UNIVERSITI PUTRA MALAYSIA

DESIGN AND SIMULATION OF STATIC VAR COMPENSATOR FOR VOLTAGE SAGS MITIGATION

ARSHAD BIN MD YUSOF

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

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Dedicated to:

My lovely wife Fauziah Zakaria and our children; Ahmad Redzuan, Ahmad Rasyadan, Nur Fadhilah, Nur Farahhin, Nur Farhanah, and Nur Faranadia.

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

DESIGN AND SIMULATION OF STATIC VAR COMPENSATOR FOR VOLTAGE SAGS MITIGATION

By

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October 2002

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Modern power networks are loaded more heavily than ever before to fully utilize the existing transmission facilities while power quality has become an important issue in power system, this is due to the fact that the usage of power electronic equipment and electronic-based loads, which are sensitive to power quality has increased, and thus normal operations in industrial and commercial environments are becoming more vulnerable to power quality problems. One of the problems associated with power quality is voltage sag.

Voltage sag is a major power quality problem. It occurs because most voltage sags are due to short circuit on transmission and distribution lines. High technology industries are highly sensitive to voltage sags. A small voltage sag for several cycle, (short duration) is sufficient to interrupt the operation of the facility resulting in costly downtime.

Traditional voltage regulating devices such as electromechanical transformer taps and shunt capacitor have been used extensively at the transmission and distribution. However, they are too slow to response to correct voltage sags. This problem can be overcome by replacing them with power-electronics based devices known as Flexible Alternating Currents Transmission System (FACTS). FACTS devices can provide a real-time control of transmission line impedance, voltage magnitude and phase angle. With advancement of high power electronics, fast response of FACTS device is now available. Through proper coordination, they can be utilized to control system power flow, increase power transfer capabilities, improve system transient stability, and damp power system oscillations.

Static Var Compensator, SVC is a shunt connected FACTS device having capability of supplying reactive power and thus could protect the system from the potential threats of voltage sags.

The objective of this research is to investigate and design SVC for voltage sags mitigation on a small test power system. This work has indicated SVC has the potential to mitigate voltage sag if properly designed and located.

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

MEREKABENTUK DAN SIMULASI PEMAMPAS KUASA REAKTIF BAGI MERENGANKAN VOLTAN LENDUT

Oleh

ARSHAD BIN MD YUSOF

Oktober 2002

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Rangkaian sistem kuasa moden berbeban tinggi adalah untuk menggunakan sepenuhnya kemudahan-kemudahan pada talian penghantaran manakala kualiti kuasa menjadi amat penting kepada sistem kuasa, ini disebabkan penggunaan peralatan-perlalatan elektronik kuasa dan beban-beban berasaskan elektronik yang sensitif kepada kualiti kuasa telah meningkat, maka itu pengendalian normal dalam industri dan persekitaran perdagangan menjadi lebih mudah menyebabkan permasalahan kualiti kuasa. Satu daripada gabungan permasalahan kualiti kuasa ialah voltan lendut.

Voltan lendut ialah pemasalahan besar kualiti kuasa. Ia berlaku disebabkan kebanyakan voltan lendut berpunca dari litar pintas pada talian penghantaran dan pengagihan. Industri berteknologi tinggi lebih sensitif kepada voltan lendut.

Walaupun sedikit voltan lendut berlaku pada tempoh yang amat singkat, sudah memadai mengganggu operasi sistem dan melibatkan kerugian yang besar.

