

TESTING OF UNIFIED POWER FLOW CONTROLLER ( UPFC ) MODEL IN IEEE 9 BUS  
POWER SYSTEM NETWORK USING  
PSCAD/EMTDC AND MATLAB SOFTWARE

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## ABSTRACT

Unified Power Flow Controller (UPFC) is the most widely used Flexible ac Transmission system ( FACTS ) device to control the power flow and to optimize the system stability in the transmission line. It should be installed to control the voltage, as well as to control the active and reactive power flow through the transmission line. This project is using PSCAD/EMTDC and MATLAB software to model and to verify the UPFC system in order to improve its performance in power system. MATPOWER in MATLAB software used to run the power flow of IEEE 9 bus power system network. Then, by using PSCAD/EMTDC software, IEEE 9 bus system was designed and the result of power flow 9 bus system using PSCAD/EMTDC was compared with the power flow in MATPOWER. The result of active power,  $P$  (MW) , reactive power , $Q$  (MVar) and power loss were compared to make sure that both software have the similar answer with only 1% difference. The power flow in both softwares must be similar before injecting the UPFC system. Then, the active power and reactive power performance will be improved due to injecting the UPFC device. Stability and transient performance of active and reactive power was analyzed.

## ABSTRAK

UPFC merupakan salah satu alat di dalam Sistem Penghantaran Arus Ulang-Alik Fleksibel ( FACTS) yang paling meluas digunakan untuk mengawal pengaliran kuasa dan meningkatkan keupayaan kestabilan sistem di dalam talian penghantaran sistem kuasa. Pemasangan UPFC bertujuan untuk mengawal pengaliran voltan, sekaligus mengawal pengaliran kuasa aktif dan kuasa reaktif di dalam sesebuah talian penghantaran sistem kuasa. Dalam melaksanakan projek ini, perisian PSCAD/ EMTDC dan MATLAB digunakan bagi merekabentuk dan mengenalpasti keupayaan sistem dalam meningkatkan keupayaan kestabilan sistem kuasa. Perisian MATPOWER didalam aplikasi MATLAB digunakan untuk mendapatkan aliran kuasa keseluruhan 9 bas sistem IEEE. Kemudian, dengan menggunakan perisian PSCAD/ EMTDC talian 9 bas system IEEE direkabentuk dan jumlah aliran kuasa di dalam sistem tersebut diambil serta diperbandingkan dengan aliran kuasa di dalam perisian MATPOWER tadi. Jumlah aliran kuasa aktif,  $P$  (MW), kuasa reaktif,  $Q$  (MVar) dan kehilangan kuasa di kedua-dua perisian mestilah sama atau menghampiri dengan ralat yang sangat kecil dengan hanya 1% perbezaan sebelum model UPFC dipasangkan. Kemudian, kestabilan dan transien bagi kuasa aktif dan kuasa reaktif dianalisis.

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## LIST OF ABBREVIATIONS

<b>AC</b>	Alternating Current
<b>EMTDC</b>	Electromagnetic Transient Direct Current
<b>GTO</b>	Gate Turn Off
<b>IEEE</b>	The Institute of Electrical and Electronics Engineers
<b>IGBT</b>	Insulated Gate Bipolar Transistor
<b>MATLAB</b>	Matrix Laboratory
<b>P</b>	Active power
<b>PLL</b>	Phase Locked Loop
<b>PSCAD</b>	Power System Computer Aided Design
<b>p.u.</b>	Per-unit
<b>SPWM</b>	Sinusoidal Pulse Width Modulation
<b>Q</b>	Reactive power
<b>SSSC</b>	Series Synchronous Compensator
<b>STATCOM</b>	Static Synchronous Compensator
<b>VSC</b>	Voltage-sourced Converter

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# CHAPTER 1

## INTRODUCTION

### 1.1 Introduction

Unified Power Flow Controller ( UPFC ) is the universal and most flexible FACTS (Flexible ac Transmission System). It is used to control the power flow in the transmission systems by controlling the impedance, voltage magnitude and phase angle. This device can allow the path of power as we desire. UPFC consist of two Voltage Supply Inverters, one series converter and one shunt converter. This device is actually a combination of two FACTs device which are STATCOM (Static Synchronous Compensator) and SSSC (Static Series Synchronous Compensator). SSSC is used to add controlled voltage magnitude and phase angle in series with the line, while shunt converter STATCOM is used to provide reactive power to the ac system, beside that, it will provide the dc power required for both inverter [1]. The reactive power can be compensated either by improving the receiving voltage or by reducing the line reactance [2].



