SIMULATION OF POWER IMPROVEMENT (STATCOM) USING PSCAD/EMTDC

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22ND APRIL 2009

"I hereby declare that I have read this project report and in my opinion this project report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Electrical Engineering (Power industry)"

Signature : ....

Name of supervisor : Puan Elia Erwani Bt. Hassan

Date : 22ND April 2009

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This report is submitted in partial fulfillment of requirements for the degrees of Bachelor of Electrical Engineering (Power industry)

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"I hereby declare that this project report is the result of my own work and all sources of references have been clearly acknowledged"

Signature : ....

Name : Muhammad Fikri Bin Mohamed Puaid

Date : 22ND April 2009

To my beloved parents,

En. Mohamed Puaid Bin Ahmad and Pn. Fatimah Binti Ahmad

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ABSTRACT

A power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure of end user equipments. Utility distribution networks, sensitive industrial loads and critical commercial operations suffer from various types of outages and service interruptions which can cost significant financial losses. This paper describes the technique of correcting the overvoltage and voltage drops in the distribution system. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications. A PWM based control scheme has been proposed that only requires voltage measurements and no reactive power measurements are required. The operation of the proposed control method is presented for STATCOM. The STATCOM, which consists of a GTO based voltage source inverter, uses advanced power electronics to provide voltage stabilization, power factor correction, and other power quality solutions for both utility and industrial applications. In this paper however, the concern will be regulation of overvoltage and voltage drops on the 11kV distribution system and proves the existence of harmonics generated by the device. STATCOM simulations are done by using the PSCAD/EMTDC version 4.1.1 electromagnetic transient program.

ABSTRAK

Masalah kualiti kuasa dapat diterjemahkan dalam bentuk voltan, arus, atau frekuensi yang tidak mengikut piawai yang menyebabkan kegagalan pada peralatan pengguna. Sistem pengagihan utiliti, peralatan industri yang sensitif dan operasi komersial kritikal yang lain terjejas teruk yang mengakibatkan kerugian besar kesan daripada masalah ini. Kertas kerja ini membentangkan teknik memulihkan keadaan lebihan dan kejatuhan voltan dalam system pengagihan. Pada masa kini, pelbagai jenis alat kawalan yang fleksibel yang menggunakan applikasi elektronik kuasa dalam pengendalian sistem kuasa. Skim kawalan PWM telah dicanang dimana alat kawalan ini hanya menggunakan ukuran voltan dan tidak menggunakan ukuran lebihan VAR . Sistem kawalan ini direka untuk mengendalikan sistem STATCOM. STATCOM terdiri daripada GTO yang menggunakan prinsip songsangan voltan mempunyai keupayaan sebagai penstabil voltan, pembetulan faktor kuasa, dan penyelesaian kualiti kuasa bagi utiliti dan penggunaan industri. Walaubagaimanapun, dalam kertas kerja ini, hanya membentangkan kaedah pemulihan lebihan dan kejatuhan voltan dalam sistem pengagihan 11kV dan untuk membuktikan kehadiran arus harmonik yang terhasil dengan penggunaan sistem STATCOM. Simulasi STATCOM dijalankan menggunakan perisisan PSCAD/EMTDC version 4.1.1 electromagnetic transient.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The last decade has seen a marked increase on the deployment of end-user equipment that is highly sensitive to poor quality control electricity supply. Several large industrial users are reported to have experienced large financial losses as a result of low quality of electricity supply. Many efforts have been made to remedy the situation, where solutions based on the use of the latest power electronic technology figure significantly. Indeed, custom power technology, the low-voltage counterpart of the more widely known flexible ac transmission system (FACTS) technology, expected at high-voltage power transmission applications, has emerged as a convincing solution to solve many of the problems relating to continuity of supply at the end-user level.

