UNIFIED POWER FLOW CONTROLLER AND ITS ROLE IN POWER TRANSMISSION NETWORK

By

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DISSERTATION

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
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(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Nor Izzati Binti Abdul Razak

ABSTRACT

The performance of unified power flow controller (UPFC) is analyzed in controlling the flow of power over the transmission line. The application of UPFC in steady-state analysis is to demonstrate the capabilities of UPFC in controlling the real and reactive power flow within any electrical network. Voltage sources model will be utilized to study the behavior of the UPFC in regulating the active, reactive power flow as well as the voltage. This model is using the Newton Raphson algorithm for power flow studies. Simultaneous method are need to be done in which equations of UPFC and the power balance equations of network are combined into one set of non-linear algebraic equations [1,2]. Then it is solved according to the Newton Raphson method. In this project, the PSCAD EMTDC software is used for the simulation. The result of network with and without using the UPFC are compared in terms of active and reactive power flows in the line and bus powers to analyze the performance of UPFC.

ACKNOWLEDGEMENTS

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ABBREVIATIONS AND NOMENCLATURE

FACTS	Flexible Alternating Current Transmission System
UPFC	Unified Power Flow Controller
SVC	Static Var Compensator
TCSC	Thyristor Controlled Series Compensator
SSSC	Static Synchronous Series Compensator
IGBT	Insulated Gate Bipolar Junction
GTO	Gate Turn Off Thyristor
STATCOM	Static Synchronous Compensator

CHAPTER 1
INTRODUCTION

1.1 Background of Study

The Unified Power Flow Controller (UPFC) is a combination of Static Synchronous Compensator and Static Synchronous Series Compensator. It is the most versatile and complex power electronic equipment that has emerged for the control and optimization of power flow in electrical power transmission system. UPFC can control concurrently or selectively the transmission line voltage, impedance, as well as reactive power flow [1,2]. The performance of UPFC is investigated in controlling the flow of power over the transmission line. Voltage sources model is used to study the behavior of the UPFC in regulating the active, reactive power, and voltage profile [3]. It used Newton Raphson algorithm for power flow studies. Simultaneous method is employed in which equations of UPFC and the power balance equations of network are combined into one set of non-linear algebraic equations. It is solved according to the Newton Raphson algorithm.

1.2 Problem Statement

The problem statement is to improve the power flow performance in a transmission network by stabilizing the voltage so that the required voltage can be achieved in order to reduce the power loss.

1.3 Objectives and Scope of Study

The purpose of this study is to use the UPFC to improve the power flow performance in a transmission network employing PSCAD Software.

The scopes of study of the project are as follows:

i. To study on the basic power flow problem.
ii. To explain the operation of UPFC and understand the need for UPFC.
iii. To analyze the operational of UPFC in power transmission network.
iv. To familiarize the use of MATLAB & PSCAD software.

1.3.1 Revelancy of the Project

The project aims basically is to study on the behaviour of UPFC and its efficiency when given a power flow problem. Therefore, a good understanding on the power flow analysis is needed so that the problem related can be solved and the objective of the project itself can be achieved.

1.3.2 Feasibility of the Project within the Scope and Time Frame

This project is a two semester project, where the first semester is devoted to research and study on the power flow analysis, while in the second semester the effect of UPFC to a power system is analyzed by using PSCAD EMTDC.

CHAPTER 2
LITERATURE REVIEW

2.1 Power Flow Analysis

The power flow analysis is the most fundamental study in Power System, which are carried out during the Planning and Operational phases. Major part of electric utility is constituted by the power flow. The study focuses on the normal steady state operation of power system and requires to determine of bus voltages and power flows for a given network configuration and loading condition [4].

All the results obtained from the power flow analysis will give two major impacts. Firstly, the result of the power flow analysis will help us to know the present status of the power system, which is required for the continuous monitoring. Apart from that, it will also help us to have an alternative plans for system expansion to meet their increasing demand.

2.1.1 Development of Power Flow Model

There are two types of equations that relate the complex power injection to complex bus voltages, which are:

i. Network equations

ii. Bus power equations

2.1.1.1 Network Equations

Network equations can be written in a number of alternative forms. The equations describing the performance of the network in the bus admittance form is given by **I = YV.**

I indicate the bus current vector

V indicates the bus voltage vector

Y indicates the bus admittance matrix

The expanded form for the network equations is:

$$\begin{bmatrix} \mathbf{I}_1 \\ \mathbf{I}_2 \\ \vdots \\ \mathbf{I}_N \end{bmatrix} = \begin{bmatrix} \mathbf{Y}_{11} & \mathbf{Y}_{12} & \cdots & \mathbf{Y}_{1N} \\ \mathbf{Y}_{21} & \mathbf{Y}_{22} & \cdots & \mathbf{Y}_{2N} \\ \vdots & \vdots & \vdots & \vdots \\ \mathbf{Y}_{N1} & \mathbf{Y}_{N2} & \cdots & \mathbf{Y}_{NN} \end{bmatrix} \begin{bmatrix} \mathbf{V}_1 \\ \mathbf{V}_2 \\ \vdots \\ \mathbf{V}_N \end{bmatrix} \quad (2.1)$$

Where **N** = number of buses

The typical element of the bus admittance matrix is:

$$\mathbf{Y}_{ij} = |\mathbf{Y}_{ij}| \angle \boldsymbol{\theta}_{ij} = |\mathbf{Y}_{ij}| \cos \boldsymbol{\theta}_{ij} + j\, |\mathbf{Y}_{ij}| \sin \boldsymbol{\theta}_{ij} = \mathbf{G}_{ij} + j\, \mathbf{B}_{ij} \quad (2.2)$$

Voltage at a typical bus i is

$$\mathbf{V}_i = |\mathbf{V}_i| \angle \boldsymbol{\delta}_i = |\mathbf{V}_i| \, (\cos \boldsymbol{\delta}_i + j \sin \boldsymbol{\delta}_i) \quad (2.3)$$

The current injected into the network at bus *i* is given by

$$\mathbf{I}_i = \mathbf{Y}_{i1} \mathbf{V}_1 + \mathbf{Y}_{i2} \mathbf{V}_2 + \cdots\cdots + \mathbf{Y}_{iN} \mathbf{V}_n$$

$$= \sum_{n=1}^{N} \mathbf{Y}_{in} \mathbf{V}_n \quad (2.4)$$

2.1.1.2 The Bus Power Equations

The problem as power flow is the bus power equation is also taken into account, which results the power flow model become non- linear. Equation of complex power entering the network at bus i :

$$\boxed{\mathbf{P}_i + \mathbf{Q}_i = \mathbf{V}_i \mathbf{I}_i^*} \quad (2.5)$$

Then the conjugate of $\mathbf{P_i} + \mathbf{jQ_i} = \mathbf{V_i} \, \mathbf{I_i^*}$ is written as:

$$\mathbf{P_i} - \mathbf{jQ_i} = \mathbf{V_i^*} \, \mathbf{I}_i$$

$$= \mathbf{V_i^*} \sum_{n=1}^{N} \mathbf{Y_{in}} \, \mathbf{V_n}$$

$$= |\mathbf{V_i}| \angle -\boldsymbol{\delta}_i \sum_{n=1}^{N} |\mathbf{Y_{in}}| \angle \boldsymbol{\theta}_{in} \, |\mathbf{V_n}| \angle \boldsymbol{\delta}_n$$

$$= \sum_{n=1}^{N} |\mathbf{V_i}| \, |\mathbf{V_n}| \, |\mathbf{Y_{in}}| \quad \angle\, \boldsymbol{\theta}_{in} + \boldsymbol{\delta}_n - \boldsymbol{\delta}_i \tag{2.6}$$

P (real part) and Q (imaginary part) are separately written :

$$\mathbf{P_i} = \sum_{n=1}^{N} |\mathbf{V_i}| |\mathbf{V_n}| |\mathbf{Y_{in}}| \cos(\boldsymbol{\theta}_{in} + \boldsymbol{\delta}_n - \boldsymbol{\delta}_i) \tag{2.7}$$

$$\mathbf{Q_i} = - \sum_{n=1}^{N} |\mathbf{V_i}| |\mathbf{V_n}| |\mathbf{Y_{in}}| \sin(\boldsymbol{\theta}_{in} + \boldsymbol{\delta}_n - \boldsymbol{\delta}_i) \tag{2.8}$$

The calculated powers should be equal to the specified powers. If real power and reactive power injection at bus *i* are specified, the non-linear equations can be solved as:

$$\sum_{n=1}^{N} |\mathbf{V_i}| |\mathbf{V_n}| |\mathbf{Y_{in}}| \cos(\boldsymbol{\theta}_{in} + \boldsymbol{\delta}_n - \boldsymbol{\delta}_i) = \mathbf{PI}_i \tag{2.9}$$

$$- \sum_{n=1}^{N} |\mathbf{V_i}| |\mathbf{V_n}| |\mathbf{Y_{in}}| \sin(\boldsymbol{\theta}_{in} + \boldsymbol{\delta}_n - \boldsymbol{\delta}_i) = \mathbf{QI}_i \tag{2.10}$$

Some notations are done:

PQ buses = $\mathbf{N_1}$

PV buses = $\mathbf{N_2}$

$\mathbf{N} = \mathbf{N_1} + \mathbf{N_2} + \mathbf{1}$

The unknowns to be obtained are:

- phase angle , $\boldsymbol{\delta}$ at the $\mathbf{N_1 + N_2}$ number of PQ and PV buses
- voltage magnitudes $|\mathbf{V}|$ at the $\mathbf{N_1}$ number of PQ buses

Number of equations = Number of variables = **$2N_1 + 2N_2$**

Thus the equations to be solved are: For i = 1, 2… N

$$\sum_{n=1}^{N} |\mathbf{V_i}||\mathbf{V_n}||\mathbf{Y_{in}}| \cos(\boldsymbol{\theta}_{in} + \boldsymbol{\delta}_n - \boldsymbol{\delta}_i) = \mathbf{PI}_i \qquad (2.11)$$

For i = 1, 2… N

i ≠ PV buses

$$-\sum_{n=1}^{N} |\mathbf{V_i}||\mathbf{V_n}||\mathbf{Y_{in}}| \sin(\boldsymbol{\theta}_{in} + \boldsymbol{\delta}_n - \boldsymbol{\delta}_i) = \mathbf{QI}_i \qquad (2.12)$$

The unknown that are to be solved are:

For δ_i i = 1, 2… N,

$|V_i|$ i = 1, 2… N, ,$i \neq$ PV buses

2.1.2 Power Flow Solution by Newton Raphson Method

Power flow problems in a system are formulated in mathematical equations where it is found to be non-linear algebraic equations. For the solution of non-linear algebraic equations, two common iterative methods are used. These methods are Gauss Seidel and Newton Raphson. Among these two methods, Newton Raphson is more popular because of exact problem formulation and has avery good convergence characteristic. Thus, in this project Newton Raphson is used.

The steps that are involved in the Newton Raphson method to achieve power flow solution are as follows:

i) Develop Bus Admittance Matrix

The line data is used to construct bus admittance matrix.

$$\mathbf{Ybus} = \begin{bmatrix} \mathbf{Y_{11}} & \mathbf{Y_{12}} & \cdots & \mathbf{Y_{1N}} \\ \mathbf{Y_{21}} & \mathbf{Y_{22}} & \cdots & \mathbf{Y_{2N}} \\ \vdots & \vdots & \vdots & \vdots \\ \mathbf{Y_{N1}} & \mathbf{Y_{N2}} & \cdots & \mathbf{Y_{NN}} \end{bmatrix} \tag{2.13}$$

ii) Initial voltage solution

Set the iteration constant k = 0. Assume a starting solution. Usually a FLAT START is assumed in which all the unknown phase angles are taken as zero and unknown voltage magnitudes are taken as 1.0 p.u [4].

iii) Compute Mismatch power vector

$$\begin{bmatrix} \Delta \mathbf{P} \\ \hline \Delta \mathbf{Q} \end{bmatrix}$$

Where ΔP = Pspecified – Pcalculated

ΔQ = Qspecified – Qcalculated

Calculated real and reactive power :

$$\mathbf{PI}_i = \sum_{n=1}^{N} |\mathbf{V_i}||\mathbf{V_n}||\mathbf{Y_{in}}| \cos(\theta_{in} + \delta_n - \delta_i) \tag{2.14}$$

$$\mathbf{QI}_i = -\sum_{n=1}^{N} |\mathbf{V_i}||\mathbf{V_n}||\mathbf{Y_{in}}| \sin(\theta_{in} + \delta_n - \delta_i) \tag{2.15}$$

Develop the elements of Jacobian matrix. Separating the term with n = i we get:

$$\mathbf{PI}_i = |\mathbf{V_i}|^2 \mathbf{G_{ii}} + \sum_{\substack{n=1 \\ n \neq i}}^{N} |\mathbf{V_i}||\mathbf{V_n}||\mathbf{Y_{in}}| \cos(\theta_{in} + \delta_n - \delta_i) \quad (2.16)$$

$$\mathbf{QI}_i = -|\mathbf{V_i}|^2 \mathbf{B_{ii}} - \sum_{\substack{n=1 \\ n \neq i}}^{N} |\mathbf{V_i}||\mathbf{V_n}||\mathbf{Y_{in}}| \sin(\theta_{in} + \delta_n - \delta_i) \quad (2.17)$$

Jacobian matrix, J = $\begin{bmatrix} \mathbf{H} & \mathbf{N} \\ \mathbf{M} & \mathbf{L} \end{bmatrix}$

Where $\mathbf{H} = \frac{\partial \mathbf{P}}{\partial \boldsymbol{\delta}}$; $\mathbf{N} = \frac{\partial \mathbf{P}}{\partial |\mathbf{V}|}|\mathbf{V}|$; $\mathbf{M} = \frac{\partial \mathbf{Q}}{\partial \boldsymbol{\delta}}$ **and** $\mathbf{L} = \frac{\partial \mathbf{Q}}{\partial |\mathbf{V}|}|\mathbf{V}|$

To obtain the diagonal elements:

$$\mathbf{H_{ii}} = \frac{\partial \mathbf{P_i}}{\partial \boldsymbol{\delta}_i} = \sum_{\substack{n=1 \\ n \neq i}}^{N} |\mathbf{V_i}||\mathbf{V_n}||\mathbf{Y_{in}}| \sin(\theta_{in} + \delta_n - \delta_i)$$

$$= -\mathbf{Q_i} - |\mathbf{V_i}|^2 \mathbf{B_{ii}} \quad (2.18)$$

$$\mathbf{N_{ii}} = \frac{\partial \mathbf{P_i}}{\partial |\mathbf{V_i}|}|\mathbf{V_i}| = 2|\mathbf{V_i}|^2 \mathbf{G_{ii}} + \sum_{\substack{n=1 \\ n \neq i}}^{N} |\mathbf{V_i}||\mathbf{V_n}||\mathbf{Y_{in}}| \cos(\theta_{in} + \delta_n - \delta_i)$$

$$= \mathbf{P_i} + |\mathbf{V_i}|^2 \mathbf{G_{ii}} \quad (2.19)$$

$$\mathbf{M_{ii}} = \frac{\partial \mathbf{Q_i}}{\partial \boldsymbol{\delta}_i} = \sum_{\substack{n=1 \\ n \neq i}}^{N} |\mathbf{V_i}||\mathbf{V_n}||\mathbf{Y_{in}}| \cos(\theta_{in} + \delta_n - \delta_i)$$

$$= \mathbf{P_i} - |\mathbf{V_i}|^2 \mathbf{G_{ii}} \quad (2.20)$$

$$\mathbf{L_{ii}} = \frac{\partial \mathbf{Q_i}}{\partial |\mathbf{V_i}|}|\mathbf{V_i}| = -2|\mathbf{V_i}|^2 \mathbf{B_{ii}} - \sum_{\substack{n=1 \\ n \neq i}}^{N} |\mathbf{V_i}||\mathbf{V_n}||\mathbf{Y_{in}}| \sin(\theta_{in} + \delta_n - \delta_i)$$

$$= \mathbf{Q_i} - |\mathbf{V_i}|^2 \mathbf{B_{ii}} \quad (2.21)$$

To obtain the off-diagonal elements:

$$\mathbf{H}_{ij} = \frac{\partial \mathbf{P}_i}{\partial \boldsymbol{\delta}_j} = -\,|\mathbf{V}_i||\mathbf{V}_j||\mathbf{Y}_{ij}| \ \ \mathbf{sin}\,(\boldsymbol{\theta}_{ij} + \boldsymbol{\delta}_j - \boldsymbol{\delta}_i) \tag{2.22}$$

$$\mathbf{N}_{ij} = \frac{\partial \mathbf{P}_i}{\partial |\mathbf{V}_j|}|\mathbf{V}_j| = |\mathbf{V}_i||\mathbf{V}_j||\mathbf{Y}_{ij}| \ \ \mathbf{cos}\,(\boldsymbol{\theta}_{ij} + \boldsymbol{\delta}_j - \boldsymbol{\delta}_i) \tag{2.23}$$

$$\mathbf{M}_{ij} = \frac{\partial \mathbf{Q}_i}{\partial \boldsymbol{\delta}_j} = -\,|\mathbf{V}_i||\mathbf{V}_j||\mathbf{Y}_{ij}| \ \ \mathbf{cos}\,(\boldsymbol{\theta}_{ij} + \boldsymbol{\delta}_j - \boldsymbol{\delta}_i) \tag{2.24}$$

$$\mathbf{L}_{ij} = \frac{\partial \mathbf{Q}_i}{\partial |\mathbf{V}_j|}|\mathbf{V}_j| = -\,|\mathbf{V}_i||\mathbf{V}_j||\mathbf{Y}_{ij}| \ \ \mathbf{sin}\,(\boldsymbol{\theta}_{ij} + \boldsymbol{\delta}_j - \boldsymbol{\delta}_i) \tag{2.25}$$

If the elements of error vector are less than the specified tolerance, the problem is solved, otherwise proceed to next step.

iv) Correction vector is obtained by solving

$$\begin{bmatrix} \mathbf{H} & \mathbf{N} \\ \mathbf{M} & \mathbf{L} \end{bmatrix} \begin{bmatrix} \Delta\boldsymbol{\delta} \\ \frac{\Delta|\mathbf{V}|}{|\mathbf{V}|} \end{bmatrix} = \begin{bmatrix} \Delta\mathbf{P} \\ \Delta\mathbf{Q} \end{bmatrix} \tag{2.26}$$

v) Update the solution

$$\begin{bmatrix} \dfrac{\delta}{|\mathbf{V}|} \end{bmatrix}_{\mathbf{k}+1} = \begin{bmatrix} \dfrac{\delta}{|\mathbf{V}|} \end{bmatrix}_{\mathbf{k}} + \begin{bmatrix} \dfrac{\Delta\delta}{\Delta|\mathbf{V}|} \end{bmatrix} \tag{2.27}$$

vi) Set k = k+1 when the value of error vector is larger than tolerance given and go to step (iii), else stop.

