Elimination of Chaotic Ferroresonance in power transformers including Nonlinear Core Losses applying of Neutral Resistance

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Abstract

This paper studies the effect of neutral resistance on the onset of chaotic ferroresonance and chaotic transient in a power transformer including nonlinear core losses. It is expected that this resistance cause ferroresonance ‘dropout'. Time-domain study has been carried out to study this effect. Simulation has been done on a three phase power transformer rated 50 MVA, 635.1 kV with one open phase. The magnetization characteristic of the transformer is modeled by a single-value two-terms polynomial. The core loss is modeled by third order power series in terms of voltage includes nonlinearities in core model.The simulation results reveal that connecting the neutral resistance to the transformer, exhibits a great mitigating effect on voltage ferroresonance. Phase plane along with bifurcation diagrams are also derived. Having Significant effect on the onset of chaos, the range of parameter values that may lead to chaos along with ferroresonance voltages has been obtained and presented.

Key word: Chaos, Bifurcation diagram ,Ferroresonance ,Power transformer ,Neutral Resistance

1. Introduction

Ferroresonance may be initiated by switching actions, or load shedding in power system. It can produce unpredictable over voltages and high currents. The prerequisite for ferroresonance is a circuit containing nonlinear iron core inductance and a capacitance. Such a circuit is characterized by simultaneous existence of several steady-state solutions for a given set of circuit parameters. The abrupt transition or jump from one state to another is triggered by a disturbance, switching action or a gradual change in system parameters.
Typical cases of ferroresonance are reported in. [1], [4]. Theory of nonlinear dynamics has been found to provide deeper insight into the phenomenon [5].

Fundamental theory of nonlinear dynamics and chaos can be found in [4], [7]. The susceptibility of a ferroresonance circuit to a quasiperiodic and frequency locked oscillations are presented in [8], [9], The effect of initial conditions which is investigated. [10] is a milestone contribution highlighted the effect of transformer modeling on the predicted ferroresonance oscillations. Using a linear model, [11] has shown the effect of core loss in damping ferroresonance oscillations. Reference [12] emphasizes treating core loss as a nonlinear function of voltage. An algorithm for calculating core losses based on no-load characteristics of transformer is given in [13].The mitigating effect of transformer connected in parallel to a MOV arrester is illustrated in [14].Effect of circuit breaker grading capacitance on ferroresonance in VT is investigated in [15]. In all previous studies, the effects of neutral resistance including nonlinear core losses are neglected. In these works, it has been shown that nonlinear core loss can decrease ferroresonance phenomena in power transformer . Later, the effect of neutral resistance on power transformer including linear core loss has been investigated [16]. Current paper studies the effect of neutral resistance on the global behavior of a ferroresonance circuit with nonlinear core loss.

1. System Modeling (Base System)

System Modelling Without Neutral Resistance in Transformer is assumed to be connected to the power system while one of the three circuit breaker poles is open and only two phases of it are energized, which produces induced voltage in the open phase. This voltage, back feeds the line, and consequently ferroresonance will occur if the distribution line is enough capacitive. System involves the nonlinear magnetizing reactance of the transformer's open phase and resulted shunt and series capacitance of the distribution line.

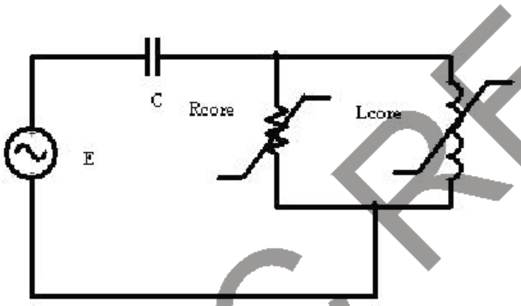

Fig 1. Equivalent circuit of system

Fig.1. shows the equivalent circuit of system described above. The magnetization branch is modelled by a nonlinear inductance in parallel with a nonlinear resistance accordingly represent the nonlinear saturation characteristic $\lambda - i_{Lm}$ and nonlinear hysteresis and eddy current characteristics $(v_m - i_{Rm})$, respectively. The hysteresis and eddy current characteristics of core can be obtained from no-load statues of transformer by applying the algorithm given in [13]. The iron core saturation cure characteristic is given by:

$i_{Lm} = s_1\lambda + s_2\lambda^q$ (1)

Exponent q depends on the degree of saturation. It has been found that for adequate representation of the saturation characteristics of a power transformer the exponent q may acquire values 5, 7, and 11. Fig.2 shows iron core characteristic for q=5, 7, 11.

