

APPROVAL

The thesis titled “**Study and Analysis of Switching Transients in Power Distribution System**” submitted by Md. Mahadi Hasan (201416112), Md. Mahfuzur Rahman (201416082), Md. Farhan Haider (201416093) and Zarin Tasnim Tishad (201416016), session 2013-2014 has been accepted as satisfactory in partial fulfilment of the requirements for the degree of **BACHELOR OF SCIENCE IN ELECTRICAL, ELECTRONIC AND COMMUNICATION ENGINEERING** on December 2017.

APPROVAL OF THE SUPERVISOR

DR. ABDUL HASIB CHOWDHURY

PROFESSOR

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING (EEE)

BANGLDESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY (BUET)

DHAKA-1000

DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the reward of any degree or diploma.

SUBMITTED BY

MD. MAHADI HASAN

(Id No: 201416112)

MD. MAHFUZUR RAHMAN

(Id No: 201416082)

MD. FARHAN HAIDER

(Id No: 201416093)

ZARIN TASNIM TISHAD

(Id No: 201416016)

DEDICATION

To our beloved parents and our respected supervisor

ABSTRACT

The switching transient is not a new phenomenon; it has been around for many decades. However, it has received more attention recently because of the greater number of failure of many electrical equipments like transformer, circuit breaker etc. because of the phenomena. Both energization and de-energization of transformer and shunt capacitor bank produce considerable amount of transient overvoltage which in turn can cause insulation failure of transformer and malfunctioning of protective equipments. The worst case occurs if the frequency of the transients matches the resonance frequency of the transformer causing voltage and current magnification to a level that exceeds the BIL of transformer. The purpose of this thesis work is to study the switching transient over-voltages that occur during different switching events in an arbitrary distribution network. We have analysed the network for switching actions like switching of transformer, capacitor bank and switching of load. The analysis is done considering both overhead lines and underground cables to make a comparative study. Transient short circuit fault also causes high frequency overvoltage; which is analysed in this work. Finally, the analyses of the output data is done to find out the main reasons for this transient and some recommendations are given to minimize the effects of transient overvoltage.

ACKNOWLEDGMENTS

We are thankful to Almighty Allah for giving us strength, integrity and patience for the successful completion of our thesis work. We are greatly indebted and respectful to our supervisor Dr. Abdul Hasib Chowdhury for his great support, guidance and encouragement, not only to our research work but also his diligence and generosity. His valuable suggestion greatly helped us in understanding the intricate problem involved in completion of the work. He has guided us with his remarkable expertise in this sector during the entire progress of the work.

We would like to thank Dr. Abdul Hasib Chowdhury, Professor, Department of Electrical and Electronic Engineering, BUET, a brilliant teacher and human being who lighted our way through the course of our undergraduate work. His enthusiasm, broad knowledge and sharp thinking gained our most sincere admiration. His caring and understanding touched us deeply. Through his teaching, discussion and contribution, we gained significant insight into the field of different types of transient analysis in the distribution sides of power system.

We also extent our thanks and gratitude to the teachers and students of EECE department, MIST who helped us time to time in the laboratory and also in the department to carry out our research work smoothly.

TABLE OF CONTENTS

	Page number
APPROVAL	ii
DECLARATION	iii
DEDICATION	iv
ABSTRACT	v
ACKNOWLEDGEMENTS	vi
TABLE OF CONTENTS	vii
LIST OF FIGURES	xii
LIST OF TABLES	xvi
LIST OF ABBREVIATIONS	xvii
Chapter 1: Introduction	
1.1 Introduction	1
1.2 Review of previous works	3
1.3 Thesis objectives	7
1.4 Thesis organization	8
Chapter 2: Transients in power system	
2.1 Introduction	9
2.2 Transients in power system	10
2.2.1 Impulsive transients	11