UPFC should be installed to control the voltage, as well as to control the active and reactive power flow through the transmission line. However, the right transmission line to be injected by UPFC and the effect of injection will only know by doing the analysis using MATLAB and PSCAD software.

Thus, this project presents the active and reactive power control through a transmission line by placing the UPFC using computer simulation. PSCAD and MATLAB program are used to model and to verify the performance of UPFC in order to increase the ability of the system.

## **1.2 Problem statement**

Unified Power Flow Controller (UPFC) is the most widely used Flexible ac Transmission system ( FACTS ) device to control the power flow and to optimize the system stability in the transmission line. It should be installed to control the voltage, as well as to control the active and reactive power flow through the transmission line.

## **1.3 Objectives**

The objectives of this project are to:

- i. simulate IEEE 9 bus power system network using PSCAD software and comparing with MATLAB power flow result.
- ii. model UPFC in IEEE 9 bus power system network sample and determine the most efficient transmission line to be injected.
- iii. analyze the steady-state analysis of the 9 bus power system network before and after UPFC applied.

## **1.4 Scope of Work**

The scopes of this project are:

- i. modeling UPFC in IEEE 9 bus power system network.
- ii. simulation on the IEEE 9 bus power system network power flow using MATLAB and PSCAD software.
- iii. analyze and compare the performance of 9 bus system before and after UPFC applied.

## **1.5 Outline thesis**

For the thesis outline, the progress elements are divided into chapters and the details are as follows:

### **i. Chapter 1**

This chapter consists of introduction, objectives, scope of work and thesis outline. In introduction, the problem statement is stated here along with the relevant solution. It's to support the main objectives and the relevancy of the proposed title. In the objectives, the goal of the project is stated in here. It's consists of the aim that must be achieved at the end of the project. In the scope of work, the detailed work flow stated in here. This step by step flow work is to keep the project's progress on track and to meet the objective. Lastly in thesis outline, the overall elements needed in the thesis are stated.

**ii. Chapter 2**

Chapter 2 is about literature review. It is the study on the others papers, journal, website citation and other dependable sources that related to the project. Literature review is crucial for every thesis not only to support the proposed title but also for guidelines and references on the conducted thesis.

**iii. Chapter 3**

Chapter 3 explains the methodology of the project. It is to describe in details about the scope of project. In this part, every step on how to approach the solutions to overcome the stated problems is described in details. It shows how the work will be done. The details such as flow chart and schematic diagram are shown in here.

**iv. Chapter 4**

Chapter 4 is about result and discussions. In this chapter, all the finding related to the project is stated in here. Every output produce from the project are stated, analyzed and explained briefly.

**v. Chapter 5**

This chapter consists of conclusion and future recommendations section. In the conclusion, the project's objectives and achieved result are concluded. In future recommendations, the suggestions to improve the existed project are stated.

