MITIGATION OF FERRESONANCE IN POWER SYSTEM

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This thesis is dedicated to my beloved mother and father

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ABSTRACT

The onset of a ferroresonance phenomenon in power systems is commonly caused by the reconfiguration of a circuit into the one consisting of capacitances in series and interacting with transformers. The reconfiguration can be due to switching operations of de-energisation or the occurrence of a fault. Sustained ferroresonance without immediate mitigation measures can cause the transformers to stay in a state of saturation leading to excessive flux migrating to transformer tanks via internal accessories. The symptom of such an event can be unwanted humming noises being generated but the real threatening implication is the possible overheating which can result in premature ageing and failures. The main objective of this project is to determine the accurate models for transformers, transmission lines, circuit breakers and cables under transient studies, particularly for ferroresonance. The second objective is to find out methods to mitigate these phenomena. All simulation studies are carried out using an electromagnetic transient program, called ATP Draw. Simulation studies revealed that the key circuit parameter to initiate transformer ferroresonance in a transmission system is the circuit-to-circuit capacitance of a double-circuit overhead line. The extensive simulation studies also suggested that the ferroresonance phenomena are far more complex and sensitive to the minor changes of system parameters and circuit breaker operations. Adding with the non-linearity of transformer core characteristics, repeatability is not always guaranteed for simulation and experimental studies.

ABSTRAK

Bermulanya fenomena ferosalunan dalam sistem kuasa biasanya disebabkan oleh konfigurasi litar yang terdiri daripada kemuatan siri dan saling tindakan dengan pengubah. Konfigurasi ini boleh disebabkan oleh operasi pensuisan nyahtenaga atau berlakunya kerosakan. Ferosalunan mapan tanpa langkah-langkah mitigasi segera boleh menyebabkan pengubah dalam keadaan tepu berdepan kepada penghijrahan fluks yang berlebihan ke tangki pengubah melalui aksesori dalaman. Gejala seperti ini boleh menjanakan bunyi berdengung yang tidak diingini tetapi implikasi mengancam sebenar adalah pemanasan lebih mungkin boleh mengakibatkan penuaan pra-matang dan kegagalan. Objektif utama projek ini adalah untuk mengkaji tingkah laku ferosalunan dalam sistem kuasa dan untuk mengetahui beberapa kaedah yang paling sesuai untuk mengurangkan fenomena ini. Program simulasi ATP-EMTP digunakan untuk model pelbagai komponen sistem kuasa dan mensimulasikan fenomena ferosalunan. Kaedah untuk mengelakkan keadaan ferosalunan daripada berlaku, maka dengan itu mengelakkan kerosakan peralatan dan kerugian juga dicadangkan berdasarkan kerja-kerja simulasi. Talian Penghantaran 33kV digunakan dengan pengubah 33KV/100V. Untuk memperkenalkan fenomena ferosalunan dalam sistem, suis kawalan masa digunakan dengan pemuat bersiri. Kemudian kaedah untuk mengurangkan fenomena ini telah dijalankan. Dalam kajian ini lima teknik yang berbeza digunakan mengenai pengurangan ferosalunan; dengan mengubah pemuat siri, pemuat pirau, dan rintangan kemagnetan, kemudian dengan menambah rintangan pada bahagian sekunder pengubah dan akhir sekali dengan menukar sambungan antara belitan utama dan sekunder pengubah.

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LIST OF ABBREVIATIONS

AC	-	Alternating Current
ATP	-	Alternative Transient Program
CB	-	Circuit Breaker
DC	-	Direct Current
EMTP	-	Electro Magnetic Transient Program
GB	-	Grading Bank
HV	-	High Voltage
LV	-	Low Voltage
PT	-	Potential Transformer

LIST OF SYMBOLS

E_{Thev}	-	Thevenin's Voltage Source
VLm	-	Voltage across Transformer (Lm)
XL	-	Inductance Reactance
XC	-	Inductance Capacitance
VL	-	Load Voltage
Cg	-	Line-To-Ground Capacitor
Cm	-	Line-To-Line Capacitor
VC	-	Voltage across Capacitance (C)
Us	-	Rated Secondary Voltage
Pt	-	VT rated Output (VA)
Pm	-	Power required for Measurement (VA)
C	-	Capacitance
L	-	Inductance
R	-	Resistance
E	-	Voltage Source
w	-	Frequency
Z	-	Impedance
I	-	Transformer Current
λ	-	Transformer flux-linkage
$\emptyset$	-	Flux in the Transformer Core

CHAPTER 1

INTRODUCTION

1.1 Introduction

Ferroresonance refers to the resonance between network parameters with ferromagnetic material, particularly with the presence of transformers working at no-load conditions. It generally refers to a condition where power system voltages resonate at the natural frequency of certain excited components within the same system. Most of such components usually include nonlinear ironclad inductance typical transformer windings. The capacitance must be considered for the resonance to occur. The common sources of this include capacitor banks that are used for voltage regulation and power factor correction.

