

**MITIGATION OF VOLTAGE VIOLATIONS IN JAFFNA
PENINSULA DISTRIBUTION SYSTEMS**

Nagaratnam Ravindran

(159375U)

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

Department of Electrical Engineering

University of Moratuwa
Sri Lanka

October 2019

DECLARATION

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 of the Student:
N. Ravindran

Date:

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

Signature of the supervisor:
Dr. Asanka S. Rodrigo
Senior Lecturer
Department of Electrical Engineering
University of Moratuwa

Date:

Signature of the supervisor:
Dr. W.D. Prasad
Senior Lecturer
Department of Electrical Engineering
University of Moratuwa

Date:

Signature of the supervisor:
Prof.A. Atputharajah
Professor
Department of Electrical & Electronic Engineering
University of Jaffna

Date:

ACKNOWLEDGEMENT

I wish to express my sincere appreciation to my supervisors of the research **Dr.W.D.A.S.Rodrigo** and **Dr.W.D.Prasad** senior lecturers of the department of Electrical Engineering, Faculty of Engineering, University of Moratuwa, Sri Lanka and **Prof.A.Atputharajah** department of Electrical and Electronic Engineering, Faculty of Engineering, University of Jaffna, Sri Lanka who guided me during the research and provided me with the necessary reading materials.

Also I wish to thank **University College of Jaffna** the leading provider of vocational training in Northern Province of Sri Lanka, for provided me full time study leave.

Mr.Gunathilake Deputy General Manager (DGM) Ceylon Electricity Board (CEB), Northern Province, Planning Engineer **Mrs.Kamalalogini**, Site Engineer **Miss.Anusha** and Jaffna branch site superintend **Mr.Karthik** who supported throughout my research.

I also gratefully acknowledges the support given by **Department of Electrical Engineering**, University of Moratuwa, Sri Lanka and **Department of Electrical and Electronic Engineering**, University of Jaffna, Sri Lanka.

N.Ravindran

159375U

University of Moratuwa.

ABSTRACT

Mitigation of voltage violations are always a challenging task in distribution networks. Because the distribution networks are directly connected to the consumer loads, which are continuously varying. Under voltage and over voltage, voltage sag, swell and transients/fast variations are the voltage violations that limit the expansion of the electrical distribution networks. This can be eliminated by a step by step systematic approach/methods while providing a cost effective solution. Few examples are use of de-energized tap changer, on-load tap changer and the STATCOM to improve the performance of the distribution system.

This thesis presents the work of studying voltage violations in distribution systems and the case study was done with Jaffna peninsula electrical distribution system. The full day load pattern showed voltage problem in some bus bars especially during peak load conditions. Solutions are proposed, and healthy operation are validated using PACAD simulations to overcome the said problems.

Further a simple network was modelled to study the OLTC operations and a control system was developed to achieve the best customized operation to avoid voltage violation.

Considering the future development of Sri Lanka's potential renewable energy development, the STATCOM applications were studied to eliminate the fast variations in the voltage. A STATCOM detail model using IGBT switches and a small scale distribution network were modelled. STATCOM converter control, AC terminal voltage droop control and DC-Link voltage regulatory control were designed to study the performance of the network on eliminating the voltage violations during the transient operations or fast variations on voltage. This was studied under the STATCOM control and its integrated applications together with the OLTC.

The study proposed three methods to mitigate voltage violations in distribution system network. This was done using de-energized tap changer, on-load tap changer and the STATCOM to improve the performance of the distribution system network. And it is validated using simulation results.

TABLE OF CONTENTS

Declaration of the candidate and supervisor	i
Acknowledgement	ii
Abstract	iii
Table of content	iv
List of figures	vi
List of tables	viii
List of abbreviations	ix
1. Introduction	1
1.1 Voltage violations in the distribution network	1
1.1.1 Under voltage and Over voltage	1
1.1.2 Voltage sag, Voltage swell and interruption	1
1.1.3 Voltage Transients	1
1.2 Voltage issue in Jaffna peninsula	2
1.3 Objectives	3
1.4 Overview of the thesis	4
2. Modelling and studying the performance of Jaffna distribution network	5
2.1 Single line diagram of the equivalent circuit of the Jaffna peninsula distribution network	5
2.2 System Modelling	7
2.2.1 Lines	7
2.2.2 Transformer	10
2.2.3 Load	10
2.2.4 Simulation	13
2.2.5 Model Validation	16
3 Proposed solutions to mitigate Voltage violations in Jaffna peninsula	17
3.1 General methods used to solve the voltage violations	17
3.1.1 Proposed solutions to the Jaffna peninsula distribution system using De-Energized tap changer (DETC)	18

