# ANALYSIS OF LIGHTNING-CAUSED FERRORESONANCE IN CAPACITOR VOLTAGE TRANSFORMER (CVT) USING HARMONIC METHOD

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A report submitted in partial fulfilment of the requirement for the degree of Bachelor of Electrical Engineering (Industrial Power)

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"I hereby declare that I have read trough this report entitle "Analysis Of Lightning-Caused Ferroresonance in Capacitor Voltage Transformer (CVT) Using Harmonic Method" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

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Date :………………………………………………

“I declare that this report entitle “Analysis Of Lightning-Caused Ferroresonance in Capacitor Voltage Transformer (CVT) Using Harmonic Method” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree”

Signature :………………………………………………

Name : AHMAD ZAKUAN BIN AHMAD DAHALAN

Date :………………………………………………

I dedicate to my family especially my mother and father who always supporting me. Also always beside me are brother, my nephews, lectures and my friend. Last but not least, my most beloved late sister recently. Hope her soul rest in peace. Al-fatihah.

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## ABSTRACT

The incident of explosion and failure of CVT due to lightning stroke is reported recently. The sudden high current of lightning cause output current and voltage in CVT change to high amplitude and high frequency. The ferroresonance in CVT occurred due to the existence of charging components such as inductor and capacitor. The phenomenon of rapidly change of current and voltage output may lead to over thermal and vital damage on CVT. Conventional mathematical calculation is complicated because of the high frequency and high current saturation is occurred. Therefore, the aims of this study are to analyze ferroresonance in capacitor voltage transformer (CVT) by analyzing the spectrum of harmonic and investigate the best method of ferroresonance reduction by applying ferroresonance suppression circuit (FSC) in CVT. Variety lightning current strength (34.5 kA, 100 kA and 200 kA) is applied base on the potential lightning strength in Malaysia. Passive FSC, parallel active FSC, series active FSC and electronic switching active FSC is used for ferroresonace reduction analysis. The scope of study is based on 132 kV capacitor voltage transformer is struck by lightning. The PSCAD software is applied for CVT simulation. The CVT current output is measured at secondary CVT transformer in time domain measurement

# ABSTRAK

Tujuan kajian ini adalah untuk menganalisis ferroresonance dalam kapasitor voltan pengubah (CVT) dengan menganalisis spektrum harmonik dan menyiasat kaedah terbaik pengurangan ferroresonance dengan menggunakan litar penindasan ferroresonance (FSC) dalam CVT. Pelbagai kekuatan kilat (34,5 kA, 100 kA dan 200 kA) dikenakan berdasarkan kekuatan kilat yang berpotensi di Malaysia. FSC pasif, selari aktif FSC, siri aktif FSC dan elektronik pensuisan aktif FSC digunakan analisis pengurangan ferroresonace. Insiden letupan dan kegagalan CVT kerana sambar kilat dilaporkan baru-baru ini. Suntikan arus yang tinggi secara tiba-tiba semasa kilat menjadi penyebab arus dan voltan dalam perubahan CVT dalam altitud tinggi dan kekerapan yang tinggi. Ferroresonance dalam CVT adalah kerana kewujudan komponen seperti pearuh dan pemuat. Fenomena perubahan arus dan voltan yang mendadak boleh membawa kepada lebih kerosakan dan penting dalam CVT. Pengiraan matematik konvensional rumit kerana frekuensi yang tinggi dan arus tepu yang tinggi berlaku. Skop kajian adalah berdasarkan kepada 132 kV pengubah voltan kapasitor disambar oleh petir. Perisian PSCAD digunakan untuk simulasi CVT. Output CVT semasa dikira pada menengah CVT pengubah dalam pengukuran domain masa.

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| | | |
|---|---|---|
| FSC | - | Ferroresonance Supression Circuit |
| CVT | - | Capacitor Voltage Transformer |
| C | - | Capacitor |
| R | - | Resistor |
| L | - | Inductor |
| Z | - | Impedence |
| V | - | Voltage |
| I | - | Current |
| P | - | Power |

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.0 Overview

This chapter will address the introduction of the study and problem statement. The problem of ferroresonance cause by lightning strike is described briefly. Besides, the objective of study and scope is explained in this chapter.

## 1.1 Background

In power network system, monitoring system is used for protection and power quality analysis. At 132 kV substation, high voltage is distributed to consumer trough transmission line. Step down the high voltage to low voltage by using conventional transformer is expensive and unpractical because it needs large number of winding. The fault which is caused from lightning, switching and existence of inductance and capacitance component may lead to ferroresonance effect in substation equipment. In this study, CVT is used for monitoring the ferroresonance by using harmonic characteristic study. The existence of ferroresonance may lead over thermal to equipment in substation and can cause explosion. The simulation of ferroresonance response during lightning strike is applied by using PSCAD.

