CHAPTER 1
INTRODUCTION

1.1 Background Of Study

Static Synchronous Compensator (STATCOM) is shunt connected reactive power compensation device that is capable of supplying or absorbing reactive power into the transmission network. It is a family of the Flexible AC Transmission Systems (FACTS).When system voltage is low, the STATCOM generates reactive power (STATCOM capacitive). When system voltage is high, it absorbs reactive power (STATCOM inductive). Thus, it can be used to control the reactive power at any bus and hence the bus voltage.

1.2 Problem Statement

A transmission network may have poor power flow or voltage regulation that will affect its performance. Voltage stability in a network is very important to minimize power loss. Static synchronous compensator or STATCOM is installed to overcome this problem.

1.3 Objective

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

1.4 Scope of Study

The scopes of study for this project are:

- Understand the need of STATCOM
- Explain the operation of STATCOM
- Familiarize with the PSCAD software
- Demonstrate the role of STATCOM in power transmission network

CHAPTER 2
LITERATURE REVIEW

2.1 Power Flow Analysis

For better understanding, a problem of a bus system is analyzed for steady state analysis purposes. In this case, we use the 5-bus system.

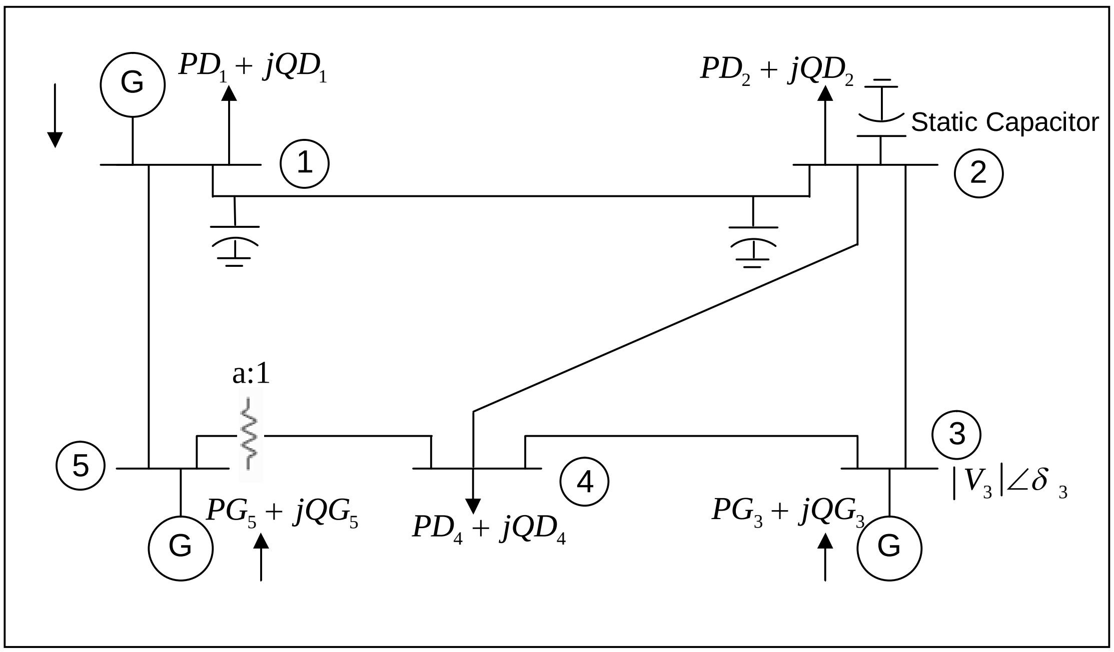

Figure 1 : A Power System Model [1]

2.1.1 Classification of Buses

PI indicates the real power injected into the bus
QI indicates the reactive power injected into the bus
|V| indicates the magnitude of the bus voltage
δ indicates the phase angle of the bus voltage

Any two of these four may be treated as independent variables or specified, while the other two need to be computed by solving the power flow equations. Based on these two variables which have been specified, buses are classified into three types, which are the slack bus, PV bus and PQ bus.