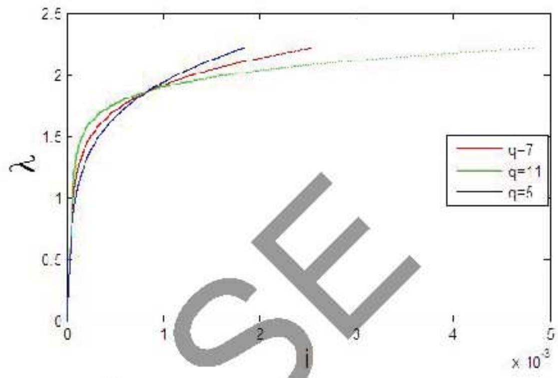

Fig. 2. Nonlinear characteristics of transformer core with different values of q

Beside,to study the case, the core loss model is formulated by a third order power series whith coefficients, fitted to match the hysteresis and eddy current nonlinear characteristics given in [1]:

$$i_{Rm} = h_0 + h_1 v_m + h_2 v_m^2 + h_3 v_m^3 \quad (2)$$

Per unit value of i_{Rm} is given in (3)

$$i_{Rm} = -.000001 + .0047V_m - .0073V_m^2 + .0039V_m^3 \quad (3)$$

The differential equation for the circuit in fig. 1 neglecting neutral resistance can be presented as follows:

$$V = \frac{d\lambda}{dt} \quad (4)$$

$$\dot{V}_c = \frac{1}{C}(h_0 + h_1V + h_2V^2 + h_3V^3 + a\lambda + b\lambda^q) \quad (5)$$

$$dE - \dot{V}_c - \dot{V}_L = 0 \quad (6)$$

$$dE - \frac{1}{C}(h_0 + h_1V + h_2V^2 + h_3V^3 + a\lambda + b\lambda^q)$$

$$= \frac{d^2\lambda}{dt^2} \quad (7)$$

Where E is the peak value of the voltage source, shown in fig.1.

Typical values for system parameters without neutral resistance are as follows:

$for\ q = 11\ \ s_1 = .0067, s_2 = .0001$

$for\ \ q = 7\ \ s_1 = .0067, s_2 = .001$

$for\ \ q = 5\ \ s_1 = .0071\ s_2 = .0034$

$\omega = 377$ rad/sec

$R = 8067\Omega$

$C_{pu} = 0.7955$

$V_{base} = 635.1kv$, $I_{base} = 78.72A$

And initial conditions are:

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

1.1. Simulation Results

Table 1 shows different values of E, considered for analyzing the circuit in absence of neutral resistance.

Table 1: Simulation results (Without Neutral Resistance)

q/E	1	3	5	7	9	10
5	P2	P2	P3	P6	Chaotic	P9
7	P2	P2	P3	chaotic	Chaotic	Chaotic
11	P2	P3	chaotic	chaotic	P4	P4

*Pi: Period i

Fig.3, 4, and 5 show the phase plane plot of system states without neutral resistance For E=3 p.u. Figs.6, 7 and 8 show the corresponding bifurcation diagrams of system states without neutral resistance and including nonlinear core losses for q=5, 7, 11 which depicts chaotic behaviour.

