Effect of Circuit Breaker Shunt Resistance on Ferroresonance phenomena in Voltage Transformer

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Abstract

In this work, it is shown that chaotic ferroresonant oscillations involving voltage transformers (VTs) may be initiated by existing power system apparatus capacitances. It has been shown that various modes of ferroresonant oscillations may exist for the same VT type depending on the initial conditions and on the network capacitance. The effect of line and circuit breaker grading capacitance in ferroresonance and route to chaos has been investigated. It is also shown that switch capacitance has great effect on system behavior.

1. Introduction

Ferroresonance or nonlinear resonance is a complex electrical phenomenon, which may cause over voltages and over currents in an electrical power system which endangers the system reliability and continuous safe operating. Ferroresonant overvoltage on electrical power systems were recognized and studied as early as 1930s [1].Kieny [2] first suggested applying chaos to the study of ferroresonance in electric power circuits. 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. One of the most possible cases may happen when a nonlinear iron core inductor is fed from a series capacitor. These capacitances can be due to number of elements, such as the line-to-line capacitance, parallel lines, conductor to earth capacitance and circuit breaker grading capacitance, etc. Voltage transformer has typical construction and related powers are typically low due to their measuring function rather than supplying power [1]. The magnetizing characteristic of a typical 100VA VTs can be presented by 7 order polynomial [3]. These VTs fed through circuit breaker grading capacitance, and studied using nonlinear dynamics analysis and packages such as Rung kutta Fehlberg algorithm and Matlab Simulink. The system exhibits quasi periodic route to chaotic ferroresonance. Also by changing the type of breaker, it is shown that ferroresonance may drop out.

Ferroresonance in bulk power systems has been studied in previous works [4].combination of system capacitance and nonlinear inductance of transformer make a parasitic resonance circuit which creates dangerously high voltages. Recently, the possibility of ferroresonance in low capacity VTs that fed via capacitively circuit breaker has been investigate [5, 6], and in this work we analysis a 63KV substation, closed as a test circuit.

Conventional linear models are inappropriate in this study and application of nonlinear dynamics or chaos theory is highly needed for further analysis, to describe the phenomenon. Many studies address the solution of nonlinear equations for a typical ferroresonance circuit containing power transformer [7]. Accordingly Araujo etal [8] identified three types of ferroresonant states: periodic, quasiperiodic and chaotic. In this work VTs ferroresonance is analyzed from view point of nonlinear dynamics. In particular, the effect of varying system, breaker capacitance and type of breaker on the behaviour of the system has been studied.

2. System Description and Modeling (1)

During Voltage Transformer (VT) ferroresonance an oscillation occurs between the nonlinear iron core inductance of the VT and existing capacitances of network. In this case, energy is coupled to the nonlinear core of the voltage transformer via the open circuit breaker grading capacitance or system capacitance to sustain the resonance. The result may be saturation and high currents at sub-harmonic or fundamental frequency. Very high voltage of up to 4 p.u can theoretically gained in worst case conditions. Voltage transformers have a relatively low thermal capacity and overheating can cause insulation failure as soon as than what we may expected.

Fig.1 shows the single line diagram of the most commonly encountered system arrangement that can give rise to VT ferroresonance. Ferroresonance can occur upon opening of disconnector 3 with circuit breaker open and either disconnector 1 or 2 closed. Alternatively it can also occur upon closure of both disconnector 1 or 2 with circuit breaker and disconnector 3 open.

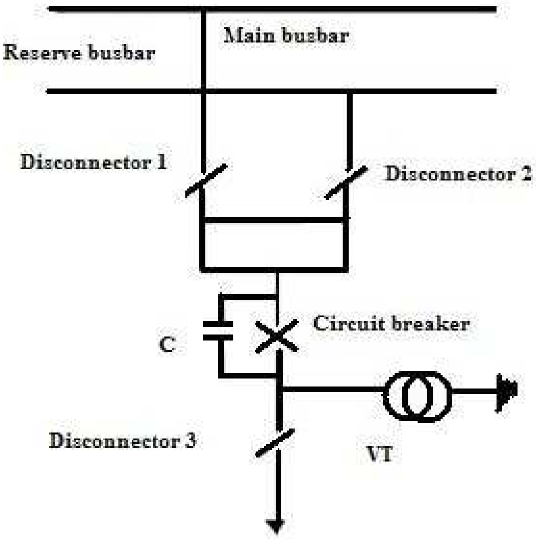

Fig.1.System one line diagram arrangement resulting to VT ferroresonance

The system arrangement shown in Fig. 1 can effectively be reduced to an equivalent circuit as shown in Fig. 2[9].

