Analysis of Ferroresonance Phenomena in Power Transformers Including Neutral Resistance Effect

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Abstract

This Paper studies the effect of a neutral resistance on the ferroresonance oscillations of the power transformer. It is expected that this resistance generally cause ferroresonance 'dropout'. Time-domain simulation has been carried out using MATLAB SIMULINK to study this effect. Simulation has been done on a three phase power transformer with one open phase. Effect of varying input voltage has been studied. The simulation results reveal that connecting the neutral resistance to the transformer, exhibits a great mitigating effect on ferroresonant over voltages. Phase plane along with bifurcation diagrams are also presented. Significant effect on the onset of chaos, the range of parameter values that may lead to chaos and magnitude of ferroresonant voltages has been obtained, showed and tabulated.

1. Introduction

Ferroresonance is a complex electromagnetic phenomenon that may be neglected in power system studies which carried out for routine designs,planning and operations[1]. Ferroresonance can be categorized as a nonlinear resonance which is unpredictable which can cause damage in power distribution and transmission system apparatus [2]. Mostly in power system, Ferroresonance occurs when only one or two phases are lost while the transformer is unloaded or lightly loaded. This can happen due to burning of fuse in one or two lines, operation of single phase reclosers or the performance of single phase switching procedures or even malfunction of three phase breaker. Consequently the open phase may experience high ferroresonance voltages. This induced voltage will "backfeed"the distribution line, back to the opened switch. Ferroresonance will occur if the distribution line is highly capacitive [3]. Power system elements in this case, are nonlinear magnetizing reactance of the transformer's open phase and the shunt capacitance of the distribution line. Ferroresonance is a nonlinear phenomenon that may lead to chaotic oscillations which may brings up many possibilities [4]. To study ferroresonance in this point of view method of "slowly varying amplitude method" is used to derive an analytical solution for the equivalent ferroresonance circuit [5]. The solution of the nonlinear equation for typical ferroresonance circuit containing a power transformer is shown that accurate magnetization curve modeling would greatly affects the results. Generally, probability of falling to chaotic modes increases as system losses decreases or the nonlinearity of transformer magnetization curve increases [5, 6]. Results show high dependency of occurring chaos to initial conditions [7]. It is shown that a small change in the initial conditions leads to the large divergence of system trajectories in long-term run and the basins of attraction for different chaotic regions will be obtained [8]. The MATLAB program is used to simulate ferroresonance and related phase plane and bifurcation diagrams. The result of the case study confirms that system states, lead to chaos and bifurcation occurs in proposed model. The presence of the neutral resistance tends to clamp the Ferroresonant over voltages. The neutral resistance successfully, reduces the chaotic region for higher exponents. Simulation of system consists of two cases, at first, system modeling of power transformer without neutral resistance and second, system contains neutral resistance. Finally compare the result of these two cases.

2. System Modeling Without Neutral Resistance

Transformer is assumed to be connected to the power system while one of the three switches are open and only two phases of it are energized, which produces induced voltage in the open phase. This voltage, back feeds the distribution line. Ferroresonance will occur if the distribution line is highly capacitive. System involves the nonlinear magnetizing reactance of the transformer's open phase and resulted shunt and series capacitance of the distribution line.

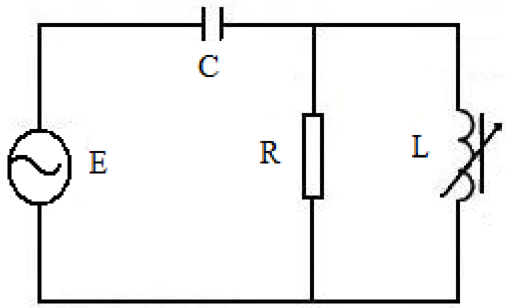

Fig. 1: basic ferroresonance circuit

Base system model is adopted from [1]. Linear approximation of the peak current of the magnetization reactance can be presented by equation 1:

$$i_L = a\phi \qquad (1)$$

However, for very high currents, the iron core might be saturated where the flux-current characteristic becomes highly nonlinear. The $\phi - i$ characteristic of the transformer can be demonstrated by the polynomial in equation 2: [1]

$$i_L = a\phi + b\phi^q \qquad (2)$$

The differential equation for the circuit in fig. 1 can be derived as follows:

$$\omega E \cos \omega t = p^2\lambda + (p\lambda / RC) +$$
$$(1/C)(a\phi + b\phi^q) \quad (3)$$