## 1.2 Problem Statement

Capacitive voltage transformer is widely used because it provides precise voltage measuring for high voltage network. The components of CVT consist of non-linear components such as inductive and capacitive component which contribute to transient phenomenon [1]. Besides, lightning and switching also may lead to ferroresonance effect. The problems that initiate for this study are:

1) The rapid changes on sinusoidal of high voltage after lightning will cause the transformer of CVT become saturated and giving overstress thermal problem. The non linear output will be produced at secondary winding transformer. Difference harmonic waveform magnitude and frequency during fault is produced.
2) The size of ferroresonance is depending on size of lightning size. The Ferroresonance waveform is suddenly increased during lightning stroke. The ferroresonance suppression circuit (FSC) is a component that may help to reduce the ferroresonance. The variety type of FSC such as passive and active filter is used to mitigate ferroresonance.
3) The CVT may become ineffective monitoring device to control switch relay due to ferroresonance effect. Many explosions in Malaysia and world at substation are caused by switch relay problem.

## 1.3 Objective

The ferroresonance problem may lead to protection relay failure. The high output voltage and saturated current output may cause the controller malfunction. From the problem statement, the project purposes that can be concluded are:

1) To study the characteristic of ferroresonance in CVT by using different type of ferroresonance suppression circuit (FSC) and size of lightning current.
2) To investigate the best method of FSC in purpose of ferroresonance reduction.
3) To identify the highest harmonic spectrum on the 132 kV substation equipment during lightning.

## 1.4 Scope of Study

Many previous simulations, journal and conference relate on CVT performance design is already developed. The studies of CVT from previous research are most focused on:

1) Transient response
2) Ferroresonance
3) Distance Protection

From the study of analysis of lightning-caused ferroresonance in capacitor voltage transformer (CVT) using harmonic method, the scopes for the project are:

1) Investigate the phenomenon ferroresonance due to lightning struck at 132 kV substation model by using PSCAD software. The method to study characteristic of ferroresonance is analyzed based on harmonic distortion spectrum. The harmonic distortion spectrum is measured at secondary transformer at CVT model output. The detail studies on the highest harmonic spectrum for identify the best method of FSC type.
2) Improvement and reduce the ferroresonance problem by using variety type of ferroresonance suppression circuit(FSC).
   a. Passive FSC
   b. Active FSC
      i. Parallel
      ii. Series
      iii. Electronic Switching
3) Analyze ferroresonance for different size of lightning current base on lightning strength in Malaysia.
   a. 34.5 kA
   b. 100 kA
   c. 200 kA

# CHAPTER 2

# LITERATURE REVIEW

## 2.0 Overview

In this chapter, the components for capacitance voltage transformer modeling are explained in details. The ferroresonance suppression circuit is discussed on different type of component connection design and architecture. Information on lightning activities in Malaysia and accident due to lightning are provided for references. The ferroresonance from the perspective of harmonic distortion frequency spectrum is described briefly.

## 2.1 Introduction

This report is a study on capacitor voltage transformer performance due to lightning struck at 132kV TNB substation in Malaysia. A sudden high current and chaotic oscillation signal is known as ferroresonance. The ferroresonance phenomenon is produced from lightning interference, switching and inductance and capacitance in equipment. Consequence from ferroresonace effect, high thermal will be produced on substation equipments and may lead to equipment damage. A case of 66 kV CVT blew in Sabah because of lightning struck has been reported in 2012 . The damage causes power outage in Kuching and Labuan. The case indicates CVT performance in Malaysia must be studied as the lightning activity in Malaysia is high and unpredicted.

## 2.2 Capacitor Voltage Transformer (CVT) Modeling

Capacitor voltage transformer is used for protective relaying purpose and monitoring purpose [2]. The monitoring equipment is required low voltage to operate. In purpose to achieve power supply requirement for monitoring equipment, capacitor voltage transformer is used to step down the high voltage to low voltage. The high voltage of transmission line is converted to standard low voltage for metering, protection and controlling high voltage network. The architecture of CVT is designed with series capacitor element and the capacitor is hermetically sealed with porcelain shell. In Figure 2.1, the CVT model is used to step down high voltage to intermediate voltage and step down voltage transformer is install in CVT is used to step down to the low voltage which used for monitoring and protection relay. Primary capacitor, $C_1$ size is small compared to secondary capacitor, $C_2$ for purpose large voltage drop. The value of capacitance and inductance is depending on size of CVT. The voltage transformer after stack capacitor is used to step down the voltage signal in purposely supply to monitoring equipment and protection relay [4].

