Nonlinear Oscillation in Potential Transformers Connected Controlling Circuit

Hamid Radmanesh, Mohammad Bakhshandeh, and Hamid Mohammad Hossein

Abstract—**In this work at first ferroresonance phenomenon is introduced and then various type of ferroresonance overvoltages in a potential transformer is simulated. Then effect of neutral earth resistance on controlling these oscillations in the case of nonlinear core losses has been studied. Core losses in the potential transformer are modelled by third order power series in terms of voltage and include nonlinearities in core losses. It is expected that neutral earth resistance generally can cause ferroresonance 'dropout'. For confirmation this aspect Simulation has been done on a one phase potential transformer rated 100VA, 275kV. The simulation results show that connecting the neutral earth resistance on the system configuration, shows a great controlling effect on ferroresonance oscillation.**

Index Terms—**Ferroresonance oscillation, stabilizing, chaos control, potential transformer, nonlinear core losses, 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]. 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. Modeling iron core nonlinearities has been illustrated in [3]. Mozaffari has been investigated the ferroresonance in power transformer and effect of initial conditions on this phenomena [4], [5]. The controlling effect of potential transformer connected in parallel to a MOV arrester has been illustrated in [6]. Effect of circuit breaker shunt resistance on chaotic ferroresonance in potential transformer was shown in [7]. It has been shown C.B shunt resistance successfully can cause ferroresonance drop out and can control it. Then controlling ferroresonance has been investigated in [8], [9] and [10]. In [11], power transformer has been studied in the case of nonlinear core losses by applying metal oxide surge arrester in parallel with it and simulations have shown that a change in the value of the equivalent line to ground capacitance, may originate different types of ferroresonance overvoltages. Analysis of chaotic ferroresonance phenomena in unloaded transformers and potential transformers including nonlinear core losses effect has been shown in [12], [13], in this work 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 controlling of unstable and high amplitude ferroresonance oscillation is used. Using of this method results improving voltage waveform which leads to protection from insulation, fuses and switchgears. This paper organized as follow: At first the reason of occurrence ferroresonance in transformers is described. Then one type of ferroresonance in potential transformer is explained. Then general introducing of controlling ferroresonance by connecting neutral earth resistance in the case of modeling nonlinear core losses and using it in current problem is shown.

II. SYSTEM MODELING WITHOUT NEUTRAL RESISTANCE

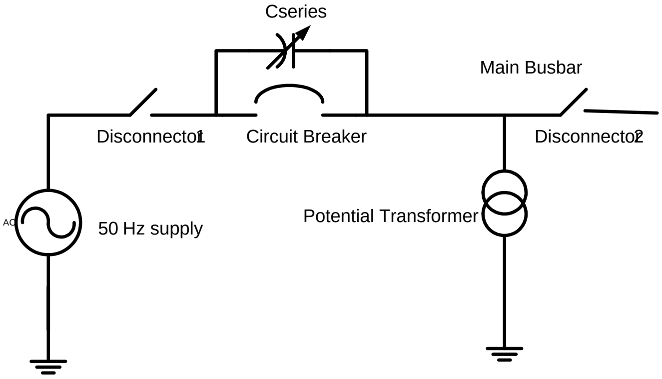

Fig. 1. System one line diagram arrangement resulting to PT Ferroresonance

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.2 shows the basic ferroresonance equivalent circuit used in this analysis. In [15] accurate model for magnetization curve of core considering hysteresis, was introduced but in current paper the nonlinear transformer magnetization curve was modeled

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by a single valued seventh order polynomial obtained from the transformer magnetization curve[9].

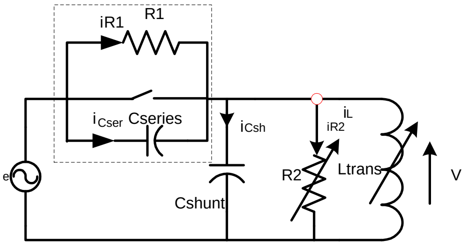

Fig. 2. Basic reduced equivalent ferroresonance circuit including nonlinear core losses and air gap resistance effect [6]

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 nonlinear core loss and R_1 is circuit breaker shunt resistance. In the peak current range for steady-state operation, the flux-current linkage can be a highly nonlinear equation, here the $\lambda - i$ characteristic of the potential transformer is modeled as in [12] by the polynomial.

