UNIVERSITI PUTRA MALAYSIA

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

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

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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.

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December 2006

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Recently, the demands of electrical supply by industries and domestics 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 quadrate components and the pole placement controller. Both of these techniques have been consider 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 pemintaan 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 membenteras masalah kualiti kuasa tersebut.

Salah satu penyelesaianya adalah dengan penggunaan peranti Kuasa Langganan. Peranti Kuasa Langganan 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 langganan 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 Langganan 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 mengunakan 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 mekanisma 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 pengunaan pengawal penetapan kutub. Kedua-dua kaedah ini telah dijadikan asas didalam merekabentuk pengawal sistem yang baru. Pengawal ini berupaya untuk menberi 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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In the Name of ALLAH, Most Gracious, Most Merciful

I am truly grateful to ALLAH The Almighty, for giving me strength and patience to complete this work. I would also like to thank ALLAH for giving me good health throughout the research until the completion of this thesis.

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I would like to thank my parents and family and to all my friends for their kind support, understanding and encouragement during the completion of my research.

Many thanks also goes to all my colleagues and UPM support staff.

I certify that an Examination Committee met on 15 December 2005. to conduct the final examination of Shamsul Aizam Zulkifli on his Mater of Science thesis entitled "Simulation of Linear Feedback Control of D-STATCOM For Voltage Sag Mitigation" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows

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This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

SHAMSUL AIZAM ZULKIFLI

Date: 17/2/06

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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 Oxside 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	• Accidents • Planned maintenance • Line faults
Overvoltage *long term increase in supply voltage	• Light system load • Poor regulation
Voltage surge *medium term (msec) *increase10-30%in amplitude	• Circuit capacitance • Switching out large loads
Undervoltage *long term lowering of the supply loading	• Heavy network loading • Lack of Var support • Peak demand operation
Voltage sags *medium term dips in the voltage amplitude	• Large load being switched in • Circuit breakers in operation • Large demand on the power supply • Inductive load
Voltage transients *short duration (ms) impulse voltage spike	• Current surges caused by fast switching • Low fault current trip protection • Non linear switching loads e.g rectifying units, variable speed drives, power

	conditioners and converter units • Transmitted noise through the supply system
Current harmonic *periodic waveforms which deform the supply signal	• Increase use of non linear circuit elements • High frequency switches, computers and fluorescent lighting • Negligent users unaware
Electrical noise	• Common disturbance between supply and earth • Series disturbance between supply and neutral
EMC/EMI effects *susceptibility generation of e-m radiation	• Generated by unshielded electrical supply • Interference with radio and tv pictures • Unknown effects regarding human health matters

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.