Reducing Chaotic Oscillations in Potential Transformers

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***Abstract*—In this work, an overview of available papers and contributors to this area is provided, at first ferroresonance phenomenon is introduced and then various type of ferroresonance in a voltage transformer is simulated. Effect of neutral earth resistance on controlling oscillations has been studied. The proposed approach was implemented using MATLAB, and results are presented. It is expected that this resistance generally can cause ferroresonance 'dropout'. The magnetization characteristic of the transformer is modeled by a single-value two-term polynomial with *q*=7. The simulation results show connecting the neutral earth resistance on the system configuration causes a great controlling effect on ferroresonance overvoltages. Significant effect on the onset of chaos, the range of parameter values that may lead to chaos along with ferroresonance overvoltages has been obtained and presented.**

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

I. Introduction

Ferroresonance overvoltage on electrical power systems were recognized and studied as early as 1930s. Kieny first suggested applying chaos to the study of ferroresonance in electric power circuits [1]. He studied the possibility of ferroresonance in power system, particularly in the presence of long capacitive lines as highlighted by occurrences in France in 1982, and produced a bifurcation diagram indicating stable and unstable areas of operation. Because of importance of this phenomenon, in recent years, many papers described it from various aspects. For example in [2] time delay feedback is used to omit chaotic ferroresonance oscillation in power transformers. 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] and [4]. Controlling ferroresonance in autotransformer connected in parallel to a MOV arrester has been illustrated in [5]. Effect of circuit breaker shunt resistance on chaotic ferroresonance in voltage transformer was shown in [6]. In this work investigation of ferroresonance oscillations has been done on the electromagnetic voltage transformer and has been shown to exhibit fundamental frequency and chaotic ferroresonance conditions. Controlling ferroresonance has been investigated in [7]-[10]. In [11], electromagnetic voltage 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 including nonlinear core losses effect has been shown in [12], [13], in these works proper nonlinear model has been considered for transformer core and effect of the core loss has been studied. In [14], effect of neutral resistance on the 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 stabilizing of unstable and high amplitude ferroresonance oscillation is used.

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II. System Modeling without Neutral Resistance

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

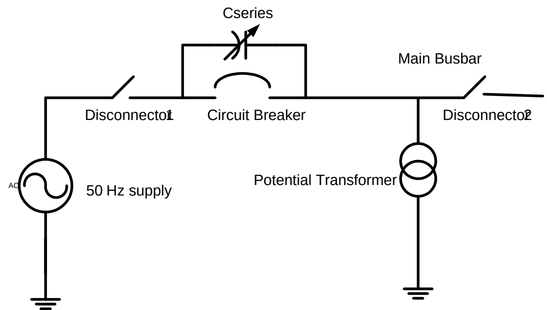


Fig. 1. System one line diagram arrangement resulting to PT ferroresonance [6]

Fig. 2 shows the basic ferroresonance equivalent circuit used in this analysis. The resistor *R* represents transformer core losses. In [15] accurate model for magnetization curve of core considering hysteresis, was introduced but in current paper the nonlinear transformer magnetization curve was modeled by a single valued seventh order polynomial obtained from the transformer magnetization curve [8].

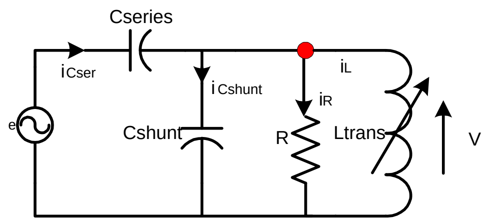


Fig. 2. Basic reduced equivalent ferroresonance circuit [6]

In Fig. 2, *E* is the RMS supply phase voltage and resistor *R* represents a potential transformer core loss. Flux-current linkage ($\lambda - i$) characteristic of the potential transformer is modeled as in [8] and [16] by the polynomial

$$i = a\lambda + b\lambda^7 \qquad (1)$$

where, $a = 3.14$, $b = 0.41$.

A small change in the value of system voltage, capacitance or losses may lead to dramatic change in the behavior of it. A more suitable mathematical language for studying ferroresonance and other nonlinear systems is provided by nonlinear dynamic methods. Mathematical tools that are used in this analysis are phase plan diagram, time domain simulation and bifurcation diagram.

III. System Dynamics and Equation

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

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

$$\left(\sqrt{2}E\cos\omega t\right) = \frac{\left(C_{series} + C_{shunt}\right)}{\omega.C_{series}}\frac{d^2\lambda}{dt^2} + \frac{1}{\omega.R.C_{series}}\frac{d\lambda}{dt} + \frac{1}{\omega.C_{series}}(a\lambda + b\lambda^7) \qquad (3)$$

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 Eq. (3).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	2π60 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	0.1	3	1900	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.