The iteration will continue until the desired solution is achieved.

2.2 Unified Power Flow Controller (UPFC)

2.2.1 Introduction

Nowadays, power systems are getting highly complex and require careful design of new devices taking into consideration on existing equipment, especially for transmission systems in new deregulated electricity markets. Flexible AC transmission system (FACTS) is a technology based solution to help electric utilities fully utilize their transmission assets. The two main objectives of FACTS are to increase the transmission capacity and control over flow over designated transmission routes [5].

These controllers are based on voltage source converters and include devices such as Static Var Compensators (SVCs), Static Synchronous Compensators (STATCOMs), Thyristor Controlled Series Compensators (TCSCs), Static Synchronous Series Compensators (SSSCs), and the Unified Power Flow Controllers (UPFCs) [6]. Among them, the UPFC is the most versatile and effective device which was introduced back in 1991 [7]. The UPFC is considered as the most effective FACTS controller, the most important characteristic of which is its multiple control functions, including power flow control, voltage control, transient stability improvement and oscillation damping.

The UPFC consists of voltage source converters, one connected in series and other in shunt and both are connected back to back through a DC capacitor. It can provide simultaneous control of all basic power system parameters, transmission voltage, impedance, and phase angle. In order to investigate the impact of UPFC on power systems effectively, it is essential to formulate their correct and appropriate model.

2.2.2 Operating Principle of UPFC

The UPFC consists of two basic components which are voltage source inverters (VSI). Both of them are sharing a common DC storage capacitor and connected to the power system through coupling transformers. It can be modeled as two ideal voltage sources, one connected in series and the other in shunt between the two buses (see Figure 1). The output of the series voltage source Vse and θse are controllable magnitude and angle between the limits $V_{se(max)} \leq V_{se} \leq V_{se(min)}$ and $0 \leq \theta_{se} \leq 2\pi$ respectively and of the shunt voltage source is V_{sh} and θ_{sh} are controllable between the limits $V_{sh(max)} \leq V_{sh} \leq V_{sh(min)}$ and $0 \leq \theta_{sh} \leq 2\pi$. Figure 1 shows the voltage source model of UPFC. The impedances of the two coupling transformer, which are Z_{se} and Z_{sh}, one connected in series and other in shunt between the line and the UPFC as shown in Figure 1 below below.

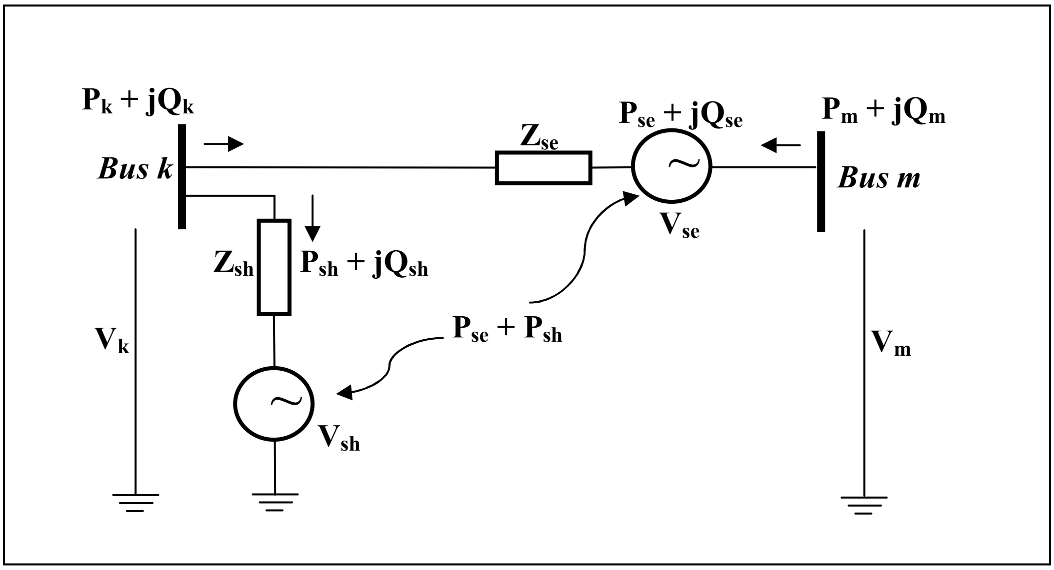

Figure 1: Voltage source model of UPFC [7]

One VSI is connected in shunt to transmission system via a shunt transformer, while the other one is connected in series through a series transformer. For the first VSI, this is connected in shunt via a shunt transformer. The shunt inverter is operated to demand DC terminal power (either positive or negative) from the line keeping the voltage across the storage capacitor constant. So, the net real power absorbed from the line by UPFC is equal to the losses of inverters and their transformers. The remaining capacity of shunt inverter used to exchange reactive power with the line is to provide a voltage regulator at the connection point. It is operating as a STATCOM which generates and absorbs reactive power to regulate the voltage magnitude at the connection point.

On the other hand, the series inverter, which is connected in series through a series transformer, is controlled to inject a symmetrical three phase voltage system (V_{se}), of controllable magnitude and phase angle in series with the line to control active and reactive power flows on the transmission line. Thus, the inverter will exchange the active and reactive power with the line. The reactive power is electronically provided by the series inverter and the active power is transmitted to the DC terminals. The series inverter is operating as SSSC that generates and absorbs reactive power to regulate the current flow, and the power flow on the transmission line [7].

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

The methodology describes the procedure of work of the project that need to be done throughout these two semesters.

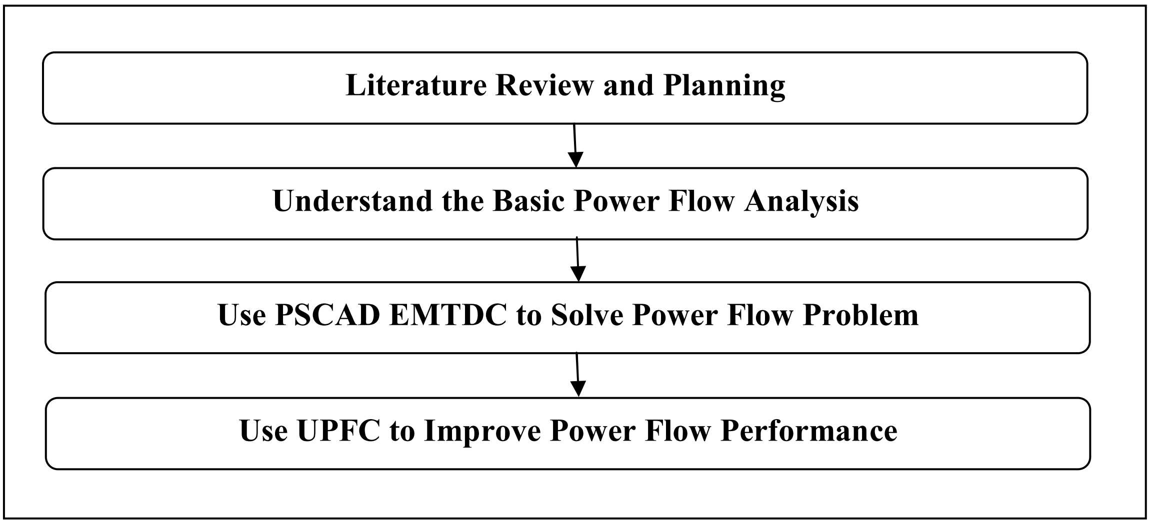

Figure 2: Sequential Procedures throughout the Project

The table below summarizes the division of works to be done for the project. See Appendix A for the project milestone.

Table 1: Division of Project Work

DIVISION	PROJECT WORK
FYP I	1. Literature review and planning. 2. Understand the basic Power Flow Analysis.
FYP II	3. Use PSCAD EMTDC software to solve the power flow problem. 4. Use UPFC to improve power flow performance.

3.2 Tools/Equipment required

3.2.1 PSCAD EMTDC Software

For this study, simulation software, PSCAD EMTDC Version 4.2.0 is used as modeling tool for designing and analyzing power system. The performance of power systems with all associated generation, transmission lines, loads, and controls can be analyzed including the capability to include a system such as UPFC in the transmission system.

3.3 Procedure

3.3.1 Literature Review and Planning

The first phase of the project is to review and plan for the whole project which consist of two semesters. Research is done to gain deeper understanding on the concepts and overall picture on what the project is all about. The study on the power flow analysis is needed so that the project can be done smoothly by having a strong understanding on the power flow itself. Then the loss in the transmission line is studied, which the characteristics of transmission lines were investigated and the mathematical interpretation of the loss. Next, understanding on the role of FACTS devices especially the UPFC is gained, and later proceed to the basic principles of operation and how the loss reduction and flat voltage profile is achieved by installing the device.

3.3.2 Understand the Basic Power Flow Analysis

The study on the power flow analysis as well as programming using MATLAB software was done. This was done to familiarize and to gain a deeper understanding on the concepts of the power flow. By having a strong basic knowledge on power flow analysis, then will proceed to the second phase, which is to improve the power flow performance in a transmission network by using other software, which is PSCAD EMTDC, the proposed software that need to be use in this project.

3.3.3 Use PSCAD Software to Solve the Power Flow Problem

a) Familiarization of PSCAD Software

At this stage of project, which is the second semester, a simulation of a transmission system was done by using PSCAD EMTDC software. Before proceed on any simulation, user need to familiarize with the software itself. During this process, the first step is to browse through the Master Library of PSCAD EMTDC to see available components. The help command is useful to learn and search for details information on the related components. To have more understanding on how to model a system using this software, there are example cases and tutorials provided is studied.

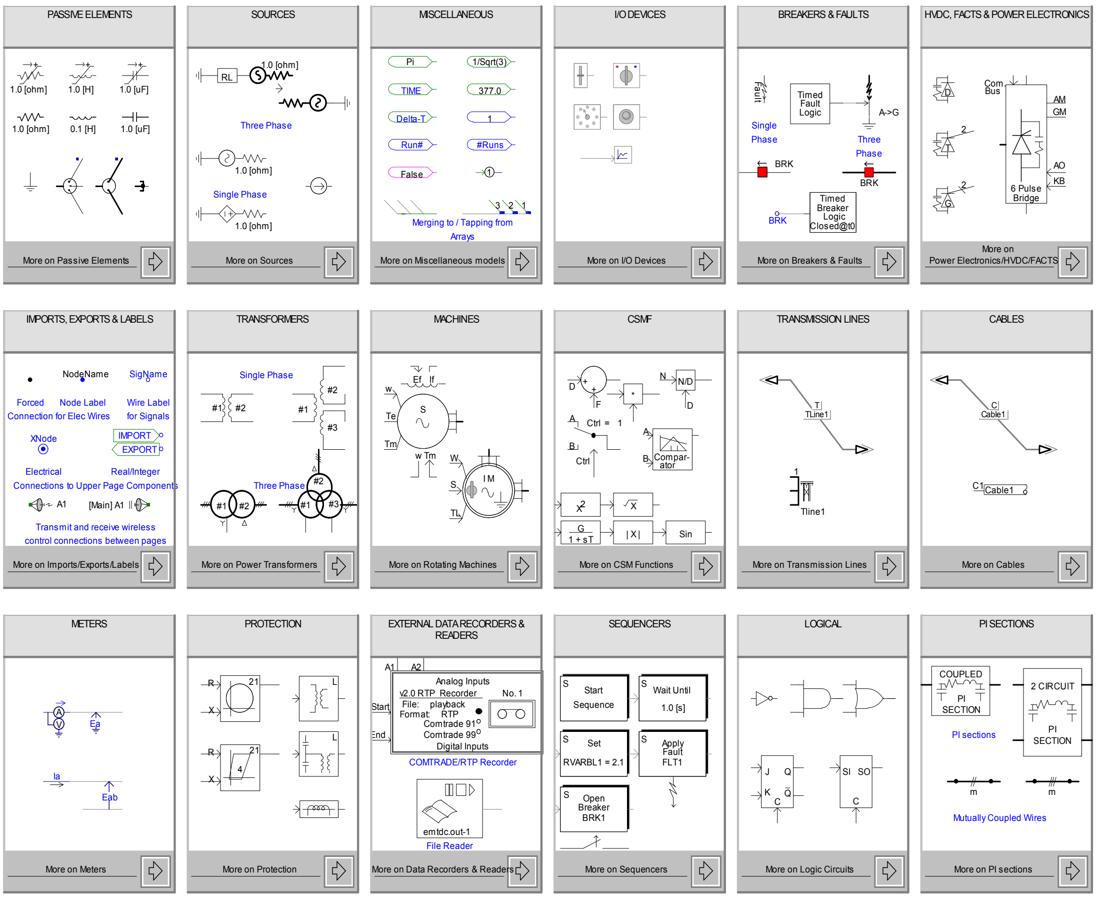

Figure 3: PSCAD EMTDC V4.2.0 Master Library

During the familiarization process, the EMTDC user guide is important to have a basic knowledge on the software. There are some criteria needed to be focused on which are:

i. nodes and data labeling
ii. components and connectivity
iii. performance and measurement indication
iv. components configuration
v. plotting graphs
vi. data manipulation and analysis

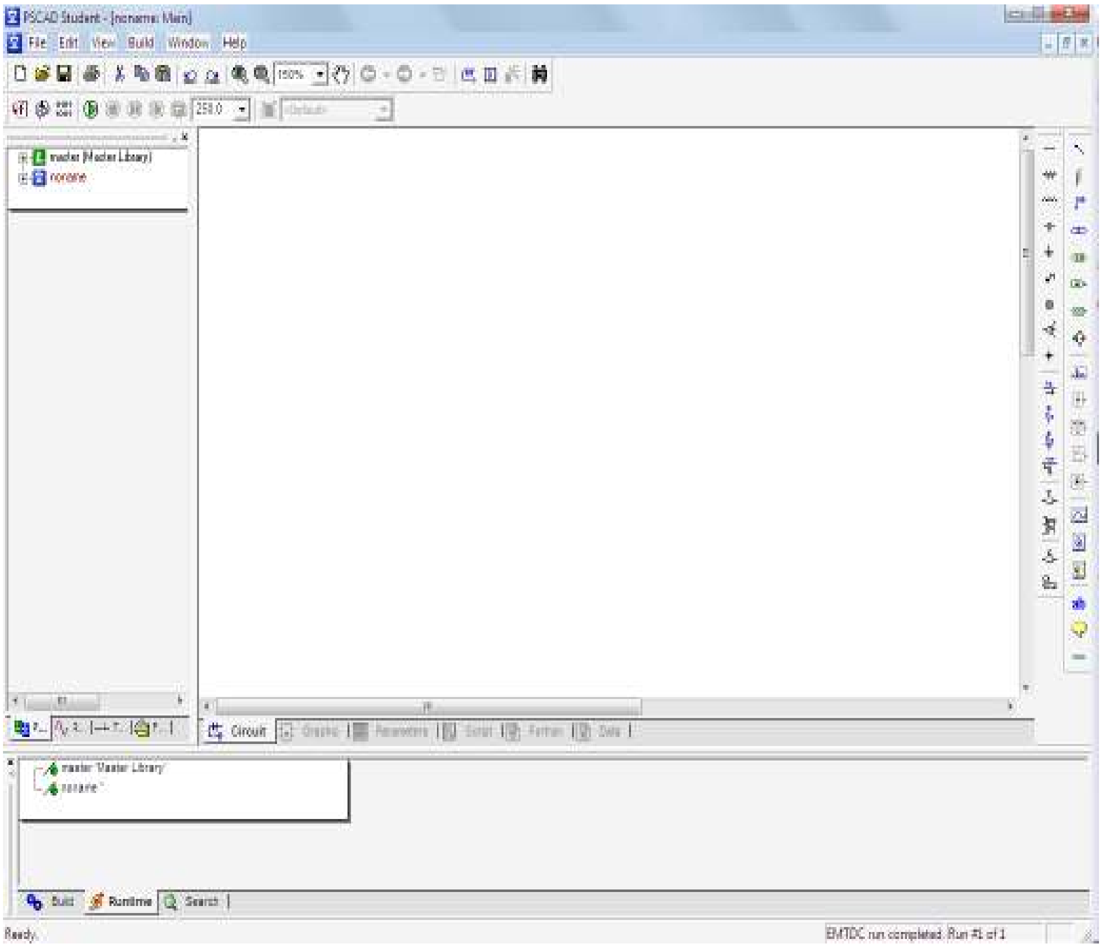

Figure 4: PSCAD Graphic User Interface (GUI)

b) Understanding UPFC Modeling In PSCAD

The UPFC Model consists of three major components:

i. Converter
ii. Transformer
iii. Control System

i. Converter

The solid state switches such as Insulated Gate Bipolar Junction (IGBT) and Gate Turn Off Thyristor (GTO) are widely used for switching the converters as it could deal with high voltage and current ratings, even for substantial high-power application. The first step of designing is to choose between GTO and IGBT as the switching device.

The converter is formed by using GTO. GTO is chosen since it has fully controllable switch which can be turned on and off by the GATE lead. Compared with IGBT, IGBT is turned off by zero gate voltage but GTO is turned off by applying negative gate signal. Firgure 5 shows the schematic symbol of GTO.

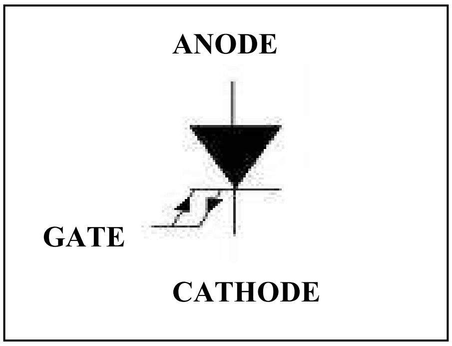

Figure 5: GTO Schematic Diagram

Characteristics of GTO are:

- Can be turned-on by a gate signal
- Can be turned-off by a gate signal of negative polarity

The firing angle of the GTO is controlled by using Pulse Width Modulator (PWM) technique. The modeling for the converter is done by using the six pulse bridge configuration for both series and shunt converter. They are separated by DC capacitor.