Peranti pengaturan voltan tradisional seperti sadap transformer elektromekanikal dan kapasitor-pirau telah digunakan pada sistem penghantaran dan pengagihan.Walaubagaimanapun, mereka amat perlahan bertindak untuk membaiki voltan lendut. Pemasalahan ini boleh di atasi dengan menukarkan mereka dengan peranti berasaskan elektronik kuasa yang dikenali sebagai 'Flexible Alternating Currents Transmission System ' atau FACTS. Peranti FACTS boleh mengawal masa-benar bagi impedan talian penghantaran, magnitud voltan dan sudut fasa. Dengan kemajuan bidang elektronik kuasa, peranti bertindak laju seperti FACTS telah pun di perkenalkan. Melalui koordinasi yang betul, mereka boleh digunakan untuk mengawal aliran kuasa sistem, menambahkan kemampuan pindahan kuasa, membaiki kestabilan ubahtika dan membaiki susutan ayunan sistem kuasa.

Pemampas Kuasa Reaktif , SVC ialah peranti FACTS bersambung pirau yang mempunyai kemampuan membekalkan kuasa reaktif, maka itu berkemungkinan mampu melindungi sistem daripada voltan lendut.

Objektif penyelidikan ini adalah untuk menyelidiki dan merekabentuk SVC bagi tujuan merengankan voltan lendut pada system kuasa ujian yang kecil. Hasil kerja penyelidikan ini telah menunjukan bahawa SVC mempunyai potensi untuk merengankan voltan lendut sekiranya direkabentuk dengan sempurna dan diletakan pada lokasi yang betul.

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Finally, thank you goes to everybody who directly or undirectly contributed to successfully accomplish this thesis.

I certify that an Examination Committee met on 15th October 2002 to conduct the final examination of Arshad Md Yusof on his Master of Science thesis entitled "Design and Simulation of Static Var Compensator for Voltage Sags 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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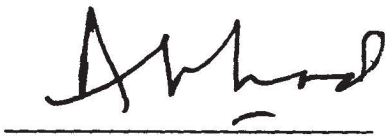
DECLARATION

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.



ARSHAD BIN MD YUSOF

Date: 3 Dec. 2002

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LIST OF ABBREVIATIONS

ASC	Advanced Series VAR Compensator
ASD	Adjustable Speed Drives
ASVC	Advanced Static VAR Compensator
AVR	Automatic Voltage Regulator
BESS	Battery Energy Storage System
CBEMA	Computer Business Equipments Manufacturer Association
DLF	Double-Line Fault
DLGF	Double-Line-To-Ground Fault
DPLL	Digital Phase-Locked Loop
DVR	Dynamic Voltage Restorer
DySC	Dynamic Sag Corrector
FACTS	Flexible AC Transmission System
FC	Fixed Capacitor
FCL	Fault Current Limiter
GTO	Gate Turn Off
HVDC	High Voltage Direct Current
IGBT	Insulated Gate Bipolar Transistor
IPC	Interphase Power Controller
IPFC	Interline Power Flow Controller
PCC	Point of Common Coupling
P-D	Proportional-Derivative
P-I	Proportional-Integral

PLC	Programmable Logic Controller
PWM	Pulse Width Modulator
RMS	Root Mean Square
SCADA	Supervisory Control And Data Acquisition
SCR	Silicon-Controlled Rectifier
SIPCON-S	Siemens Power Conditioner- Series
SLGF	Single-Line-To-Ground Fault
SMES	Super conducting Magnetic Energy Storage
SSG	Static Synchronous Generator
SSSC	Static Synchronous Series Compensator
SSVR	Static Series Voltage Regulator
STATCOM	Static Synchronous Compensator
SVC	Static VAR Compensator
TCPST	Thyristor-Controlled Phase Shifting Transformer
TCR	Thyristor-Controlled Reactor
TCSC	Thyristor-Controlled Series Capacitor
TCSR	Thyristor-Controlled Series Reactor
TSC	Thyristor-Switched Capacitor
TSSC	Thyristor-Switched Series Capacitor
TSSR	Thyristor-Switched Series Reactor
UPFC	Unified Power Flow Controller
VCR	Video Cassette Recorder
VSA	Voltage Sags Aggressiveness
VSI	Voltage Source Inverter

CHAPTER 1

INTRODUCTION

This project is very closely related to the power quality problems. The ultimate reason why the author is interested in power quality is it economic value. There are economic impacts on utilities, customers, and the suppliers of equipment.