Furthermore, a transmission line's capacity may be a key circuit element during a ferroresonant event. In the last 85 years, there has been research on ferroresonance and the word itself was used in literature in 1920, even though resonance in transformers appeared in articles as early as 1907. In practice, interest was generated in the 1930s when it was shown that the use of series capacitors for voltage regulation caused ferroresonance in distribution systems, resulting in damaging the overvoltages[1].

Transient events occur due to attended power system parameters such as resistance, inductance and capacitance of transmission line, transformer, cable, capacitive shunt reactors, inductive shunt reactors etc. The frequency range of the transient phenomena can extend from DC to several MHz due to such parameters and the addition of capacitive and inductive components into the integrated power system.

A subject of intense study, ferroresonance is also a common phenomenon on power systems. Because of the saturated magnetizing characteristics of the bus Potential Transformers (PT), ferroresonance may occur when switching or disconnecting a circuit breaker at neutral-grounded substations. In the event of the occurrence of ferroresonance, excessive voltage and current may cause the flashover of external insulation, the burn out of PTs or the destruction of metal oxide resistors. There has been an increase in incidences of ferroresonance in the last few years resulting to power cuts and the destruction of PTs[2].

Magnetic saturation of the nonlinear inductance may also cause ferroresonance. However power transformers and inductive PTs are the main contributors to the nonlinear inductance on power systems. Under normal conditions, a nonlinear inductance operates in the linear region of its excitation characteristic[3].

1.2 Background of Ferroresonance

Linear resonance only occurs, for example, in the circuit in Figure 1.1 consisting of a series-connected resistor, inductor and capacitor, when the source is tuned to the neutral frequency of the circuit. And the capacitive and inductive reactance of the circuit is identical. The resonance frequency of any AC circuit totally depends on its capacitance and inductance.

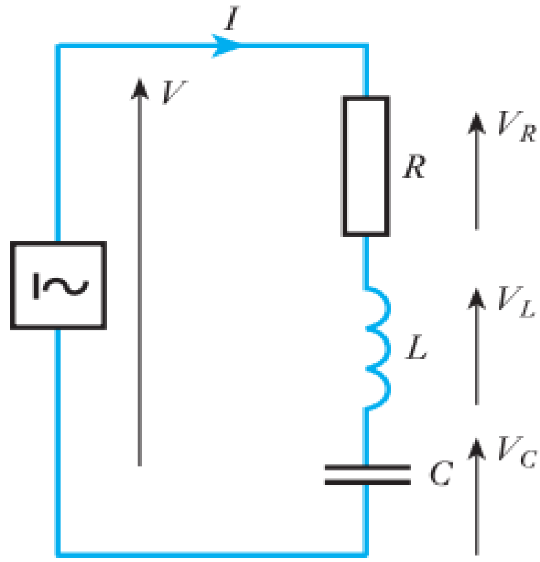

Figure 1.1: Linear resonance circuit

When the linear circuit in Figure 1.1 is subjected to a resonance condition, it produces an expected and respectable response to the applied source voltage. Sinusoidal voltages appear across any points in the circuit without any distortion[4].

In contrast, things are not quite the same in a nonlinear series circuit as what happens in a linear resonance. A nonlinear inductor (ferromagnetic material) replaced the linear inductor in Figure 1.2. A transformer core is an example of a ferromagnetic material. The series connection consists of an alternating source (ES), a resistor (R), a capacitor (C) and an alternating source (ES). This is referred to as the ferroresonance circuit.