2.2.2 Oscillatory transients	13
2.2.2.1 Types and examples	14
2.3 Oscillatory transients from switching	16
2.3.1 Shunt capacitor bank switching	16
2.3.2 Switching of Transformer	19
2.3.2.1 Causes and factors affecting Transformer inrush current	19
2.4 Sources of transients	20
2.4.1 External sources	20
2.4.2 Internal sources	22
2.5 Effects of transients in power system	22
2.5.1 Electronic equipment	23
2.5.2 Motors	23
2.5.3 Lighting	24
2.5.4 Electrical distribution equipments	24
2.5.5 Protective equipments	24
2.6 Accidents due to transients	25
 Chapter 3: Network modelling and simulation	
3.1 Introduction	28
3.2 Transmission line modelling	28
3.2.1 Overhead line	31
3.2.2 Underground cable	35
3.3 Fault module	36
3.4 Evaluation of distribution network	36

3.5 Simulation tool – PSCAD	39
3.5.1 Contents/Scope of PSCAD	40

Chapter 4: Transient analysis of overhead line and underground cable

4.1 Introduction	44
4.2 Familiarization to the analysed network	45
4.3 Switching events of the network	47
4.3.1 Energization and de-energization of transformer	47
4.3.2 Energization and de-energization of capacitor bank	50
4.3.3 Switching of load at the distribution side	58
4.4 Transient recovery voltage (TRV)	59
4.5 Result and Discussion	60
4.6 Underground Cable	63
4.7 Familiarization to the analysed network	63
4.8 Switching events of the network	65
4.8.1 Energization and de-energization of transformer	65
4.8.2 Energization and de-energization of capacitor bank	71
4.9 Result evaluation and Discussion	74
4.10 Comparison between cable and overhead line	76

Chapter 5: Transient short circuit fault analysis

5.1 Introduction	78
5.2 Short circuit fault	81
5.2.1 Single line to ground fault analysis	82
5.2.2 Double line to ground fault analysis	84
5.2.3 Three phase to ground fault analysis	86
5.3 Result and discussion on fault analysis	88

Chapter 6: Analyses of the results and Recommendations

6.1 Formation of transients in circuit breaker	90
6.2 Doubling effect	91
6.3 Effects of the time of switching on transients	92
6.4 Effects of the size of capacitor bank	93
6.5 Recommendations to minimize transients	94
6.5.1 Minimization of transients due to shunt capacitor bank	94
6.5.1.1 Synchronous closing control	95
6.5.1.2 Optimum closing/opening resistors	95
6.5.1.3 Metal Oxide Varistor (MOV)	96
6.5.1.4 Harmonic filters	97
6.5.1.5 Surge arrester	97
6.5.1.6 Snubber circuit	98
6.5.2 Minimization of transients due to transformer switching	99
6.6 Discussion	101

Chapter 7: Conclusion

7.1 Introduction	102
7.2 Difficulties faced while accomplishing thesis	102
7.3 Limitations of study and analysis	103
7.4 Future works	105
7.5 Conclusion	106
REFERENCES	107

