

LIBRARY  
UNIVERSITY OF MORATUWA, SRI LANKA  
MORATUWA

LB/DON/40/2011

DEE 05179

**MODELING OF POWER TRANSMISSION  
LINES FOR LIGHTNING BACK  
FLASHOVER ANALYSIS  
A CASE STUDY: 220kV BIYAGAMA -  
KOTMALE TRANSMISSION LINE**

**Master of Science Dissertation**

**M.CHANAKA**

**Department of Electrical Engineering  
University of Moratuwa, Sri Lanka**

621.3"10"

621.3(043)

TH

**December 2010**

96441

University of Moratuwa



96441

96441



**MODELING OF POWER TRANSMISSION LINES  
FOR LIGHTNING BACK FLASHOVER  
ANALYSIS  
A CASE STUDY: 220KV BIYAGAMA - KOTMALE  
TRANSMISSION LINE**

A dissertation submitted to the Department of Electrical Engineering,  
University of Moratuwa in partial fulfillment of the requirement for the  
Degree of Master of Science

by

**MALLIKARACHCHIGE CHANAKA**

Supervised by: Prof. H.Y.R. Perera

Eng. K.P.K. Shanthi

**Department of Electrical Engineering  
University of Moratuwa, Sri Lanka**

December 2010

## DECLARATION

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

.....

M. Chanaka

30<sup>th</sup> December 2010

We endorse the declaration by the candidate.

### ***UOM Verified Signature***

Prof. H.Y.R. Perera

.....

Eng. K.P.K. Shanthi

# CONTENTS

Declaration.....	i
Abstract.....	v
Dedication.....	vi
Acknowledgement.....	vii
List of Figures.....	viii
List of Tables.....	x
<b>CHAPTER - 1.....</b>	<b>1</b>
<b>Introduction.....</b>	<b>1</b>
1.1 Historical overview of lightning .....	1
1.2 The lightning phenomena.....	2
1.2.1 Charge separation of thunder clouds .....	2
1.2.2 Electric fields and energy in thunder clouds .....	3
1.2.3 Leader formation and breakdown mechanism.....	4
1.2.4 Types of lightning.....	5
1.2.5 Frequency of occurrence of lightning.....	5
1.3 Lightning data of Sri Lanka .....	5
1.4 Introduction to transmission system of Sri Lanka.....	6
1.5 Lightning effects on power transmission lines.....	7
1.6 Lightning Parameters .....	9
1.6.1 The quantity of lightning activity in a given area.....	9
1.6.2 The distribution of the crest current of a lightning flash .....	9
1.6.3 The wave shape of a lightning flash .....	10
1.6.4 Total charge delivered by a lightning stroke .....	10
1.7 Selected transmission line for the study.....	11
1.7.1 Transmission Towers and configuration .....	12
1.7.2 Insulators and arc horn gaps .....	13
1.7.3 Phase conductors .....	13
1.7.4 Earthing of towers .....	13
<b>CHAPTER - 2.....</b>	<b>15</b>
<b>Problem identification .....</b>	<b>15</b>
2.1 Introduction .....	15
2.2 Preliminary studies.....	15
2.2.1 The relationship between monthly Isokeraunic level and line failures .....	16
2.2.2 Line sections having higher probability of insulator failures .....	17
2.3 Back flashover effects on transmission lines .....	17
2.3.1 Earth faults at power frequency voltage due to back flashover events .....	18
2.4 Prevention of Back flashover events.....	18
2.5 Project objectives .....	19

<b>CHAPTER - 3</b> .....	<b>20</b>
<b>Methodology</b> .....	<b>20</b>
3.1 EMTP/PSCAD modeling and simulation .....	20
3.2 Proposed electromagnetic transient model for 220kV Biyagama-Kotmale transmission line.....	21
3.3 Electromagnetic fast front transient sub models for transmission line elements	22
3.3.1 Frequency dependent (Phase) model representing Transmission line sections and spans.....	22
3.3.2 Loss-Less Constant Parameter Distributed Line (CPDL) model representing the transmission towers .....	23
3.3.3 Tower grounding resistance model.....	25
3.3.4 Line insulators and back flashover model .....	26
3.3.5 Line termination model .....	28
3.3.6 Surge arrester model.....	29
3.3.7 Lightning stroke current generator model .....	31
3.3.8 Power frequency phase voltage generator model .....	33
3.4 Selection of a Transmission Line Arrester (TLA) .....	34
<b>CHAPTER - 4</b> .....	<b>36</b>
<b>Application of the methodology</b> .....	<b>36</b>
4.1 Introduction .....	36
4.2 Power Systems CAD (PSCAD) modeling tool .....	36
4.2.1 PSCAD Graphical User Interface (GUI) window .....	36
4.3 Creation of sub models in PSCAD.....	38
4.3.1 Transmission line model.....	38
4.3.2 Transmission tower model.....	40
4.3.3 Tower grounding resistance model.....	40
4.3.4 Line insulator string with back flashover model .....	41
4.3.5 Power frequency phase voltage generator model .....	42
4.3.6 Line end termination model.....	43
4.3.7 Surge Arrester model.....	43
4.3.8 Lightning surge generator model.....	48
4.4 Assembly of sub models and data signal coordination .....	49
4.5 Method of simulation .....	49
4.5.1 Multiple Run component and variable settings .....	49
4.5.2 Simulation criteria .....	51
4.5.3 Project simulation settings.....	53
<b>CHAPTER - 5</b> .....	<b>54</b>
<b>Results and analysis</b> .....	<b>54</b>
5.1 Introduction .....	54