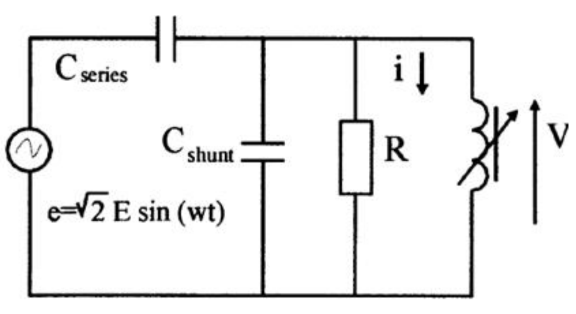

Fig.2. Basic reduced equivalent ferroresonance circuit

In Fig. 2, E is the rms supply phase voltage, Cseries is the circuit breaker grading capacitance and Cshunt is the total phase-to-earth capacitance of the arrangement. The resistor R represents a voltage transformer core loss that has been found to be an important factor in the initiation of ferroresonance [5, 6], ω is supply frequency and λ is flux linkage.

The VT itself is a low thermal capacity, 63kV/110V, 100VA Voltage Transformer. Cseries and Cshunt were represented as lumped parameters. The resistance R was represented dynamically based on [10]

$$R = \frac{R_{os} - R_{MS}}{1 + \left(\frac{|B|}{B_s}\right)^a} + R_{MS} \qquad (1)$$

In(1)

$$R_{os} = 60\Omega,\ R_{MS} = 250\Omega, a = 9.5, B_s = 1.7T$$

.at every integration time-step of MATLAB then the value of R is recalculated depending the value of B.

$$i = a\lambda + b\lambda^7 \qquad (2)$$

$$\lambda_{peak} = \sqrt{2}\,\frac{v_{RMS}}{\omega}$$

$$\frac{1}{\omega}\frac{dv}{dt} + \frac{1}{R\omega(C_{series} + C_{shunt})} + \frac{1}{\omega(C_{series} + C_{shunt})}$$

$$(a\lambda + b\lambda^7) = \frac{C_{series}}{(C_{series} + C_{shunt})}\sqrt{2}E\cos\theta \ (3)$$

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

$$a = 3.4,\ b = 0.41$$

3. Nonlinear Dynamic Systems

The basic voltage transformer ferroresonance circuit of Fig.1 can be presented by a differential equation. Because of the nonlinear nature of the transformer magnetizing characteristics, the behaviour of the system is extremely sensitive to change in system parameter and initial conditions. A small change in the value of system voltage, capacitance or losses may lead to dramatic change in the behaviour of it. A more suitable mathematical language for studying ferroresonance and other nonlinear systems is provided by nonlinear dynamic methods [11].mathematical tools that used in this analysis is phase space-time domain simulation and bifurcation diagram.

4. Simulation Results

4.1 General

In the following analysis, instead of using actual values of circuit parameters $E, \omega, C_{series}, C_{Shunt}$ etc., system equations are made dimensionless by using per unit values, equation (3) may be written as

$$\frac{1}{\omega}\frac{dV}{dt} + \frac{1}{q}V + \frac{1}{(C_{series} + C_{shunt})}(a\lambda + b\lambda^{7}) = g\cos\theta \quad (5)$$

