



**UNIVERSITI PUTRA MALAYSIA**

**SIMULATION OF LINEAR FEEDBACK CONTROL OF D-STATCOM  
FOR VOLTAGE SAG MITIGATION**

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VOLTAGE SAG MITIGATION**

By

**SHAMSUL AIZAM ZULKIFLI**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,  
in Fulfilment of the Requirement for the Degree of Master of Science**

**December 2005**



## DEDICATION

This thesis is dedicated to my parents and the one I love for their constant support, love and guidance during all moments of my life.

Abstract of thesis presented to the Senate of University Putra Malaysia in partial fulfilment of the requirement for the degree of Master of Science.

## **SIMULATION OF LINEAR FEEDBACK CONTROL OF D-STATCOM FOR VOLTAGE SAG MITIGATION**

By

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**December 2006**

**Chairman: Associate Professor Ir. Norman Mariun, Ph.D.**

**Faculty: Engineering**

Recently, the demands of electrical supply by industries and domestic customers have increased tremendously. This is due to the increase of large loads which are sensitive in industries like semiconductor and the building of new housing estates. These have caused power quality problems to both end users by the increasing demand of electricity. The major power quality problems that always occur in power systems are voltage sag, unbalanced voltage and unbalanced current. Various circuit topologies and controls have been developed, aimed at mitigating these power quality problems.

One of the solutions is by using the Custom Power devices. These Custom Power devices respond to poor power quality problems such as voltage sag, unbalanced voltage and unbalanced current by improve the quality of the system. Custom Power family consists of Distribution Static Compensator (D-STATCOM), Dynamic Voltage Restorer (DVR), Solid State Fault Current Limiter (SSFCL), Active Power Filter (APF), and Solid State Transfer Switch (SSTC) are power electronic based



devices. These Custom Power devices will solve power quality problems at the distribution system by injecting voltage or current referring to the amount of reference voltage or current from the distribution system.

In this thesis, D-STATCOM has been used as a device to solve voltage sags and unbalanced fault conditions. From the studies, the conventional D-STATCOM controller that uses Proportional Integration (PI) controller is capable of solving voltage sag but not capable of solving the unbalanced conditions. This is because the conventional PI controller cannot respond to the negative sequence components. The negative sequence component is induced by unbalanced faults which happen in a system. This negative sequence component will block the Gate Turn Off (GTO) Thyristor from firing. From the studies, there are two types of techniques in solving negative sequence components namely negative sequence controller or using DQ transformation of the current.

This thesis explains the application of DQ transformation which changes the 3 phase components to direct and quadrature components and the pole placement controller. Both of these techniques have been considered for designing the new type of controller. This new type of controller is capable of giving order to D-STATCOM to inject the current to solve voltage sag and unbalanced conditions. The simulations of the D-STATCOM and the pole placement controller were implemented in Mathematical Laboratory (MATLAB) program version 6.5 developed by MATHWORKS Inc. The D-STATCOM has been connected to the 11kV distribution system in shunt with



fault components. The results obtained from the simulations clearly showed that the designed D-STATCOM with the new pole placement controller is capable of mitigating voltage sag and unbalanced fault conditions. The developed simulation model will be useful for future power quality studies in distribution systems.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian daripada keperluan untuk ijazah Master Sains

**MEGSIMULASI PEGAWAL SUAP BALIK SELANJAR UNTUK D-STATCOM DIDALAM PENMUSNAHAN LENDUT VOLTAN**

Oleh

**SHAMSUL AIZAM BIN ZULKIFLI**

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Sejak kebelakangan ini, permintaan terhadap bekalan elektrik oleh pihak industri dan pengguna telah meningkat dengan pesat. Ini disebabkan oleh peningkatan terhadap penggunaan beban yang besar dan sensitif oleh sektor industri dan pembinaan taman-taman perumahan yang baru. Pekara ini telah menyebabkan masalah kualiti kuasa kepada kedua-dua pengguna timbul dari permintaan yang meningkat. Masalah kualiti kuasa yang utama dan kerap berlaku dalam sistem kuasa adalah seperti voltan lendut, voltan tidak seimbang dan arus tak seimbang. Pelbagai tatarajah voltan dan litar kawalan telah dibangunkan untuk membentaras masalah kualiti kuasa tersebut.