2.1.1.1 *Slack Bus*

It is referred to as the swing bus, slack bus, or reference bus. There is only one slack bus, and it can be designated to be any generator bus in the system. For the slack bus, we know the |V| and δ. The specification of |V| helps us to fix the voltage level of the system and the specification of δ serves as the phase angle reference for the system. Thus, for the slack bus, both |V| and δ are specified and PI and QI are to be determined. From Figure 1, bus 3 is the slack bus.

2.1.1.2 *Generator Bus*

It is known as the PV bus, as the PI and |V| are known, but not the QI and δ. These buses are termed as the Voltage-Controlled Buses because the ability to specify the voltage magnitude of this bus. Most generator fall under this category, whether it is independent or it has a load with it. Based on Figure 1, the generator bus of the PV bus is bus 1 and bus 5.

2.1.1.3 *Load Bus*

It is also known as the PQ bus, as the variables of PI and QI are known, but not the |V| and δ. All load buses fall into this category, including buses that have not either load or generation. The real power injections of the PQ buses are chosen according to the loading conditions modeled. Meanwhile, the reactive power injections of the PQ buses are chosen according to the expected power factor of the load. From Figure 1, the PQ bus is bus 2 and bus 4.

2.1.2 Development of Power Flow Model

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

i. Network equations
ii. Bus power equations
iii. Line flow equations

2.1.2.1 *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 indicates the bus current vector

Y indicates the bus voltage vector

V indicates the bus admittance matrix

The expanded form for the simple equations is:

$$\begin{bmatrix} \mathbf{I_1} \\ \mathbf{I_2} \\ \vdots \\ \mathbf{I_N} \end{bmatrix} = \begin{bmatrix} \mathbf{Y_{11}} & \mathbf{Y_{12}} & \cdots & \mathbf{Y_{1N}} \\ \mathbf{Y_{21}} & \mathbf{Y_{22}} & \cdots & \mathbf{Y_{2N}} \\ \vdots & \vdots & & \vdots \\ \mathbf{Y_{N1}} & \mathbf{Y_{N2}} & \cdots & \mathbf{Y_{NN}} \end{bmatrix} \begin{bmatrix} \mathbf{V_1} \\ \mathbf{V_2} \\ \vdots \\ \mathbf{V_N} \end{bmatrix} \tag{1}$$

Where N = number of buses

The typical element of the bus admittance matrix is:

$$\mathbf{Y_{ij}} = |\mathbf{Y_{ij}}| \angle \boldsymbol{\theta}_{\mathbf{ij}} = |\mathbf{Y_{ij}}| \cos \boldsymbol{\theta}_{\mathbf{ij}} + j\, |\mathbf{Y_{ij}}| \sin \boldsymbol{\theta}_{\mathbf{ij}} = \mathbf{G_{ij}} + j\, \mathbf{B_{ij}} \tag{2}$$

Voltage at a typical bus is

$$\mathbf{V_i} = |\mathbf{V_i}| \angle \boldsymbol{\delta}_{\mathbf{i}} = |\mathbf{V_i}| (\cos \boldsymbol{\delta}_{\mathbf{i}} + j \sin \boldsymbol{\delta}_{\mathbf{i}})$$

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

$$\begin{aligned} \mathbf{I_i} &= \mathbf{Y_{i1}}\, \mathbf{V_1} + \mathbf{Y_{i2}}\, \mathbf{V_2} + \cdots\cdots + \mathbf{Y_{iN}}\, \mathbf{V_n} \\ &= \sum_{\mathbf{n=1}}^{\mathbf{N}} \mathbf{Y_{in}}\, \mathbf{V_n} \end{aligned} \tag{3}$$

2.1.2.2 *The Bus Power Equations*

The bus power equation is also taken into account which results the power flow model becomes non- linear.

