

Simulation and Analysis of Ferroresonance in Power System

Mitra Patel ¹, Manish N Sinha ²

P.G. Student, Department of Electrical Engineering, BVM Engineering College, V.V.Nagar, Gujarat, India¹

Assistant Professor, Department of Electrical Engineering, BVM Engineering College, V.V.Nagar, Gujarat, India²

ABSTRACT: Ferroresonance is a nonlinear dynamic phenomenon, between a non-linear inductor and system capacitance. Hereby a study is undertaken on systems comprising of the required parameters, under which the possibility of ferroresonance may arise. For any operating voltage applied to series combination of capacitance and transformer windings at no-load, the critical value of capacitance to cause ferroresonance jump is determined using Rudenberg's graphical method. The results show the ferroresonance over-voltages reaching dangerously high peak of fundamental frequency across the circuit elements.

KEYWORDS: Component, Ferroresonance, Transformer, Harmonics, Over-Voltage

I. INTRODUCTION

The term "Ferroresonance" which appeared in the literature in the first time in 1920 refers to an oscillating phenomenon in an electric circuit consisting of a non-linear inductor in series with a capacitor, fed by an alternating voltage. A power network consists of a large number of capacitances like cables, long lines, capacitor-voltage transformers, series or shunt capacitor banks, voltage-grading capacitors in circuit breakers, metal clad substations as well as saturable inductors in the form of power transformers, voltage measurement inductive transformers (VT) and shunt reactors. Appropriate magnitude of operating alternating voltage can force the transformer to operate in non-linear region of magnetizing characteristics and ferroresonance oscillations occur if circuit capacitance and initial conditions match. However, there may be a change in the state of oscillation by jumping from one point of the characteristics to another far distance one. Hence there does not exist any definite frequency. For that reason oscillatory circuit with magnetic saturation does not have a definite frequency. Rather, such frequency will be variable depending on the intensity of the current and magnetization[4].

Ferroresonance can cause equipment damage and severe power quality problems in the form of over voltages or under-voltages whose waveforms are highly distorted. The ferroresonant voltages and level of distortion of waveforms depend on the supply voltage, value of capacitance present in the circuit, switching instant of supply and initial condition. In addition, the non-linear inductance characteristic which is described by the hysteresis characteristics of transformer greatly affects ferroresonance over-voltage. Hysteresis is the central feature of ferromagnetic material of the transformer[4].

Primary of the transformers can be delta connected or wye connected with isolated or grounded neutral. Because of switching operations, ferroresonant configurations are formed. Factors that are relevant are given below:

- Phase to phase and phase to ground capacitances
- Primary and secondary windings connections
- Voltage source grounding

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

II. RELATED WORK

In our power systems also possibilities of ferro-resonance exist. In our power systems, there are many sources of capacitances, non linear inductances and wide range of operating components. Configurations that may allow ferroresonance to happen are endless. But there are some typical configurations that may lead to ferro - resonance, viz.

- Voltage Transformer Energized Through Grading Capacitance.
- Voltage Transformers Connected to an Isolated Neutral System.
- Transformer Accidentally Energized in Only One or Two Phases.
- Voltage Transformers and HV/MV Transformers with Isolated Neutral.
- Power system grounded through a reactor.
- Transformer Supplied by a Highly Capacitive Power System with Low Short Circuit Power.

For the understanding of basic concept of ferroresonance, we intend to simulate a simple series ferroresonant circuit, where non-linear inductor would be designed so as to get non-linear relation between flux and current. The non-linear inductor is designed using integrator and look-up table with the required non-linearity.

Once the concept is understood, a three phase transformer is simulated under switching instances to observe ferroresonant effect on it. Switching plays an important factor to stimulate ferro-resonance, so it was needed to be studied. Further, a system is undertaken for study from a reputed paper, and simulated in MATLAB. It is then taken into further evaluation about its possible effects on present power system.

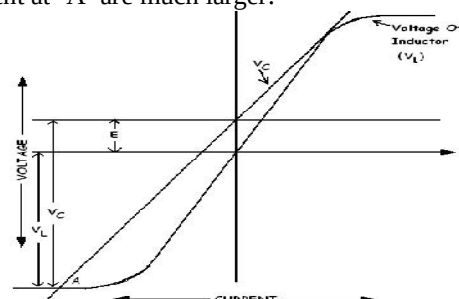
III. RUDENBERG'S GRAPHICAL METHOD

Considering fundamental sinusoidal waves of voltages and current (I), the condition of equilibrium is

