UNIVERSITI PUTRA MALAYSIA

PERFORMANCE STUDIES OF STATIC SYNCHRONOUS COMPENSATOR AND STATIC SYNCHRONOUS SERIES COMPENSATOR MODES FOR CONVERTIBLE STATIC COMPENSATOR

WAHIDAH BINTI ABD HALIM.

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By

WAHIDAH BINTI ABD HALIM

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

May 2005

Dedicated to
my beloved husband Ishak,
my parents, sisters, and in-laws
for giving a constant source of support and encouragement.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

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Chairman: Associate Professor Norman Mariun, PhD

Faculty: Engineering

This thesis presents an overview of the emerging Flexible AC Transmission System (FACTS) and Convertible Static Compensator (CSC) technologies. CSC, the flexible multifunctional compensator is an innovation from FACTS technology. These technologies are fully utilized the existing transmission system assets, that improve transmission functionality for economical and environmental reasons.

The CSC can occupy as shunt and/or series compensation devices providing various modes. The CSC can operate in 11 different configurations depending on control objectives, for voltage control at bus system as well as power flow control on two existing transmission lines. The CSC can function as a Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC) and Interline Power Flow Controller (IPFC).

This research work focused on STATCOM and SSSC for CSC as shunt and series controller, respectively. The basic operation of the controllers is explained, together with the circuit configurations and general control strategies. The STATCOM and

SSSC are based on a voltage-sourced converter (VSC) which consist of Gate Turn-Off (GTO) Thyristor as the switching devices, are used in this research work to study the performance of the controllers.

An 11-bus system as the test system is used throughout the study to verify the proposed models and its control strategies. The model of the controllers and its control are then validated through PSCAD/EMTDC simulation. Steady-state analysis is done to demonstrate the capability of the controllers designed for improving voltage regulation and power flows in the transmission systems. The result obtained from the simulations clearly showed that the designed STATCOM and SSSC controllers are capable in regulating voltage and increased the transmitting power.

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

KAJIAN PRESTASI MOD PEMAMPAS SEGERAK STATIK DAN PEMAMPAS SIRI SEGERAK STATIK UNTUK PEMAMPAS STATIK BOLEHUBAH

Oleh

WAHIDAH BINTI ABD HALIM

Mei 2005

Pengerusi: **Profesor Madya Norman Mariun, PhD**

Fakulti: **Kejuruteraan**

Tesis ini membentangkan keseluruhan mengenai perkembangan teknologi Sistem Penghantaran Arus Ulang-Alik Fleksibel (SPAUF) dan Pemampas Statik Bolehubah (PSB). PSB, pemampas fleksibel yang mempunyai pelbagai fungsi merupakan satu inovasi daripada teknologi SPAUF. Teknologi ini mengeksploitasikan sepenuhnya aset sistem penghantaran sedia ada, untuk memperbaiki fungsi penghantaran disebabkan faktor ekonomi dan alam sekitar.

PSB boleh digunakan sebagai alat pemampas secara selari dan/atau siri yang membenarkan pelbagai mod. PSB boleh beroperasi dalam 11 konfigurasi berlainan bergantung kepada tujuan kawalan, bagi kawalan voltan pada sistem bas dan juga kawalan aliran kuasa pada dua talian penghantaran sedia ada. PSB boleh berfungsi sebagai Pemampas Segerak Statik (PSS), Pemampas Siri Segerak Statik (PSSS), Gabungan Pengawal Aliran Kuasa (GPAK) dan Pengawal Aliran Kuasa Antara-talian (PAKA).

Kajian penyelidikan ini memfokuskan kepada PSS dan PSSS dalam PSB sebagai pengawal selari dan sesiri. Asas operasi bagi pengawal-pengawal tersebut diterangkan bersama dengan tatarajah litar dan strategi kawalan. PSS dan PSSS berasaskan penukar bekalan voltan yang mengandungi *Gate Turn-Off (GTO) Thyristor* sebagai alat pensuisan, digunakan di dalam kajian ini untuk mengkaji prestasi pengawal-pengawal tersebut.