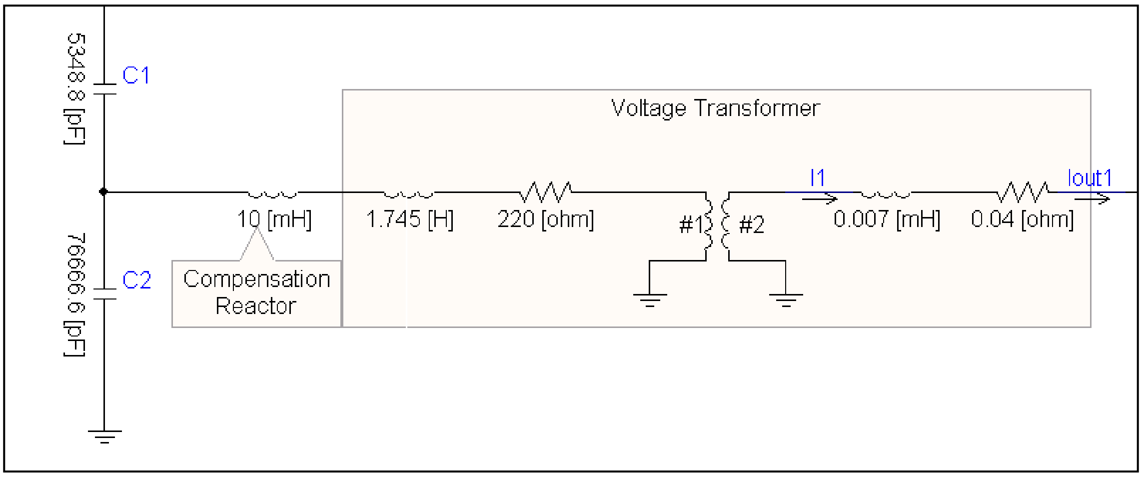



**Figure 2.1 : CVT model**

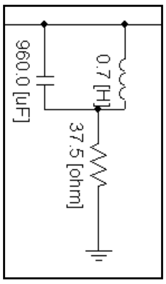
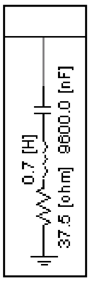
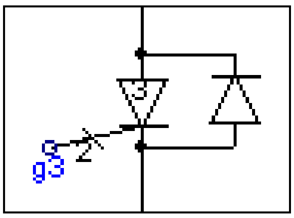
### 2.3 Ferroresonance Suppression Circuit

In theoretically, the ideal CVT voltage output should be same with the initial. Since CVT contains non-linear component such as capacitance and inductance components, transient voltage and current output will be produced [3]. The suddenly saturated current phenomenon is known as ferroresonance. Usually to reduce ferroresonance, Ferroresonance Suppression Circuit (FSC) is located in CVT. The purposes of FSC are to prevent dangerous and destructive overvoltage. FSC is installed at secondary transformer. Two types of FSC model can be used in CVT which known as Active Ferroresonance Suppression Circuit (AFSC) and Passive Active Ferroresonance Suppression Circuit (PFSC) [4]. The passive FSC is a first-order circuit which characterized by first-order differential equation. First-order equation consists of resistor and one element of energy storage, between capacitor and inductor. While active FSC is a second-order circuit which is characterized by second-order differential equation. Second-order equation consists of resistor and two elements of energy storage, capacitor and inductor. Electronic switch also known as active FSC because it is controlled by power electronic element.

#### 2.3.1 Active Ferroresonance suppression (AFSC)

Active ferroresonance suppression circuit (AFSC) is a filter consists of capacitance and inductance characteristic components. Besides, the electronics switch component also include in AFSC type. The changing frequency value will make AFSC react to reduce ferroresonance effect [5]. There are 3 types of AFSC which know as parallel AFSC, series FSC and electronic switching AFSC and as shown in Table 2.1.

**Table 2.1: Active FSC**

<table>
<tr><th>Type of AFSC</th><th>Characteristic</th></tr>
<tr><td>Parallel LC<br></td><td><ul><li>Resistor in series with parallel capacitor and inductor.</li><li>Maximum impedance value at fundamental frequency</li></ul></td></tr>
<tr><td>Series RLC Filter<br></td><td><ul><li>Resistor in series with capacitor and inductor.</li><li>Minimum impedance value at 1/3 of fundamental frequency.</li></ul></td></tr>
<tr><td>Electronic Switch (thyristor)<br></td><td><ul><li>Under normal condition, very low and inherit burden connected and accuracy CVT is good. The technique used electromagnetic reduction.</li><li>Less time to reduce ferroresonance compared to other technique.</li><li>Not consist of energy storage component and not result in transient to CVT</li></ul></td></tr>
</table>

### 2.3.2 Passive Ferroresonance Suppression Circuit

Passive ferroresonance suppression Circuit (PFSC) consists of a resistor and connected to parallel inductor as shown in Figure 2.2. During overvoltage condition, the saturation of reactor lead the reduction of inductance and series resistance causes ferroresonance diminish [6].

