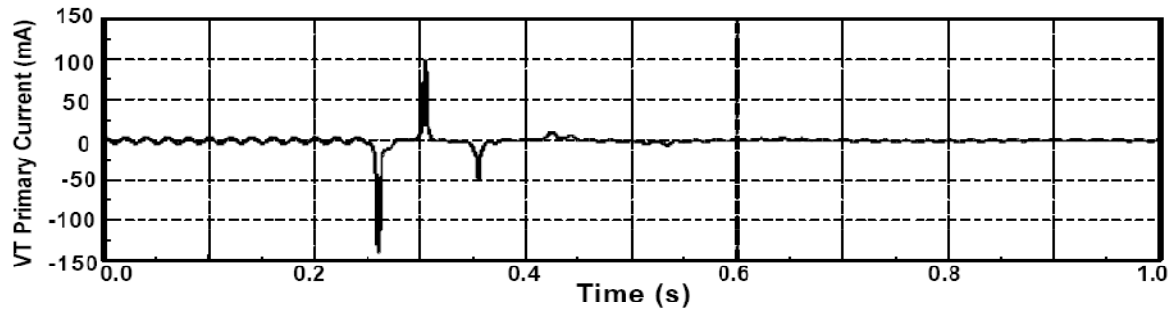
(a) field measurement
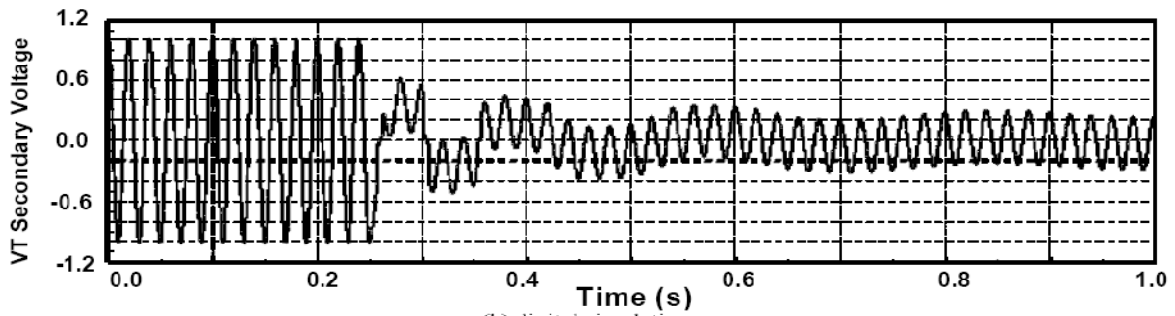
(b) digital simulation

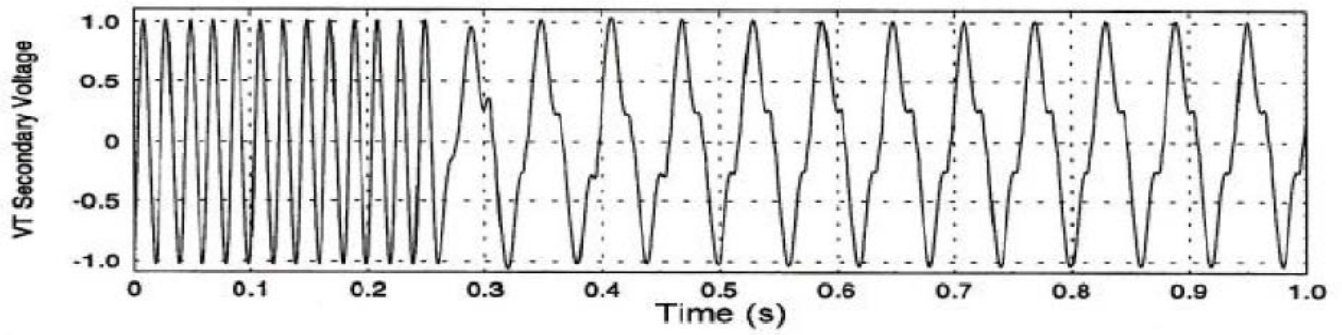Fig. 4 VT secondary voltages (values in p.u.) showing normal response
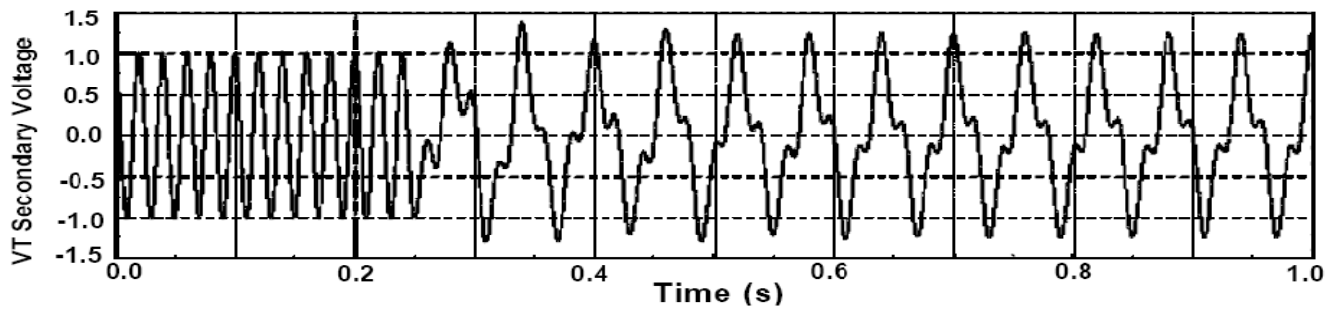