Sistem 11-bas digunakan sistem kajian pada keseluruhan tesis untuk mengesahkan model yang dicadangkan dan strategi kawalannya. Model pengawal dan strategi kawalannya disahkan melalui simulasi PSCAD/EMTDC. Analisis keadaan mantap dilakukan bagi mendemontrasi keupayaan pengawal-pengawal tersebut yang direka untuk memperbaiki pengaturan voltan dan aliran kuasa dalam sistem penghantaran. Keputusan yang diperolehi daripada simulasi yang dijalankan menunjukkan bahawa pengawal PSS dan PSSS yang direka berkeupayaan mengatur voltan dan meningkatkan kuasa penghantaran.

ACKNOWLEDGEMENTS

I would like to take this opportunity to express my sincerest gratitude to all those who have contributed, directly or indirectly, in accomplishing this project. Special thanks are extended to my project supervisor Assoc. Prof. Ir. Dr. Norman Mariun and co-supervisors Dr. Senan Mahmod Abdullah and Mr. Noor Izzri Abdul Wahab, for their invaluable guidance throughout the completion of this project.

I would like to express my appreciation and thanks to Kolej Universiti Teknikal Kebangsaan Malaysia (KUTKM) for financial support, all the lecturers involved especially Mrs. Aida Fazliana Abd Kadir from KUTKM, and all my friends; also to everyone that has contributed in completing this master project. I will never forget your help and hope that this finished product justifies your assistance.

Last, but not least, I thank my husband Mr. Ishak Suleiman and my family, who were a constant and active source of support throughout the endeavor.

I certify that an Examination Committee met on 16th May 2005 to conduct the final examination of Wahidah binti Abd Halim on her Master of Science thesis entitled "Performance Studies of Static Synchronous Compensator and Static Synchronous Series Compensator Modes for Convertible Static Compensator" 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 and 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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Date : 11 AUG 2005

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 if has not been previously or concurrently submitted for any other degree at UPM or other institutions.

WAHIDAH BINTI ABD HALIM

Date : 18 JULY 2005

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LIST OF ABBREVIATIONS

ac	Alternating Current
CSC	Convertible Static Compensator
dc	Direct Current
EMTP	Electromagnetic Transient Program
FACTS	Flexible AC Transmission System
GTO	Gate Turn Off
HVDC	High Voltage DC Transmission
IEEE	The Institute of Electrical and Electronics Engineers
IPFC	Interline Power Flow Controller
MATLAB	MATrix LABoratory
PI	Proportional Integral
PLC	Power Line Carrier
PLL	Phase Locked Loop
PSCAD/EMTDC	Power System CAD/Electromagnetic Transient DC
PWM	Pulse Width Modulation
R & D	Research and Development
SPWM	Sinusoidal PWM
SSSC	Static Synchronous Series Compensator
STATCOM	Static Synchronous Compensator
UPFC	Unified Power Flow Controller
VSC	Voltage-sourced Converter

CHAPTER 1

INTRODUCTION

This part describes the introduction to the research work. It will explain about the objectives, scope of work, research methodology and organization of the thesis.

1.1 Flexible AC Transmission System

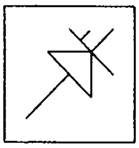
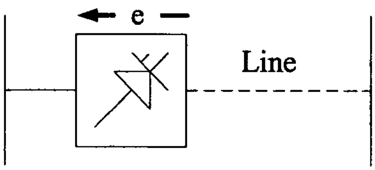
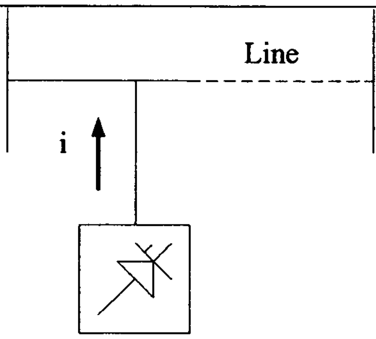
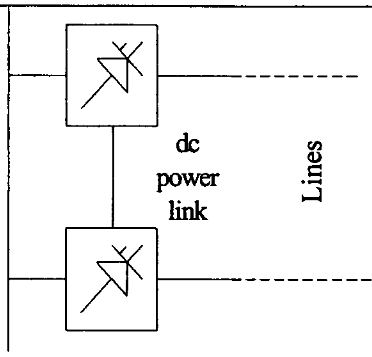
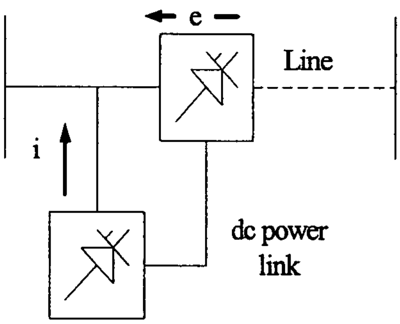
As the growth of complex electrical power network, a new approach called Flexible Alternating Current Transmission System (FACTS) has been implemented to increase the capability of the existing transmission systems. Through this approach, new power electronic controllers with high-current, high-voltage were introduced to control voltage level and power flows on transmission system without decreasing the system stability and security [1, 2].

