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IMPLEMENTATION OF p-q THEORY ON UNIFIED

Haryani binti Hassan

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IMPLEMENTATION OF p-q THEORY ON UNIFIED POWER FLOW CONTROLLER

HARYANI BINTI HASSAN

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ABSTRACT

The Flexible AC Transmission System (FACTS) became popular since it was introduced by Hingorani in the late 1988. It can be considered as the best solution to transfer higher energy without building a new transmission line. This research focuses on the design of Unified Power Flow Controller (UPFC) which are one of the best FACTS types controller. UPFC is the combination of two types of FACTS controller names Static Synchronous Compensator (STATCOM) and Static Synchronous Series Compensator (SSSC), that can be used to control either selectively or simultaneously all the three parameters (i.e. voltage, impedance and phase angle) to influence the power flow in the existing transmission line. The purpose of this research is to design the UPFC using the Matlab Simulink software and implementing the well known p-q Theory as a control strategy. The analysis of the UPFC based on p-q Theory together with the implementation of Proportional Integral (PI) controller are combined to be a controller of Pulse Width Modulation (PWM) H-bridge for both Statcom and SSSC circuit. The UPFC system in this research was automatic voltage control mode and automatic power (real and reactive) flow control without any intervention on both sending and receiving end voltage magnitude and angle. From the simulation results, it shows that the p-q Theory control strategy can effectively and promptly tracking the reference power given in an existing transmission line.

DECLARATION

I declare that this dissertation entitle "Implementation of p-q Theory on Unified Power Flow Controller" is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature : ....

Name : Haryani Binti Hassan

Date : ....

APPROVAL

I hereby declare that I have read this dissertation and in my opinion, this dissertation is sufficient in terms of scope and quality as a partial fulfillment of Master of Electrical Engineering (Industrial Power).

Signature	:………………...
Supervisor Name	:… ………Ir. Dr. Rosli bin Omar….......................................
Date	:…………………….. ....

DEDICATION

To:

my beloved husband Mohd Azrin bin Abu Bakar

my children Nur Hazwani, Mohd Haziq, Nur Haziqah, Nur Hazirah and Muhammad Hazali

my late father Hassan bin Abdullah

my mother Halimah binti Ismail

my parents in law Abu Bakar bin Khamis and Zainon Md. Sirat

my siblings Helman, Hemlan, Hanizam, Heluan, Hazlina, Haryati and Heznan

ABSTRAK

FACTS menjadi popular sejak diperkenalkan oleh Hingorani dalam tahun 1988. Ia boleh dianggap sebagai penyelesaian terbaik dalam penghantaran tenaga elektrik tanpa membina sistem penghantaran yang baharu. Kajian ini akan fokus kepada UPFC sebagai salah satu jenis komponen kawalan FACTS yang terbaik di mana ia adalah kombinasi dua jenis kawalan FACTS iaitu STATCOM dan SSSC. UPFC boleh memilih untuk mengawal sama ada satu mahupun ketiga-tiga parameter iaitu voltan, galangan dan sudut fasa yang mampu mempengaruhi pengaliran kuasa di dalam system penghantaran yang sedia ada. Tujuan kajian ini adalah untuk merekacipta UPFC menggunakan software Matlab Simulink berdasarkan strategi kawalan Teori p-q. Analisa UPFC berdasarkan strategi kawalan Teori p-q berserta penggunaan pengawal Proportional Integral (PI), yang digabungkan dengan pengawal Modulasi Lebar Denyut (PWM), H-bridge bagi kedua-dua litar Statcom dan SSSC. Sistem UPFC di dalam kajian ini menggunakan mod kawalan voltan automatik dan kawalan kuasa automatik tanpa mengganggu kedua-dua voltan dan sudut fasa penghantaran dan penerimaan voltan. Daripada keputusan simulasi dapat disimpulkan bahawa strategi kawalan Teori p-q dapat mengawal aliran kuasa di dalam talian litar yang sedia ada dengan lebih cepat dan berkesan.