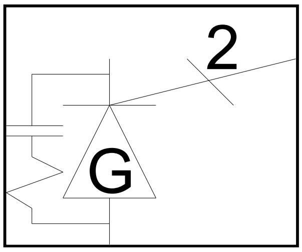

Figure 6: GTO Model in PSCAD

ii. Transformer

There are two tansformers required for the UPFC model, which are the Boost Transformer and the Potential Transformer. Both of them are having star connection on the transmission system side and delta connection on the converter side.

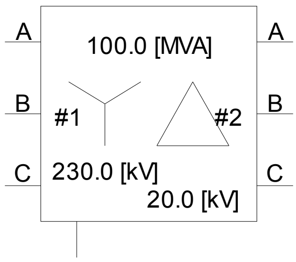

Figure 7: Potential Transformer

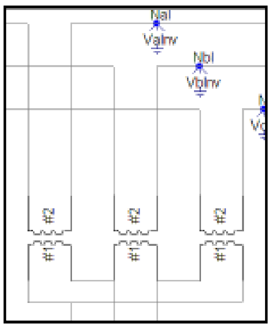

Figure 8: Boost Transformer

3.3.4 Use UPFC to Improve Power Flow Performance

After the familiarization with the PSCAD and had the basic understanding on the power flow analysis itself, then can proceed with simulation by using the software stated. A 5 bus system constructed and simulated without adding any FACTS device. Then proceed by adding UPFC into the transmission system and both results were compared in terms of the voltage magnitude and phase angle. An analysis need to be done by varying the value of phase angle in the system where UPFC were added in the system to see the best results while comparing with the one without UPFC.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 5-Bus System Without UPFC

A 5-bus system was constructed using PSCAD EMTDC and the simulation yielded the required results.

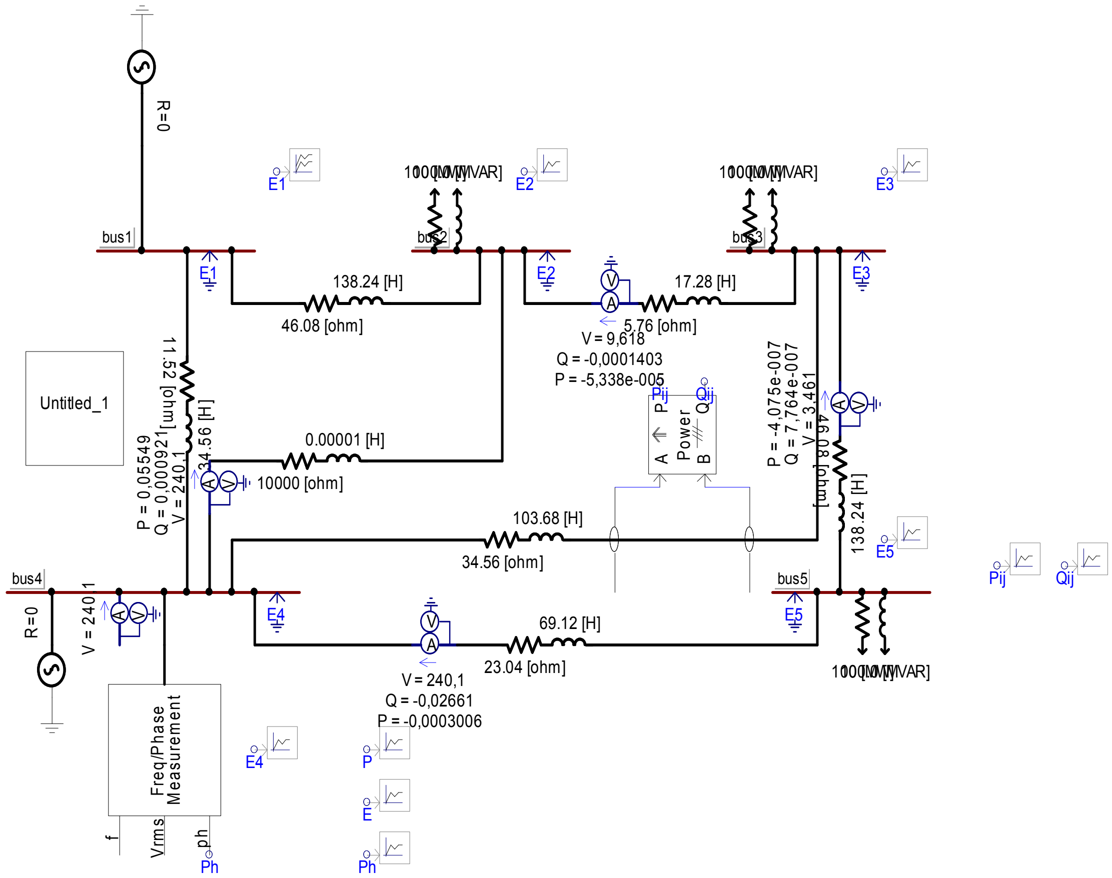

Figure 9: 5-Bus System

Thus, the simulated cases in PSCAD yielded the following results:

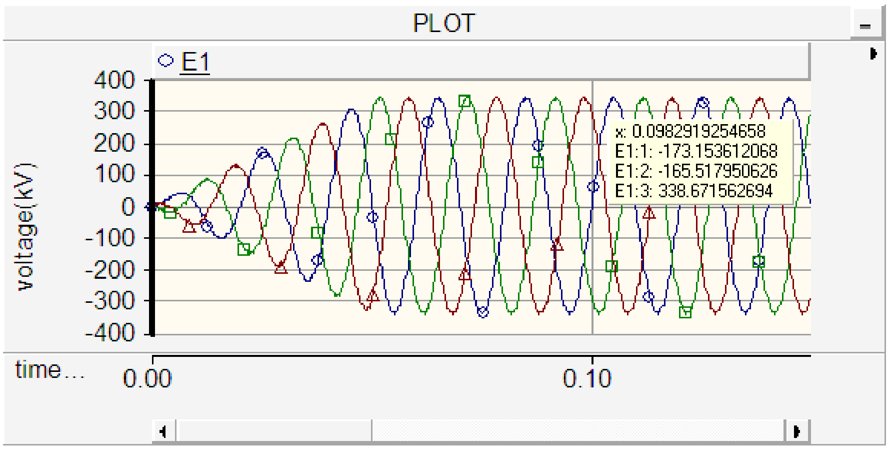

Figure 10: Voltage at Bus 1 (North)

The voltage at Bus 1 is measured to be 293kV. It can be seen by applying a voltmeter to view the measured voltage as shown in Figure 11 below.

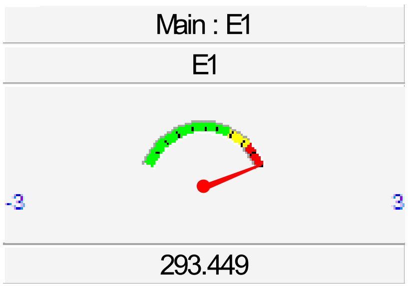

Figure 11: Voltage at E1 using Voltmeter

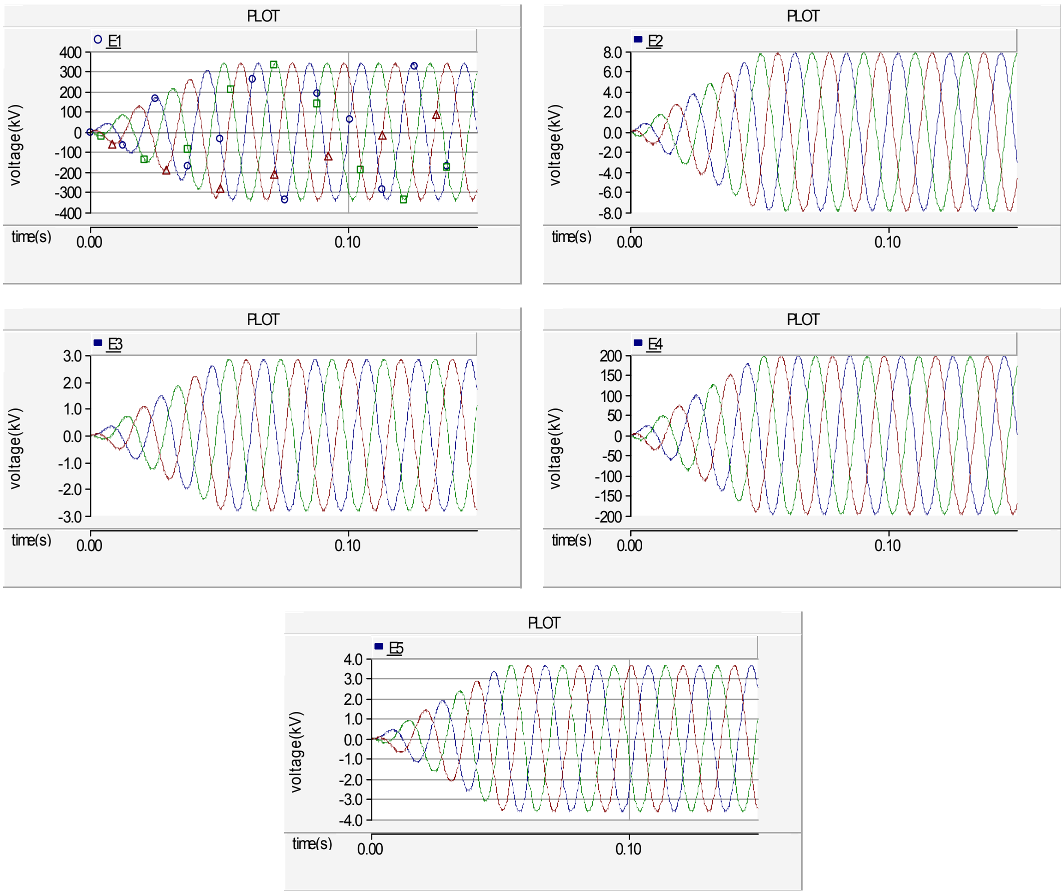

Figure 12: Voltages at each bus

The voltages were measured at each bus. At Bus 1, a clean graph is obtained as there is no inductance and resistance that has been injected to the bus and a voltage source is being injected as well. Where else, for other buses, there are some spike happened to the graph as the inductance and resistance were injected to the respective buses.

4.2 5-Bus System With UPFC

The 5 bus network is tested with UPFC to investigate its behavior. To include the UPFC in the network, an additional bus is introduced [5, 7]. The UPFC shunt converter is set to regulate node 3 voltage magnitude at 1pu while series converter regulates the power flow between the two nodes. Flat voltage start is assumed for the two UPFC voltage sources. The circuit diagram of UPFC and graphs obtained is attached in Appendix B-1 and Appendix B-2.

4.3 Simulation Results

The simulation has been conducted on 5-Bus system. The power system network was modeled. The real power and reactive power are examined. The following simulations are made for evaluating the performance of the UPFC placed between various buses. For each test case, the power system network without the UPFC is taken as reference.

4.3.1 5-Bus Test System

The power flow analysis has been performed on four test cases. The four cases are presented as follows:

i. Case 1: Power flow analysis without FACTS controller
ii. Case 2: Power flow analysis with UPFC installed between Bus 2 and Bus 3
iii. Case 3: Power flow analysis with UPFC installed between Bus 3 and Bus 5
iv. Case 4: Power flow analysis with UPFC installed between Bus 4 and Bus 5

Analysis is conducted on real power and reactive power at all buses for all four cases. The real and reactive power losses for each case are then evaluated.

i. Case 1 (Power flow analysis without FACTS controller).
   In case 1, power flow analysis is performed on the 5-Bus system without the FACTS controller. The value of active and reactive powers for each case obtained from the simulation were marked by a red coloured circles in Figure 13. The power flow parameter and graphs is attached in Appendix C-2 and Appendix C-3.

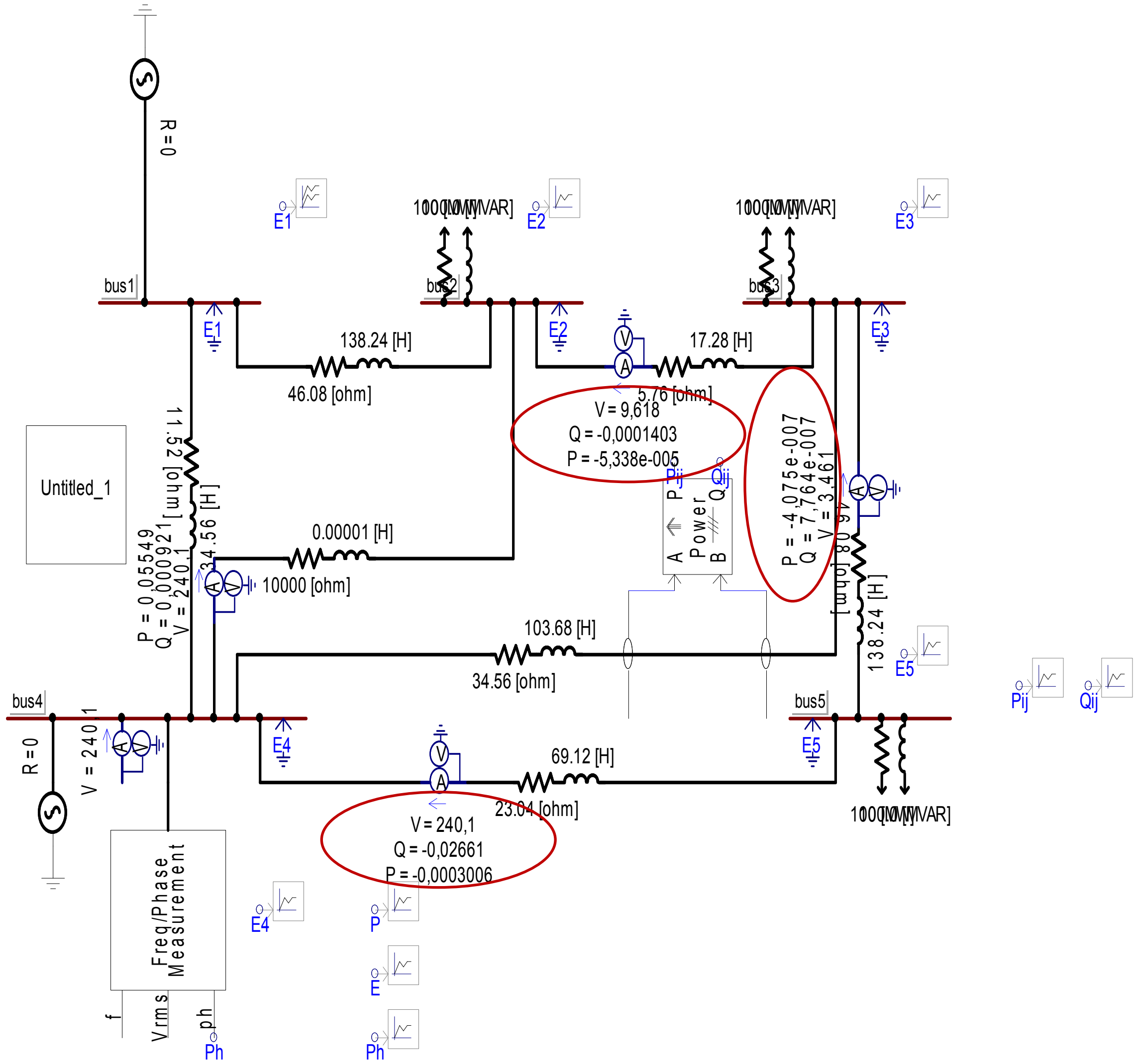

Figure 13: 5-Bus System – Case 1 Power System Model

Table 2: Case 1-Active and Reactive Powers

Bus	P Flow (p.u)	Q Flow (p.u)	P Loss (p.u)	Q Loss (p.u)
Bus 2 and Bus 3	-5.338e-005	-0.0001403	0.03647	0.00214
Bus 3 and Bus 5	-4.075e-007	7.764e-007	0.00477	-0.000749
Bus 4 and Bus 5	-0.0003006	-0.02661	0.0005835	0.05264

ii. Case 2 (Power flow analysis with UPFC installed between Bus 2 and Bus 3). In case 2, power flow analysis is performed on the 5-Bus system with the UPFC is installed between Bus 2 and Bus 3. The value of active and reactive powers obtained from the simulation were marked by a red coloured circle in Figure 14. The power flow parameter and graphs is attached in Appendix D-2 and Appendix D-3.