Hingorani, as the pioneer has put forward FACTS, and aimed to transport the control technology based on thyristor into the ac system [2-4]. FACTS is adopt modern power electronics application at the important location of the transmission system in order to control and adjust one or more of the main parameters of the transmission system, to enhance the value of ac transmission assets [3]. These parameters include voltages, impedance, phase angle, current, active power and reactive power [4]. The application of FACTS proved that the technology brings many benefits to the world and there are many areas for improvement. In the meantime, current researches are focused to increase its effectiveness.

FACTS involves reliable and high-speed power electronic switches instead of mechanically controlled devices. FACTS is also supported by advances in digital protective relays, digital controls, integrated communications and advanced control centers [2,5,6]. The heart of FACTS is thyristors: small, high voltage, semiconductor based devices that can switch electricity at megawatt levels within milliseconds [4,7]. Each controller in FACTS employs thyristor in various configurations to perform different functions.

In general, FACTS controllers can be divided into four categories. The controllers are series controllers, shunt controllers, combined series-series controllers and combined series-shunt controllers [4]. The description for each controller is shown in Table 1.1 [4].

Table 1.1 : Basic type of FACTS controller

No	Symbol	Description
1.		o General symbol for FACTS controller.
2.		o Known as series controller. o The controllers inject voltage in quadrature with the line current o The controllers supply/absorb variable reactive power
3.		o Known as shunt controller. o The controllers inject capacitive or inductive current in quadrature with the line voltage. o The controllers supply/absorb variable reactive power.
4.		o Known as combined series-series controller. o It is a combination of separate series controllers. o Provide independent series reactive compensation for each line. o Transfer real power among the lines via the dc power link.
5.		o Known as combined series-shunt controller. o It is a combination of separate series and shunt controllers. o Provide series and shunt reactive compensation. o Transfer real power between the series and shunt controllers via the dc power link.

FACTS controllers have been successfully implemented around the world. The following situations demonstrate the advantages of FACTS controller when it is put into practice [3,4,8]. Basically, different types of controllers will illustrate different attributes.

1. Control power flow so that it flows on the prescribed transmission routes.
2. Increase the loading capacity of transmission lines to their thermal capabilities.
3. Increase the system security through raising the transient stability limit, limiting short-circuit currents and overloads, managing cascading outages and damping of power systems oscillations.
4. Provide secure tie line connections to neighboring utilities and regions thereby decreasing overall generation reserve requirements on both sides.
5. Provide greater flexibility in siting new generation.
6. Upgrade of lines. FACTS redirects electric flow to improve utilization of existing transmission network.
7. Reduce reactive power flows, thus allowing the lines to transmit more active power.
8. Reduce loop flows.
9. Increase utilization of lowest cost generation. When this cannot be done, it follows that there is not enough cost-effective transmission capacity. Cost-effective enhancement of capacity will therefore allow increased use of lowest cost generation.
10. FACTS improves system stability that enables higher power transfer levels over greater distances.

In reality, any one or two of the above-cited benefits would be a principal justification for the selection of FACTS controller. Table 1.2 gives a checklist of control attributes for various controllers [4].

