Damping Nonlinear Oscillations in Potential Transformers Including Hysteresis Effect

Hamid Radmanesh, Hamid Mohammad Hossein, and Moammad Bakhshandeh

Abstract—**In this work, an overview of available papers are provided, at first ferroresonance phenomenon is introduced and then various type of ferroresonance in a potential transformer is simulated, then effect of neutral earth resistance on the onset of chaotic ferroresonance and duration of chaotic transient in a potential transformer including nonlinear core losses has been studied. It is expected that this resistance generally cause controlling ferroresonance overvoltages. The proposed approach was implemented using MATLAB, and results are presented. For confirmation this aspect simulation has been done on a one phase potential transformer rated 100VA, 275kV. Core losses is modelled in terms of voltage and includes nonlinearities in core losses .The simulation results show that connecting the neutral earth resistance on the system configuration, shows a great controlling effect on ferroresonance overvoltages.**

Index Terms—**Ferroresonance oscillation, stabilizing, chaos control, potential transformer, nonlinear core losses effect, neutral earth resistance.**

I. Introduction

Ferroresonance can occur whenever an iron cored inductance is energized via some capacitance in an unintended configuration. The result is usually unexpectedly high voltage with strange waveform across the inductance and the capacitance, together with higher than expected current flows. In recent years, many papers described it from various aspects. For example the susceptibility of a ferroresonance circuit to a quasi-periodic and frequency locked oscillations has been presented in [1], in this case, investigation of ferroresonance has been done upon the new branch of chaos theory that is quasiperiodic oscillation in the power system and finally ferroresonance appears by this route. Modeling iron core nonlinearities has been illustrated in [2]. Mozaffari has been investigated the ferroresonance in power transformer and effect of initial condition on this phenomena, he analyzed condition of occurring chaos in the transformer and suggested the reduced equivalent circuit for power system including power switch and trans [3], [4]. The controlling effect of transformer connected in parallel to a MOV arrester has been illustrated in [5]. Controlling ferroresonance has been investigated in [6]. It is shown controlling ferroresonance in potential transformer by considering circuit breaker shunt resistance effec. In [7], electromagnetic potential transformer has been studied in the case of nonlinear core losses by applying metal oxide surge arrester in parallel with it. Analysis of chaotic ferroresonance phenomena in unloaded transformers and potential transformers including nonlinear core losses effect has been shown in [8]-[10]. In [11], effect of neutral resistance on controlling ferroresonance oscillations in power transformer has been studied and it has been shown that system has been greatly affected by neutral resistance. In current paper, this control method for controlling of unstable and high amplitude nonlinear oscillation is used. Using of this method results improving voltage waveform which leads to protection from insulation, fuses and switchgears.

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II. System Modeling Without Neutral Resistance

Fig. 1 shows the circuit diagram of power system components at the 275 kV substations. VT is isolated from sections of bus bars via disconnector DS_2. Ferroresonance conditions occurred upon closure of disconnector DS_1 with C.B and DS_2 open, leading to a system fault caused by failure of the potential transformer primary winding.

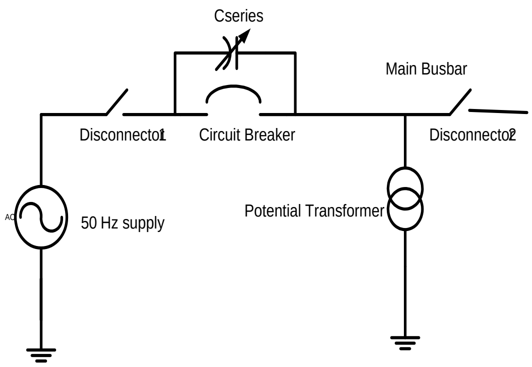

Fig. 1. System one line diagram arrangement resulting to VT Ferroresonance

Fig.2 shows the basic ferroresonance equivalent circuit used in this analysis. The resistor R represents transformer core losses where modeled the hysteresis losses effect.