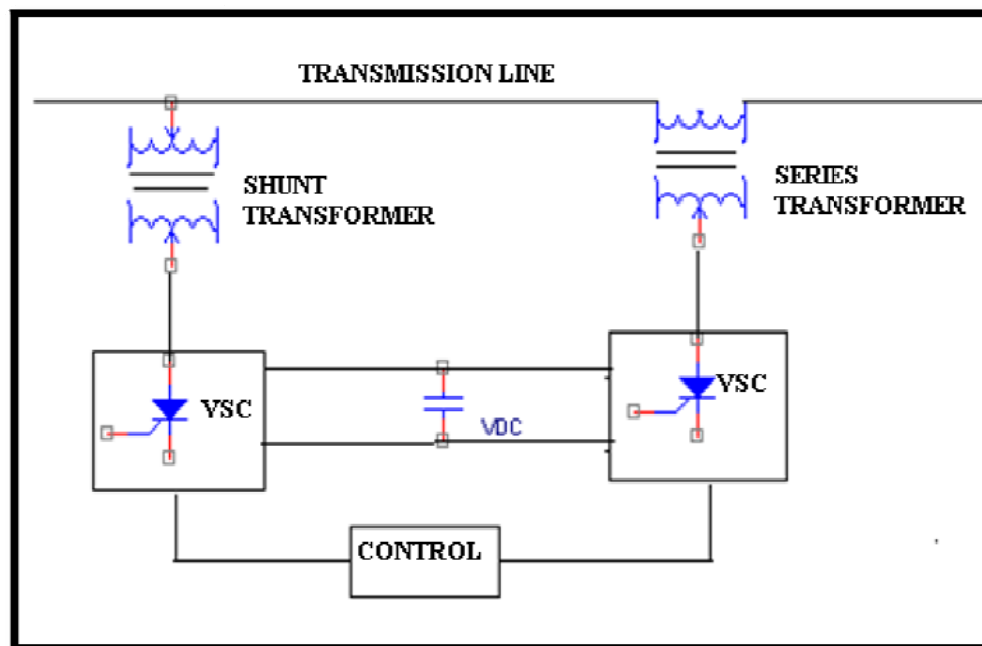
## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Unified Power Flow Controller ( UPFC )**

The cost of losing synchronous through a transient instability is extremely high in modern power systems. Consequently, utility engineers often perform a large number of stability studies in order to avoid this problem. A unified power flow controller (UPFC) is the most promising device in the FACTS concept. It has the ability to adjust the three control parameters such as the bus voltage, transmission line reactance, and phase angle between two buses, either simultaneously or independently. A UPFC performs this through the control of the in-phase voltage, quadrature voltage, and shunt compensation. UPFC can control the three control parameters either individually or in appropriate combinations at its series-connected output while maintaining reactive power support at its shunt-connected input. The mechanism of the three control methods of a UPFC in enhancing power system damping. It was shown that a significant reduction in the transient swing can be obtained by using a simple proportional feedback of machine rotor angle deviation. It is generally accepted that the addition of a supplementary controller to the UPFC can significantly enhance power system damping [3].

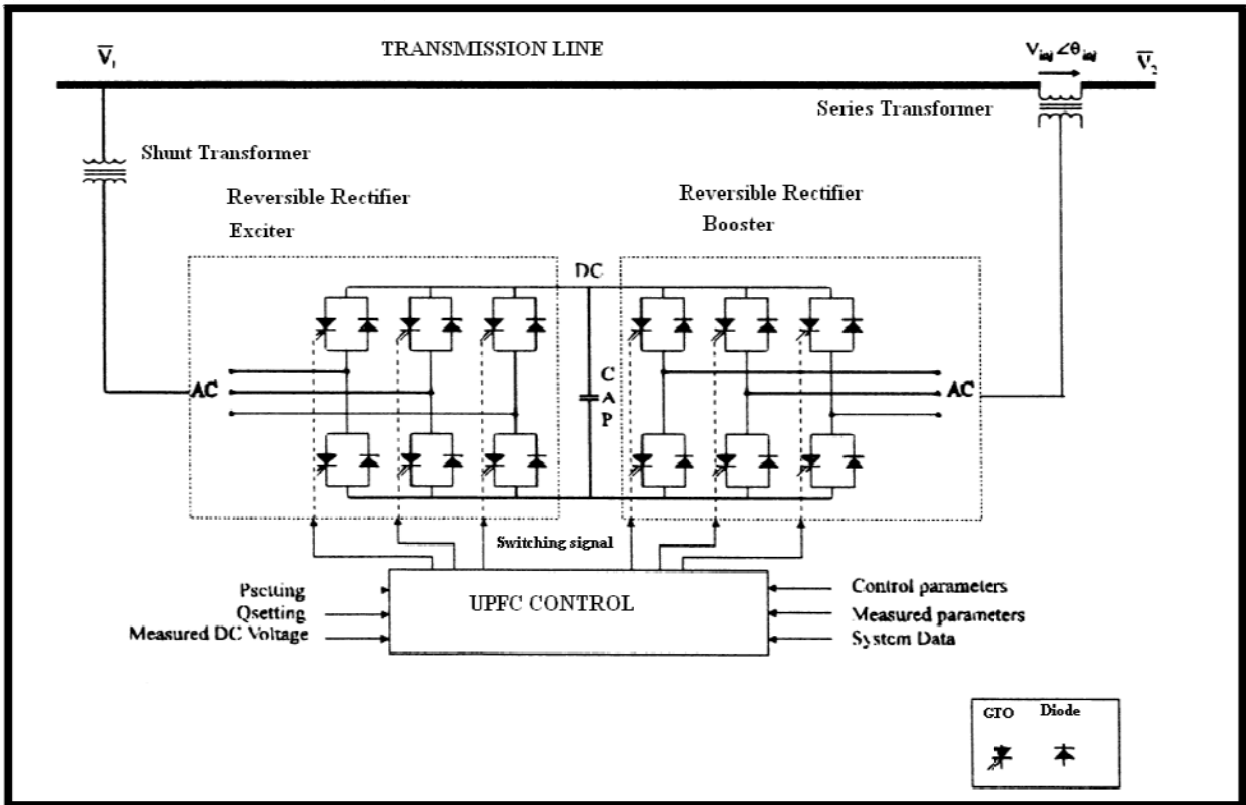
The main function of the UPFC is to control the flow of real and reactive power by injecting of a voltage in series with the transmission line. Both the magnitude and the phase angle of the voltage can be varied independently. Real and reactive power flow control can allow for the power flow in prescribed routes, loading of transmission lines closer to their thermal limits and can be utilized for improving transient and small signal stability of the power system. The schematic of the UPFC is shown in Figure 2.1.