Where g and q are the driving force amplitude and damping parameter, respectively, given by

$$g = \frac{C_{series}}{(C_{series} + C_{shunt})}\sqrt{2}E \quad (6)$$

$$\frac{1}{q} = \frac{1}{R\omega(C_{series} + C_{shunt})} \quad (7)$$

Eqns. (5) contains a nonlinear term and does not have simple analytical solution. So the equations were solved numerically using an embedded Runge-Kutta-Fehlberg algorithm with adaptive step size control. Values of E and ω were fixed at 1 p.u., corresponding to AC supply voltage and frequency. C series is the CB grading capacitance and its value obviously depends on the type of circuit breaker used. In this analysis C series was fixed at 0.5nF and C shunt vary between 0.1nF and 3nF.solutions were obtained for initial values of $V(t) = \sqrt{2},\ \lambda(t) = 0$ at t=0, representing circuit breaker operation at maximum voltage. In the following sections, three states of system have been analyzed; periodic solution, quasiperiodic and chaos by varying capacitances, circuit breaker grading capacitance and system capacity separately.

4.1. Periodic states

Figs.3 and 4 Show waveforms and diagrams for normal sinusoidal conditions calculated for value of

$$E = 1\,p.u, \omega = 1\,p.u, C_{series} = 0.5nf, C_{Shunt} = 3pf$$
$$R = 225M\Omega$$

.

This corresponds to a lightly damped, lightly driven system in which q=47.24 and g=0.02.the phase plane diagram presented in Fig 3 clearly shows the closed trajectory characteristic of a periodic waveform. Fig.4 is Time domain simulation for this case that represented the sinusoidal wave with a frequency equal to the system frequency, i.e. 50 cycles per second. In this state, system under study is periodic, and there is no nonlinear phenomenon.

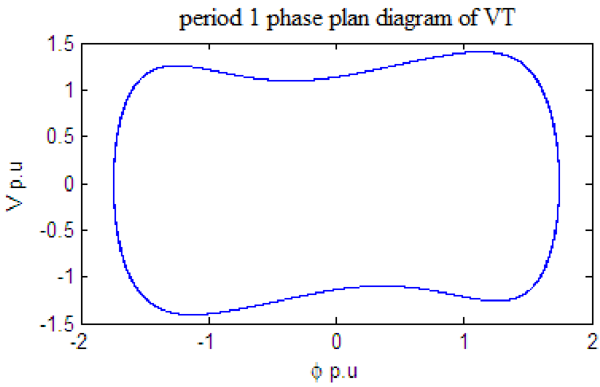

Fig.3.phase plane diagram for normal operation

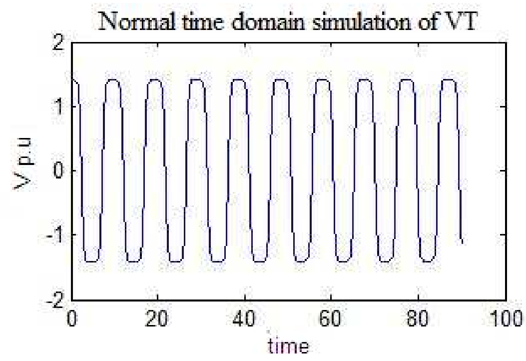

Figure 4.periodic wave for transformer voltage

4.2. Quasiperiodic States.

Figs. 5 and 6 Show waveforms and diagrams for Quasiperiodic conditions calculated for value of

$$E = 1\,p.u, \omega = 1\,p.u, C_{series} = 1.4nf, C_{Shunt} = 1.3nf$$
$$R = 100M\Omega$$

the phase plane diagram presented in Fig 5 clearly shows the system trajectory characteristic of a Quasiperiodic waveform. For Quasiperiodic motion the trajectories are constrained to the surface of the torus in the 3-D state space. Fig.6 shows Time domain simulation for this case that represented the Quasiperiodic wave with 2 frequencies that are irrational fraction to each other. In this state, system under study is Quasiperiodic and wave shape is like a torus.