$$E = V_L + V_C \quad (1)$$

$$V_L = E + (I/\omega C) \quad (2)$$

Rudenberg's graphical method leads to a simple graphical solution of the problem where the voltage 'VL' across the saturated inductance must always be equal to the sum of the constant system voltage 'E' and capacitance voltage 'VC = I/ωC' in Fig. 2. Where f is frequency of supply voltage and C is capacitance value and $\omega = 2\pi f$. There are the points of intersections between inductor voltage (VL) characteristic nonlinear line and the capacitor voltage (VC) line passing through point on the voltage axis cutting the supply voltage(E) line[2]. It has at least two possible periodic ("steady") states and the establishment either of those depend on the initial conditions, circuit parameters and instant of switching on supply voltage (E). The first periodic condition termed as normal condition is at first quadrant and a periodic condition where the quantities, although very much distorted for fundamental ferroresonance, are at A. Now if a line is drawn parallel to "VC" through rated operating voltage of the transformer which is a tangent on the magnetic characteristics of transformer at first quadrant; it intersect magnetic characteristics in third quadrant leaving only operating point at "A". And the value of capacitance(C) calculated at fundamental frequency in this circuit condition is the critical value of capacitance(C) at this voltage to cause ferroresonance oscillation causing the core of transformer to go into magnetic saturation in circuit with over-voltage across capacitor as well as transformer. The net reactance of the circuit is capacitive at 'A' and the current at 'A' are much larger.



International Journal of Innovative Research in Science, Engineering and Technology

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IV. SIMULATION

Nonlinearity of ferroresonance is very important factor on its behaviour. So representation of nonlinearity of transformer core is crucial for ferroresonance studies. Ferroresonant behaviour of the transformer under study, based on the piecewise linear and the polynomial saturation characteristics are significantly different.

Some of the effects are not only special to ferroresonance; an initial analysis can be done by looking at voltage waveforms. If it is not possible to obtain recordings or if there are possible interpretations for effects, not only system configuration should be checked but also events prior to ferroresonance.

Ferroresonance occurred because of switching operations during commissioning new 400kV substation where grading capacitance of a circuit breaker involved. It is reported that two voltage transformers are driven into sustained ferroresonance state.

The simulation has been done in a series circuit comprising of a nonlinear inductor and capacitor. The input voltage given is 230V and the value of inductance and capacitance is kept constant whereas the value of frequency is gradually reduced to encounter the phenomenon named as ferroresonance.

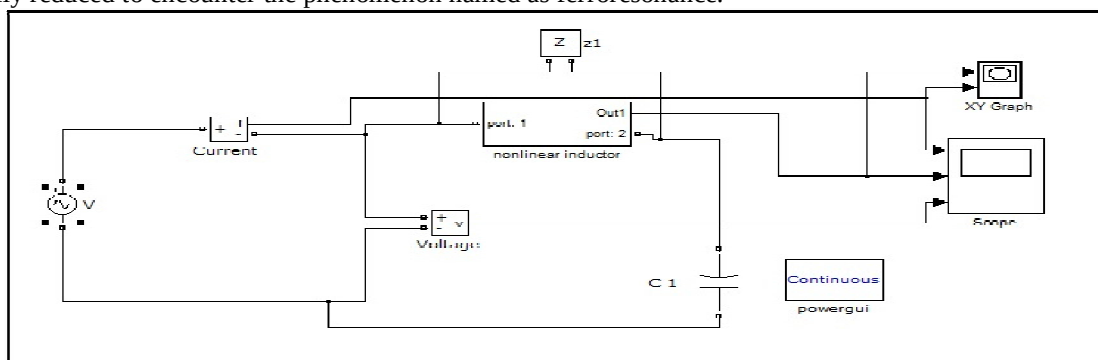


Figure 1 Basic series circuit for ferro-resonant simulation.

After studying the phenomena of ferroresonance on the series LC circuit, a normal basic distribution network has been setup to study the over-voltage and over-current.