At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are shows potential for custom power applications. Among these, the distribution static compensator (STATCOM) that based on the VSC principle, have received attention. PSCAD/EMTDC has been used in this paper to perform the modeling and analysis of such controllers for a wide range of operating conditions. PSCAD/EMTDC's highly developed graphical interface has proved instrumental in implementing the graphics-based PWM control reported in this paper for the STATCOM. It relies only on voltage measurements for its operation, i.e., it does not require reactive power measurements.

1.2 Background of the Static compensator (STATCOM)

STATCOM has played an important role in power industry since 1980s. Kansai Electric Power Co., Inc.(KEPCO) and Mitsubishi Motors, Inc. developed the first STATCOM in the world, a 20Mvar STATCOM using force-commutated thyristor inverters, and put it into operation in January 1980 [1]. In October 1986, a 1 MVAR STATCOM was put into operation, which was developed by EPRI and Westinghouse Electric Company, and was the first static compensator employing high-power GTO inverters [2]. In 1991, a 80 MVAR STATCOM developed by KEPCO and Mitsubishi Motors was installed at Inuyama Switching Station to improve the stability of a 154kV system [3]. Tennessee valley authority (TVA), together with EPRI and Westinghouse, installed a 100Mvar STATCOM [4] at Sullivan 500kV Transformer Substation in October 1996 and it kept in good operation since then. A lot of companies have developed STATCOM technology since it introduced in year 80s till nowadays. The technologies keep developing all the time in order to satisfy the unpredictable patterns of load of the world industry.

1.3 Overview

The STATCOM has a characteristic similar to the synchronous condenser, but as an electronic device it has no inertia and is superior to the synchronous condenser in several ways, such as better dynamics, a lower investment cost and lower operating and maintenance costs. A STATCOM is build with GTO with turn-off capability like thryistor or today IGCT or with more IGBTs. The structure and operational characteristic is shown in Figure 1. The advantage of a STATCOM is that the reactive power provision is independent from the actual voltage on the connection point [5]. This means, that even during most severe contingencies, the STATCOM keeps its full capability.

In the distributed energy sector the usage of voltage source converters for grid interconnection is common practice today. The next step in STATCOM development is the combination with energy storages on the DC-side. The performance for power quality and balanced network operation can be improved much more with the combination of active and reactive power.

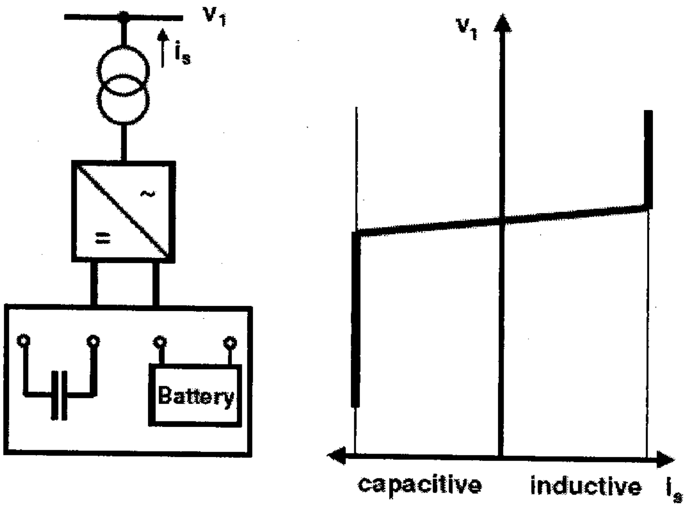

Figure 1.1: Operation Characteristic.

