DEVELOPMENT OF A SURGE PROTECTOR SUITABLE FOR EQUATORIAL BELT COUNTRIES

N.A.A.N.Dilrukshi

(149351J)

Degree of Master of Science in Industrial Automation

Department of Electrical Engineering

University of Moratuwa

Sri Lanka

July 2017

DEVELOPMENT OF A SURGE PROTECTOR SUITABLE FOR EQUATORIAL BELT COUNTRIES

Nissanka Arachchi Appuhamilage Nadeesha Dilrukshi
(149351J)

Dissertation submitted in partial fulfilment of the requirements for the
Degree Master of Science in Industrial Automation

Department of Electrical Engineering

University of Moratuwa
Sri Lanka
July 2017

DECLARATION OF THE CANDIDATE & SUPERVISOR

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: Date:

The above candidate has carried out research for the Masters Dissertation under our supervision.

Signature of the supervisor: ……. Date :
Prof. J.R. Lucas

Signature of the supervisor: ……. Date :
Dr. D.P. Chandima

DEDICATION

I dedicate this thesis to Mr. Buddhika Ranatunga, my husband for his endless encouragement and patience and to Mr. Nissanka & Mrs.Ramyalatha, my parents for earning an honest living for us and for supporting and encouraging me, to believe in myself and for nursing me with affections and love and their dedicated partnership for success in my life.

ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere gratitude to my advisors Prof. J.R. Lucas and Dr. D.P. Chandima for the continuous support of my MSc study and related research, for his patience, motivation, and immense knowledge. Their guidance helped me in all the time of research and writing of this thesis.

Besides my advisors, I would like to thank Mrs. Janaki Athuraliya and Mr. Nihal Kularathne, for their insightful comments and encouragement, but also for the hard questions which encouraged me to widen my research from various perspectives.

My sincere thanks also goes to my colleagues at the Electronic Division of Arthur C Clarke Institute for Modern Technologies who provided me an opportunity to join their team as Research Engineer, and who gave access to the laboratory and research facilities. Without their precious support it would not be possible to conduct this research.

Lastly, I should thank many individuals, friends and colleagues who have not been mentioned here personally in making this educational process a success. I could not have made it without your support.

ABSTRACT

In most tropical countries like Sri Lanka, lightning activity is high and can cause severe damage to equipment within buildings. Thus lightning surges should be prevented from entering sensitive equipment by installing high quality surge protection devices. Traditionally, surge protection circuits use non-linear devices to clamp the overvoltage. However, typical non-linear devices have low relatively short duration energy absorption ratings and cause the life of the surge protection device to decrease.

As it is known that supercapacitors have large continuous energy storage capabilities, a supercapacitor based surge energy absorption technique has been developed by combining a multi-winding magnetic component with a typical non-linear device in a novel configuration. This research presents an overview of new supercapacitor technique and the basis for selecting the magnetic core required so that the supercapacitor sub-circuit works effectively.

Selection of the magnetic core is critical for the success of the technique, since the combination of the leakage and magnetizing components of the multi-winding magnetic core plays a dominant role. Experimental results generated using a lightning surge simulator with surge capability up to 6 kV/3 kA are used to validate the results. Overall performance of this technique with optimized magnetics is compared with a typical commercially available surge protector, which is practically used to safeguard electronic systems against transient over-voltage related power quality issues.

This technique utilizes a multi-winding transformer, common surge protector devices such as metal oxide varistors combined with a supercapacitor sub-circuit to absorb part of the surge energy usually expected to dissipate within the metal oxide varistor and improve the life of the surge protective device. Also the output clamping voltage is controlled to a lower value to give better protection for the equipment.

Test results clearly indicate, the supercapacitor assisted surge protective device has a much higher energy absorption capacity than tested commercial products and can be

used in commercial surge protectors with better performance than traditional surge protectors with higher component counts.

Keywords: Lightning Protection, Supercapacitor, Metal Oxide Varistor, Non Linear Device

TABLE OF CONTENTS

DECLARATION OF THE CANDIDATE & SUPERVISOR i
DEDICATION ii
ACKNOWLEDGEMENTS iii
ABSTRACT iv
TABLE OF CONTENTS vi
LIST OF FIGURES viii
LIST OF TABLES x
LIST OF ABBREVIATIONS x
LIST OF APPENDICES x
1 INTRODUCTION 1
1.1 Background 1
1.2 Problem Statement 4
1.2.1 Typical Surge protector circuit 4
1.2.2 Associated Problems 4
1.2.3 Problem statement 5
1.3 Typical designs of SPDs 6
1.4 Objectives 7
2 LITERATURE REVIEW 8
3 METHODOLOGY 20
3.1 Background 20
3.2 Design Approach 20
3.3 Selection of components 22
3.3.1 Characteristics of MOVs 22
3.3.2 Voltage build up across MOVs 22
3.3.3 Voltage buildup across super capacitors 24
4 SYSTEM DEVELOPMENT 28
4.1 Design Overview 28
4.2 Complete Design Circuit & Its Operation 28
4.3 Impact of The Supercapacitor Subcircuit and The Magnetic Component 30
5 RESULTS AND ANALYSIS 32