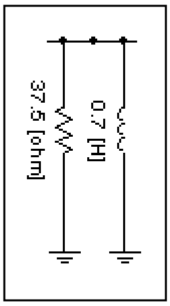



**Figure 2.2: Passive Ferroresonance Suppression Circuit**

## 2.4 Lightning

Malaysia is a country which situated at the equator climate and the weather in Peninsular Malaysia is uniform temperature, high humidity and has uniform periodic monsoon changes. Thunderstorm is a common phenomenon in Malaysia and Malaysia is recorded as a 3rd country most active lightning activity in the world which experienced 180 to 260 thunderstorm days per year [7]. The effect of lightning is depends on lightning strength, surge size and sensitivity of equipment in power network.

Figure 2.3 showed Keraunic Level Thunderstorm which is detected by using Lightning Detection System from Malaysia Meteorology Department. Keraunic level thunderstorm map is represented the lightning activity data collection. The report is important in lightning safety study and lightning safety plan. The lightning peak currents recorded for May 2009 until April 2011 is 5 kA to 25 kA [8].

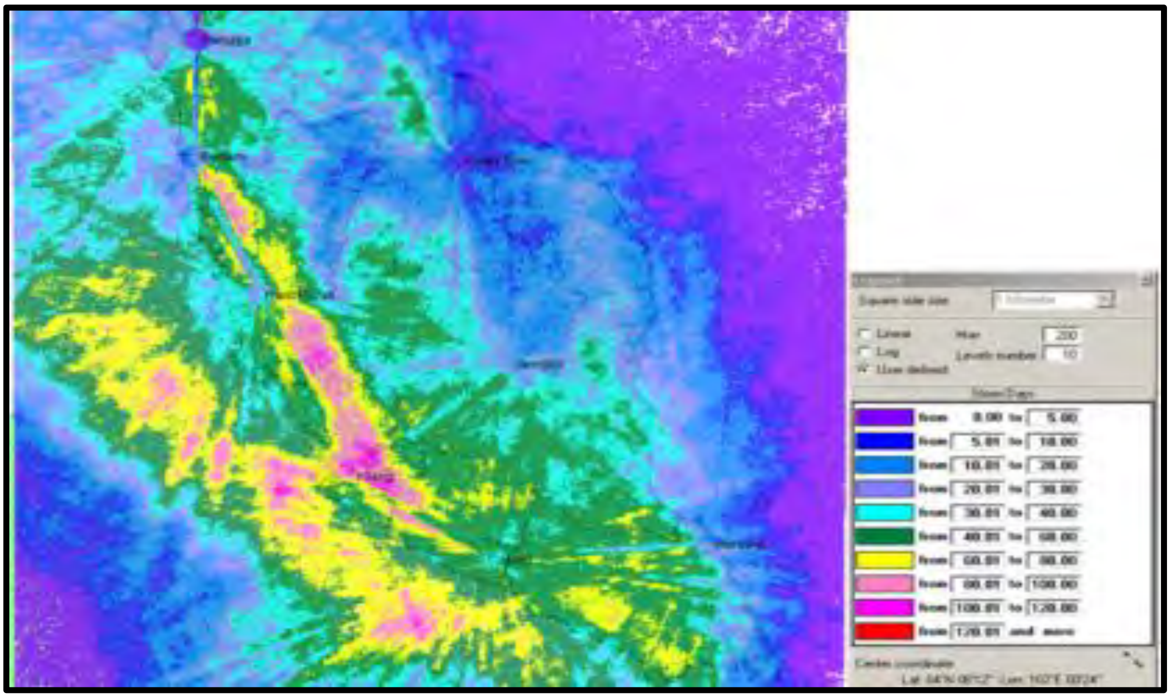


**Figure 2.3: Keraunic Level Map for 2010 [8]**

One of the factors that cause active thunderstorm in Malaysia is this country received high rainfall every year. The annual rainfall for is 2000 mm to 2500 mm and the value is increased due to climate changing. Besides, the increasing of thunderstorm is cause by the pollution. The increasing of factory and development cause chemical substance released to atmosphere and encourages Thunderstorm formation

Figure 2.4 and Figure 2.5 showed the comparison current distribution between two monsoons in May 2010 until March 2011 which southwest monsoon in May to September and northeast monsoon in October to March. Graphs indicate during southwest monsoon, the lightning is more than northeast monsoon, but the strongest lightning current is stronger rather southwest in range 15 kA to 25 kA. The lightning carry large amount of current and cause power quality interruption when lightning strike on power line system. Klang Valley is the place with most active lightning Activity in Peninsular. Lightning activity in east coast during northeast monsoon is low and high lightning activity in east coast during southwest monsoon. During inter monsoon during April to October 2010 the Strait of Malacca record high activity of lightning.