

**DESIGNING OF RAILWAY ELECTRIFICATION
NETWORK CONFIGURATION TO MINIMIZE POWER
QUALITY ISSUES:
A CASE STUDY FOR PROPOSED SRI LANKAN
RAILWAY ELECTRIFICATION**

Walimuni Udara Kithsanka Mendis

149292D

Thesis submitted in partial fulfillment of the requirements for the degree Master of
Science

Department of Electrical Engineering

University of Moratuwa

Sri Lanka

December 2018

DECLARATION OF THE CANDIDATE AND SUPERVISORS

I declare that this is my own work and this thesis 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 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 thesis, 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: 05th December, 2018

The above candidate has carried out research for the Masters thesis under my supervision.

Signature of the supervisor:

Date: 05th December, 2018

(Dr. Asanka Rodrigo)

ABSTRACT

Electrified railway system is a better solution for the rapidly increasing congestion of traffic in urban areas and railway transportation has many advantages compared with other modes of land/air transportation. In Electrified railway system ,energy delivered to the train when needed(running), unlike the other modes of transportation (land, air, sea).According to the present railway passenger flow, suburban railway stations Panadura – Veyangoda sector was selected as high passenger density area which served 44% of all railway passengers and government has decided to electrified that sector first. The total track length between Panadura and Veyangoda is 156km.

Due to the rapid acceleration and frequent starts of electric trains, there may large magnetic induction current in the power circuits and it may contribute to the grid voltage drop near urban areas. The energy flow back to the grid with regenerative braking and harmonics will added to the system. So, there are lot of power quality issues with electrified railway system and it is time to accept the challenge as Electrical Engineers.

This research titled as “DESIGNING OF RAILWAY ELECTRIFICATION NETWORK CONFIGURATION TO MINIMIZE POWER QUALITY ISSUES: A CASE STUDY FOR PROPOSED SRI LANKAN RAILWAY ELECTRIFICATION” was carried out to find out an optimum voltage configuration to feed the railway system with minimum disturbing to the available power system.

Electric train model was developed using Matlab Simulink to study the behavior of power distribution system while operating of the electric trains with current time schedule of the Sri Lankan Railways.

The results were obtained and analyzed under the critical times at proposed railway substations .According to the results, optimum voltage configuration was selected in order to minimize the power quality issues to the utility grid.

ACKNOWLEDGEMENTS

Gratitude is due with much respect towards the supervisor, Dr. Asanka Rodrigo, who guided the candidate throughout his thesis work, in spite of his busy schedules.

Candidate would like to extend his gratitude to all the lecturers of Electrical Engineering Department, University of Moratuwa for the guidance provided by them to improve the thesis, with their valuable comments.

Appreciation is also expressed to the department of Sri Lankan Railways, especially Eng. Asela Pathirathna for the information and guidance provided to improve the thesis.

It is a great pleasure to remember the kind cooperation of all my colleagues and my friends, especially Eng. Gayashan Porawagamage who have helped me throughout this Post Graduate programme.

Finally, the candidate owe his gratitude to his parents, wife and brother for their endless support and encouragement and without whom the candidate would not have come this far.

CONTENTS

DECLARATION OF THE CANDIDATE AND SUPERVISORS.....	i
ABSTRACT.....	ii
ACKNOWLEDGEMENTS	iii
TABLE OF FIGURES.....	vii
LIST OF TABLES	x
ABBREVIATIONS	xii
INTRODUCTION	1
1.1 Background.....	1
1.1.1 Sri Lankan context.....	1
1.2 Problem statement	3
1.3 Motivation.....	4
1.4 Objective.....	5
1.5 Scope of Work	5
1.6 Structure of the dissertation	6
RAILWAY ELECTRIFICATION SYSTEMS.....	8
2.1 Overview	8
2.2 Different voltage configurations	8
2.2.1 DC system.....	8
2.2.2 AC system.....	8
2.2.3 Source of primary power.....	10
2.2.4 Substation.....	10
2.2.5 Power distribution system.....	10
2.2.5.1 Feeder cables.....	11
2.2.5.2 Negative return cables.....	11
2.2.5.3 Contact system	11
2.2.5.4 Third rail system	12
2.2.5.5 Overhead contact system.....	12
2.2.5.6 Current collectors	12
2.3 Railway Electrification of Sri Lanka.....	13
2.3.1 The proposed electrification project.....	14