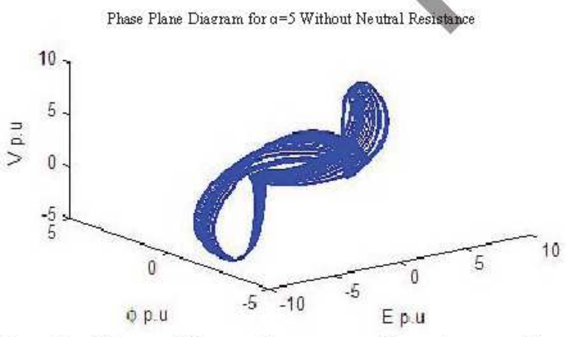

Fig. 3. Phase Plane diagram of system with q=5, without neutral resistance

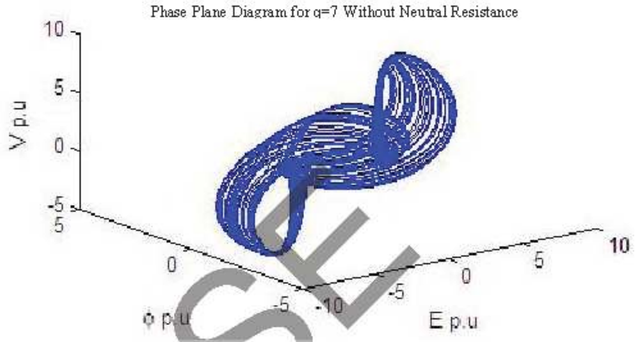

Fig 4. Phase Plane diagram of system with q=7, without neutral resistance

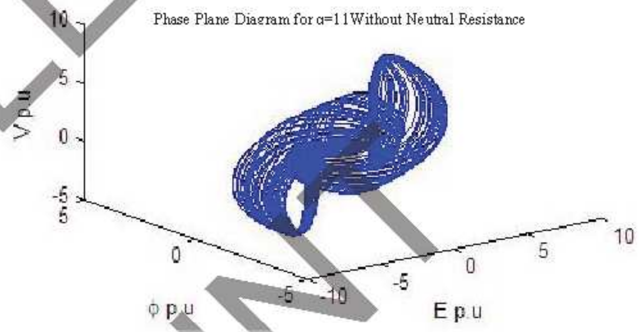

Fig 5. Phase Plane diagram of system with q=11, without neutral resistance

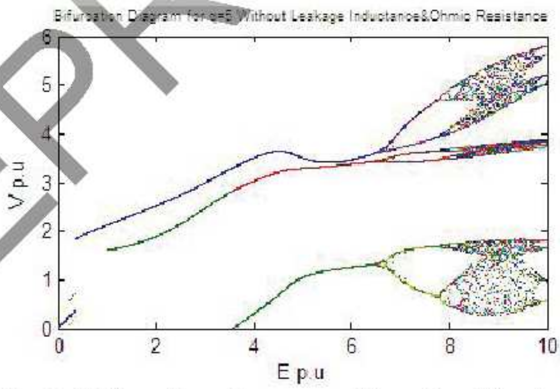

Fig 6. Bifurcation diagram with q=5, without neutral resistance

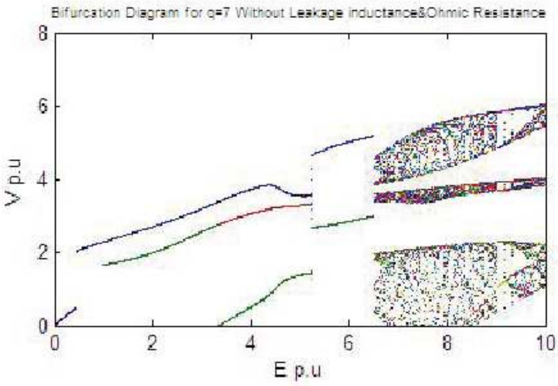

Fig 7. Bifurcation diagram with q=7, without neutral resistance

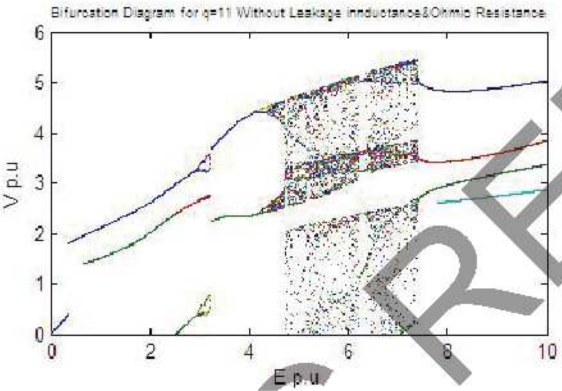

Fig 8. Bifurcation diagram with q=11, without neutral resistance

2. System modeling with neutral resistance

Including Neutral resistance,system of fig 1 , can be Modyfied as shown in fig 9.

