UNIVERSITI PUTRA MALAYSIA

POWER QUALITY IMPROVEMENT USING DISTRIBUTION STATIC COMPENSATOR (D-STATCOM) ON 11 kV DISTRIBUTION SYSTEM

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By

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

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Dedicated to my loving family, for their endless support

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in partial fulfillment of the requirement for the degree of Master of Science

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July 2002

Chairman: Associate Professor Norman Mariun, Ph.D., P.Eng.

Faculty: Engineering

The increased awareness in power quality issues has brought tremendous changes and improvements in power electronics devices. Various circuit topologies and control techniques have been developed aimed at mitigating power quality disturbances.

Custom Power concept is one of technological responses to the poor power quality presently surfacing in factories, offices and homes. It is dedicated to maintaining and improving the quality and reliability of distribution level power and to protecting customers against disturbances generated by other users in the network. Custom Power (CP) family includes power electronics based devices such as Distribution Static Compensator (D-STATCOM), Dynamic Voltage Restorer (DVR), Solid State Fault Current Limiter (SSFCL), Active Power Filter (APF) and Solid State Transfer Switch (SSTS). The CP concept is the customer's solution by the utilities sector.

In this research work, the focus will be on one of the CP family, that is, the D-STATCOM. The D-STATCOM, which consists of a thyristor-based voltage source inverter, uses advanced power electronics to provide voltage stabilization, power factor correction, harmonic control and a host of other power quality solutions for both utility and industrial applications.

This thesis describes the configuration, design and control of the 12-pulse D-STATCOM. Its simulation works are done by using PSCAD/EMTDC version 3.0.7 software, developed by Manitoba HVDC Research Center, Canada. The designed D-STATCOM is connected in shunt to an 11 kV test distribution system. Simulations have been carried out to illustrate the effectiveness of the D-STATCOM in mitigating voltage sags and voltage unbalance as well as eliminating harmonics. The results obtained from the simulations clearly showed that the designed D-STATCOM is capable in mitigating voltage sags and voltage unbalance. Furthermore, by connecting passive filters in shunt at the primary side of the step-down transformer reduces the harmonics generated by the D-STATCOM.

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

MENANGANI MASALAH KUALITI KUASA DENGAN MENGGUNAKAN PEMAMPAS STATIK (D-STATCOM) PADA SISTEM AGIHAN 11 kV

Oleh

NOOR IZZRI BIN HJ ABDUL WAHAB

Julai 2002

Pengerusi: Profesor Madya Norman Mariun, Ph.D., P.Eng.

Fakulti: Kejuruteraan

Peningkatan kesedaran dalam isu kualiti kuasa telah membawa banyak perubahan dan evolusi dalam peranti elektronik kuasa. Topologi dan teknik kawalan yang berbagai telah direka untuk menangani masalah kualiti kuasa. Konsep Kuasa Langganan adalah merupakan salah satu teknologi yang boleh menangani masalah kualiti kuasa yang rendah yang sering dialami di kilang-kilang, pejabat, dan kawasan perumahan. Kuasa Langganan adalah bertujuan untuk mengekal dan meningkatkan kualiti kuasa dan untuk melindungi pelanggan daripada gangguan yang dijana oleh pengguna sendiri. Keluarga peranti-peranti Kuasa Langganan adalah termasuk Pemampas Statik (D-STATCOM), Pemulih Voltan Dinamik (DVR), Penghad Arus Kerosakan Pepejal (SSFCL), Penapis Kuasa Aktif (APF) dan Suis Pemindah Keadaan Pepejal (SSTS). Konsep Kuasa Langganan adalah penyelesaian bagi masalah pelanggan daripada sektor pembekal.

Dalam kajian ini, fokus akan diberikan kepada satu daripada peranti Kuasa Langganan iaitu, D-STATCOM. Ianya menggunakan peranti elektronik kuasa untuk menstabilkan voltan, mengurangkan kerlipan, membetulkan faktor kuasa dan kawalan harmonik. Tesis ini menerangkan konfigurasi, reka bentuk dan kawalan D-STATCOM 12-denyut. Simulasi untuk D-STATCOM akan dijalankan dengan menggunakan program PSCAD/EMTDC versi 3.0.7 yang direka oleh Manitoba HVDC Research Center, Kanada. D-STATCOM yang telah direkabentuk akan disambungkan secara selari dengan system agihan 11 kV. Simulasi yang telah dijalankan menggambarkan D-STATCOM efektif dalam menangani masalah voltan lendut dan voltan tidak stabil serta mengurangkan harmonik. Keputusan yang diperolehi secara terang menunjukkan D-STATCOM yang direkabentuk berkebolehan dalam menangani masalah voltan lendut dan voltan tidak stabil. Seterusnya, dengan menyambung penapis pasif pada bahagian primer transformer telah mengurangkan harmonik yang dijana oleh D-STATCOM.