Where $p = d/dt$, ω represents the power frequency and E is the peak value of the voltage source, shown in fig. 1.

3. Simulation Results (Case 1)

Typical values for various system parameters considered for simulation without neutral resistance are as given below:

$$q = 5 \rightarrow \begin{cases} b = 0.0005 \\ a = 0 \end{cases}$$

$$q = 7 \rightarrow \begin{cases} b = 0.001 \\ a = 0 \end{cases}$$

$$q = 11 \rightarrow \begin{cases} b = 0.0072; \\ a = 0.0028 \end{cases}$$

$$\omega = 377 \ rad/\sec \ \ or \ 1.0 p.u;$$
$$R = 48400\Omega \ \ or \ 100 \ pu$$
$$C = 777nf \ \ or \ 0.82 \ pu$$
$$E = 110/44kv \ \ or \ \ 0-7 p.u$$
$$25MVA$$

Initial conditions:

$$\phi(0) = 0.0; \qquad p\lambda(0) = \sqrt{2}$$

Fig.2.shows nonlinear curves of transformer core for different value of q.

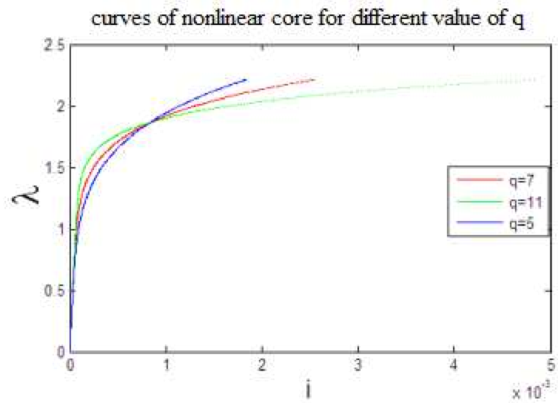

Fig. 2.curves of nonlinear core

Table 1 shows different values of E, considered for

Analyzing the circuit in absence of neutral resistance.

Table 1: Simulation results (Without arrester)

q/E	1	2	3	4	5	6
5	P1	P9	P7	chaotic	Chaotic	-
9	P1	P3	chaotic	chaotic	Chaotic	chaotic
11	P1	cha otic	chaotic	chaotic	Chaotic	chaotic

Time-domain simulations were performed using the MATLAB programs.

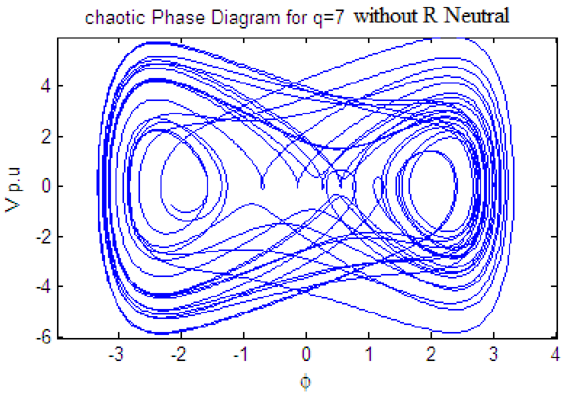

Fig.3. Phase plane diagram for chaotic waveform without neutral resistance

Fig.3, 4 show the phase plane plot of system states without neutral resistance for E=3 p.u. Figs.5, 6 and 7 shows the bifurcation diagram of system states without neutral resistance for q=5, 7, 11 p.u. which depicts chaotic behavior.