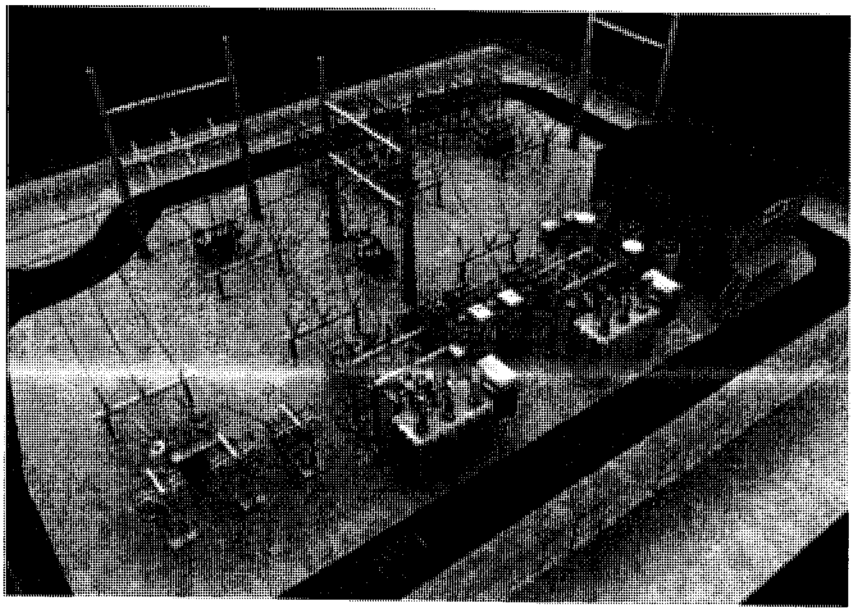

Figure 1.2: Substation with a STATCOM (Source: ABB)

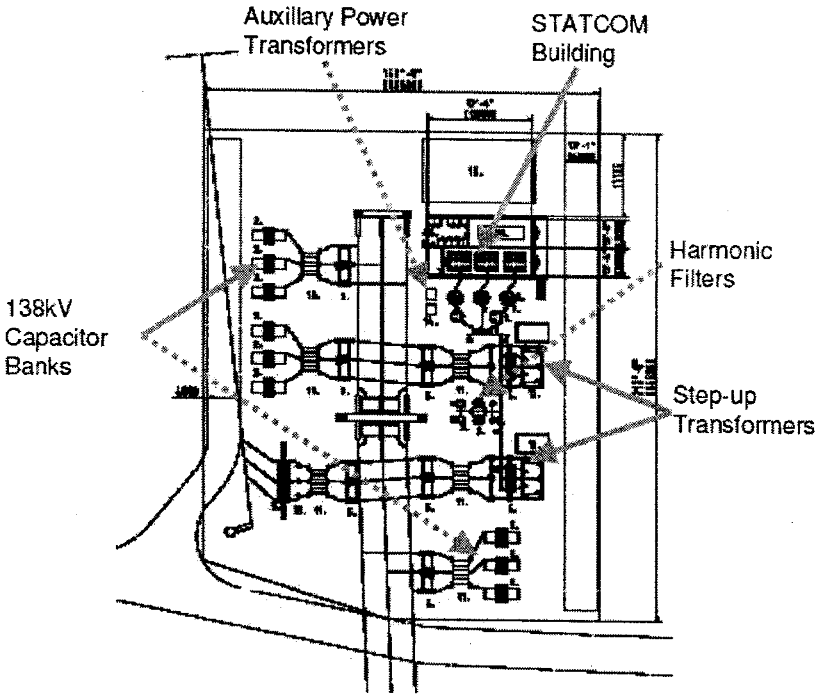

Figure 1.3: Typical substation layout with STATCOM (Source: ABB)