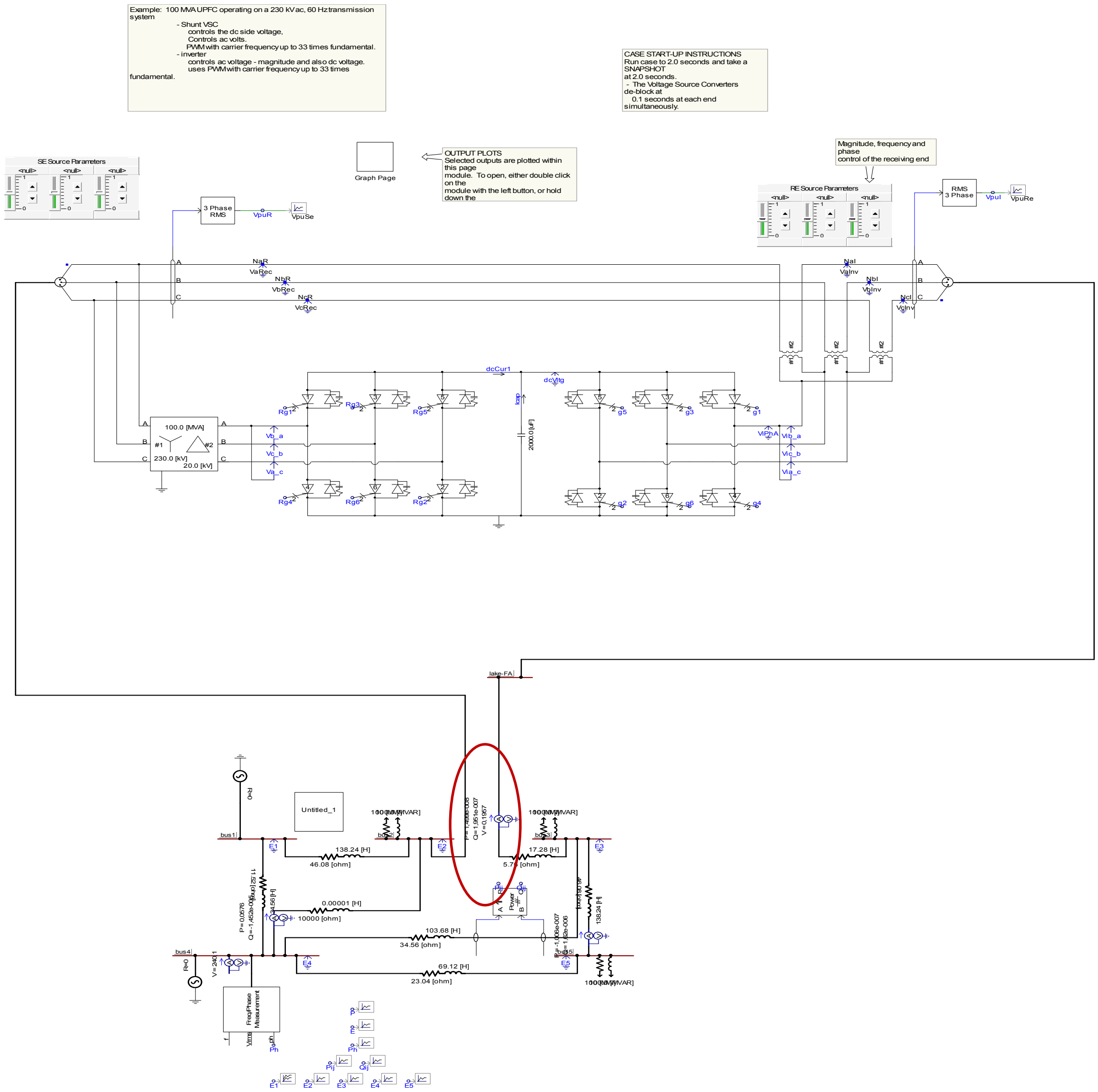

Figure 14: 5-Bus System – Case 2 Power System Model

Table 3: Case 2-Active and Reactive Powers

Bus	P Flow (p.u)	Q Flow (p.u)	P Loss (p.u)	Q Loss (p.u)
Bus 2 and Bus 3	1.499e-008	1.951e-007	0.03597	0.0001403

iii. Case 3 (Power flow analysis with UPFC installed between Bus 3 and Bus 5). In case 3, power flow analysis is performed on the 5-Bus system with the UPFC is installed between Bus 3 and Bus 5. The value of active and reactive powers obtained from the simulation were marked by a red coloured circle in Figure 15. The power flow parameter and graphs is attached in Appendix E-2 and Appendix E-3.

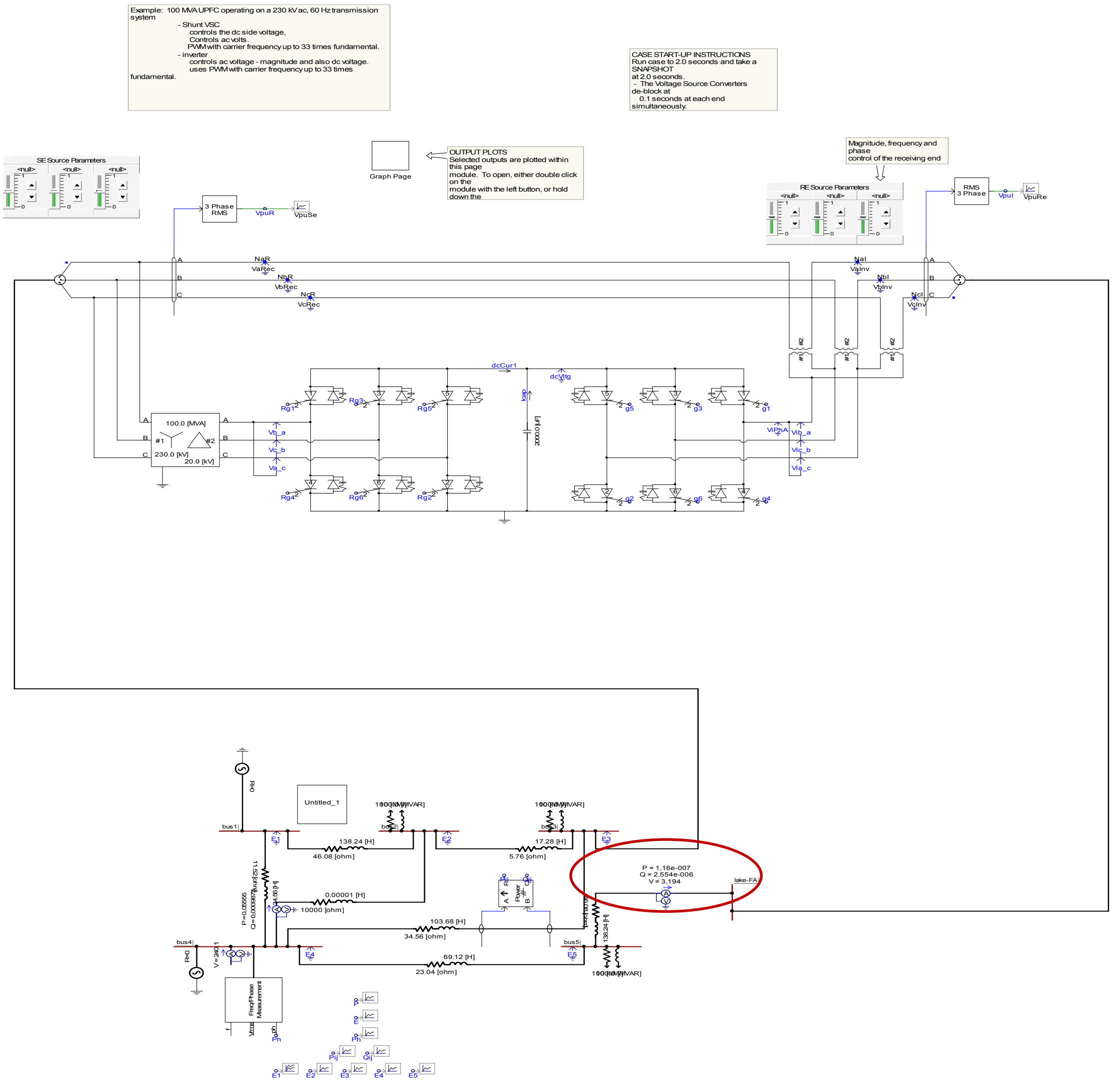

Figure 15: 5-Bus System – Case 3 Power System Model

Table 4: Case 3-Active and Reactive Powers

Bus	P Flow (p.u)	Q Flow (p.u)	P Loss (p.u)	Q Loss (p.u)
Bus 3 and Bus 5	1.16e-007	2.554e-006	0.003716	0.0070799

iv. Case 4 (Power flow analysis with UPFC installed between Bus 4 and Bus 5). In case 4, power flow analysis is performed on the 5-Bus system with the UPFC is installed between Bus 4 and Bus 5. The value of active and reactive powers obtained from the simulation were marked by a red coloured circle in Figure 16. The power flow parameter and graphs is attached in Appendix F-2 and Appendix F-3.

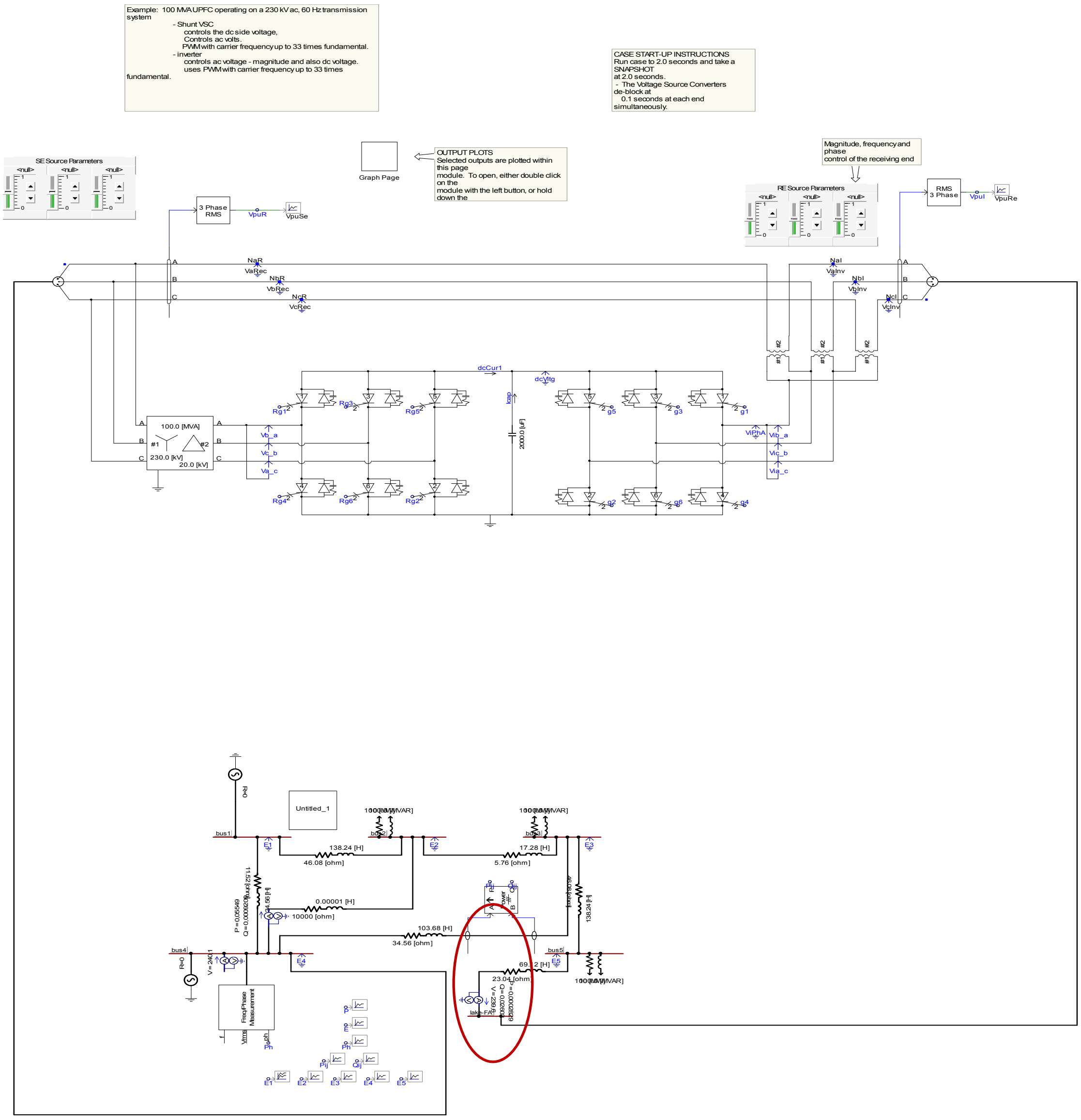

Figure 16: 5-Bus System – Case 4 Power System Model

Table 5: Case 4-Active and Reactive Powers

Bus	P Flow (p.u)	Q Flow (p.u)	P Loss (p.u)	Q Loss (p.u)
Bus 4 and Bus 5	0.0002829	0.02603	0.0003006	0.02661

Table 6: Reduction in Real and Reactive Power Losses (%) of 5-Bus System

Test Case	Reduction in Real Power Losses (%)	Reduction in Reactive Power Losses (%)
Case 2	1.37	93.44
Case 3	22.10	5.48
Case 4	48.48	49.45

For the Real Power Losses, the largest reduction is found by incorporating the UPFC between Bus 4 and Bus 5, which has been reduced by 48.48%. the least amount of reduction in real power lossses occured for case 2 (between Bus 2 and Bus 3).

The negative sign in the reactive power losses indicates that the reactive losses are capacitive, while the positive sign is inductive. For Reactive Power Losses, the greatest reduction is found between Bus 2 and Bus 3, which is case 2. It has been reduced to 93.44%. the reactive power losses reduction is in the range of 5.48% to 93.44%. The least amount of reduction in real power losses occured for case 3 (UPFC installed between Bus 3 and Bus 5).

The objective of installing the UPFC has been achieved for both real and reactive power, as the total losses have reduced in all cases.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The power flow analysis is the fundamental key in improving the performance of a transmission network. By understanding the power flow analysis, the operation and role of the UPFC are made clearer. In this project, the PSCAD EMTDC software is used to simulate a transmission system with and without UPFC whereby the effect of UPFC reduced the loss. UPFC provides solution to overcome loss in transmission line by injecting the series voltage which is controllable in magnitude and phase with the line voltage.

5.2 Recommendation

The transmission system was improved by adding the UPFC and the simulation result is compared. There are a few recommendations that can be done as below:

i. The effectiveness of UPFC can be analyzed in a large transmission system.
ii. The improvement of UPFC can also be compare with other FACTS devices.

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[5] Enrique Acha, Claudio R. Fuerte-Esquivel, Hugo Ambriz-Pérez, and César Angeles-Camacho, “FACTS Modeling and Simulation in Power Networks” Wiley, 2004.

[6] S. Tara Kalyani and G. Tularisam Das, “Simulation of Real and Reactive Power Flow Control with UPFC Connected to a Transmission Line” JATIT, 2008.

[7] Samina Elyas Mubeen, R. K. Nema, and Gayatri Agnihotri, “Power Flow Control with UPFC in Power Transmission System”, July 2008.

[8] Hadi Saadat, “Power System Analysis”, McGraw-Hill Higher Education Second Edition,, 2002.

APPENDICES

APPENDIX A
PROJECT MILESTONE

Gantt chart for Phase 1 – Final Year Project I

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Selection of Project Topic	■														
	- Propose Topic	■														
	- Confirmation of Topic Selection		■													
2	Preliminary Research Work		■	■	■											
	- Data collection			■	■											
	- Literature review motor, its major concepts and faults			■	■	■	■									
3	Submission of Preliminary Report															
4	Project Work				■	■	■	■								
	- Data reduction and presentation					■	■	■								
5	Submission of Progress Report								●							
6	Project work continue / simulation								■	■	■	■	■			
7	Submission of Interim Report Final Draft													●		
8	Submission of Interim Report														●	
9	Oral Presentation															●
		●	Milestone													
		■	Process													

Gantt chart for Phase 2 – Final Year Project II

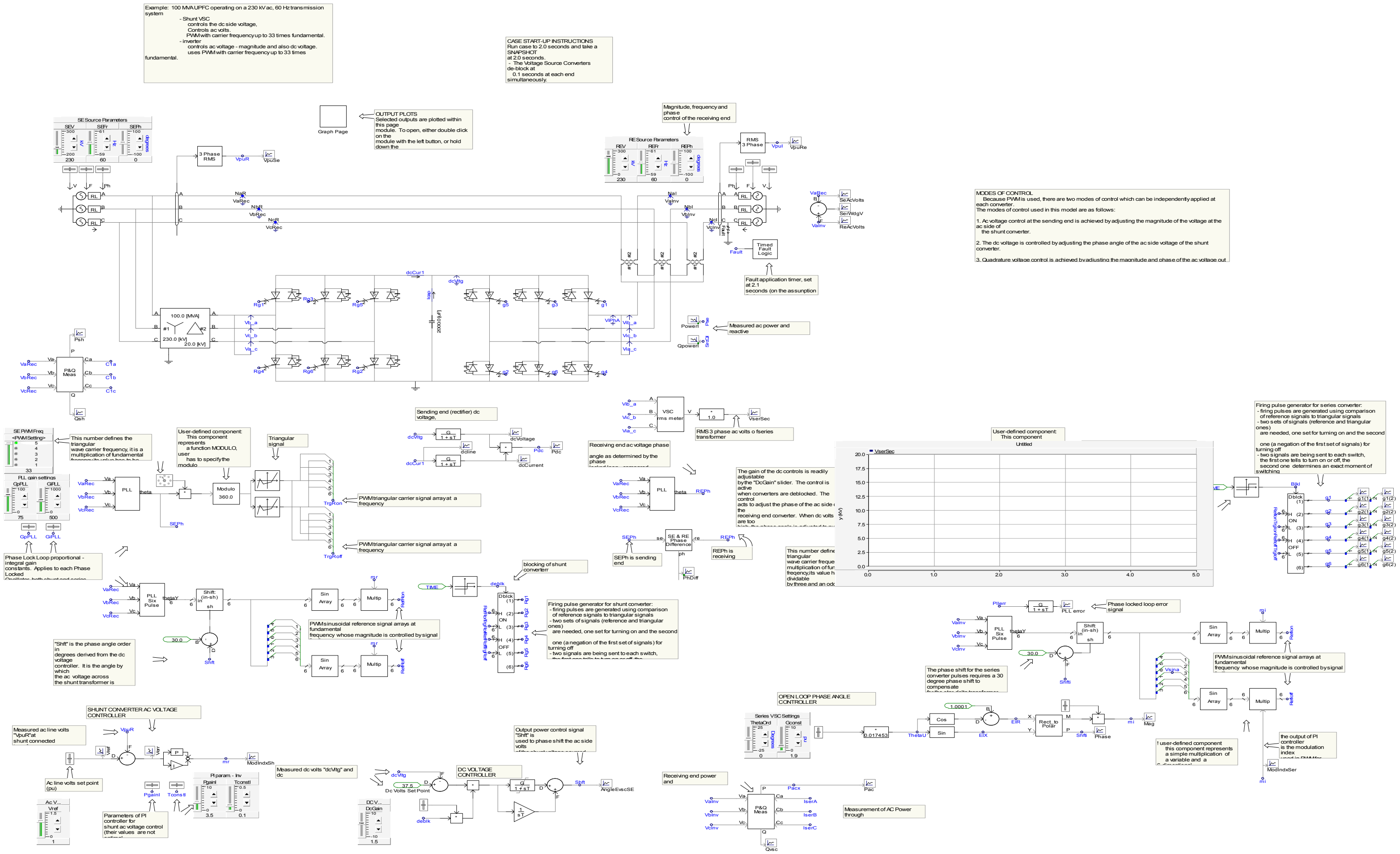
No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project Work Continue	■	■	■							Mid-Semester Break					
2	Submission of Progress Report									●						
3	Seminar											■	■			
4	Project work continue								■	■		■	■			
5	Poster Exhibition												●			
6	Submission of Dissertation (soft bound)													●		
7	Oral Presentation														●	
8	Submission of Project Dissertation (Hard															●