DATA COLLECTION AND ANALYSIS	16
3.1 Data of Transmission network parameters	16
3.2 Proposed railway substation	17
3.3 Data of electric locomotive.....	19
3.4 Analysis of railway time table	20
3.4.1 Critical situation in Panadura to Maradana section	20
3.4.2 Critical situation in Veyangoda to Colombo Fort section	21
MODELING OF RAILWAY NETWORK	23
4.1 Utility Grid	24
4.2 132kV transmission line model	25
4.3 Railway substation model.....	26
4.4 Model of overhead catenary contact wire system.....	26
4.5 Electric locomotive model.....	27
4.5.1 Selecting Torque reference (Tm) and Speed reference (Sp)	28
4.5.2 Field Orient Controller (FOC)	30
4.6 Harmonic filter.....	33
RESULTS AND MODEL VALIDATION.....	35
5.1 Model validation.....	35
5.1.1 Using characteristic curve of electric locomotives.....	35
5.1.2 Result verification for a single train	38
5.1.2.1 Motor parameter variation for one bogie of the train.....	38
5.1.2.2 Active and reactive power variation	39
5.1.2.3 132kV voltage variation.....	41
5.1.2.4 132kV line current variation	42
5.1.2.5 Total harmonic distortion of current in transmission side	43
5.1.2.6 Total harmonic distortion of voltage in transmission side.....	45
5.2 Results	48
5.2.1 Case 01:Dehiwala railway substation	48
5.2.1.1 Active and reactive power variation	49
5.2.1.2 132kV voltage variation.....	52
5.2.1.3 132kV line current variation	53

5.2.1.4 Total harmonic distortion of current in transmission side	54
5.2.1.5 Total harmonic distortion of voltage in transmission side.....	55
5.2.2 Case 02:Ragama railway substation	57
5.2.2.1 Active and reactive power variation	58
5.2.2.2 132kV voltage variation.....	60
5.2.2.3 132kV line current variation	61
5.2.2.4 Total harmonic distortion of current in transmission side	62
5.2.2.5 Total harmonic distortion of voltage in transmission side.....	63
5.3 Results analysis	65
5.3.1 Results analysis of dehiwala substation	65
5.3.2 Results analysis of Ragama substation	66
DISCUSSION AND CONCLUSION.....	68
6.1 Discussion	68
6.2 Conclusion.....	70
REFERENCES.....	71
APENDIX	73
8.1 Annex 1	73
8.2 Annex 2	77

TABLE OF FIGURES

Figure 1: Methodology for optimum railway configuration	6
Figure 2 : Railway Substation	10
Figure 3 : Feeder Cables	11
Figure 4: Negative Return via the Running Rail.....	11
Figure 5: Third Rail Contact System	12
Figure 6: Third Rail Contact Shoe	12
Figure 7: Pantograph System	13
Figure 8 : Existing Sri Lankan railway network	14
Figure 9: Sector to be electrified and technical proposal for Power Supply.....	15
Figure 10 : The map of Grid substations along the proposed railway section.....	16
Figure 11: Utility Grid Model	24
Figure 12: 132kV Transmission Line model	25
Figure 13: 132kV Transmission Line model	25
Figure 14: Distribution transformer model	26
Figure 15: Model of overhead contact wire	27
Figure 16: General AC Electric Locomotive model	27
Figure 17 : Model of Electric Locomotive.....	28
Figure 18 : Power demand variation with the rpm in starting of a M9 train.....	29
Figure 19 : Speed Reference	29
Figure 20 : Torque Reference	30
Figure 21: Schematic diagram of Field-Oriented Control Induction Motor Drive ..	30
Figure 22: Field-Oriented Controller in Electric Locomotive	31
Figure 23: Set parameters of Field-Oriented Controller	31
Figure 24: Set parameters of Field-Oriented Controller	32
Figure 25: Set parameters of Field-Oriented Controller	32
Figure 26: Total Electrified Railway System.....	33
Figure 27: Mat Lab model of total Electrified Railway System	33
Figure 28: Harmonic Filter	34
Figure 29: Ideal traction curve	35

Figure 30: Traction curve of WAG7 and WAG 9.....	36
Figure 31: Torque characteristics of the train Model	37
Figure 32: 25kV/50Hz system	38
Figure 33: 15kV/16.7Hz system	39
Figure 34: 15kV/50Hz system	39
Figure 35: 25kV/50Hz system	40
Figure 36: 15kV/16.7Hz system	40
Figure 37: 15kV/50Hz system	40
Figure 38: 25kV/50Hz system	41
Figure 39: 15kV/16.7Hz system	41
Figure 40: 15kV/50Hz system	41
Figure 41: 25kV/50Hz system	42
Figure 42: 15kV/16.7Hz system	42
Figure 43: 15kV/50Hz system	42
Figure 44: 25kV/50Hz system	43
Figure 45: 15kV/16.7Hz system	44
Figure 46: 15kV/50Hz system.....	44
Figure 47: 25kV/50Hz system.....	45
Figure 48: 15kV/16.7Hz system.....	46
Figure 49: 15kV/50Hz system.....	47
Figure 50: Simulate Mat Lab model with different configurations.	48
Figure 51: Active power variation25kV/50Hz system.....	49
Figure 52: Reactive power variation25kV/50Hz system	50
Figure 53: Active power variation15kV/16.7Hz system.....	50
Figure 54: Reactive power variation15kV/16.7Hz system	50
Figure 55: Active power variation15kV/50Hz system.....	51
Figure 56: Reactive power variation15kV/50Hz system	51
Figure 57: 25kV/50Hz system.....	52
Figure 58: 15kV/16.7Hz system.....	52
Figure 59: 15kV/50Hz system.....	52
Figure 60: 25kV/50Hz system.....	53
Figure 61: 15kV/16.7Hz system.....	53