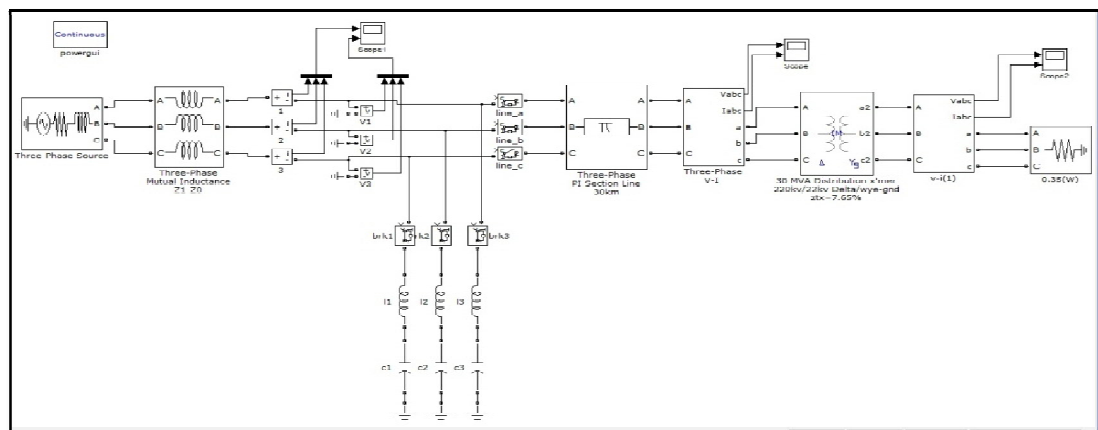


Figure 2 Main circuit simulation

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 5, Issue 3, March 2016

V. EXPERIMENTAL RESULTS

The waveforms studied show the extent of which the effects of ferroresonant circuit could be prominent on the system. This extends to our objective to study the system effects and need of ferroresonance. The waveforms of voltage, current and flux could be distinguished, also the non-linear relation between flux and current, and voltage and current are seen. The circuits under study are still needed to be modified, to achieve the better result of the ferroresonant phenomena, but the result is considerable as resonant result.

The waveform below gives the ferroresonance in series circuit. The over-voltages could be easily seen below.

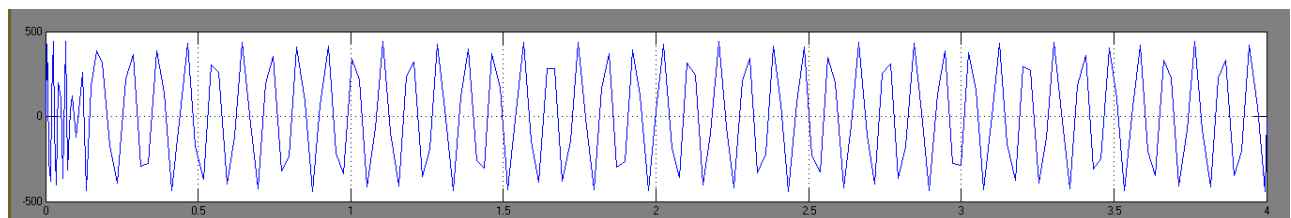


Figure 3 Series circuit waveform

Here the current and voltage of one of the phases of the considered system are shown. We can see the harmonics in the current and over-voltages could be observed.

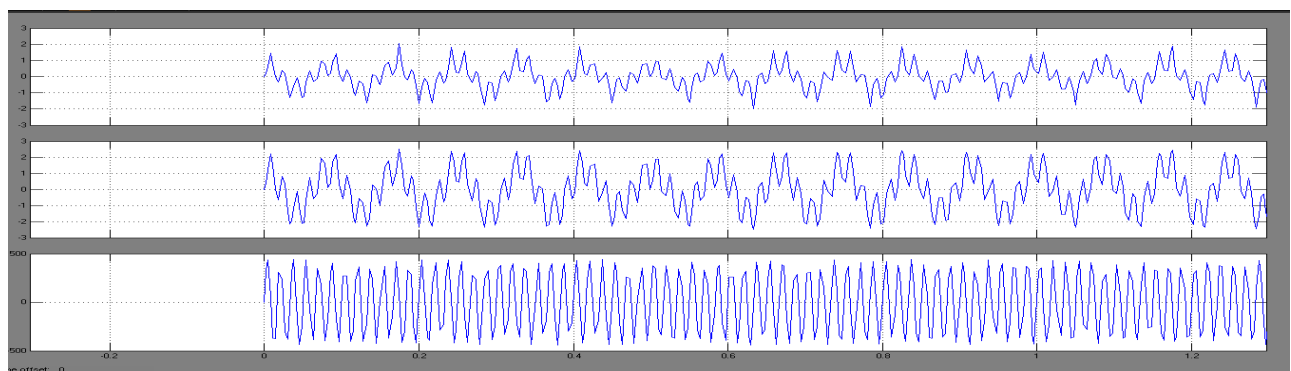


Figure 4 Output Waveform in the three phase circuit.

VI. CONCLUSION

Hereby, we conclude that the ferroresonant circuit could be easily executed using a series circuit. Single phase switching could also be applied as a source to ferroresonance, as we can see in the referred books. The results of the ferroresonant circuit could induce heating in the power system circuit, which can cause wear and tear or as a persistent problem can damage the components also. Ferro-resonant effects should be prohibited as much as possible for the protection of the existent system.

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