

DECLARATION

I, RITIKA GOUR (2K12/PSY/19) hereby declare that the work, which is being presented in the project report entitled, **“LIMITED CAPACITY DYNAMIC VOLTAGE RESTORER FOR VOLTAGE REGULATION IN RADIAL DISTRIBUTION FEEDER”** submitted for partial fulfillment of the requirements for the award of the degree of Master of Technology (Power System) is an authentic record of my own work carried out under the able guidance of Dr. VISHAL VERMA, Professor, EED, DTU. The matter embodied in the dissertation work has not been plagiarized from anywhere and the same has not been submitted for the award of any other degree or diploma in full or in part.

Submitted by:-

RITIKA GOUR

(2K12/PSY/19)

Power System

Electrical Department

DEPARTMENT OF ELECTRICAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)



CERTIFICATE

This is to certify that the thesis entitled, “**LIMITED CAPACITY DYNAMIC VOLTAGE RESTORER FOR VOLTAGE REGULATION IN RADIAL DISTRIBUTION FEEDER**”, submitted by Ms. **RITIKA GOUR**, Roll No. 2K12/PSY/19, student of Master of Technology (Power System) in Electrical Engineering department from Delhi Technological University (Formerly Delhi College of Engineering), is a dissertation work carried out by her under my guidance during session 2013-2014 towards the partial fulfillment of the requirements for the award of degree of Master of Technology in Power System.

The uniqueness of the thesis pertains to Autonomous Control of Distributed Dynamic Voltage Restorers, which has not been reported elsewhere.

I wish her all the best in her endeavors.

(Dr. VISHAL VERMA)
Professor, EED, DTU
SUPERVISOR

ACKNOWLEDGEMENT

It is my pleasure to be indebted to various people, who directly and indirectly or indirectly contributed in the development of this work and who influenced my thinking, behavior, and during the course of study. Firstly I would like to express my deep sense of gratitude to my respected and learned guide and mentor **Dr. Vishal Verma** (Professor, Electrical Department, DTU) for his guidance and constant supervision as well as for providing necessary information regarding the project & also for his support in completing the project.

I am grateful to **Prof. Madhusudan Singh**, HOD Electrical Department, for his support and acknowledgement.

I would like to extend my thanks to the **Mr. Anil Butola** for his help in offering me the resources in the Simulation Lab.

I would like to express my thanks to PhD Scholar **Mr. Amritesh, Mr. Ramesh Singh, Mrs. Lovely Goyal** and my M.Tech senior **Ms. Bhawana Rathore** for their help and supports in making me understand the concept.

I would also like to thank my friend **Mugdha Goel, Vijay Priyadarshi**, my junior **Dhruv Kumar, Daya Ram Meena, Vandana Arora** for their unconditional support and motivation during this work.

Last but not the least; I would like to thank my family for their moral support throughout.

RITIKA GOUR

2K12/PSY/19

ABSTRACT

The distribution system is one of most important and critical part of power system. The variation in the voltage at load end is of great concern in the distribution system. The voltage is required to be kept regulated within a specified range in the distribution system. Series compensation is technically more suitable solution for regulating the voltage in the radial distribution feeder when compared with shunt compensators. Two vital factors which decide the quality of compensation are the location of series compensation device and the rating of the device. The optimum location of device can be found, using various algorithms optimization technique with multiple restrain. But its optimum location changes every time a fault or large transients occur on the feeder. The rating of device increases with the amount of compensation required to achieve requisite regulation.