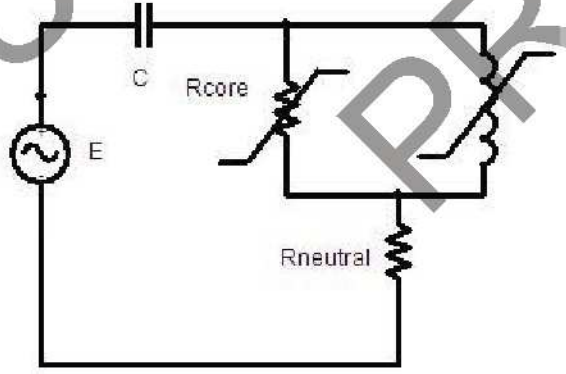

Fig. 9. Equivalent circuit of system with neutral resistance

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

$$R\,neutral = 40\mathrm{k}\Omega$$

The differential equation for the circuit in fig.**9** can be presented as follows:

$$dE - \dot{V}_c - \dot{V}_{Rneutral} - \dot{V}_L = 0$$

$$dE - \frac{1}{C}(h_0 + h_1 V + h_2 V^2 + h_3 V^3 + a\lambda + b\lambda^q) -$$

$$R_{Neutral}(+h_1 \frac{d^2\lambda}{dt^2} + 2h_2 \frac{d^2\lambda}{dt^2}\frac{d\lambda}{dt} + 3h_3 \frac{d^2\lambda}{dt^2}(\frac{d\lambda^2}{dt}) +$$

$$a\frac{d\lambda}{dt} + qb\frac{d\lambda}{dt}\lambda^{q-1}) = \frac{d^2\lambda}{dt^2}$$

Where λ is the flux linkage and V, is the voltage of transformer
Initial conditions:

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

2.1. Simulation results

Fig.10 shows the corresponding phase plane diagram and Fig .11 shows voltage wave form for system in fig.9 in case of q=11. Consequently figs.12, 13 and 14 shows bifurcation diagrams for corresponding system including neutral resistance. It can be seen that chaotic region mitigates by applying neutral resistance and there is no chaotic region. wich is means, tendency to chaoticbehaviour reducesdramaticallyif neutral resistance effect been included.
Comparing to table 1 table 2 includes the results considering circuit with neutral resistance. Again , its clear that ferroresonance drop will be occurred.

Table 2: Simulation results (with neutral resistance)