Salah satu penyelesaiannya adalah dengan penggunaan peranti Kuasa Lngganan. Peranti Kuasa Lngganan dapat menyelesaikan masalah kualiti kuasa yang teruk seperti lendut voltan , voltan tak seimbang dan arus tak seimbang dengan memperbaiki kualitinya di dalam sistem. Antara keluarga peranti kuasa lngganan adalah seperti Pemampas Statik Agihan (D-STATCOM), Pemulih Voltan Dinamik (DVR), Penghad Arus Kerosakan Keadaan Pepejal (SSFCL), Penapis Kuasa Aktif



(APF) dan Suis Pemindah Keadaan Pepejal (SSTS) yang berasaskan peranti elektronik kuasa. Peranti Kuasa Langgan dapat menyelesaikan masalah kualiti kuasa pada sistem pengagihan dengan menyuntik voltan atau arus kedalam sistem berkenaan dan berpandukan kepada voltan dan arus sistem yang dijadikan sebagai rujukan.

Di dalam kajian ini, D-STATCOM telah digunakan untuk menyelesaikan masalah voltan lendut dan keadaan voltan atau arus yang tak seimbang. Lazimnya pengawal D-STATCOM menggunakan kaedah Kamilan Berkadaran (PI) yang berupaya untuk menyelesaikan masalah voltan lendut tetapi tidak berkeupayaan untuk keadaan bekalan voltan yang tak seimbang. Ini disebabkan oleh pengawal PI yang tidak memberi sambutan kepada komponen jujukan negatif. Komponen jujukan negatif dihasilkan oleh bekalan voltan yang tak seimbang yang berlaku dalam sistem pengagihan. Ia menyebabkan halangan kepada GTO untuk beroperasi. Hasil daripada pembacaan, terdapat dua kaedah penyelesaian yang ia menggunakan mekanisme pengawal komponen jujukan negatif atau penggunaan penjelmaan DQ bagi arus.

Didalam kajian ini, penggunaan penjelmaan DQ telah digunakan dimana ia menukarkan fasa 3 sistem kepada komponen wujud dan khayalan dan penggunaan pengawal penetapan kutub. Kedua-dua kaedah ini telah dijadikan asas didalam merekabentuk pengawal sistem yang baru. Pengawal ini berupaya untuk memberi arahan kepada D-STATCOM untuk menyuntik arus atau voltan bagi menyelesaikan masalah voltan lendut dan keadaan bekalan yang tidak stabil. Simulasi terhadap D-



STATCOM dan pengawal penetapan kutub yang baru telah dijalankan dengan menggunakan program MATLAB versi 6.5 yang direka oleh MATHWORKS Inc. D-STATCOM yang telah direkabentuk akan disambungkan secara selari dengan sistem agihan 11kV dengan kerosakan komponen pada sistem pengagihannya. Daripada keputusan yang diperolehi, ia menunjukkan D-STATCOM dan pengawal penetapan kutub yang baru dapat menyelesaikan masalah voltan lendut dan keadaan bekalan yang tidak stabil yang mana dihasilkan oleh kerosakan komponen. Daripada simulasi model ini, ia berharap dapat digunakan pada masa hadapan didalam kajian kualiti kuasa pada sistem pengagihan yang lain.

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## TABLE OF CONTENTS

	Page
<b>DEDICATION</b>	<b>ii</b>
<b>ABSTRACT</b>	<b>iii</b>
<b>ABSTRAK</b>	<b>vi</b>
<b>ACKNOWLEDGEMENTS</b>	<b>ix</b>
<b>APPROVAL SHEET 1</b>	<b>x</b>
<b>APPROVAL SHEET 2</b>	<b>xi</b>
<b>DECLARATION</b>	<b>xii</b>
<b>LIST OF TABLES</b>	<b>xv</b>
<b>LIST OF FIGURES</b>	<b>xvi</b>
<b>LIST OF ABBREVIATION</b>	<b>xx</b>
 <b>CHAPTER</b>	
<b>I INTRODUCTION</b>	
Research Background	1
Proposed Solution	4
Aim and Objectives of Research	7
Scope of Thesis	8
 <b>II LITERATURE REVIEW</b>	
Power Quality Problems in Distribution System	9
Power Quality Standards	10
Voltage Sag	10
Unbalanced Voltage	13
Unbalanced Current	15
D-STATCOM Theory	18
D-STATCOM Configuration and Descriptions	19
Basic Operation of D-STATCOM	21
SPWM Switching Technique	23
Power Electronic Devices	25
Types of D-STATCOM Controller	26
Proportional Integration (PI) Controller	28
Pole Placement Controller	29
Synchronous Frame Voltage Regulator	31
Negative Sequence Detector	32
Linear Quadratic Regulator (LQR) Controller	33
Adaptive Controller in Stationary Reference Frame	34
Dissipativity Based Controller	34
D-STATCOM Issues in Mitigating Voltage Sag, Unbalanced Voltage and Unbalanced Current	35
D-STATCOM in State Space Condition	38
Modeling of the D-STATCOM	38
DQ Transformation and Theory	40
Transformation on Equation of D-STATCOM to	