● Suggested milestone

■ Process

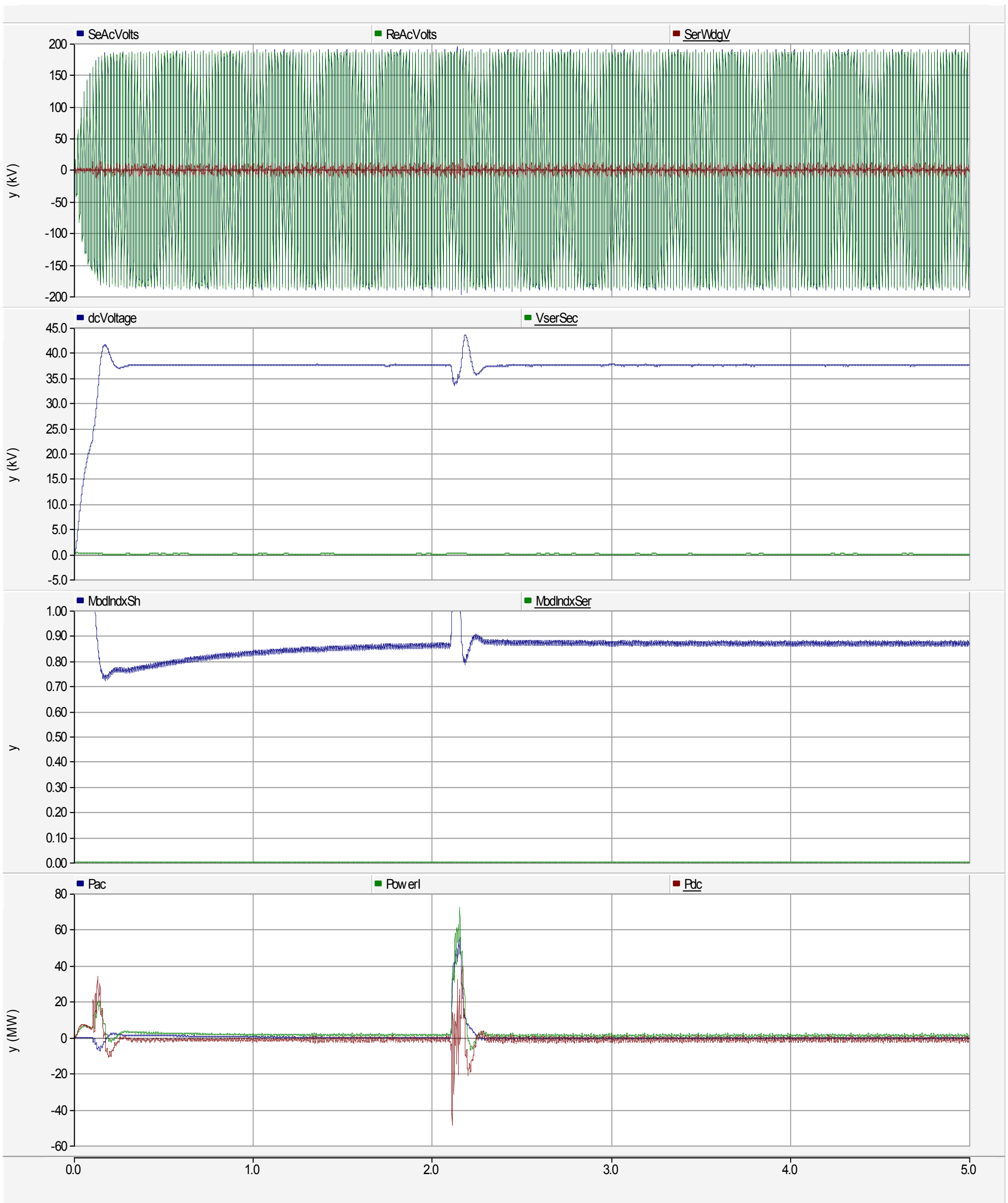
APPENDIX B
UPFC DIAGRAM

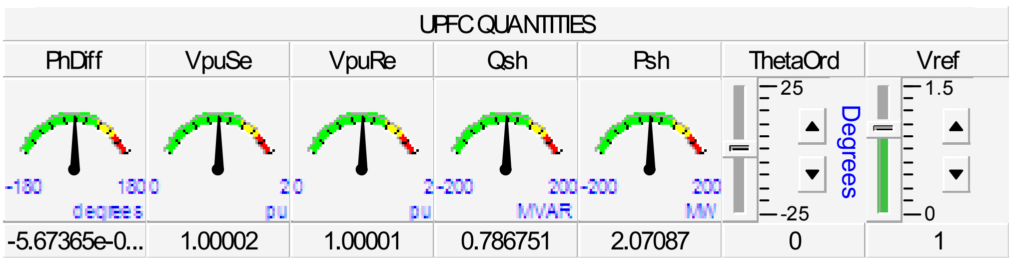
APPENDIX B-1
UPFC CIRCUIT DIAGRAM



APPENDIX B-2

UPFC: GRAPH



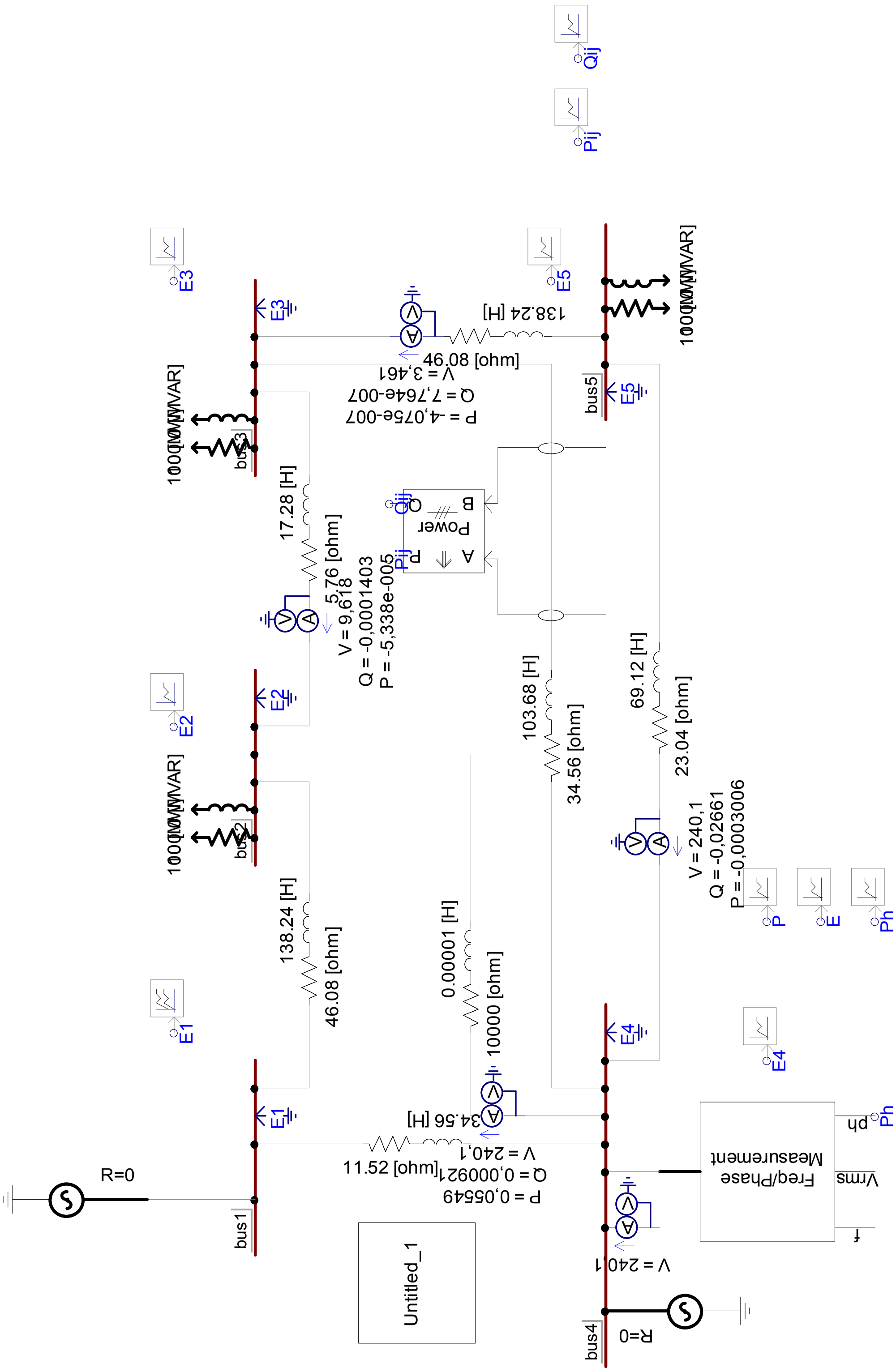


APPENDIX C

CASE 1: POWER FLOW ANALYSIS WITHOUT FACTS CONTROLLER

APPENDIX C-1

CASE 1: CIRCUIT DIAGRAM



APPENDIX C-2

CASE 1: POWER FLOW PARAMETER

POWER FLOW PARAMETER BETWEEN BUS 2 AND BUS 3

NAME	CAPTION	TYPE	UNIT	MINIMUM	MAXIMUM	DATA	VALUE
MeasI	Measure Instantaneous Current	Choice				0	0
MeasV	Measure Instantaneous Voltage	Choice				0	0
MeasP	Measure Active Power flow	Choice				1	1
MeasQ	Measure Reactive Power flow	Choice				1	1
RMS	Measure RMS voltage	Choice				1	1
MeasPh	Measure Phase Angle	Choice				2	2
S	Base MVA for per unitizing	Real	MVA	0	500	100.0 [MVA]	100.0
BaseV	Base voltage for per unitizing	Real	kV	0	500	1.0 [kV]	1.0
TS	Smoothing Time Constant	Real	s	0	1	0.02 [s]	0.02
Freq	Frequency	Real	Hz	0	1,00E+38	50.0 [Hz]	50.0
Dis	Animated Display?	Choice				1	1
CurI	Instantaneous Current	String					
VolI	Instantaneous Voltage	String					
P	Active Power	String				P23	P23
Q	Reactive Power	String				Q23	Q23
Vrms	RMS voltage	String					
Ph	Phase Angle	String				Ph23	Ph23
hide1	power	Choice				1	1
hide2	rms voltage	Choice				1	1
Pd	Active Power	String				-5,34E-05	-5,34E-05
Qd	Reactive Power	String				-0,0001403	-0,00014
Vd	RMS Voltage	String				9,618	9,618

POWER FLOW PARAMETER BETWEEN BUS 3 AND BUS 5

NAME	CAPTION	TYPE	UNIT	MINIMUM	MAXIMUM	DATA	VALUE
MeasI	Measure Instantaneous Current	Choice				0	0
MeasV	Measure Instantaneous Voltage	Choice				0	0
MeasP	Measure Active Power flow	Choice				1	1
MeasQ	Measure Reactive Power flow	Choice				1	1
RMS	Measure RMS voltage	Choice				1	1
MeasPh	Measure Phase Angle	Choice				2	2
S	Base MVA for per unitizing	Real	MVA	0	500	100.0 [MVA]	100.0
BaseV	Base voltage for per unitizing	Real	kV	0	500	1.0 [kV]	1.0
TS	Smoothing Time Constant	Real	s	0	1	0.02 [s]	0.02
Freq	Frequency	Real	Hz	0	1,00E+38	50.0 [Hz]	50.0
Dis	Animated Display?	Choice				1	1
CurI	Instantaneous Current	String					
VolI	Instantaneous Voltage	String					
P	Active Power	String				P35	P35
Q	Reactive Power	String				Q35	Q35
Vrms	RMS voltage	String					
Ph	Phase Angle	String				Ph35	Ph35
hide1	power	Choice				1	1
hide2	rms voltage	Choice				1	1
Pd	Active Power	String				-4,08E-07	-4,08E-07
Qd	Reactive Power	String				7,76E-07	7,76E-07
Vd	RMS Voltage	String				3,461	3,461

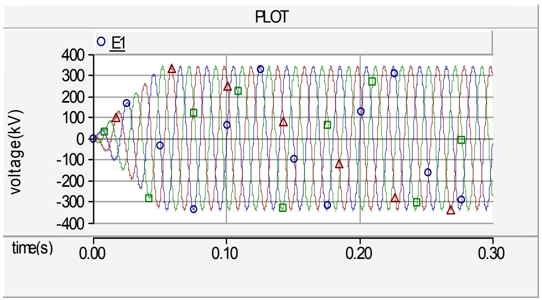
POWER FLOW PARAMETER BETWEEN BUS 4 AND BUS 5

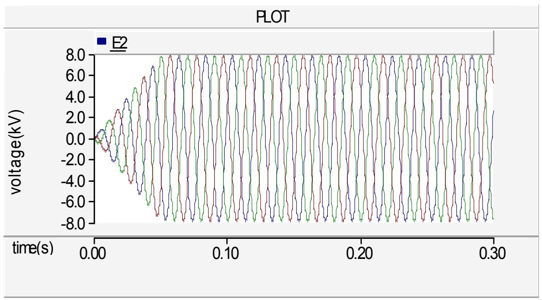
NAME	CAPTION	TYPE	UNIT	MINIMUM	MAXIMUM	DATA	VALUE
MeasI	Measure Instantaneous Current	Choice				0	0
MeasV	Measure Instantaneous Voltage	Choice				0	0
MeasP	Measure Active Power flow	Choice				1	1
MeasQ	Measure Reactive Power flow	Choice				1	1
RMS	Measure RMS voltage	Choice				1	1
MeasPh	Measure Phase Angle	Choice				2	2
S	Base MVA for per unitizing	Real	MVA	0	500	100.0 [MVA]	100.0
BaseV	Base voltage for per unitizing	Real	kV	0	500	1.0 [kV]	1.0
TS	Smoothing Time Constant	Real	s	0	1	0.02 [s]	0.02
Freq	Frequency	Real	Hz	0	1,00E+38	50.0 [Hz]	50.0
Dis	Animated Display?	Choice				1	1
CurI	Instantaneous Current	String					
VolI	Instantaneous Voltage	String					
P	Active Power	String				P45	P45
Q	Reactive Power	String				Q45	Q45
Vrms	RMS voltage	String					
Ph	Phase Angle	String				Ph45	Ph45
hide1	power	Choice				1	1
hide2	rms voltage	Choice				1	1
Pd	Active Power	String				-3,01E-04	-3,01E-04
Qd	Reactive Power	String				-2,66E-02	-2,66E-02
Vd	RMS Voltage	String				240,1	240,1