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

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I would like also to thank my parents and family for their kind support, understanding and encouragement during the course of my Master program.

Many thanks are also to all my colleagues, friends and UPM support staff.

I certify that an Examination Committee met on 8th July 2002 to conduct the final examination of Noor Izzri bin Abdul Wahab on his Master of Science thesis entitled "Power Quality Improvement Using Distribution Static Compensator (D-Statcom) on 11 kV Distribution System" 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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The thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as a partial fulfillment 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 equations 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.

(NOOR IZZRI BIN ABDUL WAHAB)

Date: 26th August 2002

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LIST OF ABBREVIATIONS

AC	Alternating Current
APF	Active Power Filter
ASD	Adjustable Speed Drive
avg	average
CP	Custom Power
DC	Direct Current
DVR	Dynamic Voltage Restorer
D-STATCOM	Distribution Static Compensator
FACTS	Flexible AC Transmission System
FFT	Fast Fourier Transform
GTO	Gate Turn Off
HID	High Intensity Discharge
HVDC	High Voltage DC
IEC	International Electrotechnical Commission
IEEE	The Institute of Electrical and Electronics Engineers
LVUR	Line Voltage Unbalance Rate
max	maximum
NEMA	National Equipment Manufacturer's Association
pf	Power Factor
PI	Proportional Integral
PLC	Programmable Logic Controller
PLL	Phase Locked Loop

PQ	Power Quality
PSCAD/EMTDC	Power System CAD/Electromagnetic Transients DC
PVUR	Phase Voltage Unbalance Rate
PWM	Pulse Width Modulator
RMS	Root Mean Square
SCR	Switched Controlled Rectifier
SLG	Single Line to Ground
SPWM	Sinusoidal Pulse Width Modulation
SSFCL	Solid State Fault Current Limiter
SSTS	Solid State Transfer Switch
SVC	Static VAR Compensator
THD	Total Harmonic Distortion
UPS	Uninterruptible Power Supply
VAR	Volt Ampere Reactive
VSD	Variable Speed Drive
VSC	Voltage Sourced Converter
VUF	Voltage Unbalance Factor

CHAPTER 1

INTRODUCTION

This section describes introduction to the research work. It will start with some background on the research work. Then, the solution of the problems will be discussed through which D-STATCOM will be selected. Next, the objectives, scope and importance of the research are explained.

1.1 Research Background

Electricity supply plays an important role in the economic development and technology advancement throughout the world. The quality and reliability of power supplies relates closely to the economic growth of a country. However, power quality disturbances such as sags, swells, flicker, harmonics, voltage imbalance etc., create a lot of problems in achieving a reliable and quality power supply. These power quality problems are very common in the electrical distribution systems [1].

Power quality concerns the factors affecting, and the standard of, the received electrical power supply [2].

increasingly concerned about the quality of electric power. There are four major reasons for the growing concern which are described as follows [3].

1) Load equipment is more sensitive to power quality variations than equipment applied in the past. Many new load devices contain microprocessor-based controls and power electronic devices that are sensitive to many types of disturbances.

2) The increasing emphasis on overall power system efficiency has resulted in a continued growth in the application of devices such as high-efficiency,

speed motor drives and shunt capacitors for power factor correction to reduce losses. This

concerned about the future impact on system capabilities.

3) Increased awareness of power quality issues by the end users. Utility customers are becoming better informed about power quality problems.

4) Many things are now interconnected in a network. Integrated processes means that the failure of any component has much more economic consequences.

From the four major reasons stated above it can be deduced that the responsibilities and challenges of the utility sector are great in providing quality,

supply to the end users such as factories,

quality is ultimately a customer-driven issue and the customer's point of reference takes precedence.

New demands,

becoming increasingly difficult to provide a consistent reliable

using existing present day technology [2]. Traditionally,

the approach has been to desensitize critical loads while 'cleaning up'

installing uninterruptible power supplies,

surge suppressor and standby power generators [4]. However,

been accomplished,

improvement. In these cases,

Building a new dedicated circuits or substations is difficult for utilities, and may not even provide the needed degree of improvement.