State Space Using DQ transformation	42
Summary	45
<b>III MATERIAL AND METHODS</b>	
Brief Description on MATLAB	47
The Distribution System for Simulation	48
Proposed D-STATCOM Design	50
Response of D-STATCOM in State Space	52
Linear Feedback Controller	55
Pole Placement Method Theory	55
Conditions in The Pole-Placement Controller Design	57
New Eigenvalues Selection	58
Linear Feedback Controller Design	62
SPWM Switching Technique	69
Selection of Power Electronic	71
DQ to ABC / ABC to DQ Block	72
Balanced and Unbalanced Fault Simulation Model	73
Three Phase Transformer Block Diagram	74
Selection of Power Quality Problems in this Research	75
<b>IV RESULTS AND DISCUSSION</b>	
Verification of Pole Placement Controller using M-File and Simulink Block	76
Analysis and Operation of D-STATCOM to Improve the Voltage	78
Analysis and Operation of D-STATCOM in Balanced Fault Conditions	84
Analysis and Operation of D-STATCOM in Unbalanced Fault System Conditions	94
Single Phase to Ground Fault	94
Double Phase to Ground Fault	98
<b>V CONCLUSION AND FUTURE WORK</b>	
Conclusion	102
Future work	105
REFERENCES	106
APPENDICES	
A	112
B	118
C	124
D	126
E	128
F	130
G	137
LIST OF PUBLICATIONS	134
BIODATA OF THE AUTHOR	135



## LIST OF TABLES

<b>Table</b>		<b>Page</b>
1.1	Electric problems and it causes	2
2.1	Example data of currents in each phase	16
2.2	Source and solutions to unbalanced current	17
2.3	Brief description of each function in D-STATCOM configuration	20
2.4	Performance comparison in each controller	37
4.1	Comparison between programming and Simulink simulation	78

## LIST OF FIGURES

Figure		Page
2.1	Voltage Sag Condition	11
2.2	Example of Unbalanced Voltage Waveform	14
2.3	Schematic Representation of the D-STATCOM	19
2.4	Simplified Diagram for the AC Grid and The D-STATCOM	21
2.5	$V_s > V_i$	21
2.6	$V_s < V_i$	21
2.7	SPWM Waveform	24
2.8	Power Electronic Devices	25
2.9	Block Diagram of PI Controller	28
2.10	Pole Placement Controller	30
2.11	Negative Sequence Detector	32
2.12	Equivalent Circuit of D-STATCOM	39
2.13	Single Line Diagram for D-STATCOM without Capacitor	40
2.14	Synchronously Rotating in DQ Axes	40
3.1	Layout of Distribution System	48
3.2	Proposed D-STATCOM With Linear Feedback Controller	50
3.3	Open Loop Response	54
3.4	Closed Loop Diagram of Linear Feedback Controller	57
3.5	Response When Poles at [-1000 -1000 -15.9]	60
3.6	Response When Poles at [-5000 -5000 -60]	61
3.7	Response When Poles at [-5000 -5000 0]	62
3.8	Proposed Control Block Diagram	63

