UNIVERSITI PUTRA MALAYSIA

TRANSIENT ANALYSIS OF CURRENT TRANSFORMERS

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By

MUHAMMAD RAMZAN GHUMMAN

Thesis Submitted in Fulfilment of the Requirement for the Degree of Master of Science in the Faculty of Engineering Univeristi Putra Malaysia

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DEDICATION

This report is dedicated to my parents

for their patience and tolerance

during my study in

Malaysia.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of requirement for the degree of Master of Science

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Chairman : Nasrullah Khan, Ph.D.

Faculty : Engineering

The objective of present work is to investigate the performance and transient behavior of conventional electromagnetic current transformers in comparison to the unconventional current transducers during power system faults. The research has been carried out using PSPICE simulation tools and experimental testing of current transducers. Different types of transducers considered in this research include normal electromagnetic current transformers (EMCT) and its various types, Hall effect current transformers (HECT) and Opto-couplers. The simulation results have shown that electromagnetic current transformers (EMCT) can suffer from transient saturation during high frequency disturbances or permanent saturation during high fault currents.

The electromagnetic current transformers (EMCT) were found to saturate above 20 kHz current surges whilst the Hall effect current transducers (HECT) were found to work up to several 100 kHz. The transformation capability of opto-coupler current transducers, using LED/Si based opto-coupler, was found to be more than 1 MHz.

It was estimated that a laser and avalanche photo-detector (APD) based magneto-optic current transformer (MOCT) could effectively translate 1 GHz frequency surges. The simulation results have been experimentally tested and found to be correct within the accuracy resolution of available test and measurement equipment. Based on this work it is safe to declare that EMCT can be used for normal monitoring and measurement applications in utility. It is not good for the reliable protection and control application. Anyway, it does not compete the alternate options such as HECT and MOCT in protection and control applications regarding bandwidth, rise time and fault current diagnostics.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

ANALISIS FANA BAGI PENGUBAH ARUS

Oleh

MUHAMMAD GHUMMAN GHUMMAN

Oktober 2001

Pengerusi: **Nasrullah Khan, Ph.D.**

Fakulti: **Kejuruteraan**

Tujuan kajian penyelidikan ini adalah untuk menguji keupayaan dan tabiat fana bagi pengubah arus elektromagnet lazim dalam mambandingkannya dengan pengubah arus bukan lazim semasa kerosakan sistem kuasa. Kajian ini telah menghasilkan keluaran dengan menggunakan perisian simulasi PSPICE dan diikuti oleh ujikaji pengujian pengubah arus. Kajian ini merangkumi pelbagai jenis pengubah ianya meliputi pengubah arus electromagnetik normal (EMCT), pengubah arus kesan Hall (HECT) dan gandingan-opto. Keputusan simulasi menunjukkan bahawa pengubah arus electromagnetik (EMCT) boleh melalui ketepuan fana semasa gangguan frekuensi tinggi dan ketepuan kekal semasa kerosakan arus tinggi.

Pengubah arus elektromagnetik (EMCT) mencapai ketepuan melebihi 20kHz pusuan manakala pengubah arus kesan Hall (HECT) dapat berfungsi sehingga mencecah

melebihi 100kHz. Pengubah arus gandingan opto yang menggunakan diod pemancar cahaya (LED/Si) berasaskan gandingan opto, berkeupayaan memperolehi lebih daripada 1MHz.

Laser dan fotopengesan jenis APD berasaskan magneto-optic (MOCT) dijangkakan lebih efektif untuk mentafsirkan pusuan frekuensi 1 GHz. Keputusan simulasi telah diuji secara eksperimen dan didapati ianya adalah tepat merujuk kepada ketepatan resolusi dengan menggunakan alat penguji dan pengukuran. Berdasarkan kepada kajian ini, boleh diistiharkan bahawa EMCT boleh digunakan untuk pengawasan normal dan penggunaan pengukuran oleh pihak pembekal. Ia tidak berapa baik untuk kegunaan perlindungan dan kawalan yang tetap. Bagaimanapun, ia tidak setanding dengan pilihan alternatif seperti HECT dan MOCT dalam kegunaan perlindungan dan kawalan berhubung dengan lebar jalur, masa menaik dan diagnostik arus rosak.