**Figure 2.1** : Schematic of the UPFC

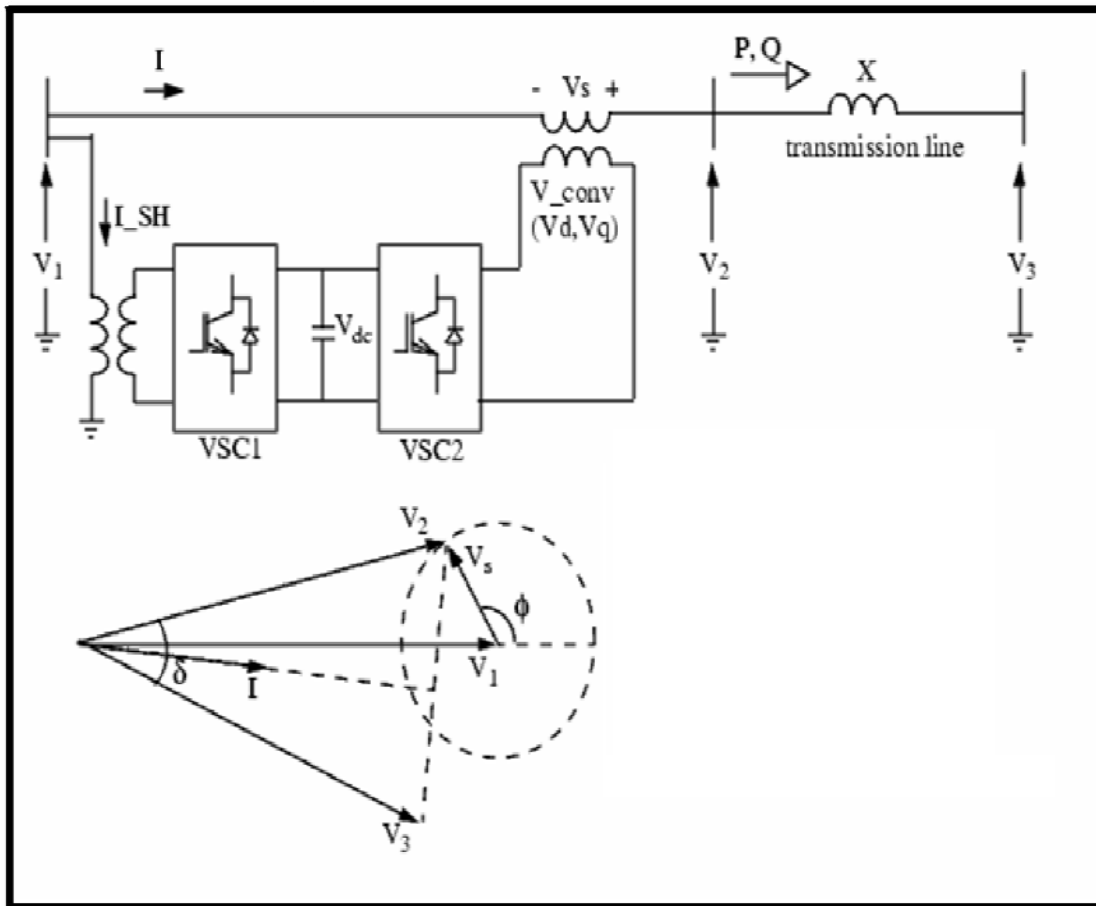
The UPFC consists of two branches. The series branch consists of a voltage source converter which injects a voltage in series through a transformer. Since the series branch of the UPFC can inject a voltage with variable magnitude and phase angle it can exchange real power with the transmission line. The energy storing capacity of this dc capacitor is generally small. Therefore, active power drawn by the shunt converter should be equal to the active power generated by the series converter. The reactive power in the shunt or series converter can be chosen independently, giving greater flexibility to the power flow control.