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d-q Theory	-	Instantaneous Current Component Theory
ET	-	Excitation Transformer
FACTS	-	Flexible Alternating Current Transmission System
HV	-	High voltage
Ki	-	Integral Gain
Kp	-	Proportional Gain
PI	-	Proportional Integral
p-q Theory	-	Instantaneous Power Theory
PWM	-	Pulse Width Modulation
SSSC	-	Static Synchronous Series Compensator
SIL	-	Surge Impedance Loading
STATCOM	-	Static Synchronous Compensator
SVC	-	Static Var Compensator
TCPS	-	Thyristor Controlled Phase Shifter
TCR	-	Thyristor-controlled reactor
TCSC	-	Thyristor Controlled Series Compensator
THD	-	Total Harmonic Distortion
TSC	-	Thyristor-switched capacitor
UPFC	-	Unified Power Flow Controller
VSC	-	Voltage Source Converter

LIST OF PUBLICATION

[1] Implementation of p-q Theory on Unified Power Flow Controller (UPFC). Accepted for presentation in National Conference "*Conference, Competition and Exhibition 2014 (CCE2014)*" on 23rd-25th June 2014.

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Almost every person in this world needs electricity for daily life from bathing, cooking, entertaining, communication until washing. This causes the demand for electricity increased rapidly due to modern and sophisticated way of life nowadays. To meet this demand, the power industry needs to find energy sources either naturally like a waterfall or using a fuel such as natural gas and coal. Unfortunately, these resources are located far from the demand which resulted in the construction of a new power plant. Since the elements of electric power system consist of generation, transmission and distribution, building a new power system require a very high cost and at the same time would disrupt the balance of ecology system that eventually led to catastrophes. Due to these problems, the power industry is trying to meet the consumer demand without interrupting the ecological system, environmental impact concern and public policy rule. One of the best approaches is to enhance the capability of the existing transmission to work adequately closed to its thermal limit without interfering the quality and security of power delivery. The conventional way of controlling the power flow using the phase shifter and mechanically switching is considered out of date due to its respond very slowly to the changes of loading condition. Furthermore, it cannot enhance power capacity of the transmission lines significantly. The other drawback of the traditional method is due to mechanical switching which also tends to wear out quickly. Hence, the system engineers have to come up with the best solutions to overcome these problems.

Flexible Alternating Current Transmission System (FACTS) is the alternative option that can be used to control the power flow in an existing transmission line. This idea was introduced by Hingorani in the late 1980's (Hingorani, 2000). The intention to use the FACTS is to enhance the controllability as well as the power transfer capability of a transmission line by using a power electronic switching device to replace the traditional way. As a result, it will help the existing transmission lines such that able to transfer higher power capacity without undermining the stability and security by controlling the main parameters that affect the power flows in a transmission line. Voltage, impedance and phase angle are the parameters that influence the power flows in a transmission line.

One of the most versatile FACTS is Unified Power Flow Controller (UPFC) that popularized by Gyugyi in 1991 (Akagi, 2007). UPFC is the combination of shunt and series controller that is used to control either selectively or simultaneously all the three parameters to influence the power flow in a transmission line. In this dissertation the UPFC will be specifically discussed in the implementation of the instantaneous active and reactive power theory to control the transmission line parameters.

The instantaneous active and reactive power theory which has been introduced by Akagi, et al in 1983 is also known as p-q Theory. This theory creates effective method of compensating instantaneous active and reactive power of three phase system by first transforming the three phase voltages and currents into $\alpha\beta 0$ coordinates which is known as Clarke Transformation. The main purpose of the Clarke Transformation is to separate the zero sequence where in this project, the zero sequence will be neglected due to assumption that the system is in balance condition. Then the calculation of the instantaneous real and reactive power can be done to obtain the references compensation of current and voltage. The application of p-q Theory is helpful in designing control strategies with the help of

Propotional Integral (PI) Controller. Moreover the presentation of mathematical equation of p-q Theory will be shown in matrix form.