5.1 General Mathlab simulation results 32
5.2 Matlab simulation results for the complete circuit 39
5.3 Energy Calculation 45
5.3.1 By using powdered core as a transformer 45
5.3.2 By using ferrite core as a transformer 48
5.4 Energy Comparison of Two Different Cores 49
5.5 Prototype implementation of the prosed system 50
5.5.1 Differential Mode 50
5.5.2 Common Mode 51
6 CONCLUSION 52
REFERENCES 54
Appendix A 55
Appendix B 56
Appendix C 69
Appendix D 71
Appendix E 72
Appendix F 80

LIST OF FIGURES

		Page
Figure 1.1	Propagation of lightning channel	1
Figure 1.2	Lightning distribution in the world	2
Figure 1.3	Percentage increase in storm surge zone, SAR Region	2
Figure 1.4	Typical Surge Protective Device	4
Figure 1.5	Typical designs of SPDs	6
Figure 2.1	Histograms of Annual Damage by lightning strike	9
Figure 2.2	TT wiring system	10
Figure 2.3	Two types of SPD connections in a TT wiring system	10
Figure 2.4	Concept of zonal protection	10
Figure 2.5	Two current test waveforms	11
Figure 2.6	Multiple MOV based SPD	14
Figure 2.7	Exploded multiple MOV based SPD module	15
Figure 2.8	SPD internal fire	15
Figure 2.9	Structural comparison of capacitors	16
Figure 2.10	Ferrite Core Characteristic	18
Figure 3.1	Flow chart of testing of the voltage protection level	21
Figure 3.2	MOV - Epcos – S20 characteristic for 6 kV	23
Figure 3.3	MOV - B722 PANASONIC characteristic for 6 kV	23
Figure 3.4	Terminal voltage development versus number of surges	24
Figure 3.5	Terminal voltage development versus number of surges	25
Figure 3.6	Terminal voltage development versus number of surges	26
Figure 3.7	Terminal voltage development versus number of surges	26
Figure 4.1	Circuit Diagram – Differential Mode	28
Figure 4.2	Differential and common mode surges	29
Figure 4.3	Mathematical relationship	29
Figure 4.4	Possible Sub Circuits	30
Figure 4.5	TT wiring system	31
Figure 4.6	Design Circuit – Common Mode	31
Figure 5.1	Capacitor charging curves	33

Figure 5.2	1.2/50us - Normalized open circuit voltage	34
Figure 5.3	1.2/50us – Fourier transform of open circuit voltage	34
Figure 5.4	8/20us - Normalized short circuit current	35
Figure 5.5	8/20us – Fourier transform of short circuit current	35
Figure 5.6	Impact on an RC circuit	36
Figure 5.7	MOV V-I observation curve	37
Figure 5.8	MOV Log scale V-I curve	37
Figure 5.9	Current and voltage variation of MOV	38
Figure 5.10	Power variation for different supercapacitors	38
Figure 5.11	Energy variation for different supercapacitors	39
Figure 5.12	Primary and secondary winding current variation	40
Figure 5.13	Primary voltage variation	40
Figure 5.14	Sub-circuit voltage variation	41
Figure 5.15	Secondary voltage variation	41
Figure 5.16	Open circuit voltage (No-load)	42
Figure 5.17	Sub-circuit voltage variation for different capacitors	42
Figure 5.18	Sub-circuit voltage variation for different resistors	43
Figure 5.19	Sub-circuit voltage variation for different combinations	43
Figure 5.20	Power distribution across NLD and sub circuit	44
Figure 5.21	Power-Total, across NLD and sub circuit with magnetic Core	44
Figure 5.22	Current, voltage & power waveforms across MOV	45
Figure 5.23	Total current, voltage & power waveforms across MOV	45
Figure 5.24	Power across MOV	46
Figure 5.25	Total power at the input	46
Figure 5.26	Power across MOV	47
Figure 5.27	Total power at the input	47
Figure 5.28	Total power at the input and across MOV	48
Figure 5.29	Total power at the input and across MOV	49
Figure 5.30	Proposed design of SPD (Differential Mode)	50
Figure 5.31	Proposed design of SPD (Common Mode)	51

LIST OF TABLES

	Page
Table 1.1 Comparison of TVS devices	5
Table 2.1 Impulse current waveforms	11
Table 2.2 The current handling capacity of SPDs	11
Table 3.1 Comparison of two types of MOVs	22
Table 3.2 Comparison of clamping voltage	22
Table 3.3 Voltage build up across 1F-2.5 V SC	24
Table 3.4 Voltage build up across 5F-2.7 V SC (Maxwell)	25
Table 3.5 Voltage build up across 5F-2.7 V SC(DCN)	25
Table 3.6 Voltage build up across 150F-2.7 V SC	26
Table 5.1 Energy levels of powdered/ferrite cores	49
Table 5.2 Output voltage at load end (Differential mode)	50
Table 5.3 Output voltage at load end (Common mode)	51

LIST OF ABBREVIATIONS

Abbreviation	Description
BBD	Bidirectional Break-Over Diode
HV	High Voltage
MOV	Metal Oxide Varistor
NLD	Nonlinear Device
SC	Supercapacitor

LIST OF APPENDICES

Appendix	Description	Page
Appendix - A	Cost of implemented units	55
Appendix - B	Data sheet (MOVs)	56
Appendix - C	Data sheet (Supercapacitors)	69
Appendix - D	Data sheet (Powdered core)	71
Appendix - E	Energy calculation data (Powdered core)	72
Appendix - F	Energy calculation data (Ferrite core)	80