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Last but not the last, my heartfelt appreciation to the technical staff of the Electrical and Electronic Engineering Department and my colleagues.

I certify that an Examination Committee met on 22nd October 2001 to conduct the final examination of Muhammad Ramzan Ghumman on his Master of Science thesis entitled "Transient Analysis of Current Transformers" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

Muhammad Ramzan Ghumman

Date: 23-10-2001

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LIST OF ABBREVIATIONS

AC	Alternating Current
DC	Direct Current
CT	Current Transformer
DACT	Distributed Air-gap Current Transformers
EMCT	Electromagnetic Current Transformer
FOCT	Fiber Optic Current Transformer
EOPT	Electro-optic current transducer
HECT	Hall Effect Current Transformer
LCCT	Linear Coupler Current Transformer
MOCT	Magneto-optic Current Transformer
OCT	Optical Current Transformer
PT	Potential Transformer
VT	Voltage Transformer
OPGW	Optical Ground Wire
YIG	Yittrium Garnet
I_p	Primary current
I_s	Secondary current
I_e	Excitation current
V_v	Verdet constant
LED	Light emitting diode

CHAPTER 1

INTRODUCTION

1.1 Introduction

Current transformers are an important integral component of electric power generation, transmission and distribution systems. All types of protection and control devices require current transformers to perform measurement of current and voltage at ground level. It is well known that current and voltage profiles may carry several transient features about the nature of fault. Some of these features are very high frequency components. To perfectly transform these transients the electromagnetic current transformers sometime are found incapable due to their magnetic saturation [1].

Recent advances in electronics and integrated circuit technology have miniaturized the size of relays. Electromechanical relays previously used to understand signals on average basis but the recent digital/numerical relays sample the signal many times in every cycle. Thus the potential susceptibility of protection and control devices is becoming more and more dependent on the instantaneous values of the current signals [2]. The electromagnetic current transformers (EMCT) have natural tendency of transient or permanent saturation due to ferroresonance [2].

There is a general trend to switch over to alternate types of current transformers that can better transform the fault details instant by instant. Now a days two types of such unconventional current transformers (CT) namely 1- Hall effect current transformers (HECT) and 2- Faraday effect magneto-optic current transformers (MOCT) are under intensive research [3-5]. Several international power equipment manufacturing companies such as ABB (USA), Siemens (Germany), Hitachi Japan and Next-Phase (Canada) have started building prototypes of optical and fiber optic CTs for subsequent commercial designs after field testing [3]. This research has been carried out to test the transient performance of conventional and unconventional current transformers.

1.2 Aim and Objectives

The aim of this project is to investigate the transient performance of electromagnetic, Hall effect and magneto-optic current transformers. This study has been carried out on normal single-phase 220 voltages.

The main objectives of this research are,

- to simulate and test the transient performance of EMCTs,
- to simulate and test the transient performance of HECTs, and
- to simulate and test the transient performance of Opto-couplers/or MOCTs.

1.3 Scope of Work

The work was initiated by simulation of EMCT, HECT and opto-coupler.

To verify the simulation results the experimental study of input-output characteristics of EMCT, HECT, Opto-coupler and MOCT was under taken.

This research work was carried out by a detailed literature review followed by PSPICE simulation and experimental verification of the transient performance of both conventional and unconventional current transformers. Critical review of literature was used to optimize the PSPICE simulation and subsequent experiments. The bandwidth analysis of current transformers was initiated by PSPICE simulation of Electromagnet, Hall effect and Opto-coupler current transformers. Current signals of different randomly chosen frequencies such as 50 Hz, 20 kHz, 100kHz, 1.0 MHZ, 5.0 MHz were passed through primary circuit/winding of the devices to observe their transient transformation into the secondary side. This study helps to set limits on useful bandwidth of various type of current transformers.