5.2 Back flashover minimum current variation results and analysis.....	55
5.2.1 Results of simulations without arrester protection (Step-1) .....	55
5.2.2 Results of simulations with arrester protection (Step-2) .....	58
<b>CHAPTER - 6.....</b>	<b>62</b>
<b>Conclusion and recommendations .....</b>	<b>62</b>
6.1 Conclusion.....	62
6.2 Recommendations .....	62
<b>REFERENCES.....</b>	<b>63</b>
Annex-1 Present Transmission system of Sri Lanka .....	A1
Annex-2 Transmission system of Sri Lanka (Single line diagram).....	A2
Annex-3 220kV Biyagama – Kotmale transmission line parameters.....	A3
Annex-4: A typical transmission tower used in the selected transmission line .....	A4
Annex-5: Tower schedule .....	A5
Annex-6 Grounding Resistance variation of towers due to soil ionization effect .....	A6
Annex-7 Simplified selection procedure of an ABB surge arrester .....	A7-1

## **Abstract**

Performance of power transmission lines has a great impact on reliability aspects of a particular power supply system of a country. Unreliable power transmission lines can even lead to total power failures resulting with great financial losses. The lightning back flashover effects are recognized as one of the major causes of transmission line outages.

Several types of solutions are presently available to address the issue of lightning back flashovers. However the modern concept of transmission line mounted surge arresters is of great popularity due to its excellent performance, ease of installation and the low cost compared to the other traditional solutions.

This report describes a case study which was carried out on one of critical 220kV power transmission lines of the Sri Lankan transmission network, having several past records of lightning back flashover related outages resulting with total system failures.

The study described in this report is mainly focuses on the way of analyzing the back flashover events by transient modeling and subsequent simulation of the selected transmission line in an electromagnetic transient computer program. The study uses the Power System CAD (PSCAD) software program as the software tool for the purpose of modeling and simulation of selected 220kV Biyagama-Kotmale power transmission line.

Simulation of the created transmission line model is carried out with and without Transmission Line Arrester (TLA) model to evaluate the improvements in lightning back flashover performance after installation of TLAs in the selected transmission line.

The result of the simulations shows that the installation of 02nos.of TLAs at top phases of each selected towers improves the lightning performance of the selected power transmission line.

## **Acknowledgement**

Thanks are due first to my supervisors, Professor H.Y.R. Perera and Eng. K.P.K. Shanthi, for their great insights, perspectives, guidance and sense of humor. My sincere thanks goes to the officers in the Post Graduate Office, Faculty of Engineering, University of Moratuwa, Sri Lanka for helping in various ways to clarify the things related to my academic works in time with excellent cooperation and guidance. Sincere gratitude is also extended to the course coordinators and rest of the staff who serve in the Department of Electrical Engineering office.

My special thanks goes to Dr. Dharshana Muthumuni who spent his valuable time to guide me and providing valuable information required for this study.

I would like to express my sincere gratitude to Eng. L.A.S. Fernando, Eng. (Mrs.) N Amarasiri, Eng. W.W.R. Pitawala, Eng. W.D.A.J. Chandrakumara, Eng. N.L.A.A. Chandranath, Eng. W.A. Jayalath and Eng. U. Ranathunga working at Ceylon Electricity Board for their excellent support and the encouragement towards the success of this academic work.

Further my heartfelt thanks goes to Eng. L.A.A.N. Perera, Eng. K.P.D.S.K. Dharmadasa and Eng. D.L.P. Munasinghe for their valuable help and the continuous encouragement.

Finally, I would like to thank many individuals, friends and colleagues who have not been mentioned here personally in making this educational process a success. I could not be able to done it without your support.