This thesis presents an alternative for the conventional lumped series compensation devices prevalent in distribution power systems. The two measures presented in the thesis are curative measures and remedial measures. Curative measure is implemented with the distributed capacity limited DVR as a future course of action to enable efficient and cost-effective voltage regulation on radial feeder. Number of capacity limited DVR are incorporated into the feeder without affecting its power flow. An autonomous control for controlling the D-DVR is investigated to efficiently regulate the voltage on radial feeder in a cost-effective manner. The performance of the D-DVR is evaluated using MATLAB simulation environment to validate the concept of D-DVR and its autonomous control through simulated results under perturbing load and source conditions. Remedial measure is also been studied to improve the response of OLTC transformer installed on the feeder by operating it in conjunction with the capacity limited DVR for step-less operation. Control algorithm for the same is developed. The performance of duo has been investigated and validated using MATLAB/SIMULINK environment under load and source dynamics.

TABLE OF CONTENT

Declaration	<i>i</i>
Certificate	<i>ii</i>
Acknowledgement	<i>iii</i>
Abstract	<i>iv</i>
Table of Content	<i>v</i>
List of Figures	<i>viii</i>
List of Tables	<i>ix</i>
Acronyms	<i>xi</i>
1. INTRIDUCTION	1
1.1 Background and Motivation	1
1.2 Distribution System	2
1.3 Voltage Regulation In Distribution System	3
1.3.1 Capacitor Bank	3
1.3.2 Tap Changing Transformer	3
1.3.3 DSTATCOM	4
1.3.4 DVR	4
1.3.5 UPQC	5
1.4 Scope of Work	6
1.5 Objective and Approach	6
1.6 Organization of Thesis	7
2. LITERATURE SURVEY	9
2.1 Introduction	9
2.2 Review of Literature	9

2.2.1 Distributed Static Series Controller	11
2.2.2 Distributed Power Flow Controller	13
2.2.3 Dynamic Voltage Restorer	14
2.2.4 On Load Tap Changing Transformer	20
2.3 Scope of Work	21
2.4 Conclusion	22
3. SYSTEM CONFIGURATION	23
3.1 Introduction	23
3.2 System Configuration for Lumped Series Compensation	23
3.2.1 Injection Transformer	23
3.2.2 Voltage Source Converter (VSC)	24
3.2.3 LC Filter	25
3.2.4 DC Link and Energy Storage	25
3.2.5 Control and Protection	25
3.2.6 Bypass Switch	27
3.3 System Configuration for Distributed Series Compensation	27
3.4 System Configuration for OLTC Transformer With Capacity Limited Dynamic Voltage Restorer	29
3.5 Merits of Distributed Compensation Over Lumped Compensation	30
3.6 Conclusion	32
4. MODELING AND CONTROL THEORY	33
4.1 Introduction	33
4.2 System Modeling and Control Strategy for Series Compensation Unit on Radial Feeder	33
4.2.1 System Modeling	33
4.2.2 Control Strategy	41

4.3 System Modeling and Control Algorithm for OLTC Transformer With Capacity Limited DVR	43
4.3.1 System Modeling	43
4.3.2 Control Strategy	44
4.4 Conclusion	45
5. MATLAB SIMULATION AND PERFORMANCE EVALUATION	46
5.1 Introduction	46
5.2 Simulation Model and Performance Evaluation of Distributed Series Compensation	46
5.2.1 Simulation Model	46
5.3.2 Performance Evaluation	47
5.3 Simulation Model And Performance Evaluation of OLTC Transformer With Capacity Limited DVR	51
5.3.1 Simulation Model	51
5.3.2 Performance Evaluation	52
5.4 Conclusion	52
6. MAIN CONCLUSION AND FUTURE SCOPE OF WORK	55
6.1 Introduction	56
6.2 Main Conclusion	56
6.3 Future Scope of Work	58
REFERENCES	59