In Fig. 2, E is the RMS supply phase voltage, C_{series} is the circuit breaker grading capacitance and C_{shunt} is the total phase-to-earth capacitance of the arrangement. The resistor R represents a potential transformer core loss that has been found to be an important factor in the initiation of ferroresonance and has been modeled as a nonlinear resistance in this paper. λ-i characteristic of the potential transformer is modeled as in [12], [13] by the polynomial

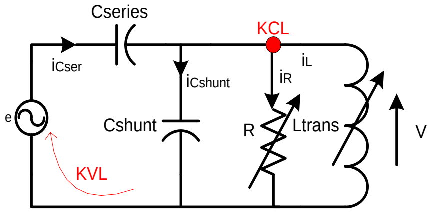

Fig.2. Basic reduced equivalent ferroresonance circuit [6]

$$i = a\lambda + b\lambda^7 \tag{1}$$

where $a = 3.14,\ b = 0.41$

III. System Dynamic and Equation

Mathematical analysis of equivalent circuit by applying KVL and KCL has been done and equations of system can be presented as below:

$$e = \sqrt{2}E\sin(\omega t) \tag{2}$$

$$i_R = h_0 + h_1 v_L + h_2 v_L{}^2 + h_3 v_L{}^3 \tag{3}$$

$$\frac{(C_{ser} + C_{sh})}{C_{ser}}\frac{d^2\lambda}{dt^2} = C_{ser}\sqrt{2}E\omega\cos\omega t - \frac{1}{C_{ser}}\left(h_0 + h_1 v_L + h_2 v_L{}^2 + h_3 v_L{}^3\right) - \frac{1}{C_{ser}}\left(a\lambda + b\lambda^7\right) \tag{4}$$

where ω is supply frequency, E is the rms supply phase voltage, C_{series} is the circuit breaker grading capacitance and C_{shunt} is the total phase-to-earth capacitance of the arrangement. The time behavior of the basic ferroresonance circuit is described by (4). Results for one parameter sets showing one possible type of ferroresonance. Table I shows base values used in the analysis and parameters different states are given in Table II.

TABLE I: Base Values of the System Used for Simulation

Base value of input voltage	158 kV
Base value of volt-amperes	100 VA
Base angular Frequency	$2\pi 60$ rad/sec

TABLE II: Parameters Used for Various States Simulation

System Parameters	C_{shunt} (nf)	C_{series} (nf)	R_{core} (MΩ)	R_n (MΩ)	Ω (rad/sec)	E (kV)
value	3	0. 5	225	25	314	275

IV. System Descriptions with Neutral Earth Resistance

In this case, the system which was considered for simulation is shown in Fig.3.

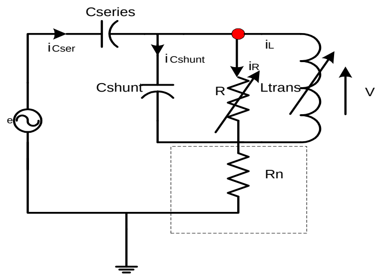

Fig. 3. Basic reduced equivalent ferroresonance circuit considering neutral earth resistance

Typical values for various system parameters has been considered for simulation were kept the same by the case 1, while neutral resistance has been added to the system and its value is given below:

$$R_{neutral} = 25M\Omega$$

The differential equation for the circuit in Fig.3 can be presented as follows:

$$C_{ser}C_{sh}R_n\frac{d^2v_L}{dt^2} = C_{ser}\sqrt{2}E\omega\cos\omega t - \left(C_{ser} + C_{sh} + C_{ser}R_n h_1 + 2C_{ser}R_n h_2 v_L + 3C_{ser}R_n h_3 v_L{}^2\right)\frac{dv_L}{dt} - \left(C_{ser}R_n a + C_{ser}R_n q b\lambda^6 + h_1\right)v_L - \left(h_0 + h_2 v_L{}^2 + h_3 v_L{}^3 + a\lambda + b\lambda^7\right) \tag{5}$$

V. Simulation Results

In this section of simulation, one state of ferroresonance has been studied in two cases, without connecting neutral earth resistance and with considering neutral resistance.