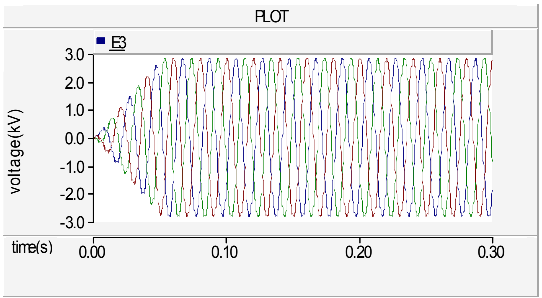
APPENDIX C-3

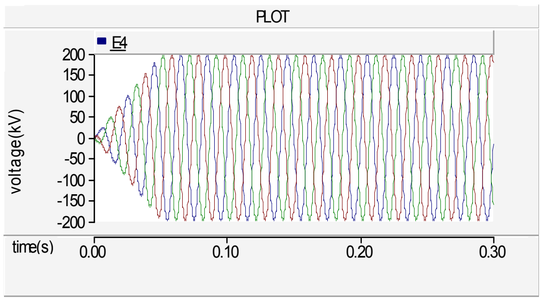
CASE 1: GRAPH

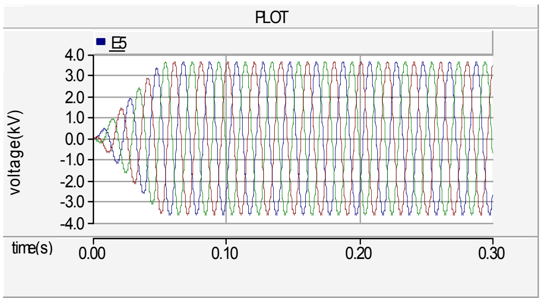
VOLTAGES AT EACH BUS

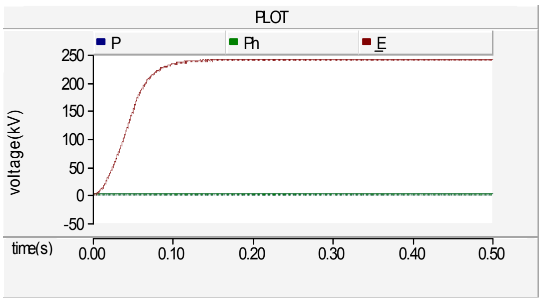










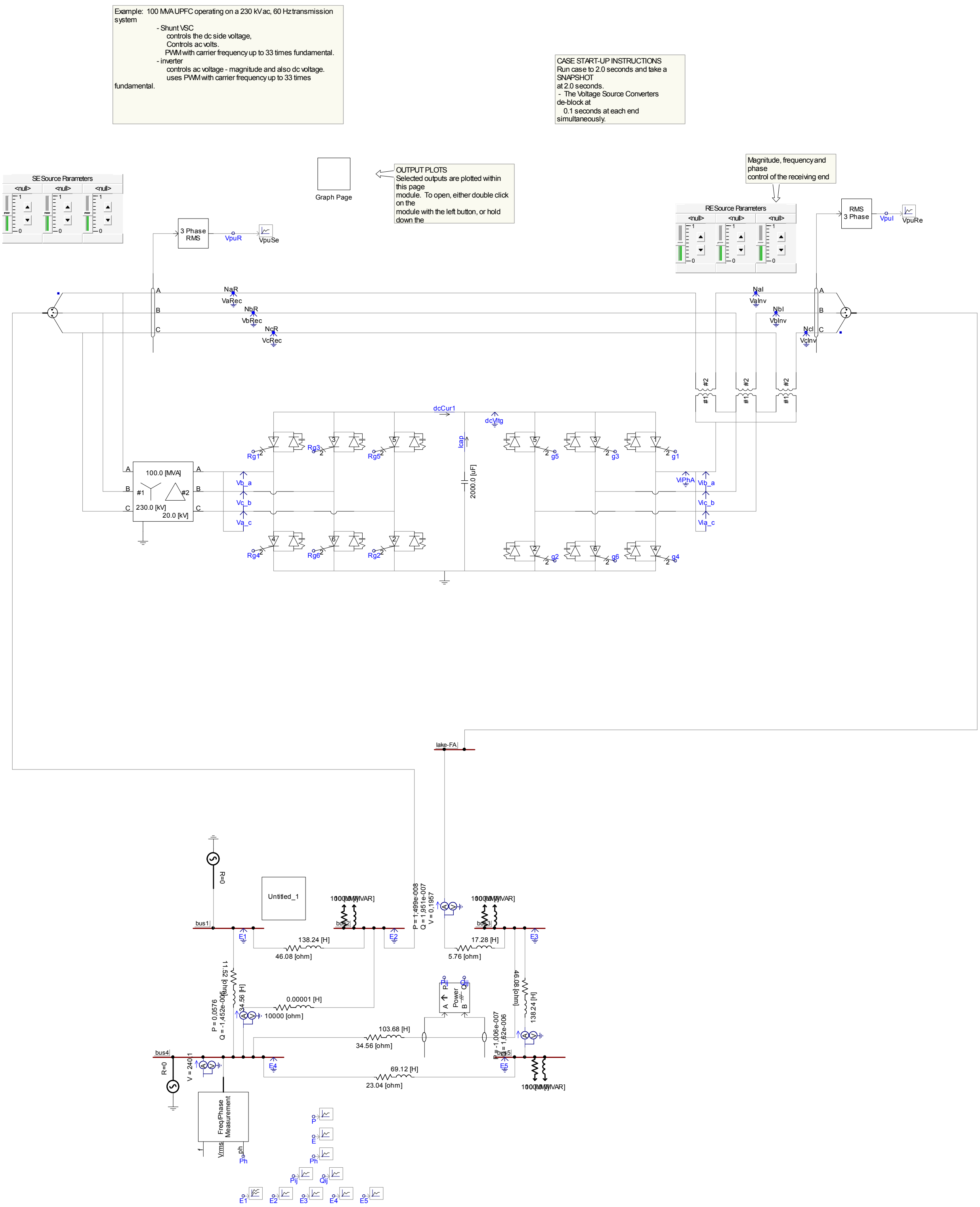


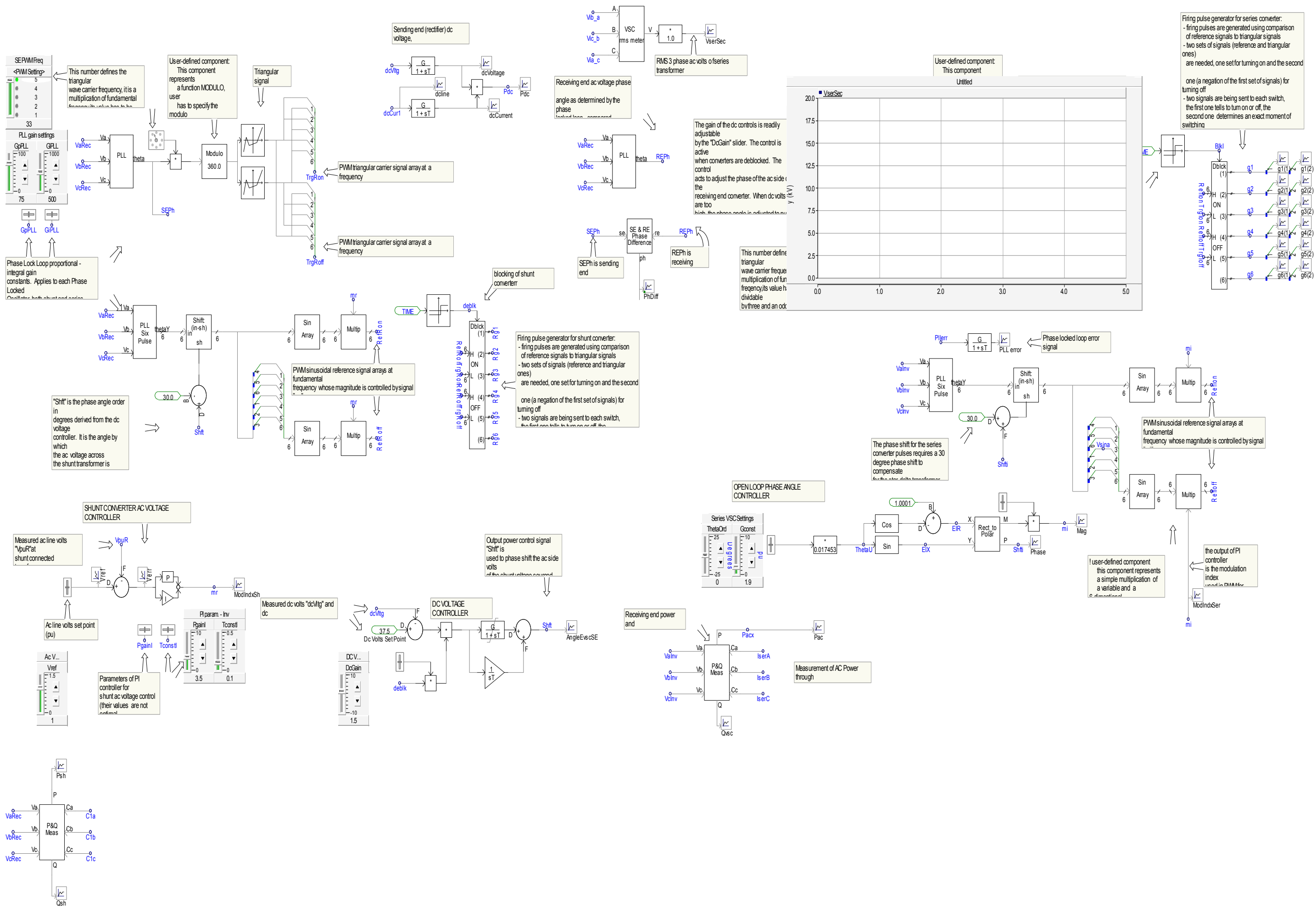
APPENDIX D

CASE 2: POWER FLOW ANALYSIS WITH UPFC INSTALLED BETWEEN BUS 2 AND BUS 3

APPENDIX D-1

CASE 2: CIRCUIT DIAGRAM





APPENDIX D-2

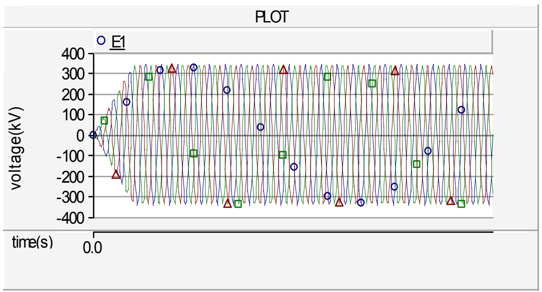
CASE 2: POWER FLOW PARAMETER

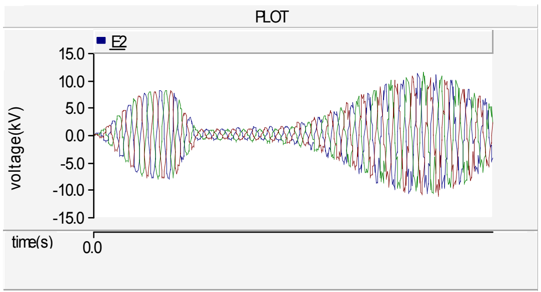
NAME	CAPTION	TYPE	UNIT	MINIMUM	MAXIMUM	DATA	VALUE
MeasI	Measure Instantaneous Current	Choice				0	0
MeasV	Measure Instantaneous Voltage	Choice				0	0
MeasP	Measure Active Power flow	Choice				1	1
MeasQ	Measure Reactive Power flow	Choice				1	1
RMS	Measure RMS voltage	Choice				1	1
MeasPh	Measure Phase Angle	Choice				2	2
S	Base MVA for per unitizing	Real	MVA	0	500	100.0 [MVA]	100.0
BaseV	Base voltage for per unitizing	Real	kV	0	500	1.0 [kV]	1.0
TS	Smoothing Time Constant	Real	s	0	1	0.02 [s]	0.02
Freq	Frequency	Real	Hz	0	1,00E+38	50.0 [Hz]	50.0
Dis	Animated Display?	Choice				1	1
CurI	Instantaneous Current	String					
VolI	Instantaneous Voltage	String					
P	Active Power	String				P23	P23
Q	Reactive Power	String				Q23	Q23
Vrms	RMS voltage	String					
Ph	Phase Angle	String				Ph23	Ph23
hide1	power	Choice				1	1
hide2	rms voltage	Choice				1	1
Pd	Active Power	String				1,50E-08	1,50E-08
Qd	Reactive Power	String				1,95E-07	1,95E-07
Vd	RMS Voltage	String				0,1957	0,1957

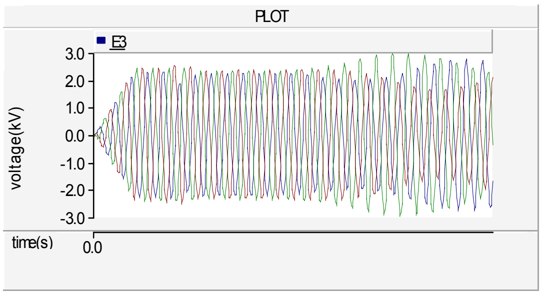
APPENDIX D-3

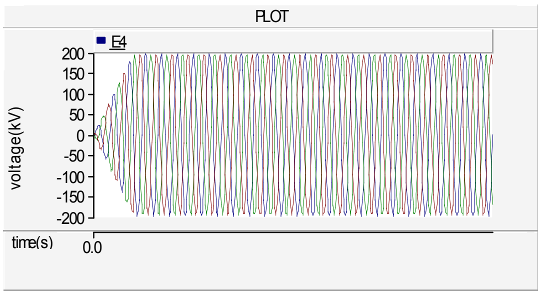
CASE 2: GRAPH

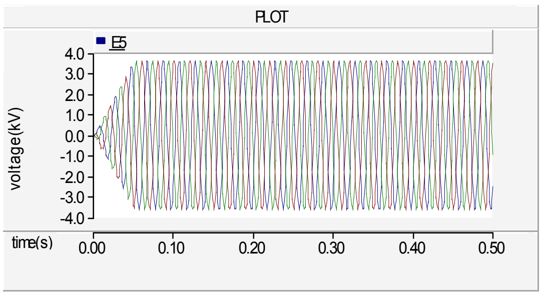
VOLTAGES AT EACH BUS

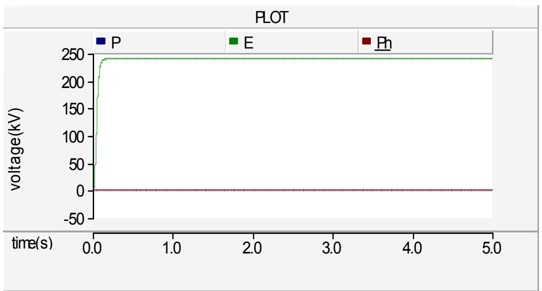


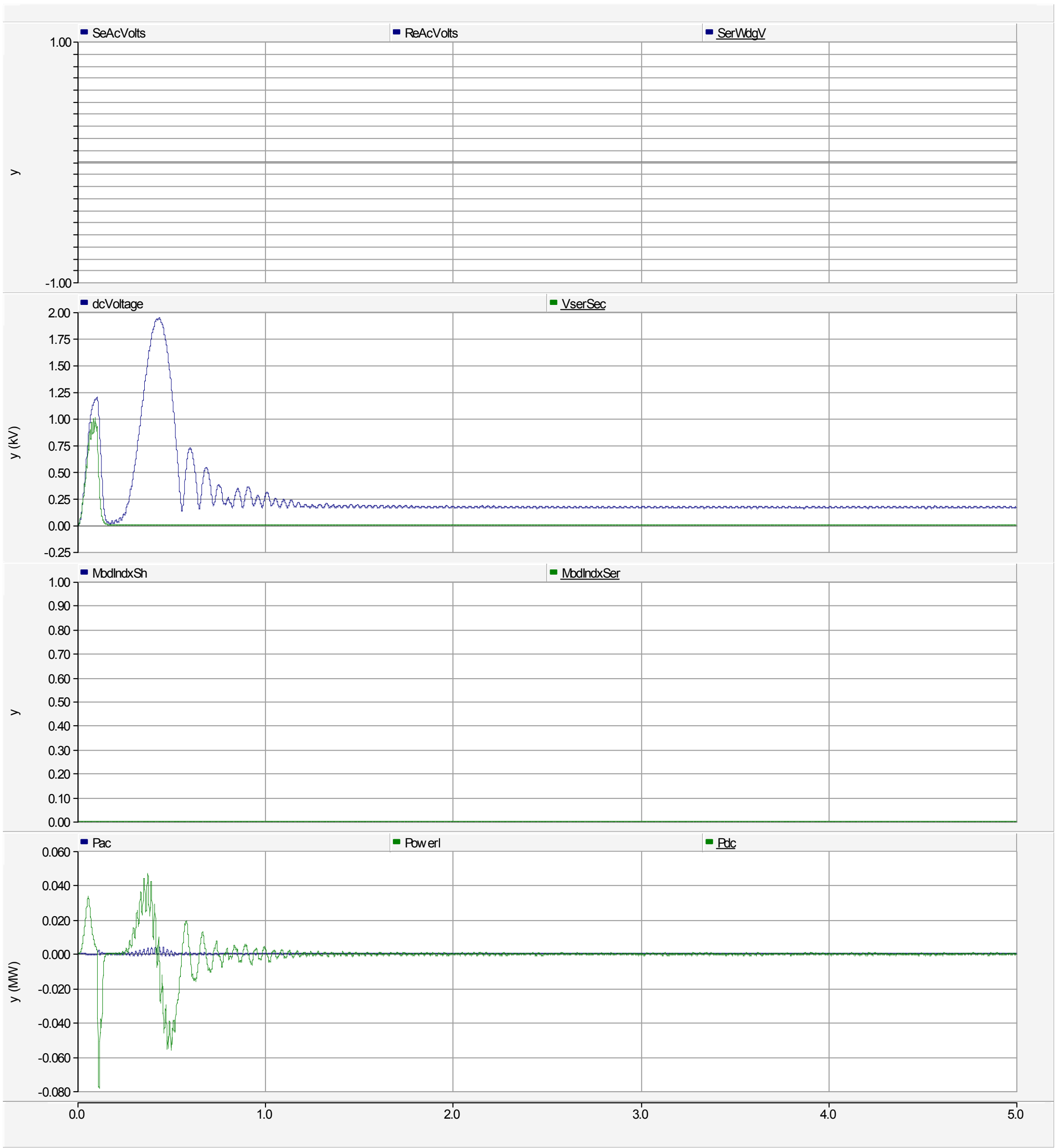











SeAcVolts
ReAcVolts
SerWdgV
dcVoltage
VserSec
MbdIndxSh
MbdIndxSer
Pac
Powerl
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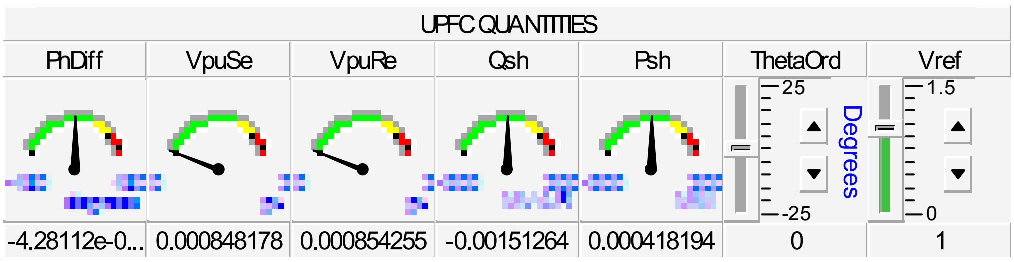
y
y (kV)
y
y (MW)
0.0
1.0
2.0
3.0
4.0
5.0


UPFC QUANTITIES
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VpuRe
Qsh
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ThetaOrd
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-25
Degrees
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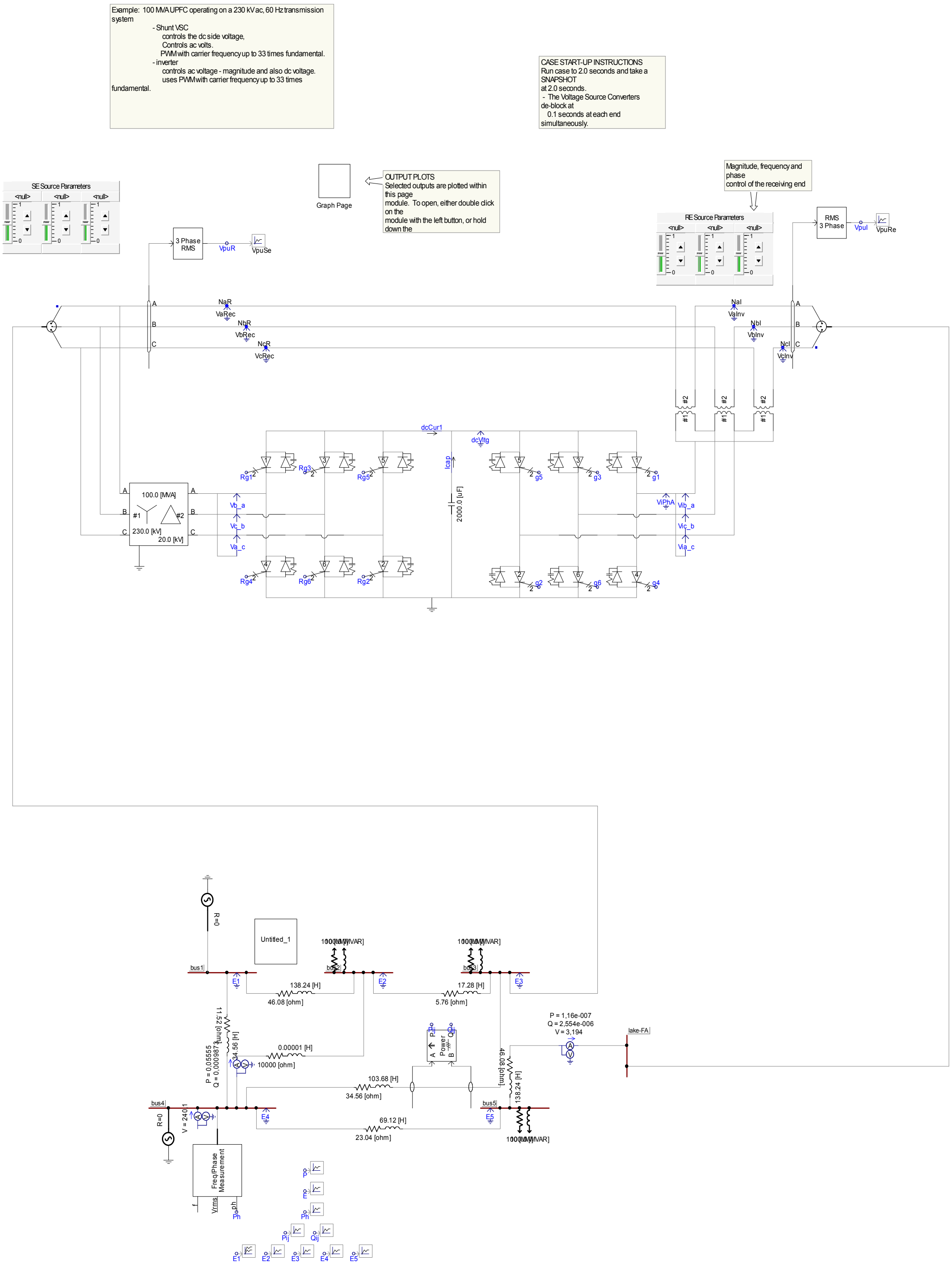
0
1