Power quality problems can be defined as; any power problem manifested in voltage, current, or frequency deviations that result in failure or misoperation of customer equipment. Alternating current power system are designed to operate at sinusoidal voltage of a given frequency and magnitude [1]. Although the voltage can be controlled perfectly, there is always a close relationship between voltages and current, the current passing through the impedance of the system can cause a variety of disturbances to the voltage. There are cases representing voltage disturbances due to the current in the system such as:

a. large short-circuit current resulting in voltage sags or total collapse of voltage,
b. high impulse voltage due to the current from lightning current passing through the power system, and
c. harmonics current from non-linear loads causes voltage waveforms distortions.

Power quality phenomenon or power quality disturbance can be divided into two types, which need to be treated in a different way. They are [2]:

a. characteristic of voltage or current is never exactly equal to its nominal or desired value. The small deviations from the nominal or desired value are called "voltage variation" or "current variation". A property of any variation is that it has a value at any moment in time, and

b. occasionally the voltage or current deviates significantly from its normal or ideal wave shape. These sudden deviations are called "events" .

Voltage sags is one of the "voltage variations" as mentioned above and is a major power quality problems.

A voltage sag is a momentary decrease in the root mean square (rms) voltage magnitude, usually caused by a remote fault somewhere on the power system. It is important to understand the difference between an interruption and voltage sag.

An interruption occurs when a recloser actually interrupts the circuit serving a particular customer. This will normally only occur if there is a fault on that circuit. Voltage sags occur during the period of a fault for faults over a wide part of the power system [3]. Normally, the magnitude of voltage sags is in the range of 0.1 to 0.9 per units of its normal voltage, and the duration is between 0.01 second to 1.0 second.

In this project, the emphasis is given to the occurrences of voltage sags on the power system, and its mitigation.

1.1 Problem Statements

According to Policarpo and Abreau [4], voltage sags are the main cause of several failure on electrical equipments and industrial processes interruptions. Voltage sags may cause malfunction to some electrical equipments such as programmable logic controller (PLC), adjustable speed drives (ASD), motor speed control, and commutation failure in silicon controlled rectifier, SCR [4]. Table 1.1, presents the probability of failure to some electrical equipments due to voltage sags occurrences.

Table 1.1: Probability of Failure [4].

Electric Equipment	Failure incident Per year	Percent of Failure probability Per year
Video Cassette Recorder, VCR	1.84	3%
Microwave oven	0.44	1%
Digital clock	0.44	1%
Programmable Logic Controller (PLC)	3.0 – 29.59	4 – 41%
Adjustable Speed Drives (ASD)	1.67 – 37.42	2 – 52%
Relay	0.33 – 1.84	0.5 – 3%
Microprocessor	0.33 – 1.84	0.5 – 3%
Contactor	0.66 – 1.84	1.0 – 3%

Another example to show the impact of voltage sags is in a large cheese factory where a study had been carried out. Figure 1.1, shows the result of the system voltage sags

study at the cheese factory. The study predicts that 50 voltage sags per year at the cheese factory yield less than 70% of normal voltage for 2.5 cycles or greater.