(a) field measurement

(b) digital simulation

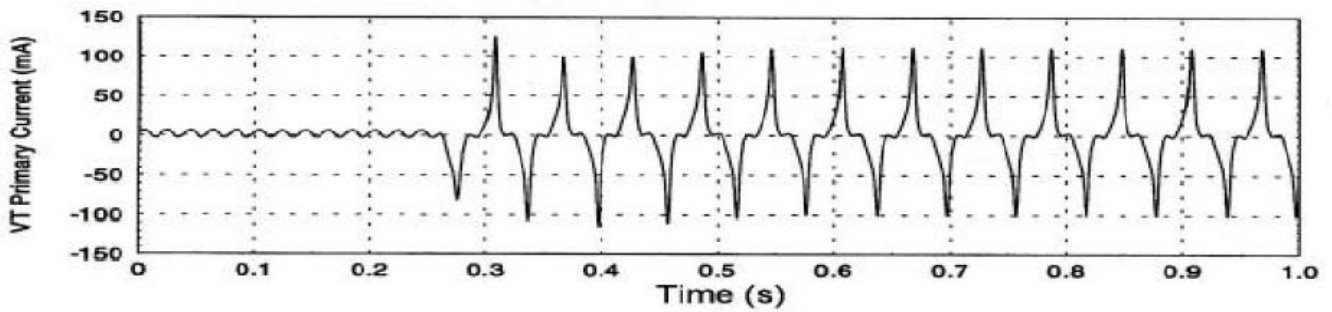Fig. 5 VT primary currents showing normal response
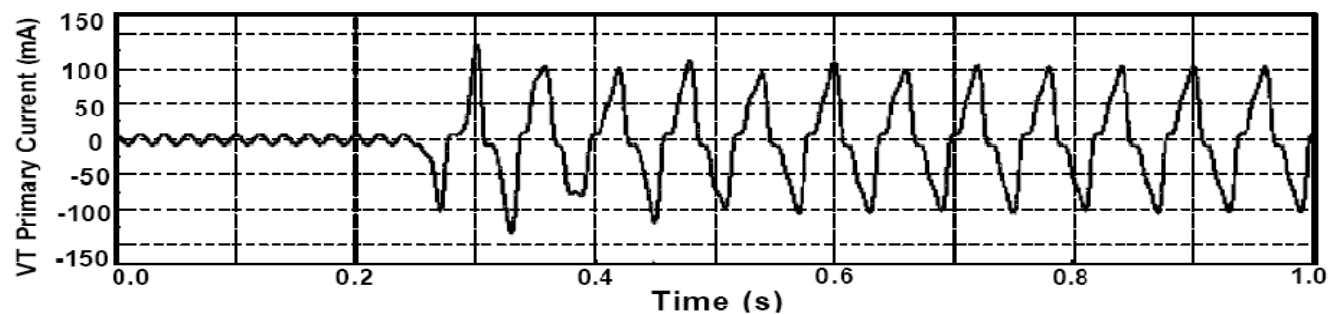
(a) field measurement

(b) digital simulation

Fig. 6 VT secondary voltages (values in p.u.) showing sub-harmonic (16.6Hz) ferroresonance

(a) field measurement

(b) digital simulation

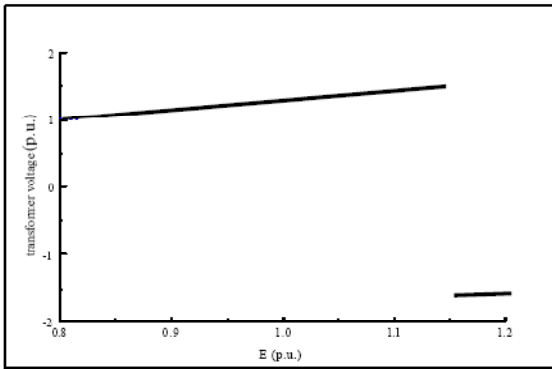Fig.7 VT primary currents showing sub-harmonic (16.6Hz) ferroresonance

Fig. 10 Bifurcation diagram showing sensitivity of model to E (all other parameters kept constant)

VI. CONCLUSIONS

A reliable prediction of the ferroresonant voltage and current in advance can provide valuable information to planners to design the system, engineers to specify the equipment and operators to run the transmission plant within all the design and tested criteria and capabilities.

This comprehensive understanding can be achieved if all the parameters of the system and plant in question are available or can be estimated with reasonable accuracy. Although the model used in this study providedcomparable result with those of field measurements, many more questions, such as the effect of magnetization hysteresis and remnance and the Point-on-Cycle switching etc are still to be examined. Boundary approach can be adopted to establish theinteraction between the system and the plant, and subsequently bringing forward an operating window with the lowest ferroresonance risk.

VII. REFERENCES

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