1.2 Proposed Solution

The increased awareness in power quality issues has brought tremendous changes and improvements in power electronics devices. Different circuit topologies, control techniques and strategies are created aimed at mitigating power quality problems.

The Custom Power concept is one of technological responses to the poor power quality presently surfacing in factories, offices and homes [1]. Custom Power is dedicated to maintaining and improving the quality and reliability of distribution level power received and to protect customers against disturbances generated by other users on the network. This is to offer a 'Total Solution ' package to the customer [2]. The Custom Power concept is to provide customer's solution by the utilities sector [1]. Utility participation occurs at the distribution substation and/or at the front end of the power supply.

There is also Flexible AC Transmission System (FACTS) devices that are concerned with improving power in the transmission system. The distinction between Flexible AC Transmission System (FACTS) and Custom Power is shown in Figure 1.1 [1]. The Custom Power offers the customer no power interruptions, tight voltage regulation, low harmonic voltage and acceptance of fluctuating and non-linear loads without affecting the terminal voltage [4]. The Custom Power family includes Dynamic Voltage Restorer

(DVR), Distribution Static Compensator (D-STATCOM), Solid State Fault Current Limiter (SSFCL), Solid State Transfer Switch (SSTS) and Active Power Filter (APF).

Although the Custom Power concept is very interesting and acceptable, the turning point will be the cost. This common question will arise, i.e. How much money has to be invested in order to install Custom Power products in a distribution system? The route to improving power quality can be considered as a three stage process, with costs almost exponentially increasing at each step [5] as shown in Figure 1.2.

The steps start with applying good electrical sense to desensitize critical loads such alternate supply paths and clear earthing paths, followed by the replacement of weak parts of the infrastructure. If these measures fail to yield, the solutions will be costly. Custom Power is intended to provide wide area solution that represents an economic alternative to the last step of the power quality improving process [5].

It can be anticipated that the cost of components will also reduce in time when they are produced in bulk, providing cost benefits for large production. Comparing with the traditional methods of improving power quality, the Custom Power products would negate the need for the utility to install additional feeders or substation or the customer to install power conditioners at the load level. Not only would the Custom Power systems cost less but they would also