A. *CASE I*

Phase space and waveform of voltage for chaotic response were shown in Figs. (4.a) and (4.b). The phase plane diagram clearly shows the chaotic characteristic of the waveform. Amplitude of chaotic ferroresonance has been reached to 6p.u and nonlinear behavior is obvious.

B. *Case II(comparative study)*

Phase space and waveform of voltage for quasiperiodic response were shown in Figs. (5.a) and (5.b). The phase plane diagram clearly shows the closed trajectory characteristic of a quasiperiodic waveform.

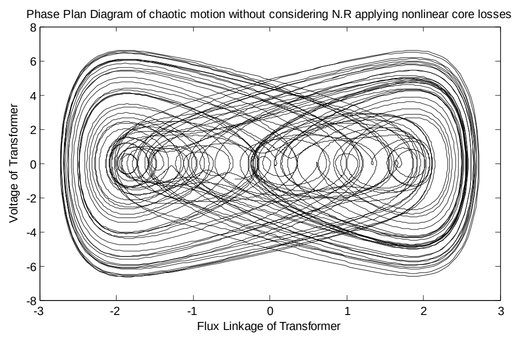

Fig. (4.a). Phase plan diagram for chaotic motion without neutral earth resistance

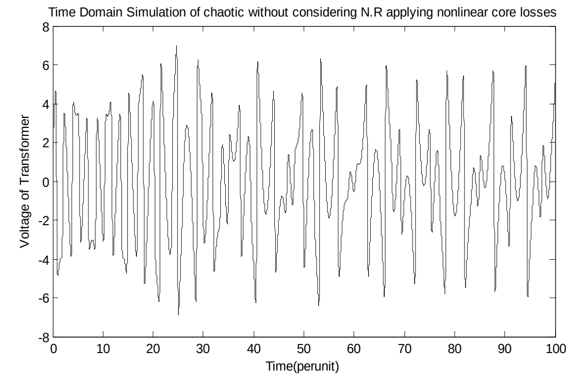

Fig. (4.b). Time domain simulation for chaotic motion without neutral earth resistance effect

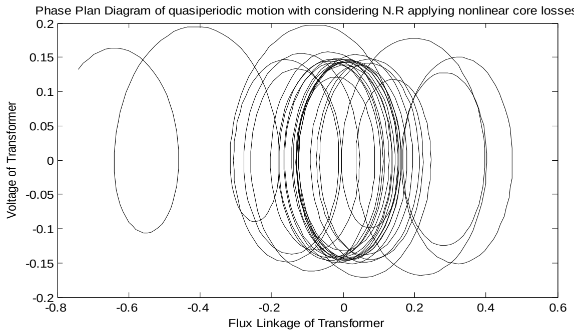

Fig. (5.a). Phase plan diagram for quasiperiodic motion with neutral earth resistance effect

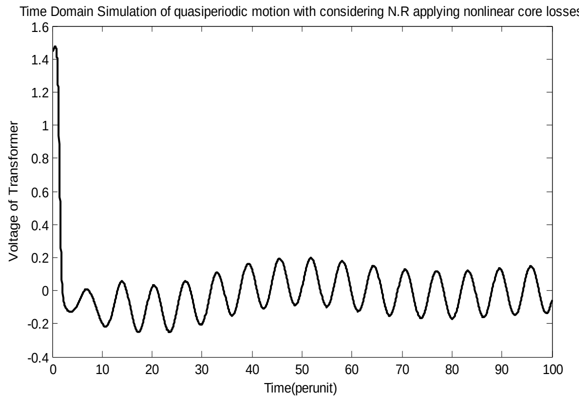

Fig (5.b). Time domain simulation for quasiperiodic motion with neutral earth resistance effect