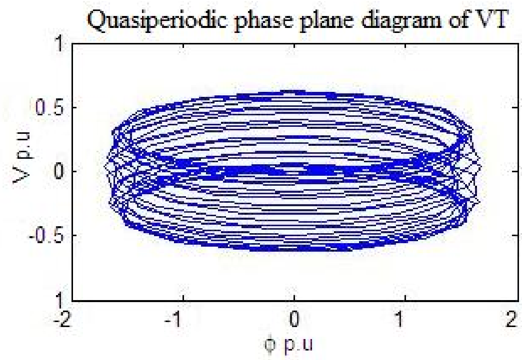

Fig.5.Quasiperiodic trajectory in phase plane diagram (torus waveform)

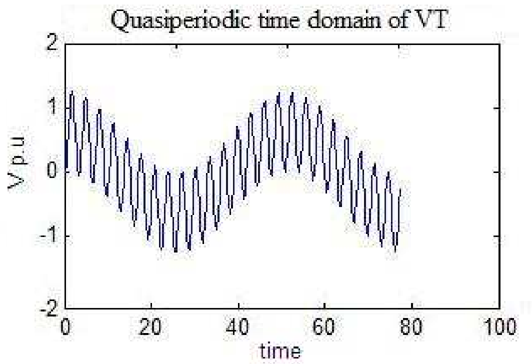

Fig.6. Quasiperiodic wave for transformer voltage

4.3. Chaotic states1.

An example of chaotic ferroresonance conditions is presented in Figs.7 and 8 that shows chaotic ferroresonance for C series =3nF, C shunt =0.1nF, $R = 1900 M\Omega$ .in Fig.9 Bifurcation diagram (quasiperiodic route to chaos) with all parameters fix and C_{series} is varying. In this plot at first system behaviour is Quasiperiodic and then goes to chaos. Parameters in this case are as below:

$$E = 1\, p.u, \omega = 1\, p.u, C_{Shunt} = 3nf, R = 400 M\Omega$$

According to equations (3) and (5), both of capacitances, C series and C shunt are in cumulative form. So simulation results for both of them are the same and give a similar bifurcation diagram.

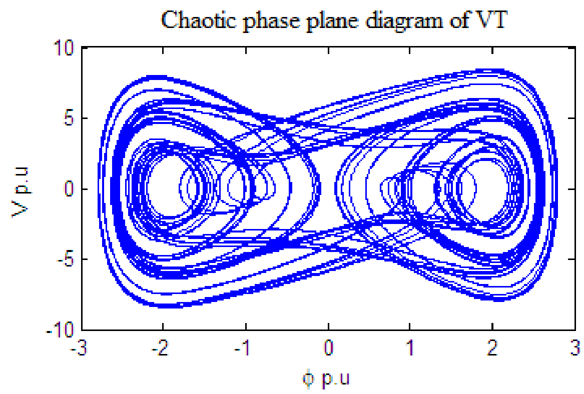

Fig.7. Chaotic trajectory in phase plane diagram

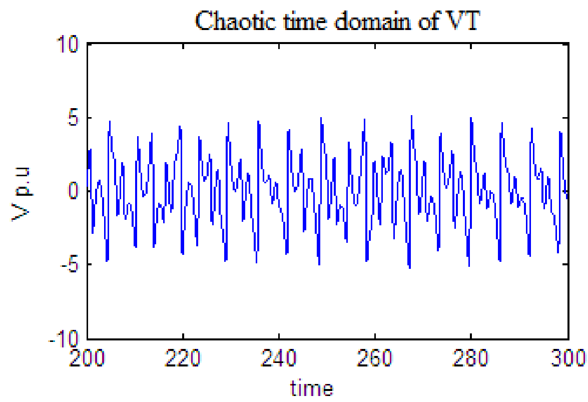

Fig.8. chaotic waveform of VT in time domain

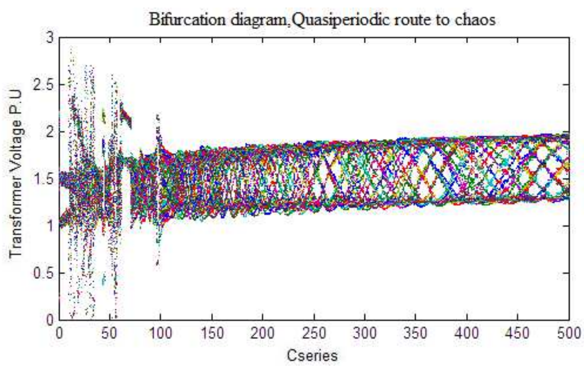

Fig.9. Bifurcation diagram (for C series)

4.3. Chaotic states2.

Bifurcation diagrams for varying E other parameters are constant.