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

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 the system can be presented as below:

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

$$\begin{aligned}
&\frac{1}{R_{C.B}\left(C_{ser} + C_{sh}\right)}.(\sqrt{2}ESin(\omega t) - \frac{d\lambda}{dt}) \\
&+ \frac{C_{ser}}{(C_{ser} + C_{sh})}\sqrt{2}\omega ECos(\omega t) \\
&= \frac{d^2\lambda}{dt^2} + \frac{1}{(C_{ser} + C_{sh})}\begin{pmatrix} \left(a\lambda + b\lambda^7\right) \\ + \left(h_0 + h_1 v_L + h_2 {v_L}^2 + h_3 {v_L}^3\right) \end{pmatrix}
\end{aligned} \tag{3}$$

where ω is supply frequency, and E is the rms supply phase voltage and in equation (1) a=3.4 and b=0.41 are the seven order polynomial sufficient [6]. The time behavior of the basic ferroresonance circuit is described by (3).

IV. SYSTEM DESCRIPTIONS WITH NEUTRAL EARTH RESISTANCE

In this case, the system which was considered for simulation is shown in Fig.3. 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 primary purpose of inserting ferroresonance limiter impedance between the star point of a transformer and earth is to limit earth fault current. The value of impedance required is easily calculated to a reasonable approximation by dividing the rated phase voltage by the rated phase current of the transformer. Ferroresonance limiter impedance is conventionally achieved using resistors rather than inductors, so as to limit the tendency for the fault arc to persist due to inductive energy storage. These resistors will dissipate considerable heat when earth fault current flows and are usually only short term rated, so as to achieve an economic design. Due to the explanation above, In Fig. 3, R_n is the ferroresonance limiter resistance.

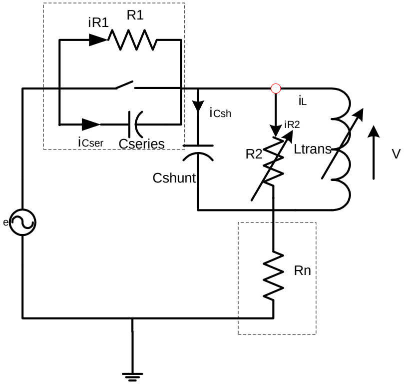

Fig. 3. Basic reduced equivalent ferroresonance circuit with connecting neutral earth resistance

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

$$\begin{aligned}
&C_{series}C_{shunt}R_n\frac{d^2 v_L}{dt^2} = C_{series}\sqrt{2}E\omega\cos(\omega t) \\
&+ \frac{1}{R_1}\sqrt{2}E\sin(\omega t) - \\
&\begin{pmatrix} C_{series} + C_{shunt} + C_{series}R_n h_1 + 2C_{series}R_n h_2 v_L \\ + 3C_{series}R_n h_3 {v_L}^2 \end{pmatrix}\frac{dv_L}{dt} \\
&- \left(C_{series}R_n a + C_{series}R_n bq\lambda^6\right)\frac{d\lambda}{dt} - \\
&\left(h_0 + h_1 v_L + h_2 {v_L}^2 + h_3 {v_L}^3 + a\lambda + b\lambda^7\right) \\
&- \frac{1}{R_1}\begin{pmatrix} v_L + R_n C_{shunt}\frac{dv_L}{dt} + R_n h_0 + R_n h_1 v_L + R_n h_2 {v_L}^2 \\ + R_n h_3 {v_L}^3 + R_n\left(a\lambda + b\lambda^7\right) \end{pmatrix}
\end{aligned} \tag{4}$$

V. SIMULATION RESULTS

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

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	2π0 rad/sec

TABLE II: PARAMETERS USED FOR VARIOUS STATES SIMULATION

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

A. Subharmonic Response

An example of subharmonic ferroresonance conditions is presented in Figs. (4a) and (4b) showing waveform and phase space for corresponding values in Table II.