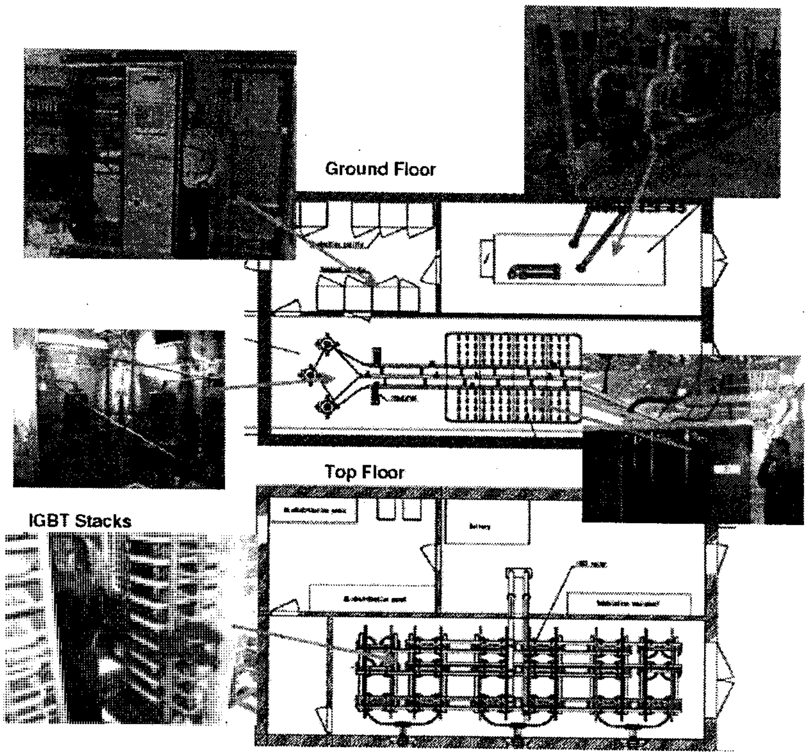

Figure 1.4: Typical layout of a STATCOM-building (Source: ABB)

1.4 Problem Statement

The transmission system nowadays becoming more heavily loaded and are being operated in ways not originally envisioned. The industrial sector consumes power in unpredictable time interval cause the distribution system have a difficulty to handle the situation. On the other hand, such phenomena now appear more frequently in the power system because of systematic growth in the number and power of nonlinear and frequently time-variable loads. Many efforts have been made to remedy the situation with solutions based on the use of the latest power electronic technology. At present, a wide range of very flexible controllers are emerging for power system applications. Among these, the distribution Static Compensator (STATCOM) has been used in this paper to perform the modeling and analysis of such controllers for a wide range of operating conditions

1.5 Thesis Objectives

The objective of this project is to shows the capability of one of FACTS devices (STATCOM) to overcome the disturbances of the power system that leads to the power improvement in the distribution network. The simulation is done using the PSCAD/EMTDC software.

The PWM technique is reliable as the switching control of power electronics switch in power delivery applications. The second objectives are to develop the distribution system network that consisted with STATCOM that control by the PWM controller, and to gain the better understanding of PWM concept.

The third objective is to analyze the voltage improvement at the load point when the STATCOM is installed to the system. Analysis will compare the voltage level of the system with and without STATCOM at the time interval of disturbances.

1.6 Thesis Scope

The simulation of the power improvement for the distribution consisted with STATCOM is using the PSCAD/EMTDC version 4.1.1 software. The scope of the thesis is regarding the operation of the STATCOM and the control method. The disturbances of system are referring to voltage drops and the overvoltage of the system. The others type of disturbance such as arc and others is outside the thesis scope.

The scope of the power improvement is regarding the voltage level at the load point of the distribution network system. The simulation will perform the voltage improvement by the distribution system with and without STATCOM. The analysis will compare the regulation of voltage drops and overvoltage for the system with and without STATCOM. The voltage level is measured by the RMS per unit voltmeter that available in the features of the software.

The method of the STATCOM controller is using the PWM technique. PI controller will developed as the combination of the PWM controller to control the GTOs. The project will use GTOs as the power electronic switch as the valves of the reactive power injection. The term of reactive power is referring to inductive and capacitive reactive power.

CHAPTER 2

LITERATURE REVIEW

2.1 Operation Principles of STATCOM

A STATCOM is usually used to control transmission voltage by reactive power shunt compensation. Typically, a STATCOM consists of a coupling transformer, an inverter and a DC capacitor. For such an arrangement, in ideal steady state analysis, it can be assumed that the active power exchange between the AC system and the STATCOM can be neglected, and only the reactive power can be exchanged between them. A STATCOM can provide fast capacitive and inductive compensation and is able to control its output current independently of the AC system voltage (in contrast of SVC), which can supply only diminishing output current with decreasing system voltage) [8]. This feature of the compensator makes it highly effective in improving the transient stability. Therefore, STATCOM systems with GTO thrystors have been initially used for improving flexibility and reliability of energy transmission in FACTS applications [4-7].