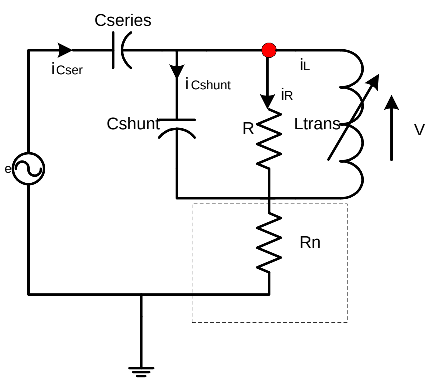


Fig. 3. Basic reduced equivalent ferroresonance circuit connecting neutral earth resistance

In Fig. 3, E is the RMS supply phase voltage, the resistor R represents a potential transformer core loss and R_n is the 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:

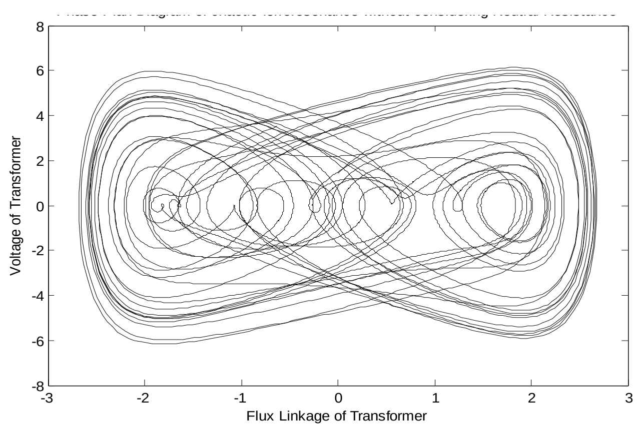
$$\left(R_n RC_{ser}C_{shunt}\right)\frac{d^2v_L}{dt^2} = R.C_{ser}\sqrt{2}E\omega\cos\omega t - \left(1 + R_n RC_{ser}a + R_n RC_{ser}qb\lambda^6\right)v_L - \left(RC_{sh} + RC_{ser} + R_n C_{ser}\right)\frac{d^2\lambda}{dt^2} - R\left(a\lambda + b\lambda^7\right) \qquad (4)$$

V. Simulation Results

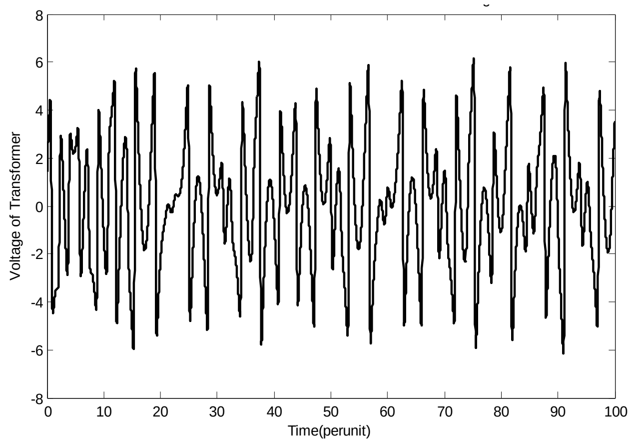
In this section of simulation, system has been considered without neutral resistance and time-domain simulations were performed using the MATLAB programs. One state of ferroresonance has been studied in two cases, without considering neutral earth resistance and with considering neutral resistance.

A. Chaotic Ferroresonance

An example of chaotic ferroresonance conditions is presented in Fig. 4 (a) and (b) showing waveform and phase space for corresponding values in Table II. Waveforms demonstrate the possibility of chaotic ferroresonance and overvoltages reach up to 6p.u.



(a)

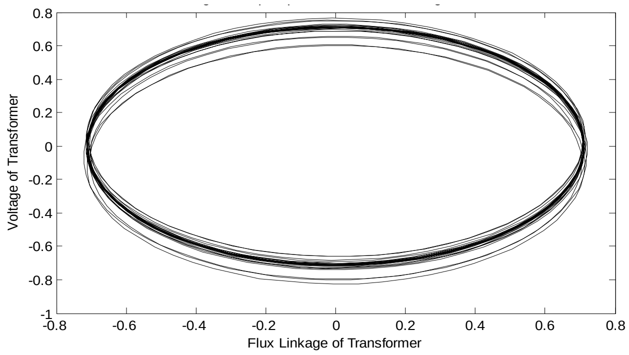


(b)