LIST OF FIGURES

Figure No.	Name of the figure	Page No.
Fig-2.1	Typical current impulsive transient caused by lightning	11
Fig-2.2	Oscillatory Transient Due to Back-to-Back Capacitor Switching	15
Fig-2.3	Single line diagram of a simple network	17
Fig-2.4	Simplified equivalent circuit of the simple network	17
Fig. 2.5	Simple equivalent circuit for three-phase shunt capacitor switching.	18
Fig-2.6	Magnetizing curve and hysteresis loop of a transformer core	19
Fig- 2.7	Damage of PT but fuses remained intact	27
Fig-2.8	Failure of transformer during energization and de-energization	27
Fig-3.1	Equivalent two port network for line with lumped losses	30
Fig-3.2	Resistivity of overhead lines	33
Fig-3.3	Tower model and relevant parameters used in overhead transmission line tower design	34
Fig-3.4	Typical cross section of a single core underground cable	35
Fig-3.5	Cross section of three single core cable used for analysis	35
Fig-3.6	Three phase view of fault module	36
Fig-3.7	Single line view of fault module	36
Fig- 4.1	Overhead Transmission Line	44
Fig-4.2	Considered network for switching transient analysis of overhead lines	46
Fig-4.3	Primary side voltage of T1 (i.e.bus-1) due to energization	47
Fig-4.4	Secondary side voltage of T1 (i.e. bus-2) due to energization	48
Fig-4.5	Voltage at the primary side of T2 (i.e. bus-5) due to energization of transformer, T1	48
Fig-4.6	Primary side voltage of T2 (i.e.bus-5) during energization of T2	49
Fig-4.7	Secondary side voltage of T2 (i.e. bus-6) due to energization of T2	49
Fig-4.8	Primary side voltage of T2 (i.e. bus-5) due to de-energization	50
Fig-4.9	Power factor improvement (PFI) panel	51
Fig-4.10	Inrush charging current through the 2.0MVAR capacitor bank	51

Figure No.	Name of the figure	Page No.
Fig-4.11	Inrush charging current through the 10MVAR capacitor bank	52
Fig-4.12	Voltage at the primary side of T2 due to 2.0MVAR capacitor bank switching	52
Fig-4.13	Phase-A voltage of bus-5 due to capacitor bank switching	53
Fig-4.14	Phase-B voltage of bus-5 due to capacitor bank switching	53
Fig-4.15	Phase-C voltage of bus-5 due to capacitor bank switching	54
Fig-4.16	Primary side voltage of T3 (i.e. bus-9) due to 2.0 MVAR capacitor bank switching	54
Fig-4.17	Current at the primary side of T2 due to 2.0MVAR capacitor bank switching	55
Fig-4.18	Primary side voltage of T2 (i.e. bus-5) during de-energization of capacitor bank	55
Fig-4.19	Primary side voltage of T3 (i.e. bus-9) due to 1.0MVAR capacitor bank switching	56
Fig-4.20	Phase-A voltage of bus-9 due to 1.0MVAR capacitor bank energization	56
Fig-4.21	Phase-B voltage of bus-9 due to 1.0MVAR capacitor bank energization	57
Fig-4.22	Phase-C voltage of bus-9 due to 1.0MVAR capacitor bank energization	57
Fig-4.23	Primary side voltage of T3 due to de-energization of 1.0MVAR capacitor bank	58
Fig-4.24	Voltage of bus-10 due to switching of load	58
Fig-4.25	Inrush current due to switching of load	59
Fig-4.26	Figure showing current, transient recovery voltage (TRV) and recovery voltage	59
Fig-4.27	Transient recovery voltage (TRV) across the circuit breaker	60
Fig-4.28	BRB underground cable structure	63
Fig-4.29	Considered network for transient analysis of underground cable	64
Fig-4.30	Primary side voltage of T1 (i.e. bus-1) due to energization of transformer	65
Fig-4.31	Secondary side voltage of T1 (i.e. bus-2) due to energization	66
Fig-4.32	Voltage at the primary of T2 due to energization of transformer, T1	66
Fig-4.33	Charging current through the cable during unloaded condition	67
Fig-4.34	Primary side voltage of T3 (i.e. bus-9) due to transformer energization	67
Fig-4.35	Voltage at the load side due to the transformer energization	68
Fig-4.36	Voltage at the secondary of T2 (i.e. bus-6) due to energization	68