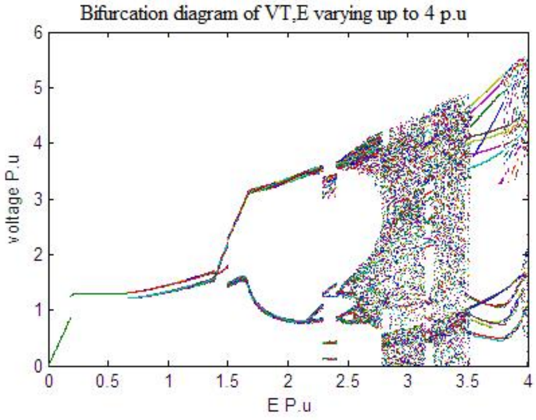

Fig.10. Bifurcation diagram for E

5. System Description and Modeling (2)

In this case, system under study similar the above, but the model of circuit breaker was changed. Schematic diagram of this case illustrated in fig.11.

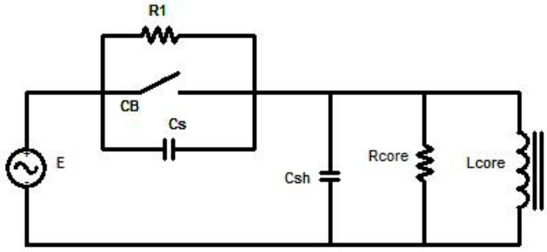

Fig.11. Basic reduced equivalent ferroresonance circuit

Equations of this circuit are as below:

$$\omega ECos(\omega t) - \frac{ESin(\omega t)}{R_1 C_s}$$
$$-\frac{1}{C_s}\left[\frac{-d\lambda}{R_1} + a\lambda + b\lambda^q + \frac{d\lambda}{R_2}\right]$$
$$-(\frac{C_{sh}+C_s}{C_s})d^2\lambda = 0 \qquad (8)$$

In this model of circuit breaker $R_1 = .00004$p.u was paralleled with Cseries of breaker and other parameters of system are similar with case 1.

Simulation results are as below:

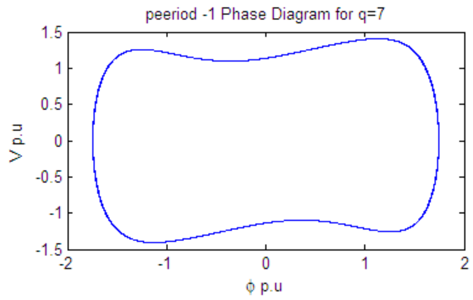

Fig.12. phase plane diagram for normal operation

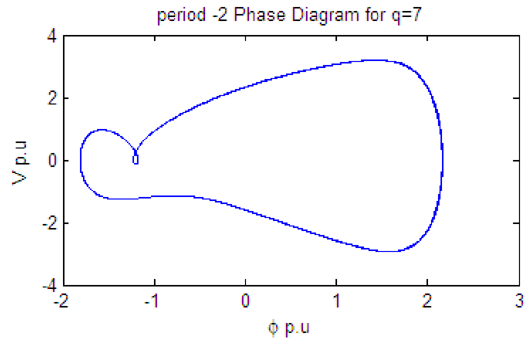

Fig.13. phase plane diagram for normal operation (period2)

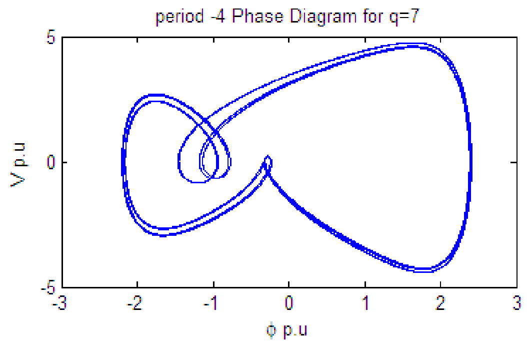

Fig.14. phase plane diagram for normal operation (period4)