3.9	Signal Flows Diagram of the D-STATCOM	65
3.10	Signal Flow Diagram of The Feedback	67
3.11	Complete Signal Flow Diagram of The Pole Placement Controller	68
3.12	Complete Block Diagram of Pole Placement Controller Using SIMULINK Blocks	69
3.13	SPWM Technique Block	69
3.14	Firing Pulse for SPWM Technique	70
3.15	Universal Bridge and Properties	71
3.16	ABC to DQ/ DQ to ABC Block	72
3.17	Fault Component Connected to Fault Impedance for Voltage Sag Simulation	73
3.18	Fault Component Connected in Shunt to the Distribution System	74
3.19	Three Phase Transformers Model	75
4.1	Simulation on Linear Feedback Controller	77
4.2	Layout of 11kV Distribution System without D-STATCOM	79
4.3	Without D-STATCOM: a) RMS Value and b) Current at Load	79
4.4	The 11kV Distribution System With D-STATCOM Connected in Shunt	80
4.5	With D-STATCOM: a) RMS Value, b)Voltage at Load and c) Current at Load	82
4.6	a) Injected Current at phase A and b) Current Flows at D-STATCOM	83
4.7	With D-STATCOM : $V_{dc}$ Voltage at Inverter Input	83
4.8	Layout of the 11kV Distribution System in Three Phase Fault	84
4.9	Voltage sag 16%: a) RMS Voltage and b) Current at Load	85
4.10	The 11kV Distribution System with D-STATCOM in Three Phase Fault	86

4.11	Voltage Sag Mitigation of 16% : a) RMS Value, b) Voltage at Load and c) Current at Load	88
4.12	Voltage Sag Mitigation of 16%: Injected Current at D-STATCOM	88
4.13	Voltage Sag Mitigation of 16%: a) Current Flows at transformer and b) Current flows from the D-STATCOM	89
4.14	Voltage sag 10%: a) RMS Voltage and b) Current at load	90
4.15	Voltage Sag Mitigation of 10 %: a) RMS Value, b) Voltage at Load and b) Current in A at load	92
4.16	Voltage Sag Mitigation of 10%: Injected Current at D-STATCOM	92
4.17	Voltage Sag Mitigation of 10%: a) Injected Current at D-STATCOM and b) Current Flows in phase A	93
4.18	With SLG Fault: a) Voltage at Load and b) Current at Load	95
4.19	Mitigation of SLG Fault: a) Voltage at Load and b) Current at Load	96
4.20	Mitigation of SLG Fault: Injected Current during the SLG Fault	97
4.21	The D-STATCOM Profiles inside The Inverter	97
4.22	With DPG Fault: a) Voltage at Load, b) Current at Load	99
4.23	Mitigation of DPG Fault: a) Voltage at Load, b) Current at Load	100
4.24	Mitigation of DPG Fault: Injected Current at Load	100
4.25	The D-STATCOM Profiles inside The Inverter	103
A.1	$i_d$ and $i_q$ reference	112
A.2	Load Current During Sag	113
A.3	Single line to Ground Diagram	114
A.4	Voltage Sag	115
A.5	Voltage Sag	116





A.6	Load Current During SLG	116
A.7	Load Current with D-STATCOM Application	117
A.8	Load Current During DPG	117
A.9	Load Current with D-STATCOM Application	118
B.1	Linear Feedback Control Circuit Using Matlab	119
B.2	Circuit Design in MATLAB Having Three Phase Fault	120
B.3	Circuit Design in MATLAB Having Single Line to Ground Fault	121
B.4	Circuit Design in MATLAB Having Double Line to Ground Fault	122
B.5	Circuit Design in MATLAB for D-STATCOM Application	123
C.1	Equivalent Circuit Diagram in Calculation of Fault Current	124
F.1	Circuit Configurations Using PSCAD	130
F.2	Output of The D-STATCOM in PSCAD	130
F.3	a) The Injected Current of D-STATCOM Using PSCAD b) The Source Current at D-STATCOM Using PSCAD	131



## LIST OF ABBREVIATIONS

A	ampere
AC	Alternating Current
APF	Active Power Filter
ASD	Adjustable Speed Drive
avg	average
CP	Custom Power
dc	Direct Current
dev	deviation
DPG	Double Phase to Ground
D-STATCOM	Distribution Static Compensator
DVR	Dynamic Voltage Restorer
DQ	Direct and Quadrate
FACTS	Flexible AC Transmission System
GTO	Gate Turn Off
HID	High Intensity Discharge
IEEE	The Institute of Electrical and Electronic Engineers
IGBT	Insulated Gate Bipolar Transistor
kV	kilo volt
LQR	Linear Quadratic Regulator
MATLAB	Mathematical Laboratory
MIMO	Multi Input and Multi Output
MOSFET	Metal Oxide Semiconductor Field Effects Transistors
pf	power factor