Figure No.	Name of the figure	Page No.
Fig-4.37	Primary side voltage of T3 (i.e. bus-9) due to transformer energization	69
Fig-4.38	Primary side voltage of T1 (i.e.bus-1) due to de-energization of transformer	69
Fig-4.39	Secondary side voltage of T1 (i.e. bus-2) due to de-energization of transformer	70
Fig-4.40	Primary side voltage of T3 (i.e. bus-9) due to transformer de-energization	70
Fig-4.41	Voltage at the primary side of T2 (i.e. bus-5) due to capacitor bank switching	71
Fig-4.42	Primary side voltage of T3 (i.e.bus-9) due to capacitor bank switching	71
Fig-4.43	Charging current through [2.0MVAR] capacitor bank during switching	72
Fig-4.44	Voltage at the secondary of T2 due to de-energization of the capacitor bank	72
Fig-4.45	Primary side voltage of T3 (i.e.bus-9) due to capacitor bank switching	73
Fig-4.46	Voltage at the load side (i.e.bus-10) due to the switching of capacitor bank	73
Fig-5.1	Short circuit fault in a tower	78
Fig-5.2	Considered network for transient short circuit fault analysis	80
Fig-5.3	Voltage of bus-2 after single-line-ground fault	82
Fig-5.4	Voltage at the primary side of T2 (i.e. bus-5) due to single-line-ground fault	82
Fig-5.5	Voltage at the load terminal (i.e. bus-10) after single-line-ground fault	83
Fig-5.6	Current at the primary side of T2 (i.e. bus-5) due to single-line-ground fault	83
Fig-5.7	Voltage of bus-2 after double-line-ground fault	84
Fig-5.8	Voltage at the primary side of T2 (i.e. bus-5) due to double-line-ground fault	84
Fig-5.9	Voltage at the load terminal (i.e. bus-10) after double-line-ground fault	85
Fig-5.10	Fault current at the primary side of T2 due to double-line-ground fault	85
Fig-5.11	Voltage of bus-2 after three phase to ground fault	86

Figure No.	Name of the figure	Page No.
Fig-5.12	Voltage at the primary side of T2 (i.e. bus-5) due to three phase to ground fault	86
Fig-5.13	Voltage at the load terminal (i.e. bus-10) after three phase to ground fault	87
Fig-5.14	Current at the primary side of T2 due to three phase to ground fault	87
Fig-6.1	Transients developed across the circuit breaker	90
Fig-6.2	Doubling effect of transformer	91
Fig-6.3	Cross sectional view of Metal Oxide Varistor (MOV)	96
Fig-6.4	Surge arrester cross sectional view	98
Fig-6.5	RC snubber circuits	99

LIST OF TABLES

Table No.	Name of the table	Page No.
Table-2.1	Impulsive Transients Categories	12
Table-2.2	Oscillatory Transients Classification	14
Table-2.3	External sources of transient activity	21
Table-2.4	Common internal sources of transient activity	22
Table-2.5	History of Transformer failure related to primary winding vacuum breaker switching	25
Table-3.1	Frequency dependent (phase) model specifications	32
Table-3.2	Frequency dependent (mode) model specifications	32
Table-3.3	Definition Canvas (TLine_1)	33
Table-3.4	Definition Canvas (TLine_2)	33
Table-3.5	Relevant parameters used in overhead line tower design	34
Table-4.1	Output results for different switching events in overhead transmission line	61
Table-4.2	Data of the output results for transient analysis of underground cable	75
Table-5.1	Recorded data for transient short circuit analysis	89

LIST OF ABBREVIATIONS

BIL	Basic Insulation Level
PSCAD	Power System Computer Aided Design
TRV	Transient Recovery Voltage
ANN	Artificial Neural Network
UHVDC	Ultra High Voltage Direct Current
EHVAC	Extra High Voltage Alternating Current
EHVDC	Extra High Voltage Direct Current
EMTP	Electromagnetic Transient Program
EMTDC	Electromagnetic Transient including DC
ANSI	American National Standards Institute
IEC	International Electrotechnical Commission
FACTS	Flexible Alternating Current Transmission
LCP	Line Constants Program
GTO	Gate Turn On Thyristor
SVC	Synchronous Var Compensator
ENI	Electric Network Interface
ROW	Right Of Way
HVDC	High Voltage Direct Current
MOV	Metal Oxide Varistor
SPD	Surge Protection Device
TVSS	Transient Voltage Surge Suppressor