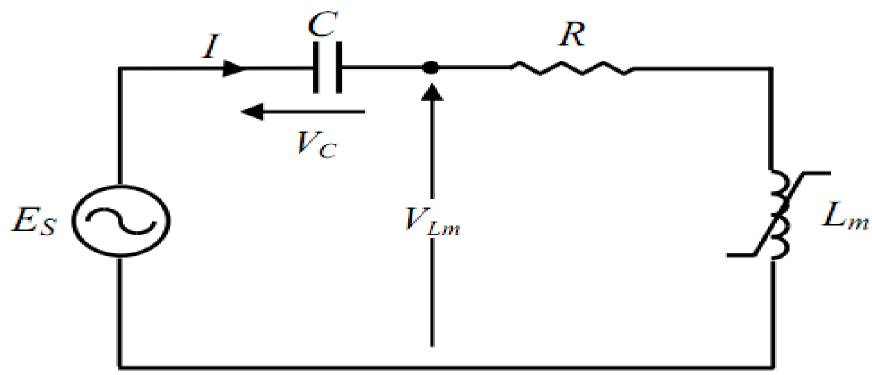

Figure 1.2: Ferroresonant circuit

Resonance condition occurs at only one frequency with a fixed value of L and C in the linear circuit. On the other hand, the nonlinear circuit can exhibit multiple values of inductances when the core is driven into saturation however this implies that will be a wide range of capacitances that can potentially lead to ferroresonance at a given frequency [5].

1.3 Types of Ferroresonance Modes

The distinctive difference between the linear resonance and ferroresonance has been described in the previous section. A resistance, a capacitance, and a nonlinear inductor are the fundamental elements involved in the ferroresonance circuit. It is the reconfiguration of a particular circuit caused by switching events that mostly caused the development of the ferroresonance circuit taking place in the power system. Immediately after the switching event, initial transient overvoltage will firstly occur and this is followed by the next phase of the transient where the system may arrive at a more steady condition. There can be several steady state ferroresonance responses randomly[6-7] induced into a system owing to the non-linearity of the ferroresonance circuit. Basically, there are four types of steady-state responses a ferroresonance circuit can possibly have. These includes: the fundamental mode, sub harmonic mode, quasi-periodic mode and chaotic mode.

1.4 Symptoms of Ferroresonance

There are various forms of ferroresonance with different physical and electrical displays [8]. Some have very high voltages and currents while others have voltages that are near to normal. This section demonstrates a few indications of ferroresonance:

I. Audible Noise
II. Overheating
III. Arrester and Surge Protector Failure
IV. Flicker
V. Cable Switching

1.5 Objectives

The main objectives of this project are:

I. Examine the effects of ferroresonace in power systems.
II. To mitigate the effects of ferroresonace through system equivalent simulation model.
III. Find out different techniques to minimize the Ferroresonance

1.6 Scope of Work

The scope of this project includes various phases which include:

I. The study of resonance and its effects in linear circuits
II. Behaviour of ferroresonance in power systems
III. Operational characteristics of a transformer in saturation
IV. Obstacles of ferroresonance in real power system and its damages
V. Study of previously work done for ferroresonance mitigation and their outputs
VI. Comparison of different techniques used for ferroresonance mitigation in previously work done in power system.

1.7 Problem Statement

The ferroresonance phenomenon in power systems is mostly due to the conformation of a circuit that includes capacitances in series and connected with transformers. The conformation can be because of switching operations of de-energisation or due to a fault. Ferroresonance without rapid mitigation can affect the transformers to keep in a state of saturation lead to high flux to damage the transformer tanks via internal components. Algorithmic system method of choosing a proper simulation model is not more common yet. There is need of practical techniques for most rapid results so that this behavior of power components should be brought into steady-state operation for safety of high cost power devices. So, the main goal in this project is to achieve the following objectives:

I. To convey good information about the technical parameters on each of the power system part needed for the simulation modelling for ferroresonance study.

II. To facilitate some modelling road maps that needed for selecting any of the suitable models.

III. To discover the types of models better and easy for the simulation to mitigate the ferroresonance from the system.

1.8 Organization of Report

The report consists of five chapters.

Chapter 2 illustrates the previous work done related on ferroresonance phenomenon in voltage transformers and power transformers. Detail of ferroresonance behaviour in power system is also explained. Besides this, it also includes some techniques for avoiding or mitigation of ferroresonance.

Chapter 3 describes the methodology of project simulation. Selection of system components as well design parameters is explained. It consists of how the simulation will be done. Basic design of ferroresonant circuit and mathematical formulation is shown. Brief details of simulation software ATP/EMTP is also presented. It presents the circuits that were used in the simulation and explains how the simulations techniques are implemented.

Chapter 4 presents the results of simulation done on basic ferroresonant model.

Lastly chapter 5 describes the conclusion and future work that is related to the project done.

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