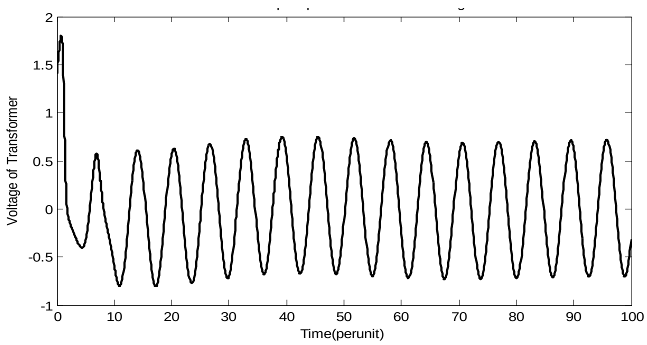
Fig. 4. (a) Phase plan diagram for chaotic ferroresonance motion without neutral earth resistance effect and (b) time domain simulation for chaotic ferroresonance motion without neutral earth resistance effect

B. Normal Sinusoidal Response (Comparative Study)

In this case of simulation, neutral earth resistance has been connected to the neutral point of the transformer. In Fig. 5 (a) trajectory of system has a periodic manner and amplitude of overvoltages reach to 0.5 p.u when compare it with Fig. 4 (a). Neutral resistance successfully clamps the ferroresonance overvoltage.

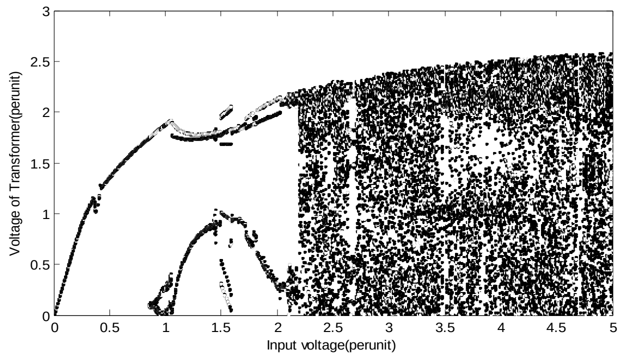


(a)

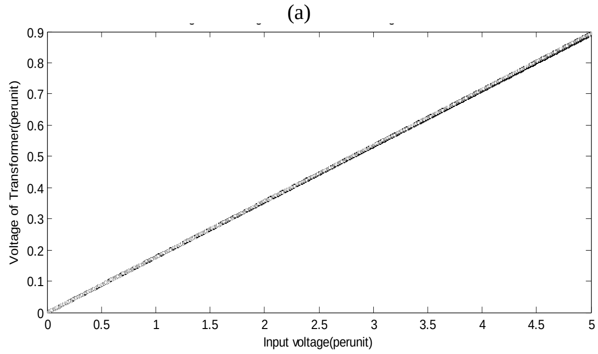


(b)

Fig. 5. (a) Phase plan diagram for quasiperiodic motion with neutral earth resistance effect and (b) Time domain simulation for quasiperiodic motion with neutral earth resistance effect



(a)



(b)

Fig. 6. (a) Bifurcation diagram for voltage of transformer versus voltage of system, without considering neutral earth resistance and (b) Bifurcation diagram for voltage of transformer versus voltage of system, with considering neutral earth resistance

VI. Bifurcation Diagram Analysis

In this paper, it is shown the effect of variation in the voltage of system on the ferroresonance overvoltages in the PT, and finally the effect of considering neutral earth resistance on this overvoltage by bifurcation diagrams. By using the bifurcation diagrams, Fig. 6 (a) clearly shows the nonlinear overvoltage in PT when voltage of system increases up to 5 p.u. in this plot, amplitude of the non-conventional overvoltages has been reached to 2.5 p.u, when input voltage reaches to 2 p.u, chaos begins and by period doubling route to chaos ferroresonance has been occurred.

Fig. 6 (b) shows effect of neutral earth resistance on the ferroresonance overvoltages. This overvoltages has been clamped to 0.9p.u, chaotic ferroresonance has been removed and period1 behavior has been remained in the system behavior, neutral earth resistance has been controlled these nonlinear overvoltages and keeps transformer in the safe operation region.

VII. Conclusions

In this work it is shown that system behaviour has been greatly changed by neutral earth resistance. The presence of the neutral resistance results in controlling the ferroresonance overvoltages in studied system. The neutral resistance successfully control the chaotic ferroresonance behaviour of proposed system. Finally, system shows less sensitivity to initial conditions in the presence of the neutral earth resistance.

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