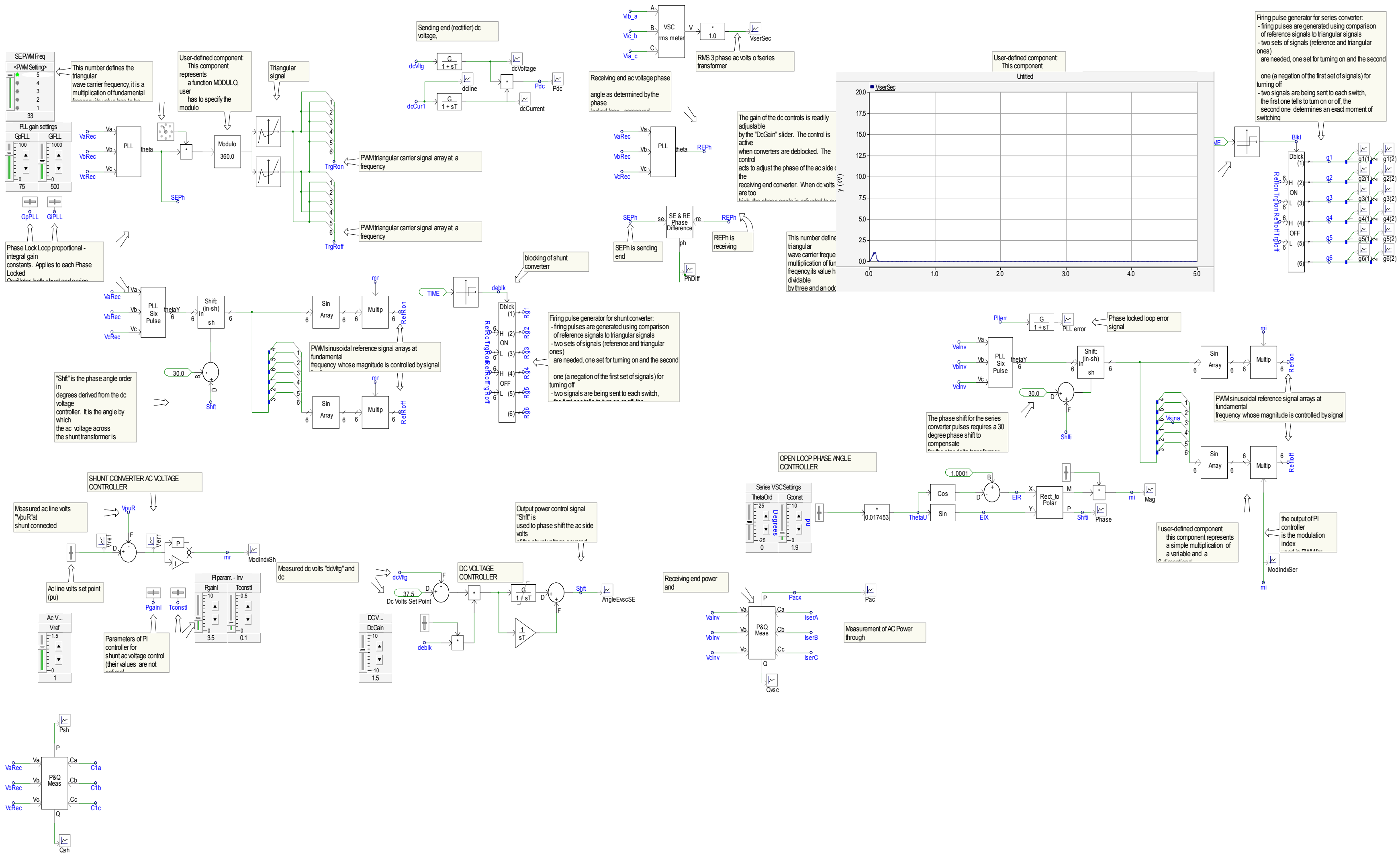
APPENDIX E

CASE 3: POWER FLOW ANALYSIS WITH UPFC INSTALLED BETWEEN BUS 3 AND BUS 5

APPENDIX E-1

CASE 3: CIRCUIT DIAGRAM




SHUNT CONVERTER AC VOLTAGE CONTROLLER
DC VOLTAGE CONTROLLER
OPEN LOOP PHASE ANGLE CONTROLLER

APPENDIX E-2

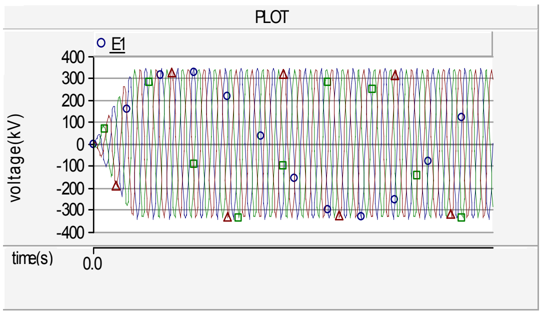
CASE 3: POWER FLOW PARAMETER

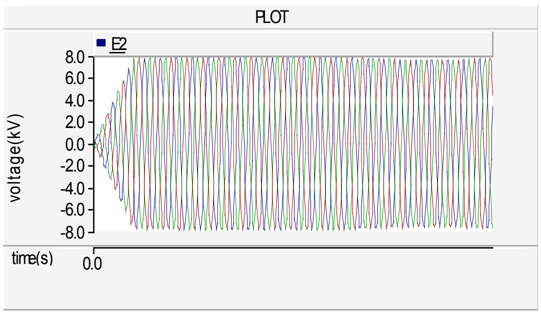
NAME	CAPTION	TYPE	UNIT	MINIMUM	MAXIMUM	DATA	VALUE
MeasI	Measure Instantaneous Current	Choice				0	0
MeasV	Measure Instantaneous Voltage	Choice				0	0
MeasP	Measure Active Power flow	Choice				1	1
MeasQ	Measure Reactive Power flow	Choice				1	1
RMS	Measure RMS voltage	Choice				1	1
MeasPh	Measure Phase Angle	Choice				2	2
S	Base MVA for per unitizing	Real	MVA	0	500	100.0 [MVA]	100.0
BaseV	Base voltage for per unitizing	Real	kV	0	500	1.0 [kV]	1.0
TS	Smoothing Time Constant	Real	s	0	1	0.02 [s]	0.02
Freq	Frequency	Real	Hz	0	1,00E+38	50.0 [Hz]	50.0
Dis	Animated Display?	Choice				1	1
CurI	Instantaneous Current	String					
VolI	Instantaneous Voltage	String					
P	Active Power	String				P35	P35
Q	Reactive Power	String				Q35	Q35
Vrms	RMS voltage	String					
Ph	Phase Angle	String				Ph35	Ph35
hide1	power	Choice				1	1
hide2	rms voltage	Choice				1	1
Pd	Active Power	String				1,16E-07	1,16E-07
Qd	Reactive Power	String				2,55E-06	2,55E-06
Vd	RMS Voltage	String				3,194	3,194

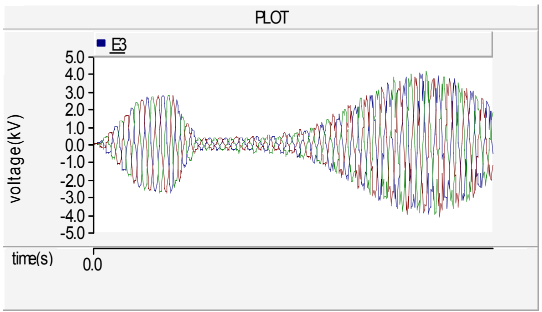
APPENDIX E-3

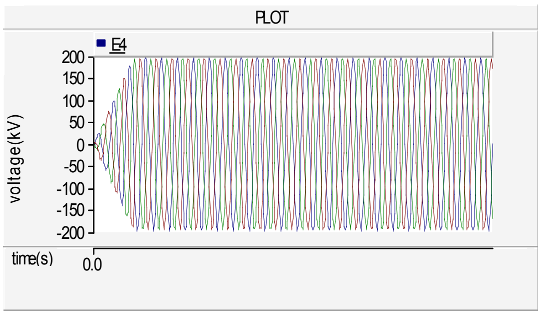
CASE 3: GRAPH

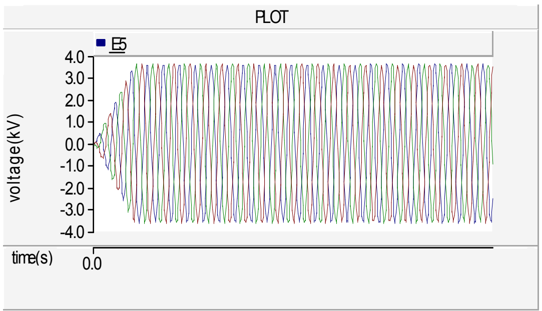
VOLTAGES AT EACH BUS

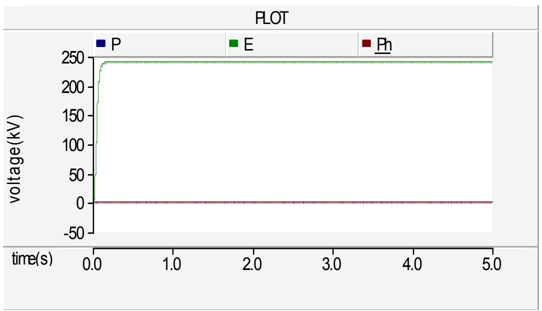


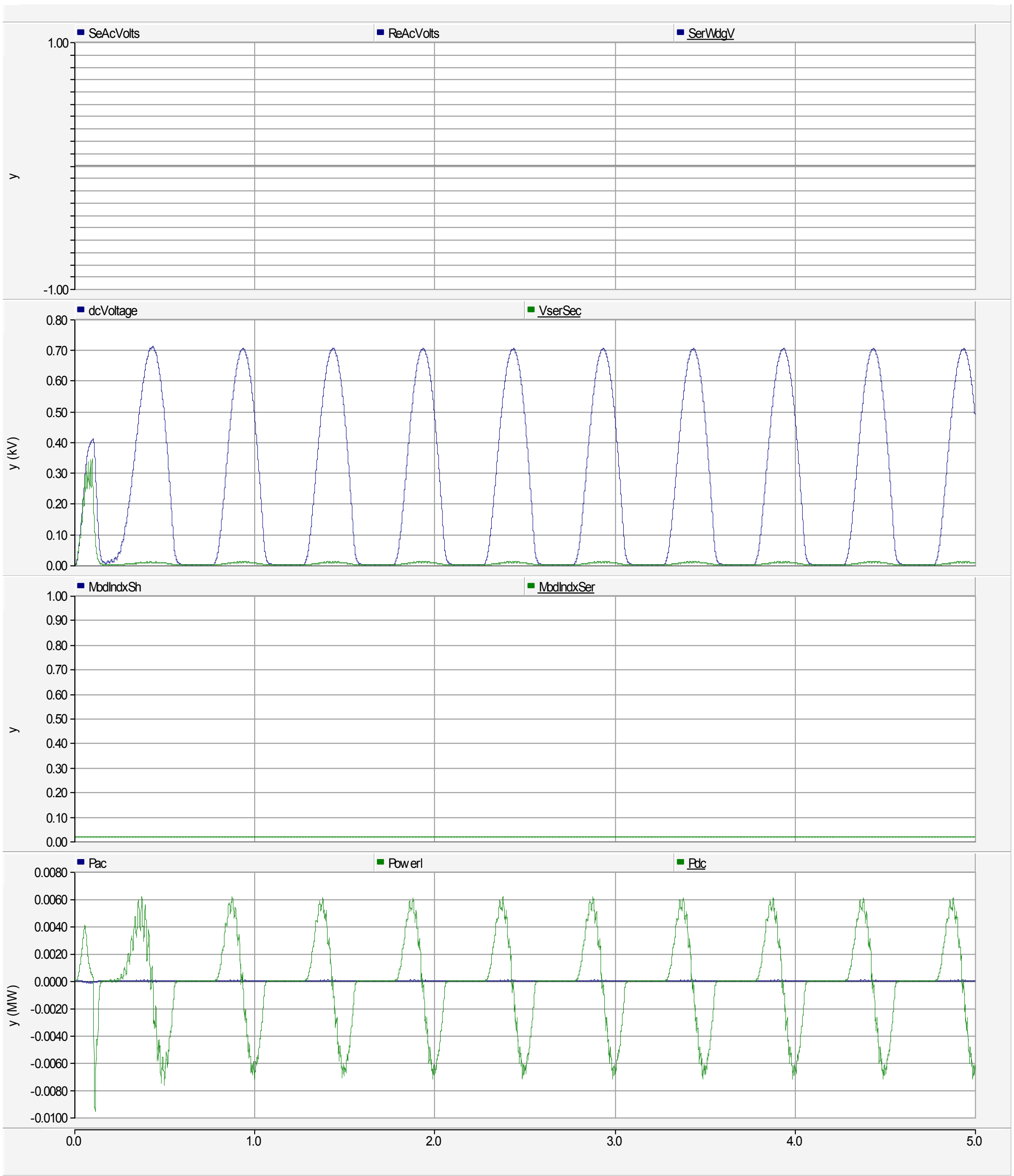


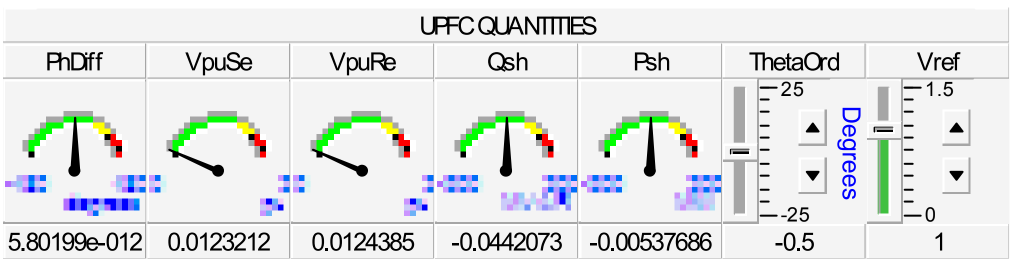









SeAcVolts
ReAcVolts
SerWdgV
dcVoltage
VserSec
MbdIndxSh
MbdIndxSer
Pac
Powerl
Pdc
y
y (kV)
y (MW)

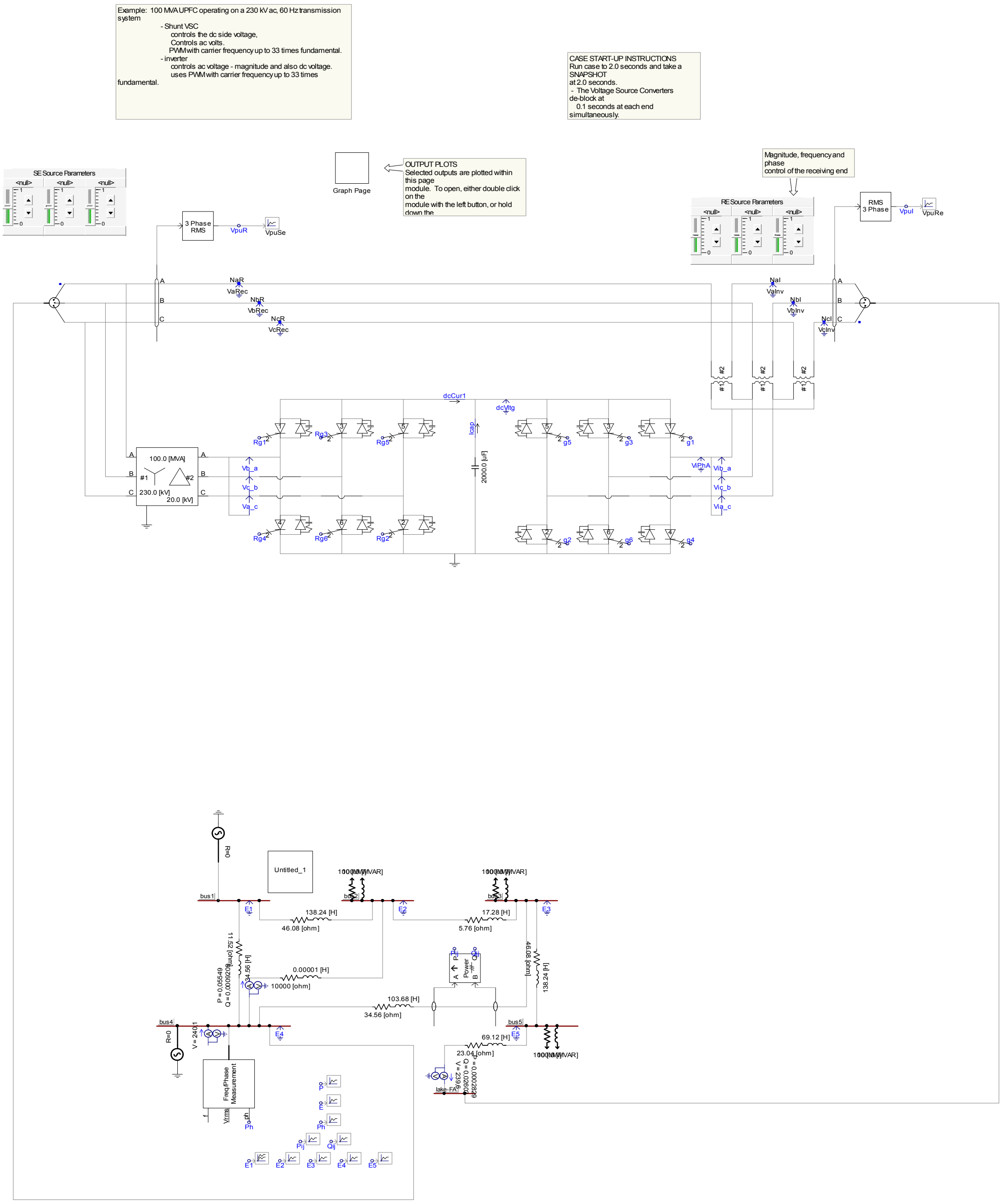

UPFC QUANTITIES
PhDiff
VpuSe
VpuRe
Qsh
Psh
ThetaOrd
Vref
25
-25
Degrees
1.5
0
5.80199e-012
0.0123212
0.0124385
-0.0442073
-0.00537686
-0.5
1