The coupling transformer is used to connect the device to the system. Figure 2.2 shows the schematic diagram of the three phase UPFC connected to the transmission line.



**Figure 2.2 :** Schematic diagram of the three phase UPFC connected to the transmission Line .

Control of power flow is achieved by adding the series voltage,  $V_s$  with a certain amplitude,  $|V_s|$  and phase shift,  $\phi$  to  $V_1$ . This will gives a new line voltage,  $V_2$  with different magnitude and phase shift. As the angle,  $\phi$  varies, the phase shift,  $\delta$  between line voltage  $V_2$  and  $V_3$  also varies. Figure 2.3 shows the single line diagram of the UPFC and phasor diagram of voltage and current.



**Figure 2.3:** Single line diagram of UPFC and phasor diagram of voltage and current

However the UPFC as a compensator cannot supply or absorb real power in steady state (except for the power drawn to compensate for the losses) unless it has a power source at its DC terminals. Thus the shunt branch is required to compensate (from the system) for any real power drawn/ supplied by the series branch and the losses. If the power balance is not maintained, the capacitor cannot remain at a constant voltage. In addition to maintaining the real power balance, the shunt branch can independently exchange reactive power with the system. The main advantage of the power electronics based FACTS controllers over mechanical controllers is their speed. Therefore the capabilities of the UPFC need to be exploited not only for steady state load flow control but also to improve stability.

However it is not obvious as to how to use the series voltage and shunt current (subject to the power balance constraint) for UPFC control. In this context it is suitable to control the strategies and controller design to achieve the same is of importance [4].

The UPFC has many possible operating modes. In particular, the shunt inverter is operating in such a way to inject a controllable current,  $i_{sh}$  into the transmission line. The shunt inverter can be controlled in two different modes [5]:

- i. ***VAR Control Mode:*** The reference input is an inductive or capacitive VAR request. The shunt inverter control translates the Var reference into a corresponding shunt current request and adjusts gate of the inverter to establish the desired current. For this mode of control a feedback signal representing the dc bus voltage,  $V_{dc}$ , is also required.
- ii. ***Automatic Voltage Control Mode:*** The shunt inverter reactive current is automatically regulated to maintain the transmission line voltage at the point of connection to a reference value. For this mode of control, voltage feedback signals are obtained from the sending end bus feeding the shunt coupling transformer. The series inverter controls the magnitude and angle of the voltage injected in series with the line to influence the power flow on the line. The actual value of the injected voltage can be obtained in several ways.
- iii. ***Direct Voltage Injection Mode:*** The reference inputs are directly the magnitude and phase angle of the series voltage.
- iv. ***Phase Angle Shifter Emulation mode:*** The reference input is phase displacement between the sending end voltage and the receiving end voltage.