Figure 62: 15kV/50Hz system.....	53
Figure 63: 25kV/50Hz system.....	54
Figure 64: 15kV/16.7Hz system.....	54
Figure 65: 15kV/50Hz system.....	55
Figure 66: 25kV/50Hz system.....	55
Figure 67: 15kV/16.7Hz system.....	56
Figure 68: 15kV/50Hz system.....	56
Figure 69: Active power variation25kV/50Hz system.....	58
Figure 70: Reactive power variation25kV/50Hz system	58
Figure 71: Active power variation15kV/16.7Hz system.....	58
Figure 72: Reactive power variation15kV/16.7Hz system	59
Figure 73: Active power variation15kV/50Hz system.....	59
Figure 74: Reactive power variation15kV/50Hz system	59
Figure 75: 25kV/50Hz system	60
Figure 76: 15kV/16.7Hz system	60
Figure 77: 15kV/50Hz system	60
Figure 78: 25kV/50Hz system	61
Figure 79: 15kV/16.7Hz system	61
Figure 80: 15kV/50Hz system	61
Figure 81: 25kV/50Hz system	62
Figure 82: 15kV/16.7Hz system	62
Figure 83: 15kV/50Hz system	63
Figure 84: 25kV/50Hz system	63
Figure 85: 15kV/16.7Hz system	64
Figure 86: 15kV/50Hz system	64

LIST OF TABLES

Table 1: Origin and destination analysis of SLR passengers	2
Table 2 : Data of transmission network paramaetrs	17
Table 3 : Locations of railway stations along track from Panadurata-Veyangoda	18
Table 4 : Distance to grid from proposed railway substations.....	19
Table 5 : Data of electric locomotive paramaetrs	19
Table 6: Critical situation in Panadura- Maradana section	20
Table 7: Critical situation in Veyangoda- Colombo Fort section	21
Table 8: Utility grid modelling details of Dehiwala Grid at 50 Hz	24
Table 9: The recorded data at the starting of the train No:867	28
Table 10: The obtain rpm for selected torque values.....	37
Table 11: Data of train model verification.....	38
Table 12: THD in current at 132kV transmission line for 25kV/50Hz system	43
Table 13 : THD in current at 132kV transmission line for 15kV/16.7Hz system	44
Table 14 : THD in current at 132kV transmission line for 15kV/50Hz system	45
Table 15 : THD in voltage at 132kV transmission line for 25kV/50Hz system.....	46
Table 16 : THD in voltage at 132kV transmission line for 15kV/16.7Hz system.....	46
Table 17: THD in voltage at 132kV transmission line for 15kV/50Hz system.....	47
Table 18: Train status in critical time in dehiwala substation.....	48
Table 19: THD in current at 132kV transmission line for 25kV/50Hz system	54
Table 20: THD in current at 132kV transmission line for 15kV/16.7Hz system	54
Table 21: THD in current at 132kV transmission line for 15kV/50Hz system	55
Table 22: THD in voltage at 132kV transmission line for 25kV/50Hz system.....	55
Table 23: THD in voltage at 132kV transmission line for 15kV/16.7Hz system.....	56
Table 24: THD in voltage at 132kV transmission line for 15kV/50Hz system.....	56
Table 25: Train status in critical time in Ragama substation.....	57
Table 26 : THD in current at 132kV transmission line for 25kV/50Hz system	62
Table 27: THD in current at 132kV transmission line for 15kV/16.7Hz system	62
Table 28: THD in current at 132kV transmission line for 15kV/50Hz system	63
Table 29: THD in voltage at 132kV transmission line for 25kV/50Hz system.....	63

Table 30: THD in voltage at 132kV transmission line for 15kV/16.7Hz system.....	64
Table 31: THD in voltage at 132kV transmission line for 15kV/50Hz system	64
Table 32: Result analysis of Dehiwala substation.....	65
Table 33: Result analysis of Ragama substation.....	66
Table 34: Result analysis for optimum voltage configuration.....	69

ABBREVIATIONS

SLR	: Sri Lanka Railways
DC	: Direct Current
AC	: Alternating Current
CEB	: Ceylon Electricity Board
THD	: Total Harmonic Distortion
OCS	: Overhead Contact Systems
FOC	: Field Oriented Control
GS	: Grid Substation
FL	: Fault Level
MW	: Mega Watt
Mvar	: Mega vars