Table 1.2: Control Attributes for Various Controllers

FACTS Controller	Control Attributes
Static Synchronous Compensator (STATCOM without storage)	Voltage control, VAR compensation, damping oscillations, voltage stability
Static Synchronous Compensator (STATCOM with storage, BESS, SMES, large dc capacitor)	Voltage control, VAR compensation, damping oscillations, voltage stability, transient and dynamic stability, AGC
Static VAR Compensator (SVC, TCR, TCS, TRS)	Voltage control, VAR compensation, damping oscillations, voltage stability, transient and dynamic stability
Thyristor-Controlled Braking Resistor (TCBR)	Damping oscillations, transient and dynamic stability
Static Synchronous Series Compensator (SSSC without storage)	Current control, damping oscillations, voltage stability, transient and dynamic stability, fault current limiting
Static Synchronous Series Compensator (SSSC with storage)	Current control, damping oscillations, voltage stability, transient and dynamic stability
Thyristor-Controlled Series Capacitor (TCSC, TSSC)	Current control, damping oscillations, voltage stability, transient and dynamic stability, fault current limiting
Thyristor-Controlled Series Reactor (TCSR, TSSR)	Current control, damping oscillations, voltage stability, transient and dynamic stability, fault current limiting
Thyristor-Controlled Phase-Shifting Transformer (TCPST or TCPR)	Active power control, damping oscillations, voltage stability, transient and dynamic stability
Unified Power Flow Controller (UPFC)	Active and reactive power control, voltage control, VAR compensation, damping oscillations, voltage stability, transient and dynamic stability, fault current limiting
Thyristor-Controlled Voltage Limiter (TCVL)	Transient and dynamic voltage limit
Thyristor-Controlled Voltage Regulator (TCVR)	Reactive power control, voltage control, damping oscillations, voltage stability, transient and dynamic stability
Interline Power Flow Controller (IPFC)	Reactive power control, voltage control, damping oscillations, voltage stability, transient and dynamic stability

1.2 Research Background

Due to deregulation of electricity markets, the need for new power flow controllers will certainly increase. The FACTS controllers offer the corrections of transmission capability, in order to fully utilize existing transmission system and controlling power flow while maintaining the system reliability [9]. FACTS controllers are based on high-power electronic switching devices called thyristors. The thyristor has indeed revolutionized the high power industry due to higher reliability, low cost, ruggedness and lower maintenance.

FACTS application studies require careful planning and coordination in the specification, design and operating stage of project. Before meaningful results can be expected from the application studies, representative models for the transmission system and relevant FACTS controllers need to be established and verified.

In this research work, it will focus on STATCOM and SSSC for Convertible Static Compensator (CSC) as shunt and series controller, respectively. The CSC is employing a combination of FACTS and conventional technologies. Depending on control needs and objectives of CSC, manipulation of the disconnect switches, circuit switches and circuit breakers provides four primary control modes. The CSC can function as a STATCOM, SSSC, UPFC and IPFC to improve the capability as well as flexibility of power system [10,11].

This research addresses the problem of regulating voltage and controlling power flow in power system using STATCOM and SSSC. These controllers are also known as controlled reactive-power compensation devices. It provides the desired reactive power generation or absorption especially at the point of connection. Evaluation on the performance of these two controllers in steady state operation will be presented.

Since the most important device for FACTS controllers are made of thyristor, Gate Turn-Off Thyristor (GTO) is used as the basic element of the voltage-sourced converter STATCOM and SSSC in this research. The GTO device is chosen because it facilitates current turn-on as well as turn-off by using control signals. Furthermore, high-power GTOs are now available (100 mm, 6 kV or 150 mm, 9 kV) due to rapidly grown technology in this area [12].

In order to study in detail about the STATCOM and SSSC, the 11-bus system has been chosen to be implemented as a test system in PSCAD/EMTDC. This system is introduced in reference [13] and some researchers also used the 11-bus system as their test system, as in reference [14] and [15]. The 11-bus system is a simple two-area system, which is suitable to illustrate the STATCOM and SSSC model. This system is divided into two areas, area 1 and area 2. Area 1 has to supply power to area 2 to overcome huge load at bus 9 [13,14]. The test system consists of several transmission lines of various lengths, which are 10 km, 25 km and 110 km.