3.1.2	Possible solutions which can be applied for future demand growth	19
3.2	Usage of on load tap changer (OLTC) for Distribution system network	21
3.2.1	Usage of on load tap changer (OLTC) for Jaffna Distribution system network	21
3.2.2	Common problems with OLTC	23
3.2.3	Usage of on load tap changer (OLTC) for a simple distribution network	25
3.3	Study the viability of STATCOM for solving problems in a distribution system network	29
3.3.1	Park Transformation	30
3.3.2	Phase Lock Loop (PLL)	31
3.3.3	A simplified network used to study the STATCOM performance of mitigating voltage violations	33
3.3.4	STATCOM Power Electronic Circuit	34
3.3.5	System Control – AC terminal Voltage Droop Control	35
3.3.6	STATCOM DC Link Voltage Regulatory control	39
3.3.7	Converter Control using Sine-Triangular PWM	41
3.3.8	Connection of STATCOM with the simple network	42
3.3.9	Simulation results	44
4	Performance of Jaffna distribution network together with STATCOM & OLTC	50
4.1	Placement of STATCOM.	50
4.2	Performance of the Jaffna distribution network without STATCOM by changing the cable type from Racoon to ELM conductor with increasing load	52
4.3	Performance of the Jaffna distribution network with STATCOM and Breaker Switch Capacitor (BSC)	53
5	Conclusion	55
	Reference List	57

LIST OF FIGURES

	Page
Figure 1.1: Voltage disturbances as per IEEE classification.	2
Figure 2.1: Single line diagram of the equivalent circuit of Jaffna Peninsula distribution network	6
Figure 2.2: Distribution line in PS-CAD Bergeron model.	9
Figure 2.3: Hourly variation of loads for feeders and the total load	12
Figure 2.4: PSCAD Simulation model of Jaffna peninsula distribution network	15
Figure 3.1: Switching sequence of the OLTC tap selector	23
Figure 3.2: Switching sequence of the OLTC diverter switch	24
Figure 3.3: A simple network was modelled to study the OLTC operations	25
Figure 3.4: A control system which was developed to operate the OLTC	27
Figure 3.5: Variation of terminal voltage and the TAP setting against time	28
Figure 3.6: V_d and the V_q components of Park transformation	30
Figure 3.7: Phase Lock Loop (PLL) model	32
Figure 3.8: Variation of PLL output value 'Theta2'	32
Figure 3.9: Derivation of V_q , Park transformation 'q' axis component	33
Figure 3.10: A simple network used to study the performance of STATCOM	34
Figure 3.11: STATCOM power electronic circuit.	35
Figure 3.12: Variation of system reference voltage V_{ref} in between V_{max} and V_{min}	36
Figure 3.13: AC terminal voltage droop control.	37
Figure 3.14: Derivation of V_d , Park transformation 'd' axis component	38
Figure 3.15: Derivation of V_d , from theta2	39
Figure 3.16: STATCOM DC-Link voltage regulatory control.	40

Figure 3.17:	Control model of DC-link voltage.	40
Figure 3.18	Converter Control using Sine-Triangular PWM	41
Figure 3.19	Converter Control Triangular wave and corresponding IGBT Pulse.	42
Figure 3.20	STATCOM connection with the simple network.	43
Figure 3.21	STATCOM internally calculated referenced voltages Va, Vb and Vc	44
Figure 3.22	Duration of time, when Vrms below 0.94pu, (A) without STATCOM and (B) with STATCOM	45
Figure 3.23	Control of DC-Link voltage	47
Figure 3.24	Source, Load and STATCOM active and reactive power variation	48

LIST OF TABLES

		Page
Table 2.1:	Cable parameter of RACOON and ELM conductors	8
Table 2.2:	Type of the distribution lines and their actual length and the half current location	9
Table 2.3:	Transformers and their losses	10
Table 2.4:	Hourly taken per phase current values of distribution lines measured at Chunnakam Grid Sub Station	11
Table 2.5:	Power factor and the peak, off peak active and reactive power consumption of the feeders	13
Table 2.6	Steady state line to line voltages at the feeders for peak and off peak conditions.	16
Table 3.1	Steady state line to line voltages at the feeders for peak and off peak conditions when Chunnakam Grid Sub Station upper stream transformer fixed tap value 0.95.	19
Table 3.2	Steady state line to line voltages at the feeders for peak and off peak conditions when apply more possible solutions.	20
Table 3.3	Steady state line to line voltages at the feeders with the tap value of 0.9 and up to 160% of the peak load conditions.	22
Table 4.1	Steady state line to line voltages at the feeders with chunnakam OLTC tap value of 0.9 and 160% of the peak load condition, With STATCOM at 'feeder6'.	51
Table 4.2	Steady state line to line voltages at the feeders with chunnakam OLTC tap value of 0.9 and 160% of the peak load condition, by changing cable type of some feeders.	53
Table 4.3	Steady state line to line voltages at the feeders with chunnakam OLTC tap value of 0.9 and 170% of the peak load condition, when 4MVAR, STATCOM connected at Feeder 6 and 1MVAR BSC at feeder13.	54

LIST OF ABBREVIATIONS

BRK	Breaker
DETC	De-Energized Tap Changers
IGBT	Insulated Gate Bipolar Transistor
OLTC	On Load Tap Changers
PLL	Phase Lock Loop
PSCAD	Power System Computer Aided Design
pu	Per Unit
STATCOM	Static Synchronous Compensator
SVC	Static Var Compensator
BSC	Breaker Switched Capacitor