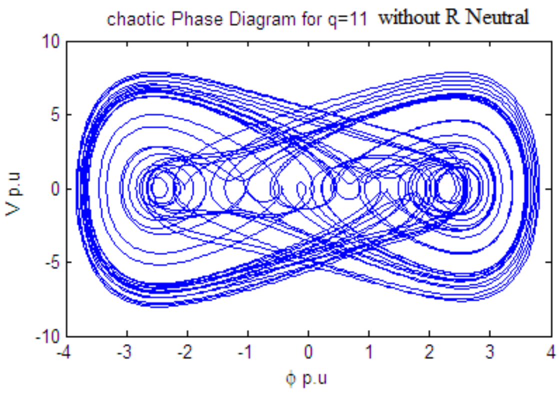

Fig.4. Phase plane diagram for chaotic waveform without neutral resistance

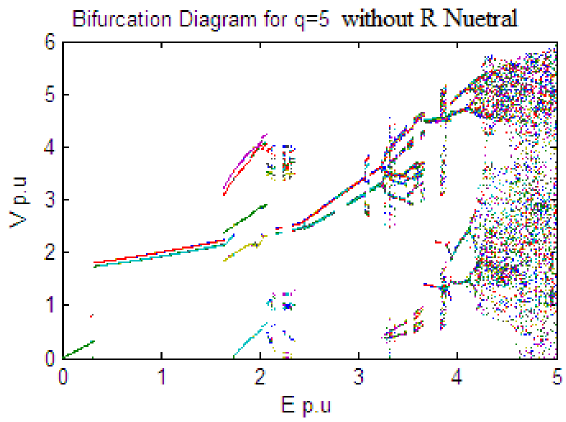

Fig.5. Bifurcation diagram (without arrester, q=5)

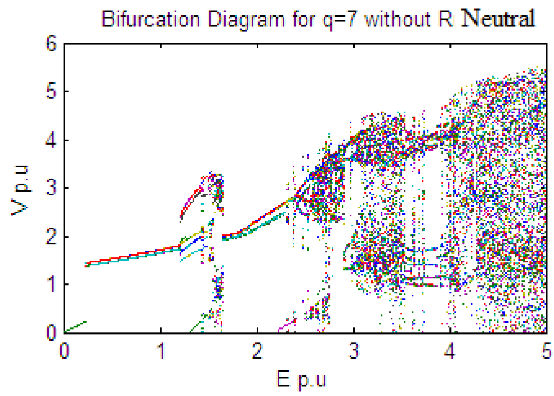

Fig. 6. Bifurcation diagram (without arrester, q=7)

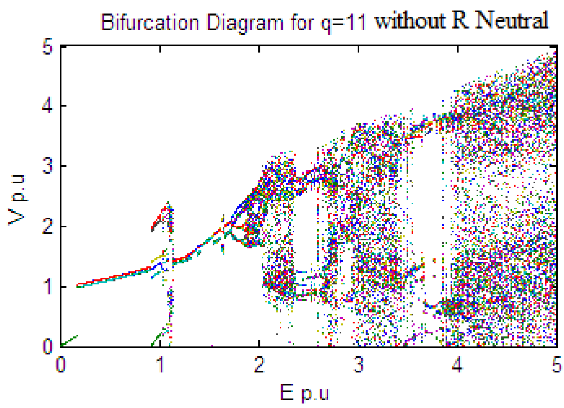

Fig.7.Bifurcation diagram (without arrester, q=11)

Tendency for chaos exhibited by the system voltage increases while q increases too.

4. Simulation Results (Case 2)

In this case, system that considered for simulation shown in fig.7.