PI	Proportional Integral
PLC	Programmable Logic Control
PQ	Power Quality
PSB	Power System Blockset
PWM	Pulse Width Modulator
RMS	Root Mean Square
SLG	Single Line to Ground
SISO	Single Input and Single Output
SPWM	Sinusoidal Pulse Width Modulation
SSFCL	Solid State Fault Current Limiter
SSTS	Solid State Transfer Switch
SVC	Static VAR Compensator
THD	Total Harmonic Distortion
VA	Volt Ampere
VAR	Volt Ampere Reactive
VSC	Voltage Sourced Converter

## INTRODUCTION

This chapter describes the introduction to the research work. It will start with some background on the research, followed by selected solutions to the problems, which is D-STATCOM. At the end of this chapter the objectives, scope and importance of the research are explained.

### Research Background

Electric problems always occur regardless of time and place. This may cause an impact to the electric supply thus may affect the manufacturing industry and impede the economic development in a country. The major electric problems that always occur in power systems are the power quality problems that have been discussed by the electrical engineers around the world, since problems have become a major issue due to the rapid development of sophisticated and sensitive equipment in the manufacturing and production industries.

Table 1.1 shows the electric problems that lead to the power quality problems and their causes [1].

Table 1.1: Electric problems and it causes

SYMPTOM	POSSIBLE CAUSE
Supply outage *complete loss of supply	<ul style="list-style-type: none"> <li>• Accidents</li> <li>• Planned maintenance</li> <li>• Line faults</li> </ul>
Overvoltage *long term increase in supply voltage	<ul style="list-style-type: none"> <li>• Light system load</li> <li>• Poor regulation</li> </ul>
Voltage surge *medium term (msec) *increase 10-30% in amplitude	<ul style="list-style-type: none"> <li>• Circuit capacitance</li> <li>• Switching out large loads</li> </ul>
Undervoltage *long term lowering of the supply loading	<ul style="list-style-type: none"> <li>• Heavy network loading</li> <li>• Lack of Var support</li> <li>• Peak demand operation</li> </ul>
Voltage sags *medium term dips in the voltage amplitude	<ul style="list-style-type: none"> <li>• Large load being switched in</li> <li>• Circuit breakers in operation</li> <li>• Large demand on the power supply</li> <li>• Inductive load</li> </ul>
Voltage transients *short duration (ms) impulse voltage spike	<ul style="list-style-type: none"> <li>• Current surges caused by fast switching</li> <li>• Low fault current trip protection</li> <li>• Non linear switching loads e.g rectifying units, variable speed drives, power</li> </ul>

	<p>conditioners and converter units</p> <ul style="list-style-type: none"> <li>• Transmitted noise through the supply system</li> </ul>
<p>Current harmonic</p> <p>*periodic waveforms which deform the supply signal</p>	<ul style="list-style-type: none"> <li>• Increase use of non linear circuit elements</li> <li>• High frequency switches, computers and fluorescent lighting</li> <li>• Negligent users unaware</li> </ul>
<p>Electrical noise</p>	<ul style="list-style-type: none"> <li>• Common disturbance between supply and earth</li> <li>• Series disturbance between supply and neutral</li> </ul>
<p>EMC/EMI effects</p> <p>*susceptibility generation of e-m radiation</p>	<ul style="list-style-type: none"> <li>• Generated by unshielded electrical supply</li> <li>• Interference with radio and tv pictures</li> <li>• Unknown effects regarding human health matters</li> </ul>

Referring to Table 1.1, it shows that certain problems occur due to certain causes. Environmental effects also give an impact to the power quality and its reliability. Major concerns on industrial power quality problems are that they affect the production, due to sensitive equipment in the industries. Where there are power quality problems, equipment may misoperate or machine may possibly shut down. Installations by industries such as Adjustable Speed Drive (ASD), switch mode power supplies and high frequency switching also affect the power quality [1]. High sensitivity equipment such as high speed motor, super computer, microprocessors and medical instruments may also be affected by the power quality problems occurring in the system.