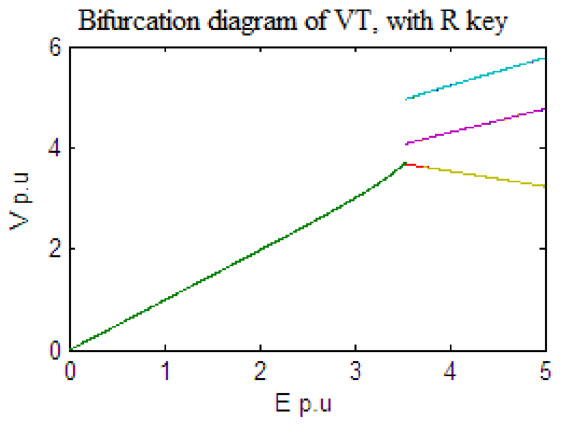

Fig.16.Bifurcation diagram with considering R breaker

Repeated simulation failed to produce any chaotic states for realistic values of model parameters, totally in agreement with practical site experience.

*6.*Conclusions

Low capacity Voltage Transformers fed through circuit breaker grading capacitance have been shown to exhibit fundamental frequency, quasiperiodic and chaotic ferroresonance conditions similar to high capacity power transformers fed via capacitive coupling from neighboring sources. Repeated solution of the system's nonlinear differential equation has shown that a change in the value of the equivalent circuit capacitance to earth, possibly as a result of a change in system configuration, can give rise to different types of ferroresonance overvoltage. It has also been shown that while fundamental frequency and Quasiperiodic ferroresonance conditions may occur under commonplace operating conditions, chaotic ferroresonance states are not likely to occur under practical site conditions.

A comprehensive understanding of the possibilities that exist for ferroresonance is very desirable for engineers so that they can operate their systems outside dangerous regions and can plan the expansion of systems without enhancing the possibility of ferroresonance.

7. References

[1] P.H. Odessey and E. Weber, "Critical conditions in ferroresonance", AIEE Trans. Vol. 57, 1938, pp. 444-452.

[2]KEINY,C,:Application of the bifurcation theory in studying and understanding the global behaviour of a ferroresonant electric power circuit, IEEE Trans.Power Deliv.,1991,6,(2),pp.866-872.

[3] Wojciech Piasecki, Marek Florkowski, Marek Fulczyk, Pentti Mahonen, and Wieslaw Nowak: Mitigating Ferroresonance in Voltage Transformers in Ungrounded MV Networks, IEEE2007.

[4]MOZAFFARI,S.,HENCHEL,S.,and SOUDACK,A.C.:Chaothic ferroresonance in Power Transformers,IEE proc.cener.Transm.Distrib.,1995,142,(3).pp.247-250

[5]B.A.T.AI Zahawi, Y.K.Tong and Z.Min: chaos in ferroresonant wound voltage transformers: effect of core losses and universal circuit behaviour, IEE proc.1998,

[6] B.A.T.AI Zahawi, Y.K.Tong and Z.Min: ferroresonance in electromagnetic voltage transformers: A study based on nonlinear dynamics, IEE proc, 1997.

[7]K.AI-Anbarri, R.Ramanujam,"Analysis of Nonlinear phenomena in MOV connected Transformer"IEEE Proceedings online no.2001-10571.

[8]ARAUJO. A.E.A., SOUDACK, A.C., and MARTI, J.R.: 'Ferroresonance in power systems: chaotic behaviour', ZEE Proc. C, 1993, ***140, (3),*** *pp. 237-240*

[9] W. Piasecki, M. Florkowski, M. Fulczyk, P. Mahonen, M. Luto, and W. No-wak, "Ferroresonance involving voltage transformers in medium voltage networks," presented at the XIV Int. Symp. High Voltage Engineering, Beijing, China, 2005, paper F-19.

[10] Zia Emin BSc MSc PhD AMIEE, Yu Kwong Tong PhD CEng MIEE:' Ferroresonance Experience in UK: Simulations and Measurements' Presented at the International Conference on Power Systems Transients (IPST'07) in Lyon, France on June 4-7, 2007

[11]BAKER, G.L., and GOLLUB, J.P.:'Chaotic dynamic: and introduction' (Cambridge University, 1994)