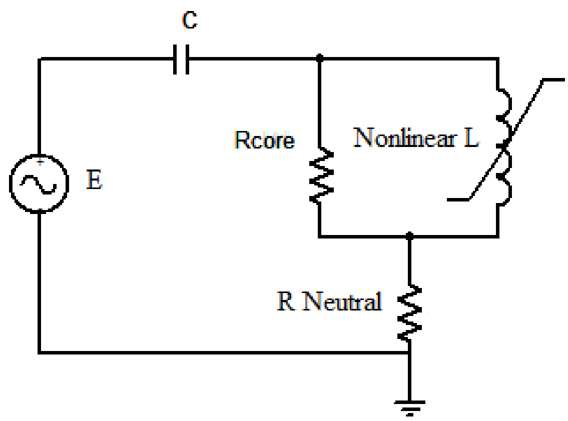

Fig. 8. Equivalent circuit of system with neutral resistance

Typical values for various system parameters considered for simulation with neutral resistance are as given below:

$$R\,neutral = 12100\Omega \;\; or \;\; 2.5\,pu$$

Initial conditions:

$$\phi(0) = 0.0; \qquad p\lambda(0) = \sqrt{2}$$

The differential equation for the circuit in fig. 7 can be derived as follows:

$$dE - (R_2 a + \frac{1}{CR_1})d\lambda - (R_2 bq\lambda^{q-1})d\lambda$$

$$-\frac{1}{C}(a\lambda + b\lambda^q) = \frac{R_1 + R_2}{R_1} d^2\lambda \qquad (5)$$

Presenting in the form of state space equations, ϕ and $P\phi$ will be state variables as follows:

$$q = x_1 \qquad \lambda = x_2 \qquad (6)$$

$$px_1 = x_2$$

$$\begin{bmatrix} 1 & 1/R_1 \\ 0 & \frac{R_2 + R_1}{R_1} \end{bmatrix} \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{cases} ax_2 + bx_2^{\,q} \quad (6) \\ E - \frac{x_1}{c} - R_2(ax_2 + bx_2^{\,q}) \end{cases}$$

It is shown that tendency to chaos reduce in this case. Simulation results are as below:

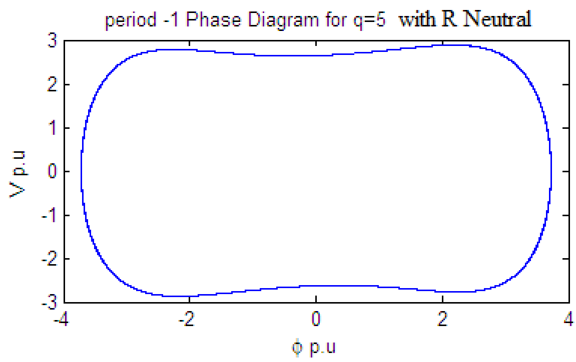

Fig.9. Bifurcation diagram (without arrester, q=9)

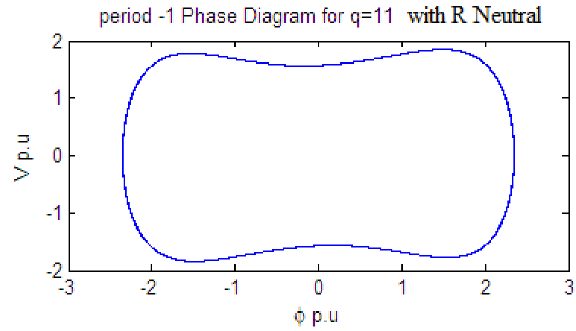

Fig. 10. Phase plane diagram for period1 waveform with neutral resistance

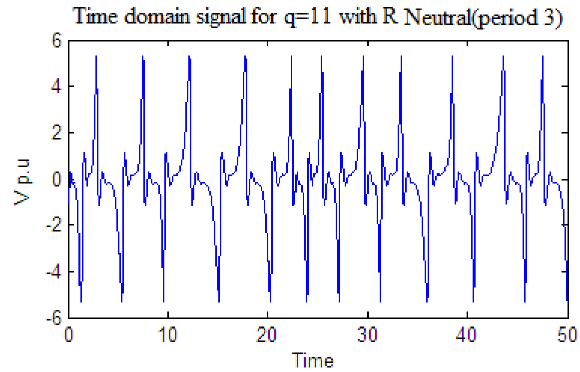

Fig.11Time domain simulation of system (period3)