To verify the above findings from the simulation, three experiments were conducted on EMCT, HECT, and Opto-couplers. Approximate currents were circulated through primary circuit within the rating of current transformers. The switching of reasonable size capacitors (connected in series/shunt) generated 5-100 kHz current surges. Transformation capability of the current transformers within and outside the bandwidth range was checked through simulation. Initially it was proposed to work on magneto-optic current transformer (MOCT) but due to non-availability of crystals only bandwidth test of opto-coupler is under taken instead of MOCT. The bandwidth of LED based opto-coupler is much less than the laser based MOCT. The bandwidth and rise time of Opto-coupler and Hall Effect current transducer found much better than conventional electromagnetic current transformer.

CHAPTER 2

LITERATURE REVIEW

2.1 Instrument Transformer

An instrument transformer may be either a current transformer or a potential (voltage) transformer (VT). The instrument transformers reproduce primary currents or voltages at reduced level and are used for measurement and protection in high voltage circuits. They work on the principle of conventional voltage transformers in which an alternating current flows in the primary winding causing magneto-motive-force (mmf) that creates alternating flux in the core. This alternating flux results in electromotive force in all the windings on the core. The instrument transformer of N: 1 or N: 5 ratio may be connected either in shunt or series mode [1-2].

In shunt mode the voltage is applied to the terminals as in conventional power or voltage transformer but in series mode the primary winding of instrument transformer is connected in series with power system. In shunt mode all the primary current excites the core whereas in series mode only a part of primary current excites the core so as to produce sufficient emf that can drive the necessary current in secondary circuit of the instrument transformer.

The current or voltage of primary winding is transformed in secondary winding according to the transformation ratio of the turns in both windings. The instrument transformers due to their high insulation from HV circuits provide safety to persons for measuring electrical and protective apparatus. The standard for instruments transformers, relays and meters are of 5 or 1A, 110 or 120 V and 50 or 60 Hz [1, 2, 6, 7]. All the equipment in substation is used of the same standard whatever is chosen. However, various standards can be mixed but it is not possible to feed a 5 A or 120 V relay or meter with 1A or 110 V instrument transformers. At least combination of one set of protective relays and measuring meters must be one standard. The 5A or 120 V standard is gradually being replaced by 1A or 110 V standard [7-9].

Recent developments in numerical relaying techniques and general miniaturization trend in power industry demands the need for even lower current level standards [3]. This if accepted would be more compatible to direct magneto-optic and electro-optic transducers that are being developed for protective relaying applications. New relays are being developed that can take optical inputs instead of electrical inputs. The conventional electrical instrument transformers have certain polarity restrictions that are marked on their terminals like P_1 and P_2 or H_1 or H_2. If it is not marked then polarity can be determined. The polarities need to be observed for relays performing addition of subtraction of signals. The single-phase over current relays do not observe these polarities.

The connections of three phase instrument transformers are done so as to allow the relay to look into its specified zone of protection. As a rule of thumb the neutral star point of BBC distance relays (model L8b) is generally towards the bus not that of the GEC distance relays (PYTS) it is towards the line [1,8]. The general theory of both types of instrument transformers i.e. CT and PT also known, as VT is that of conventional transformer used for stepping up before transmission in the power house and stepping down after transmission in the substations.

2.2 Current Transformers (CT)

The current transformers reproduce primary currents at reduced level. The current transformers (CTs) are used both for measurement of load current by ammeter or energy consumed by energy meter as well as protection of power equipment through various types of relays. The CT may be connected in delta and star. Its rating and ratio are chosen according to the maximum fault level at their location on power system. The commercial CTs have many CT ratios like (1200:1000:800:600:400:200/5) and protection engineer chooses the desired one depending upon the maximum rated current flow in the circuit [1,2,8]. If the cable capacity is for example 190A maximum then it is advisable to choose CT ratio of 200/5. Normally secondary of CT is star connected, if it is delta connected then line current must be divided by $\sqrt{3}$. The high quality stable CTs are recommended for relays. The CTs around a transformer with larger differences should use matching CTs between them.

2.2.1 Types of CTs

There are three possible types of current transformers which are conventional electromagnetic, Hall effect and magneto-optic CTs. The electromagnetic type CTs are