Based on the operating principle of the STATCOM, the equivalent circuit can be derived, which is given in Fig. 2.1. In the derivation, it is assumed that harmonics generated by the STATCOM are neglected the system as well as the STATCOM are three phase balanced. Then the STATCOM can be equivalently represented by a controllable fundamental frequency positive sequence voltage source V_{sh}. In principle, the STATCOM output voltage can be regulated such that the reactive power of the STATCOM can be changed.

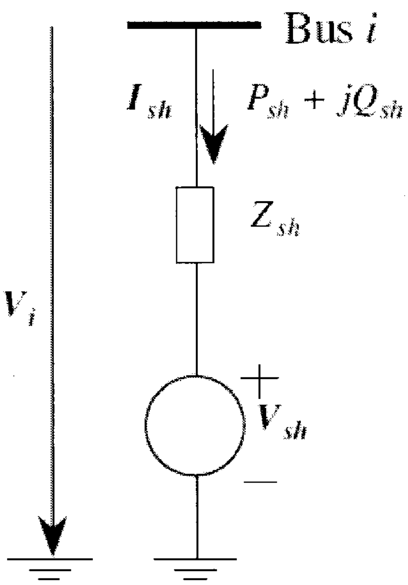

Figure 2.1: Fundamental STATCOM

According to the equivalent circuit of the STATCOM shown in Fig. 2.1, suppose $V_{sh} = V_{sh} \angle\theta_{sh}$, $Vi = Vi\angle\theta i$, then the power flow constraints of the STATCOM are [6]:

$$P_{sh} = Vi^2 g_{sh} - V_i V_{sh} (gsh \cos(\theta i - \theta sh) + b_{sh} \sin(\theta_i - \theta_{sh})) \quad (2.1)$$

$$Q_{sh} = -Vi^2 g_{sh} - V_i V_{sh} (gsh \sin(\theta_i - \theta_{sh}) - b_{sh} \cos(\theta_i - \theta_{sh})) \quad (2.2)$$

Note: The compensation method is used in this project where the STATCOM is connected in shunt with AC system to provide the capacitive and inductive reactive power compensation. The reactive power exchange will improve the transient stability of the voltage level at the load point. The GTOs will act as valves in controlling the reactive power exchange.

2.2 Multi-Control Functions of the STATCOM

Title: Multi-Control Functions of the STATCOM, FACTS: modeling and control, Springer-Verlag Berlin Heidelberg, volume 1, 27-58, 2006

In the practical applications of a STATCOM, it may be used for controlling one of the following parameters [7]:

1. Voltage magnitude of the local bus, to which the STATCOM is connected;
2. Reactive power injection to the local bus, to which the STATCOM is connected;
3. Impedance of the STATCOM;
4. Current magnitude of the STATCOM while the current I sh leads the voltage injection V_{sh} by $90^{0:}$
5. Current magnitude of the STATCOM, while the current I sh lags the voltage injection V_{sh} by $90^{0:}$
6. Voltage injection;
7. Voltage magnitude at a remote bus;
8. Reactive power flow;
9. Apparent power or current control of a local or remote transmission line.

Note: The method used in this project is controlling the voltage magnitude of the local bus (load). The reactive power will injected to the AC system depends on the voltage magnitude. If the voltage drop occurred, capacitive reactive power will injected to the system, and if the overvoltage occurred, inductive reactive power will injected.