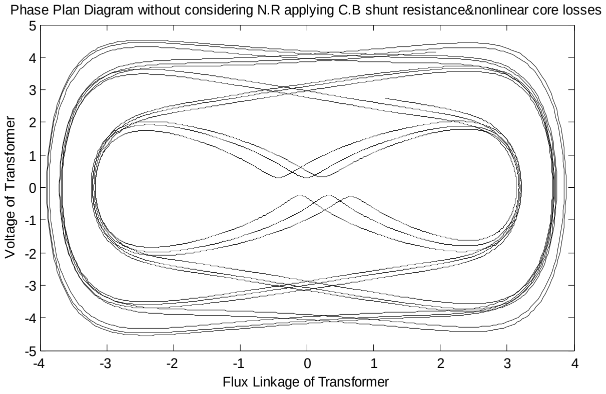

Fig. (4a). Phase plan diagram for subharmonic ferroresonance motion without neutral earth resistance effect

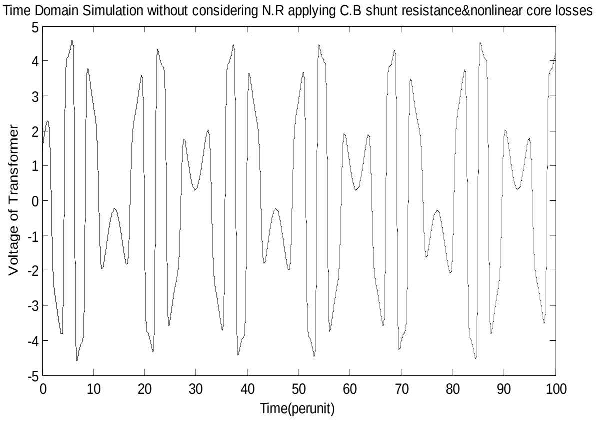

Fig. (4b). Time domain simulation for subharmonic ferroresonance motion without neutral earth resistance effect

In this plots, system trajectories show closed period9 behavior and amplitude of these overvoltages reach to 4p.u.

B. Quasiperiodic Response

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

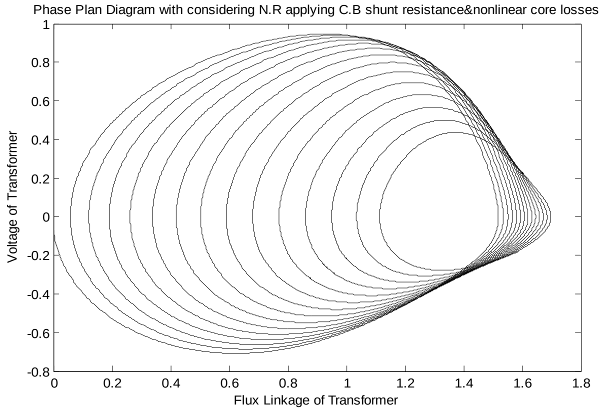

Fig. (5a). Phase plan diagram for quasiperiodic motion with neutral earth resistance effect

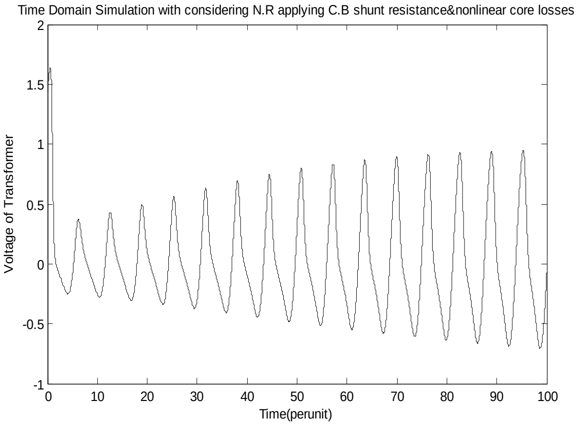

Fig. (5b). Time domain simulation for quasiperiodic motion with neutral earth resistance effect

By connecting neutral earth resistance to the system configuration, amplitude of ferroresonance overvoltages has been clamped to 0.8p.u and subharmonic ferroresonance behavior has been changed to the torus oscillation. Neutral earth resistance successfully decreased the ferroresonance overvoltages and controlled the chaotic nonlinear oscillation for all values of system parameters.

VI. CONCLUSION

In this paper it has been shown that system has been greatly influenced by neutral earth resistance. The presence of the neutral earth resistance results in controlling the ferroresonance oscillations in studied system. Neutral earth resistance successfully controls the chaotic ferroresonance in proposed model. It has been shown that by connecting neutral resistance, quasiperiodic oscillation has been take placed but amplitude of this oscillation has not been reached to 1p.u, neutral resistance is the best controlling tool and successfully can control the nonlinear overvoltages in the power system. Finally, system shows less sensitivity to initial conditions in the presence of the neutral earth resistance.

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