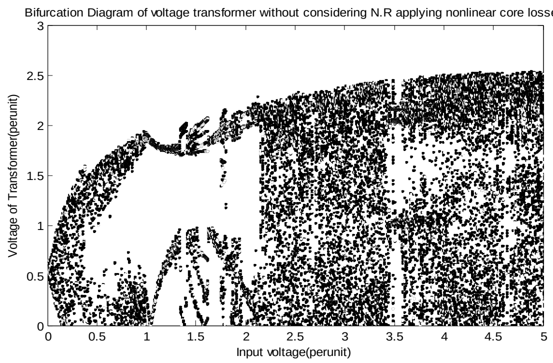

Fig. (6.a). Bifurcation diagram without neutral earth resistance

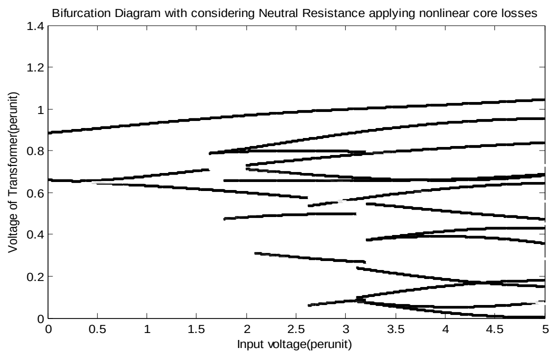

Fig. (6.b). Bifurcation diagram for voltage of transformer versus voltage of system, considering neutral earth resistance effect

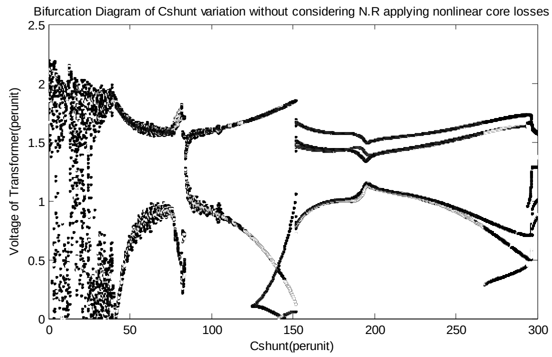

Fig. (6.c). Bifurcation diagram for variation of C_{shunt} without considering neutral earth resistance effect

In the last bifurcation diagram, C_{shunt} has been changed from 1p.u to 300p.u while neutral earth resistance has not been connected to the potential transformer.

VI. Bifurcation Diagram Analysis

In this paper, it is shown the effect of variation in the voltage and capacitance of the system on the ferroresonance overvoltage in the VT, and finally the effect of applying neutral resistance on this overvoltage by bifurcation diagrams. By using the bifurcation diagrams, Fig. (6.a) clearly shows the ferroresonance overvoltage in VT when voltage of system increase up to 5 p.u.

TABLE III: System Parameters for Bifurcation Analysis

System state / Parameters	C_{shunt} (nf)	C_{series} (nf)	R_{core} (MΩ)	R_{n} (MΩ)	Ω (rad/sec)	E (kV)
Bifurcation Diagrams	0.1	3	1900	25	314	275

VII. Conclusion

In this work it has been shown that system has been greatly influenced by neutral earth resistance. Connecting the neutral earth resistance to the system grounding, results in controlling the ferroresonance overvoltages in the studied system. Neutral earth resistance successfully, controls the chaotic behaviour of proposed model. Nonlinear core losses clearly show more chaotic behaviour when compared it with the linear model of the potential transformer, also nonlinear core losses causes more overvoltage and system shows more sensitivity to the initial condition and changing in the system parameters value. Finally, system shows less sensitivity to initial conditions and best controlling ferroresonance overvoltages in the presence of the neutral earth resistance.

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