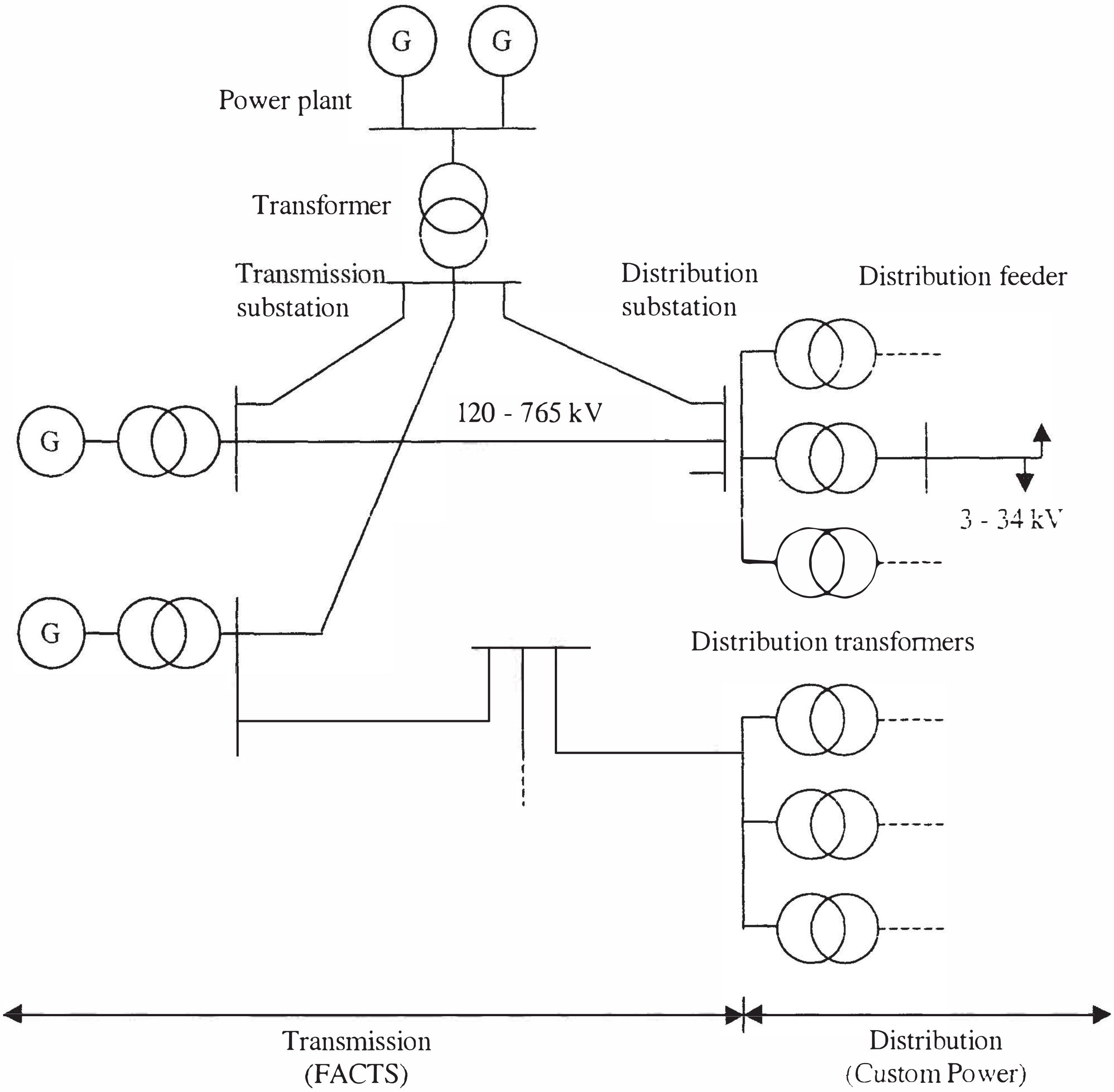

Figure 1.1: Distinction Between FACTS and Custom Power Applications in a Power System

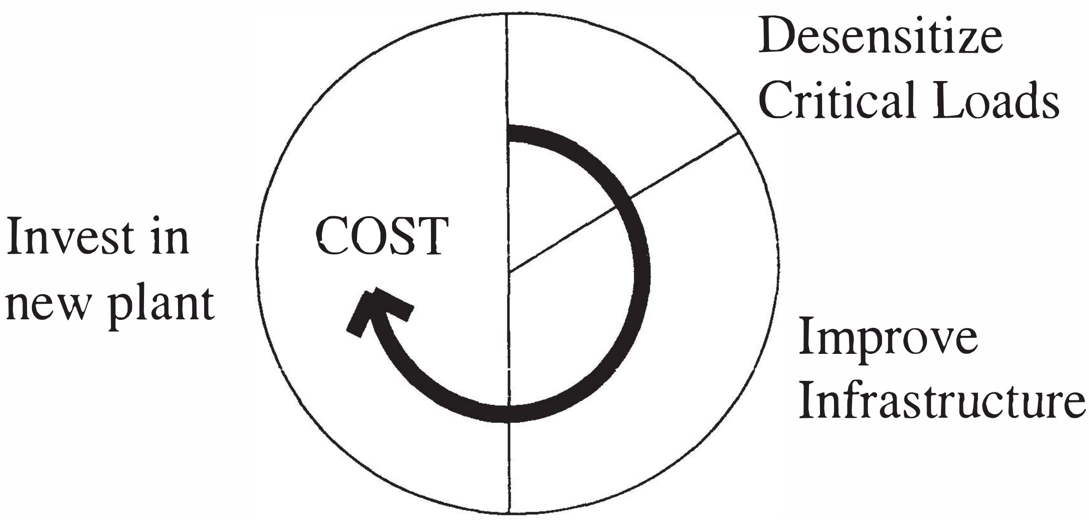

Figure 1.2: Implementing Power Quality Solutions - The 'Sag' Pie

In this research work however, the focus will be on one of the Custom Power devices, that is the D-STATCOM. The device consists of a thyristor-based voltage source inverter, uses advanced power electronics to provide voltage stabilization, flicker suppression, power factor correction, harmonic control and a host of other power quality solutions for both utility and industrial applications.

1.3 Objectives of Research

The objective of this research work is to develop a simulation model of a 12-pulse D-STATCOM on an 11 kV distribution system using the PSCAD/EMTDC program. Emphasis is also given on the design of the control strategies for the D-STATCOM.

The designed D-STATCOM will be connected in shunt to study a system, that is 11 kV distribution system for mitigating voltage sags, harmonics and unbalanced voltage