LIST OF FIGURE

Fig. 1.1: Tap Changer of a Tap Changing transfor	3
Fig. 1.2: Basic schematic representation of DSTATCOM connected in distribution system	4
Fig. 1.3: Basic schematic representation of DVR connected in distribution system	5
Fig. 1.4: Basic schematic representation of UPQC connected in distribution system	5
Fig. 2.1: Block diagram for DSSC Module	11
Fig. 2.2: Physical module of DSSC Module	12
Fig. 2.3: DPFC Module Connected in Transmission Line	13
Fig. 2.4: Block Diagram showing difference between UPFC and DPFC	14
Fig. 2.5: DVR in Distribution System	15
Fig. 2.6: Interline DVR in Dstribution System	15
Fig. 2.7: Multi level DVR	17
Fig. 2.8: Phasor Diagram for Pre-sag Compensation	18
Fig. 2.9: Phasor Diagram for In-phase Compensation	19
Fig. 2.10:Phasor Diagram for Optimum Energy Compensation	19
Fig. 3.1: Schematic diagram of lumped DVR	24
Fig. 3.2: Rectifier supported DVR	26
Fig. 3.3: Capacitor supported DVR	26
Fig. 3.4: Schematic Diagram for Distributed DVR connected in Feeder Error! Bookmark not defined. 28	28
Fig. 3.5: Schematic for OLTC transformer with Capacity Limited DVR	29

Fig. 4.1: DVR connected in distribution system	34
Fig. 4.2: Phasor diagram of limiting condition	35
Fig. 4.3: Phasor diagram showing two limiting condition	36
Fig. 4.4: Schematic of Dynamic Voltage Restorer Module	38
Fig. 4.5: Equivalent circuit for switching ripple.	39
(a) Equivalent circuit seen from VSC	
(b) Equivalent circuit for V_{VSC}	
Fig. 4.6: Equivalent circuit for V_{VSC} at fundamental frequency	40
Fig. 4.7: Equivalent circuit for V_{VSC} at harmonic frequency	40
Fig. 4.8: Control Diagram of DVR	41
Fig. 4.9: OLTC Based transformer connected with DVR in distribution system	43
Fig. 4.10: OLTC Transformer tap selection controlling	44
Fig. 5.1: Simulation Diagram for Distributed DVR	47
Fig. 5.2:(a-k): Performance evaluation of D-DVR for regulation of voltage on the feeder amid load Perturbations	48
Fig. 5.3(a-k): Performance evaluation of D-DVR for regulation of voltage on the feeder amid source side voltage disturbance	49
Fig. 5.4: Simulation Diagram of OLTC Transformer with Capacity Limited DVR	51
Fig. 5.5: Simulation results for the operation of OLTC Transformer and DVR under source side disturbance	53
Fig. 5.6:Simulation results for the operation of OLTC Transformer and DVR under Load Pertubations	54

LIST OF TABLE

Table 1:	Parameters for Distributed DVR Simulation	44
Table 2:	Parameters for OLTC Transformer with DVR Simulation	49

ABBREVIATIONS

AC	Alternating Current
ANN	Artificial Neural Network
APF	Active Power Filter
CLC	Central Limit Control
DAFS	Distributed Active Filter System
DC	Direct Current
DFACTS	Distributed FACTS
DG	Distributed Generator
DLC	Distributed Load Control
DSI	Distributed Series Impedance
DSI	Distributed Series Inductor
DSSC	Distributed Static Series Controller
D-STATCAOM	Distribution STATCOM
DVR	Dynamic Voltage Restorer
EHV	Extra High Voltage
FACTS	Flexible Alternating Current Transmission System
GTO	Gate Turn –off Thyristor
HV	High Voltage
IDVR	Interline Dynamic Voltage Restorer
IGBT	Insulated Gate Bipolar Transistors

KVA	Kilo Volt Ampere
LV	Low Voltage
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
OLTC	On Load Tap Changer
P	Real/Active Power
PCC	Point of Common Coupling
PI	Proportional Integrator
PLL	Phase Locked Loop
PWM	Pulse Width Modulation
Q	Reactive Power
SRF	Synchronous Reference Frame
STATCOM	Static Shunt Compensation
UPF	Unity Power Factor
UPFC	Unified Power Flow Controller
UPQC	Unified Power Quality Controller
VAR	Volt Ampere Reactive
VSC	Voltage Source Converter