M.Chanaka

29<sup>th</sup> December 2010



## List of figures

Figure	Description	Page
Figure 1.1	– Benjamin Franklin’s famous kite experiment in 1752 .....	1
Figure 1.2	– Charge distribution of thunder clouds and types of lightning .....	2
Figure 1.3	– Progression of the Downward Leader and formation of the Return Stroke .....	4
Figure 1.4	– Isokeraunic Level (IKL) map of Sri Lanka [5] .....	6
Figure 1.5	– Induced charges on a power transmission line .....	7
Figure 1.6	– Lightning Stroke Current Probability Distribution [6].....	10
Figure 1.7	– 220kV, Biyagama-Kotmale Transmission Line .....	11
Figure 1.8	– Single line diagram of Victoria complex with Biyagama-Kotmale line .	12
Figure 1.9	– Grounding resistance variation of towers 31-52 and 83-97 starting from Kotmale end.....	14
Figure 2.1	– Comparison of monthly line failures with IKL .....	16
Figure 3.1	– Complete transmission line model proposed for the analysis .....	21
Figure 3.2	– Frequency Dependent (Phase) Model in PSCAD and its connection arrangement .....	22
Figure 3.3	– Constant Parameter Distributed Line (CPDL) Model for Towers .....	23
Figure 3.4	– Flashover voltage-time characteristic of 220kV line insulation with 2m Arc-horn gap.....	27
Figure 3.5	– Insulator string and back flashover model.....	27
Figure 3.6	– Basic logic diagram for back flashover control module.....	28
Figure 3.7	– Grounding arrangement of a typical end termination model.....	28
Figure 3.8	– Frequency dependent surge arrester model .....	29
Figure 3.9	– V-I Relationship for nonlinear resistors $A_0$ and $A_1$ [12] .....	30
Figure 3.10	– Standard waveforms for lightning surge voltage and current .....	32
Figure 3.11	– System and Arrester parameter matching configuration [13] .....	34
Figure 3.12	– Selection procedure of electrical parameters for ABB surge arresters [13].....	35
Figure 4.1	– Typical working window of PSCAD software.....	37
Figure 4.3	– Transmission line parameter input window .....	38
Figure 4.2	– Transmission line model (Remote end method).....	38
Figure 4.5	– Typical tower model created in PSCAD .....	39
Figure 4.4	– General Line Geometry Data input .....	39
Figure 4.7	– Insulator string capacitor and Back flashover Breaker models .....	40
Figure 4.6	– Tower grounding resistance model .....	40
Figure 4.8	– Back flashover control module implemented in PSCAD.....	41
Figure 4.9	– Power frequency phase voltage generator model .....	42
Figure 4.10	– Line termination model created in PSCAD.....	43
Figure 4.11	– Surge arrester model created in PSCAD .....	44

Figure 4.12 – Created test circuit in PSCAD for surge arrester testing .....	45
Figure 4.13 – Test surge waveform 30/60us with 1kA peak .....	46
Figure 4.14 – Test result, arrester discharge voltage at 1kA .....	46
Figure 4.15 – Test surge waveform 8/20μs with 10kA peak.....	47
Figure 4.16 – Test result, arrester discharge voltage at 10kA .....	47
Figure 4.16 – Test result, arrester discharge voltage at 10kA .....	48
Figure 4.17 – Lightning surge generator model created in PSCAD .....	48
Figure 4.18 – Multiple Run simulation component in PSCAD.....	49
Figure 5.1 – Typical view of an output data file.....	54
Figure 5.2 – Results of simulation no.1 .....	55
Figure 5.4 – Results of simulation no. 2 .....	56
Figure 5.3 – Results of simulation no. 4 .....	56
Figure 5.5 – Results of simulation no. 5 .....	57
Figure 5.6 – Results of simulation no. 3 .....	57
Figure 5.7 – Results of simulation no. 6 .....	58
Figure 5.8 – Results of simulation no. 7 .....	58
Figure 5.9 – Results of Simulation no. 8 .....	59
Figure 5.11 – Results of Simulation no. 12 .....	60
Figure 5.10 – Results of Simulation no. 11 .....	60



Figure 4.12 – Created test circuit in PSCAD for surge arrester testing .....	45
Figure 4.13 – Test surge waveform 30/60us with 1kA peak .....	46
Figure 4.14 – Test result, arrester discharge voltage at 1kA .....	46
Figure 4.15 – Test surge waveform 8/20μs with 10kA peak .....	47
Figure 4.16 – Test result, arrester discharge voltage at 10kA .....	47
Figure 4.16 – Test result, arrester discharge voltage at 10kA .....	48
Figure 4.17 – Lightning surge generator model created in PSCAD .....	48
Figure 4.18 – Multiple Run simulation component in PSCAD .....	49
Figure 5.1 – Typical view of an output data file .....	54
Figure 5.2 – Results of simulation no.1 .....	55
Figure 5.4 – Results of simulation no. 2 .....	56
Figure 5.3 – Results of simulation no. 4 .....	56
Figure 5.5 – Results of simulation no. 5 .....	57
Figure 5.6 – Results of simulation no. 3 .....	57
Figure 5.7 – Results of simulation no. 6 .....	58
Figure 5.8 – Results of simulation no. 7 .....	58
Figure 5.9 – Results of Simulation no. 8 .....	59
Figure 5.11 – Results of Simulation no. 12 .....	60
Figure 5.10 – Results of Simulation no. 11 .....	60



## List of tables

Table	Description	Page
Table 1.1	– Range of values for lightning parameters [6].....	8
Table 1.2	– CEB Specifications for a single insulator disc [4].....	13
Table 2.1	– Monthly line failures and IKL.....	16
Table 3.1	– Calculated parameters for a typical tower model .....	25
Table 4.1	– Initial I, V values for $A_0$ and $A_1$ [11] .....	45
Table 4.2	– Range of values used for variables in Multiple Run component .....	50
Table 4.3	– Detailed simulation criteria for Step-1.....	52
Table 4.4	– Detailed simulation criteria for Step-2.....	53



University of Moratuwa, Sri Lanka.  
Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)