q/E	1	2	3	4	5	6
5	P1	P1	P1	P1	P2	P2
7	P1	P1	P2	P3	P3	P3
11	P1	P1	P3	P3	P3	P3

*Pi: Period i

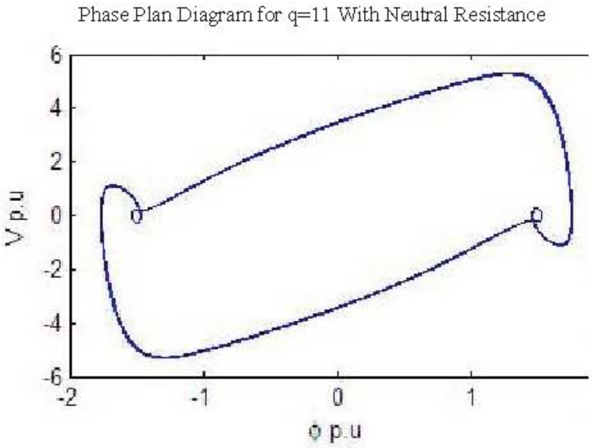

Fig 10. Phase Plan diagram of system with q=11, including neutral resistance

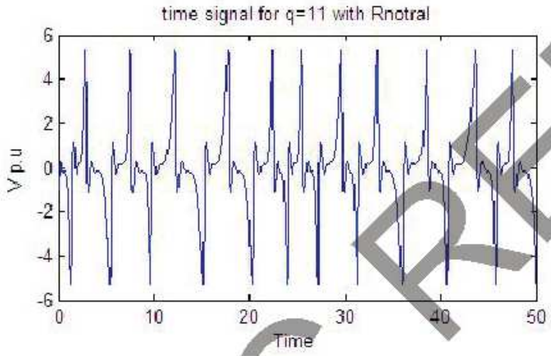

Fig 11. Time domain simulation with q=11, including neutral resistance

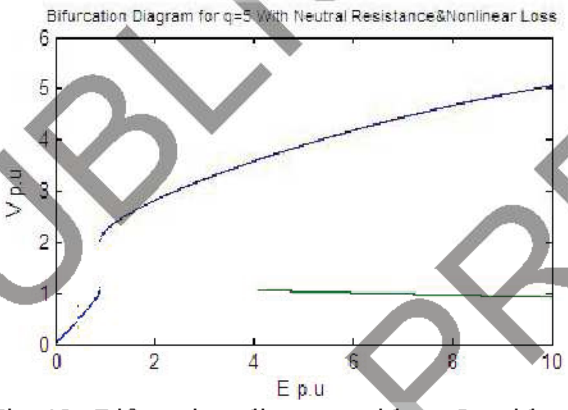

Fig 12. Bifurcation diagram with q=5, with neutral resistance

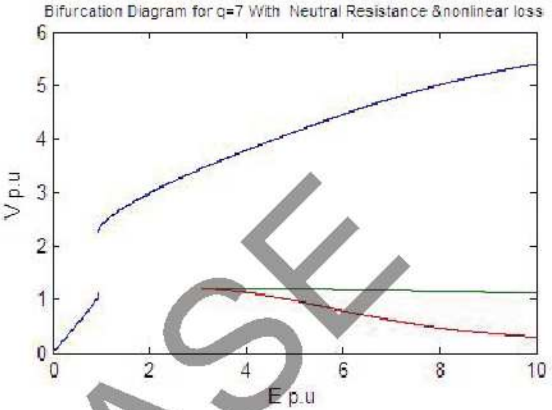

Fig 13. Bifurcation diagram with q=7, with neutral resistance

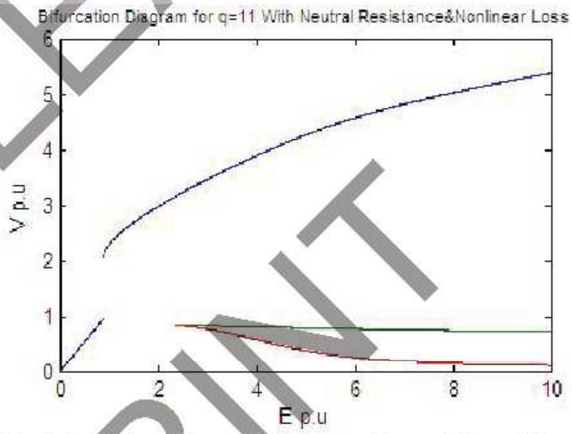

Fig 14. Bifurcation diagram with q=11, with neutral resistance

3. Conclusions

The dynamic behaviour of a transformer can be characterized by different presentation. Inclusion of nonlinearity in the core loss reveals that bifurcation diagrams will be smoother but more complicated when compared with linear models.

Adding Neutral resistance , It has been shown that system has been greatly affected by it. The presence of the neutral resistance results clamping the Ferroresonance over voltages in studied system. The neutral resistance successfully, suppresses the chaotic behavior of proposed model. Consequently, the system shows less sensitivity to initial conditions in the presence of the neutral resistance.

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