2.3 STATCOM Control Modes.

Title: STATCOM control modes, FACTS: modeling and control, Springer-Verlag Berlin Heidelberg, volume 1, 27-58, 2006

Among these control options, control of the voltage of the local bus, which the STATCOM is connected to, is the most-recognized control function. The other control possibilities have not fully been investigated in power flow analysis. The mathematical descriptions of the control functions are presented as follows.

a) Control mode 1: Bus voltage control

Let $V_{i\,Spec}$ be the bus voltage control reference. The bus control constraint is as follows:

$$V_i - V_{i\,Spec} = 0 \qquad (2.3)$$

b) Control mode 2: Reactive power control

In this control mode, the reactive power generated by the STATCOM is controlled to a reactive power injection reference. Let Q_{sh}^{Spec} be the specified reactive power injection control reference and Q_{sh} is the actual reactive power generated by the STATCOM.

$$Q_{sh} - Q_{sh}^{Spec} = 0 \qquad (2.4)$$

c) Control mode 3: Control of equivalent impedance

In principle, STATCOM compensation can be equivalently represented by an imaginary impedance or reactance. In this control mode, V_{sh} is regulated to control the equivalent reactance of the STATCOM to a specified reactance reference, and X_{shunt}^{Spec} is the specified reactance control reference of the STATCOM. X_{shunt} is the equivalent reactance of the STATCOM, which is a function of the state variables V_i and V_{sh}, is defined as:

$$X_{shunt} - X_{shunt}^{Spec} = 0 \qquad (2.5)$$

$$X_{shunt} = I_m(Vsh / I_{sh}) = Im\,[Vsh\, Z_{sh} / (V_i - Vs_{h)}] \qquad (2.6)$$

d) Control mode 4: Control of current magnitude - Capacitive compensation

In this control mode, a STATCOM is used to control the magnitude of the current I_{sh} of the STATCOM to a specified current magnitude control reference. The control constraint may be represented by $I_{sh} - I_{sh}^{Spec} = 0$. However it is found that there are two solutions corresponding to this control constraint. Due to the problem incurred, the power flow solution with such a constraint may arbitrarily converge to one of the two solutions. Since $I_{sh} = I_{sh}^{Spec}$, if further assume I_{sh} leads V_{sh} by 90^0, then;

$$I_{sh} = I_{sh}^{Spec} \angle (\theta_{sh} + 90^0) = (V_i - V_{sh}) / Z_{sh} \quad (2.7)$$

This control mode has a clear physical meaning. Since I sh lead Vsh by 90^0, this control mode provides capacitive reactive power compensation while keeping the current magnitude constant. Mathematically, such a control mode can be described by one of the following equations:

$$Re (I_{sh}^{Spec} \angle (\theta_{sh} + 90^0)) = Re [(V_i - V_{sh}) Z_{sh}]$$

$$I_m (I_{sh}^{Spec} \angle (\theta_{sh} + 90^0)) = I_m [(V_i - V_{sh}) / Z_{sh}] \quad (2.8)$$

e) Control mode 5: Control of current magnitude - Inductive compensation

In order to circumvent the same problem mentioned above, new formulation of the current control constraint needs to be introduced. In this control mode, the STATCOM is used to control the magnitude of the current I sh of the STATCOM while I sh lags Vsh by 90^0. This control mode also has a clear physical meaning, that is, it provides inductive reactive power compensation while keeping the current magnitude constant. Mathematically, such a control mode may be described by :

$$Re (I_{sh}^{Spec} \angle (\theta\ sh - 90^0)) = Re [(V_i - V_{sh}) Z_{sh}]$$

$$I_m (I_{sh}^{Spec} \angle (\theta_{sh} - 90^0)) = I_m [(V_i - V_{sh}) / Z_{sh}] \quad (2.9)$$

f) Control mode 6: Control of equivalent injected voltage magnitude Vsh of STATCOM.

In this control mode, a STATCOM is used to control the magnitude of the Vsh of the STATCOM to a specified voltage magnitude control reference. Let V_{sh} is the voltage magnitude of the equivalent injected voltage V_{sh} of the