1.2 Introduction to Power Flow Control

Electric power flow initially is the result of the interaction between power generation, transmission and distribution. This led to the interest in research of power flow control technology, which had increased since last several years.

The principle of power flow over a transmission line can be simplified as in Figure 1.1 where V_1 is the magnitudes of the sending end voltage and V_2 is the magnitude of the receiving end voltage. By ignoring the resistance and capacitance, the transmission line assumed to have purely inductive impedance, X which interconnects between the two end busses.

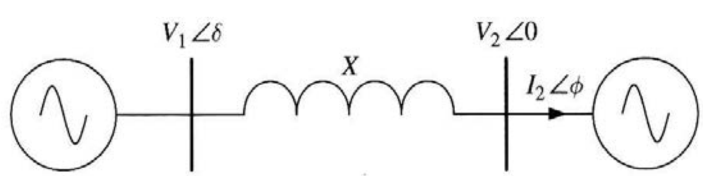

Figure 1.1: Interconnection between two synchronous systems (Arillaga, 2007)

Assume that the voltage V_2 as the phase reference meanwhile the voltage V_1 leads the V_2 by δ angle and the current I_2 lags its voltage by ∅ angle as shown in Figure 1.2, these expressions can be derived (Arillaga, 2007):

$$I_2 X \cos\phi = V_1 \sin\delta \tag{1.1}$$

$$I_2 X \cos\phi = V_1 \cos\delta - V_2 \tag{1.2}$$

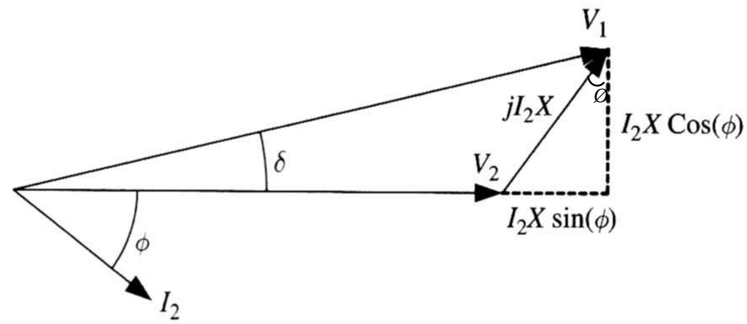

Figure 1.2: Phasor Diagram for The Interconnection of Figure 1.1 (Arrillaga, 2007)

From Equations (1.1) and (1.2) the active and reactive powers become:

$$P = V_2 I_2 \cos\phi = \frac{V_1 V_2}{X} \sin\delta \tag{1.3}$$

$$Q = V_2 I_2 \sin\phi = \frac{V_2 (V_1 \cos\delta - V_2)}{X} \tag{1.4}$$

Equations (1.3) and (1.4) show that the power flow through the transmission line can be controlled by varying one or more of these parameters V_1, V_2, δ and X. Even though the generated voltage phase and magnitude values can be controlled by the turbine governor and the generator, the controls are very slow and inefficient which tend to have stability problems. FACTS is the device that can overcome this problem.

1.3 Introduction to FACTS

FACTS controllers use power electronics to set control for one or more transmission parameters that can increase power transfer capability. It can be categorized in two classifications either based on their connection in transmission system or based on the power electronics used in the system.

1. Classification which according to the connection of the devices within the transmission system can be divided into three connections:
   a) Shunt connection
   b) Series connection
   c) Combine connection
2. Classification based upon the power electronics used in the control system or the operational concepts, which can be divided in two groups namely:
   a) Group of conventional thyristor based controller
   b) Group of voltage source converter (VSC) based controller.

   The summary of FACTS controller is shown in Table 1.1.