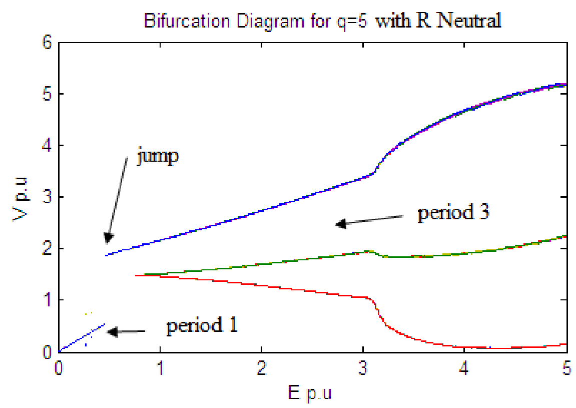

Fig.12. Bifurcation diagram (with arrester, q=5)

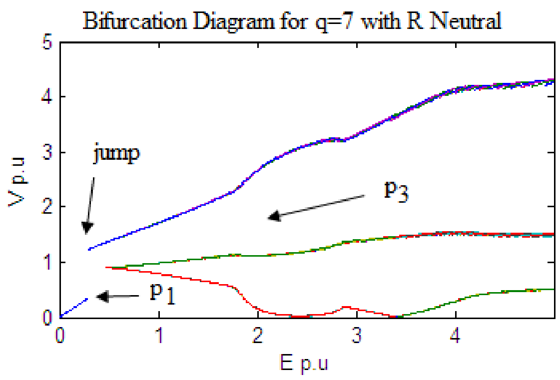

Fig.**13.** Bifurcation diagram (without arrester, q=7)

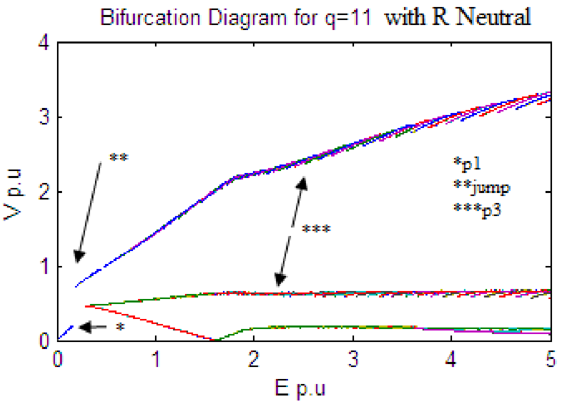

Fig.**14.** Bifurcation diagram (without arrester, q=11)

Figs.9,10 shows the corresponding phase plan diagram and Figs.11 shows time domain simulation for system in fig.7.also figs.12,13 and 14 shows bifurcation diagrams for corresponding system including neutral resistance. It is shown that chaotic region mitigates by applying neutral resistance. Table 2 includes the set of cases which are considered for analyzing the circuit including neutral resistance. For cases including neutral resistance, it can be seen that ferroresonant drop out will be occurred.

Table 2: Simulation results (with neutral resistance)

q/ E	1	2	3	4	5	6
7	P3	P3	P3	P3	P3	-
9	P3	P3	P3	P3	P3	-
11	P3	P3	P3	P3	P5	-

5. Conclusions

The system has been greatly affected by neutral resistance. Maintaining same parameters, except transformer losses, (R=750) simulations repeated, which showed that the tendency to fall in chaotic regions, increases while core losses decreases but it is not present in this work. The presence of the neutral resistance results clamping the Ferroresonant over voltages in studied system. The neutral resistance successfully, suppresses or eliminates the chaotic behaviour of proposed model. Consequently, the system shows less sensitivity to initial conditions in the presence of the neutral resistance.

6. Reference:

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