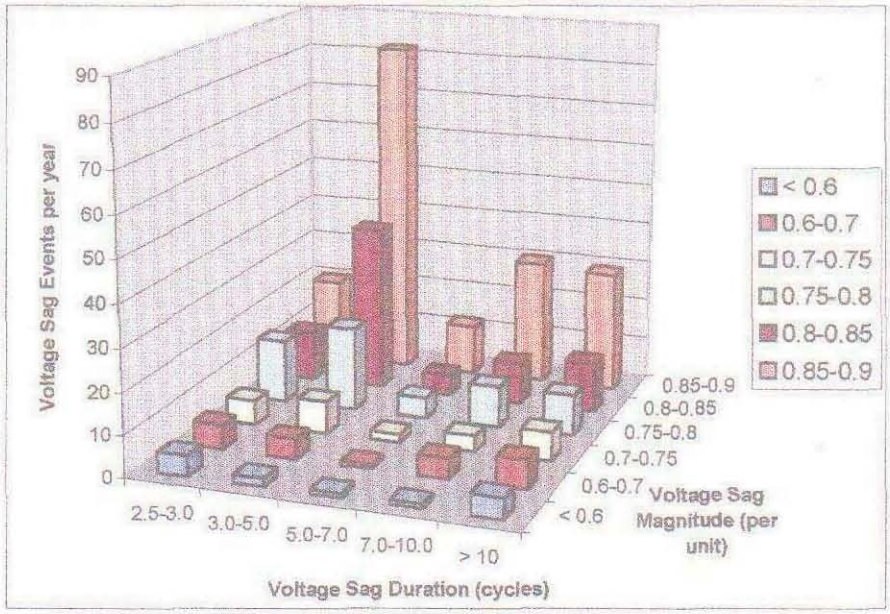

Figure 1.1: System voltage sags study result [5].

Voltage sag is one of the major components of power quality of an electric power system. In Malaysia, transmission system's disturbance becomes a dominant source. Voltage sag affects every customer, however, industrial customers are the most affected [5].

1.2 Proposed Solution

Voltage sags are usually associated with system faults but are also caused by energization of the heavy loads or starting of large motors. A voltage sag is a

momentary decrease in the rms voltage magnitude. The duration of voltage sag is normally from 0.5 cycles to 60 cycles and decreases between 0.1 p.u. upto 0.9 p.u. of normal voltage. The voltage sags can easily interrupt sensitive equipments. Several methods can be performed either via the utility or customer to reduce the number and severity of voltage sags and to reduce the sensitivity of equipments to voltage sags.

There are many ways to mitigate voltage sag problem in view of minimizing the effects on customer's production. The simplest way is to increase the normal steady state voltage to allowable highest limit. High steady state voltage can be achieved by adjusting the set point of automatic voltage regulator (AVR) of power transformer. The other method is by installing capacitor bank in blocks, which equipped with automatic control to maintain the normal voltage at desired level [5].

Faults prevention activities include tree trimming, adding line arrester, insulator washing, and adding animal guards. The other option for this method is modify fault-clearing practices. The practices may include adding line recloser, eliminating fast tripping, adding loop schemes and modifying feeder design. For the purpose of this project, a modifying feeder design is more relevant.

There are several points taken into consideration to design a system to enable voltage sags reduction on a transmission line;

a. voltage compensator which is able to compensate voltage at required magnitude,

b. compensation voltage should be in ac, similar frequency and can be synchronized with the system voltage, and

c. quick response time to any voltage sags occurrence.

As a conclusion, it is observed that the FACTS technology has the capability to overcome the problem. FACTS Controller with appropriate parameters is usually the common device used to overcome power quality problem due to voltage sags.

1.3 Features of Voltage Sags

Power quality is an increasing concern common to electrical energy utilities and customers. In context of power quality, the voltage sags are emphasized, so much so that many bibliographies refer to them as the main cause of several failures on electric equipments and industrial processes interruptions [3].

According to Policarpo and Abreau [4], an analysis had been carried out to the occurrences of voltage sags. This analysis presents the occurrences in term of magnitude and duration. Figure 1.2, shows the number of voltage sags occurrences in percent against the system voltage in per unit (p.u.). It can be seen, voltage sags of range 0 to 0.1 p.u. experiences 30% of occurrences, but the voltage sags more than 50% is very few, about 1% of occurrences. Figure 1.3, shows the number of voltage sags occurrences in percent against the duration in cycles. It can be seen that, the duration at 3 cycles and below, the number of voltage sags occurrences are less than 10%, but the duration more than 20 cycles, experiences about 10% occurrences. This