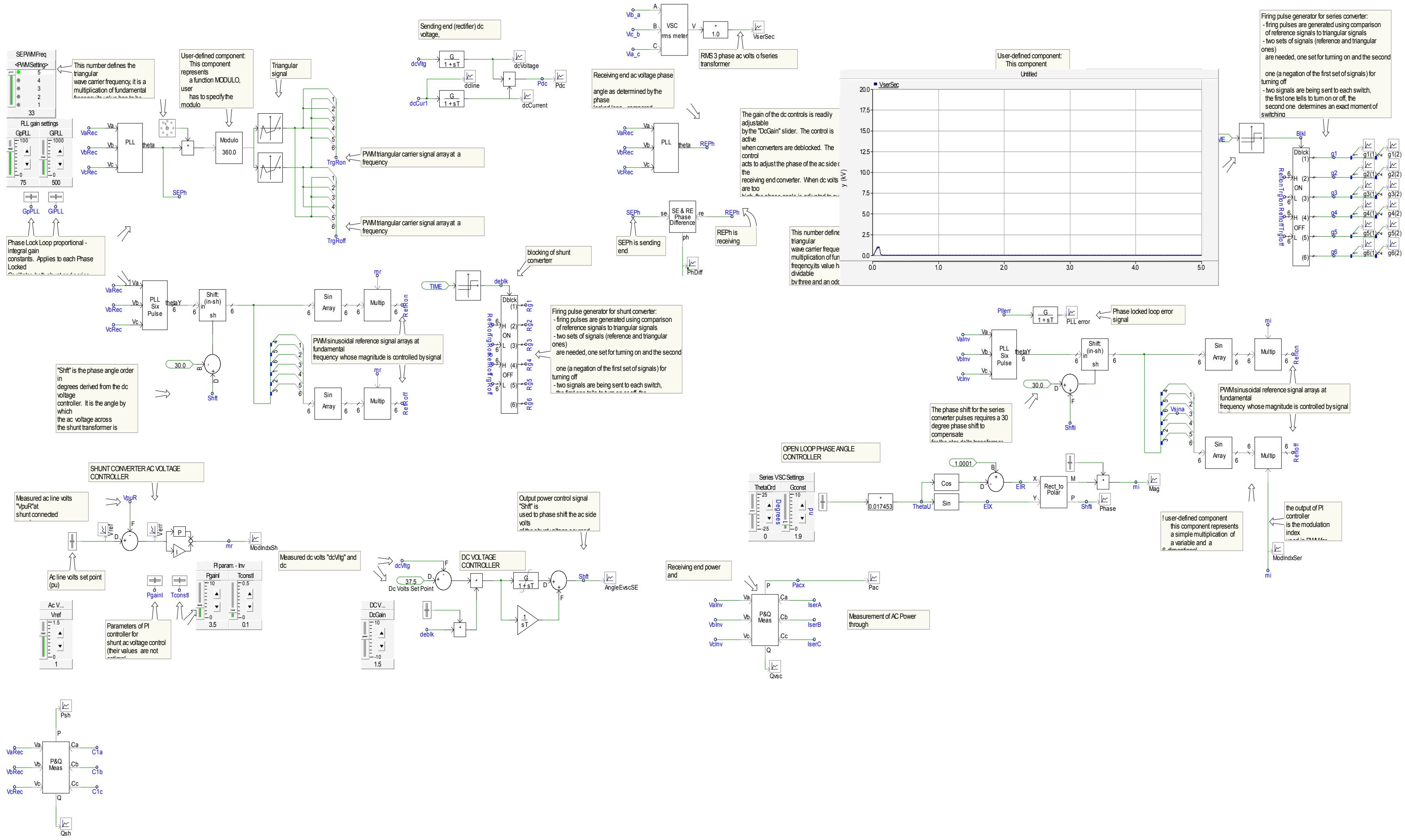
APPENDIX F

CASE 4: POWER FLOW ANALYSIS WITH UPFC INSTALLED BETWEEN BUS 4 AND BUS 5

APPENDIX F-1

CASE 4: CIRCUIT DIAGRAM





Sending end (rectifier) dc voltage.
User-defined component: This component represents a function MODULO, user has to specify the modulo
Triangular signal
This number defines the triangular wave carrier frequency, it is a multiplication of fundamental
PLL gain settings
GpPLL
GiPLL
Phase Lock Loop proportional - integral gain constants. Applies to each Phase Locked
Modulo
360.0
PWM triangular carrier signal array at a frequency
TrgRon
TrgRoff
dcVoltage
dcCurrent
Pdc
RMS 3 phase ac volts o fseries transformer
VSerSec
Receiving end ac voltage phase angle as determined by the phase
The gain of the dc controls is readily adjustable by the "DcGain" slider. The control is active when converters are deblocked. The control acts to adjust the phase of the ac side of the receiving end converter. When dc volts are too
SE & RE Phase Difference
SEPh is sending end
REPh is receiving
PhDiff
User-defined component: This component
Untitled
VserSec
y (kV)
Firing pulse generator for series converter: - firing pulses are generated using comparison of reference signals to triangular signals - two sets of signals (reference and triangular ones) are needed, one set for turning on and the second one (a negation of the first set of signals) for turning off - two signals are being sent to each switch, the first one tells to turn on or off, the second one determines an exact moment of switching
blocking of shunt converter
PWM sinusoidal reference signal arrays at fundamental frequency whose magnitude is controlled by signal
Firing pulse generator for shunt converter: - firing pulses are generated using comparison of reference signals to triangular signals - two sets of signals (reference and triangular ones) are needed, one set for turning on and the second one (a negation of the first set of signals) for turning off - two signals are being sent to each switch,
"Shft" is the phase angle order in degrees derived from the dc voltage controller. It is the angle by which the ac voltage across the shunt transformer is
Phase locked loop error signal
PLL error
The phase shift for the series converter pulses requires a 30 degree phase shift to compensate
OPEN LOOP PHASE ANGLE CONTROLLER
Series VSC Settings
ThetaOrd
Gconst
Rect_to Polar
Mag
Phase
user-defined component this component represents a simple multiplication of a variable and a
the output of PI controller is the modulation index
ModIndxSer
SHUNT CONVERTER AC VOLTAGE CONTROLLER
Measured ac line volts "VpuR" at shunt connected
Ac line volts set point (pu)
Parameters of PI controller for shunt ac voltage control (their values are not
PI param. - Inv
Pgainl
Tconstl
ModIndxSh
Measured dc volts "dcVltg" and dc
Output power control signal "Shft" is used to phase shift the ac side volts
DC VOLTAGE CONTROLLER
Dc Volts Set Point
AngleEvscSE
Receiving end power and
P&Q Meas
Measurement of AC Power through
Pac
Qvsc
Psh
Qsh

APPENDIX F-2

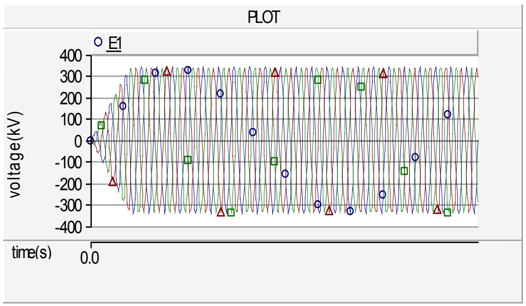
CASE 4: POWER FLOW PARAMETER

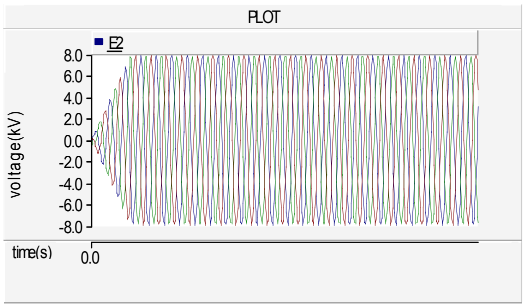
NAME	CAPTION	TYPE	UNIT	MINIMUM	MAXIMUM	DATA	VALUE
MeasI	Measure Instantaneous Current	Choice				0	0
MeasV	Measure Instantaneous Voltage	Choice				0	0
MeasP	Measure Active Power flow	Choice				1	1
MeasQ	Measure Reactive Power flow	Choice				1	1
RMS	Measure RMS voltage	Choice				1	1
MeasPh	Measure Phase Angle	Choice				2	2
S	Base MVA for per unitizing	Real	MVA	0	500	100.0 [MVA]	100.0
BaseV	Base voltage for per unitizing	Real	kV	0	500	1.0 [kV]	1.0
TS	Smoothing Time Constant	Real	s	0	1	0.02 [s]	0.02
Freq	Frequency	Real	Hz	0	1,00E+38	50.0 [Hz]	50.0
Dis	Animated Display?	Choice				1	1
CurI	Instantaneous Current	String					
VolI	Instantaneous Voltage	String					
P	Active Power	String				P45	P45
Q	Reactive Power	String				Q45	Q45
Vrms	RMS voltage	String					
Ph	Phase Angle	String				Ph45	Ph45
hide1	power	Choice				1	1
hide2	rms voltage	Choice				1	1
Pd	Active Power	String				2,83E-04	2,83E-04
Qd	Reactive Power	String				2,60E-02	2,60E-02
Vd	RMS Voltage	String				239,6	239,6

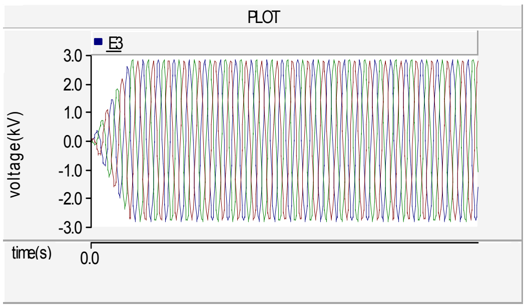
APPENDIX F-3

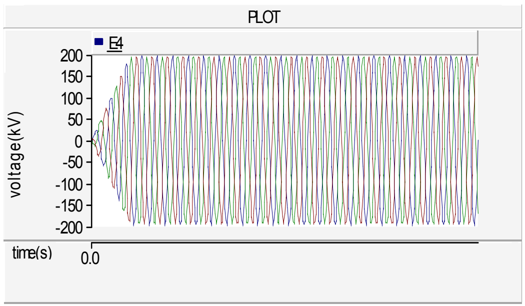
CASE 4: GRAPH

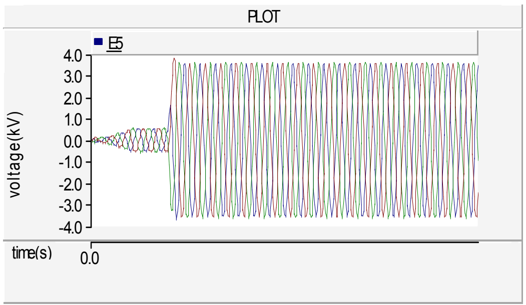
VOLTAGES AT EACH BUS

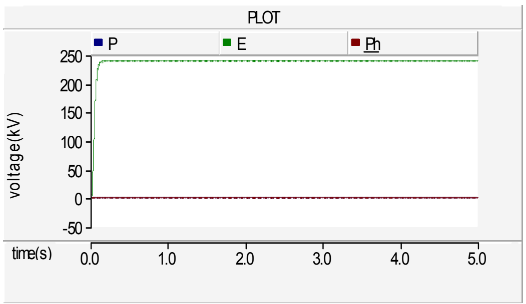


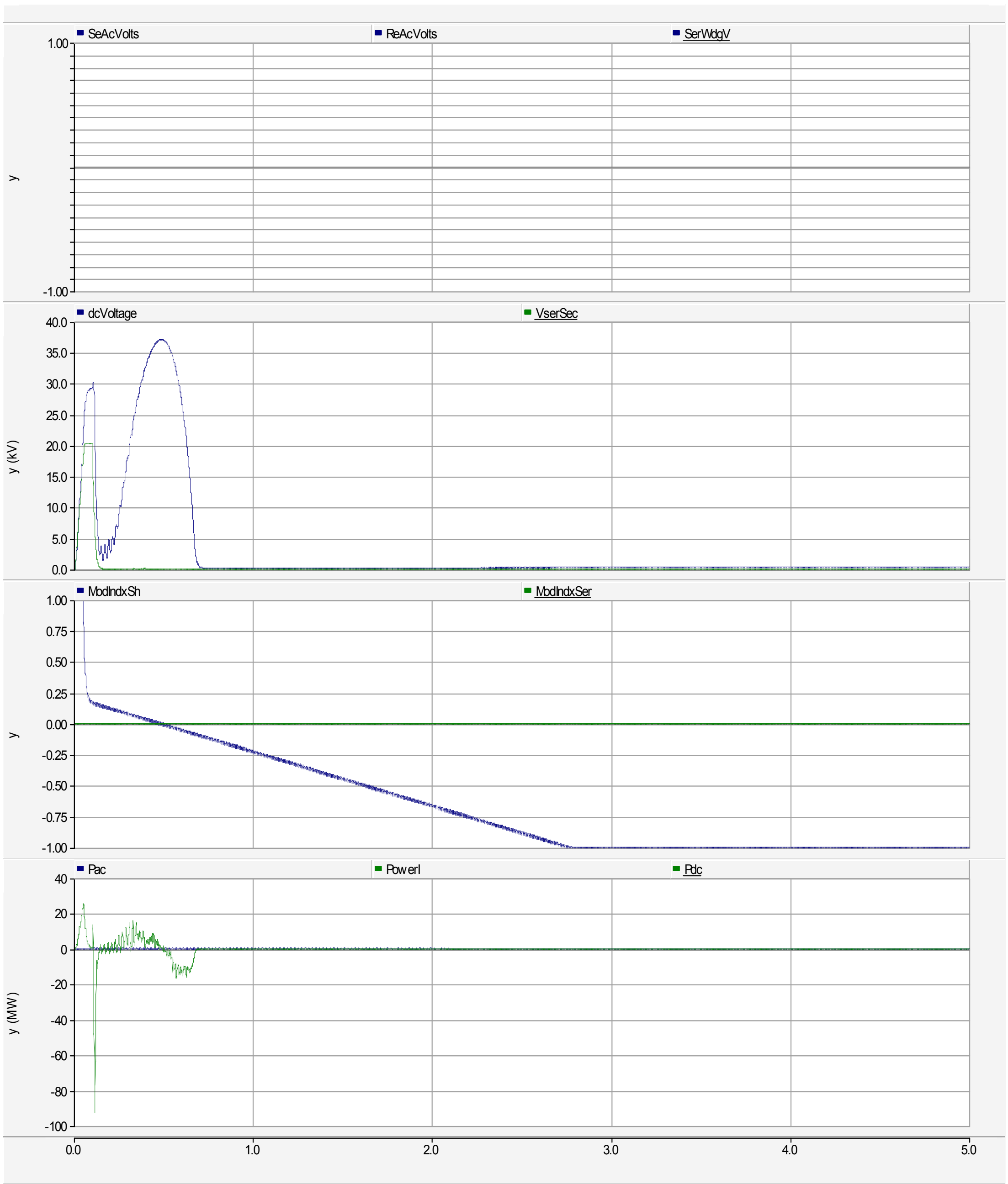




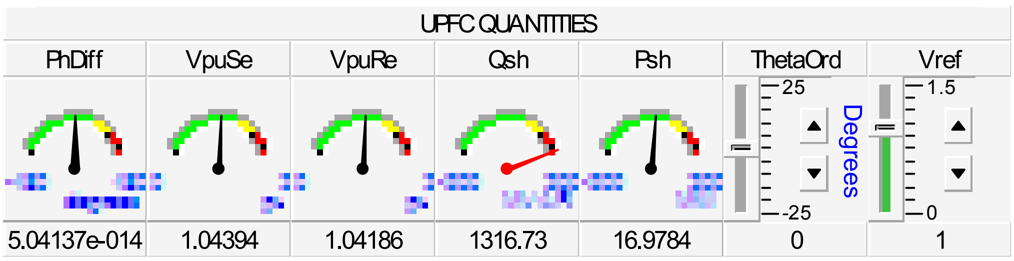








SeAcVolts
ReAcVolts
SerWdgV
1.00
-1.00
y
dcVoltage
VserSec
y (kV)
ModIndxSh
ModIndxSer
Pac
PowerI
Pdc
y (MW)
0.0
1.0
2.0
3.0
4.0
5.0



UPFC QUANTITIES
PhDiff
VpuSe
VpuRe
Qsh
Psh
ThetaOrd
Vref
25
-25
Degrees
1.5
0
5.04137e-014
1.04394
1.04186
1316.73
16.9784
0
1