Equation of complex power entering the network at bus i :

$$\mathbf{P_i} + \mathbf{jQ_i} = \mathbf{V_i}\, \mathbf{I_i^*} \tag{4}$$

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

$$\mathbf{P_i - jQ_i = V_i^* \; I}_i \tag{5}$$

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

$$= \left|\mathbf{V_i}\right| \angle -\boldsymbol{\delta}_{\mathbf{i}} \sum_{\mathbf{n=1}}^{\mathbf{N}} \left|\mathbf{Y_{in}}\right| \angle \boldsymbol{\theta}_{\mathbf{in}} \left|\mathbf{V_n}\right| \angle \boldsymbol{\delta}_{\mathbf{n}}$$

$$= \sum_{\mathbf{n=1}}^{\mathbf{N}} \left|\mathbf{V_i}\right| \left|\mathbf{V_n}\right| \left|\mathbf{Y_{in}}\right| \underline{/ \; \boldsymbol{\theta}_{\mathbf{in}} + \boldsymbol{\delta}_{\mathbf{n}} - \boldsymbol{\delta}}_{\mathbf{i}}$$

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

$$\mathbf{P_i} = \sum_{\mathbf{n=1}}^{\mathbf{N}} \left|\mathbf{V_i}\right| \left|\mathbf{V_n}\right| \left|\mathbf{Y_{in}}\right| \cos(\boldsymbol{\theta}_{\mathbf{in}} + \boldsymbol{\delta}_{\mathbf{n}} - \boldsymbol{\delta}_{\mathbf{i}}) \tag{6}$$

$$\mathbf{Q_i} = -\sum_{\mathbf{n=1}}^{\mathbf{N}} \left|\mathbf{V_i}\right| \left|\mathbf{V_n}\right| \left|\mathbf{Y_{in}}\right| \sin(\boldsymbol{\theta}_{\mathbf{in}} + \boldsymbol{\delta}_{\mathbf{n}} - \boldsymbol{\delta}_{\mathbf{i}}) \tag{7}$$

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

$$\sum_{\mathbf{n=1}}^{\mathbf{N}} \left|\mathbf{V_i}\right| \left|\mathbf{V_n}\right| \left|\mathbf{Y_{in}}\right| \cos(\boldsymbol{\theta}_{\mathbf{in}} + \boldsymbol{\delta}_{\mathbf{n}} - \boldsymbol{\delta}_{\mathbf{i}}) = \mathbf{PI_i} \tag{8}$$

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$$-\sum_{\mathbf{n=1}}^{\mathbf{N}} \left|\mathbf{V_i}\right| \left|\mathbf{V_n}\right| \left|\mathbf{Y_{in}}\right| \sin(\boldsymbol{\theta}_{\mathbf{in}} + \boldsymbol{\delta}_{\mathbf{n}} - \boldsymbol{\delta}_{\mathbf{i}}) = \mathbf{QI_i} \tag{9}$$

Some denotations are done:

$$\text{PQ buses} = \mathbf{N_1}$$

$$\text{PV buses} = \mathbf{N_2}$$

The unknowns to be obtained are :

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

$$\boxed{\text{Number of equations} = \text{Number of variables} = \mathbf{2N_1} + \mathbf{N_2}}$$

Thus the equations to be solved are :

$$\text{for } i = 1, 2, \ldots\ldots, N$$

$$\sum_{\mathbf{n=1}}^{\mathbf{N}} |\mathbf{V_i}|\,|\mathbf{V_n}|\,|\mathbf{Y_{in}}| \cos(\boldsymbol{\theta}_{\mathbf{in}} + \boldsymbol{\delta}_{\mathbf{n}} - \boldsymbol{\delta}_{\mathbf{i}}) = \mathbf{PI_i}$$

$$\text{for } i = 1, 2, \ldots\ldots, N$$

$$i \neq \text{P V buses}$$

$$-\sum_{\mathbf{n=1}}^{\mathbf{N}} |\mathbf{V_i}|\,|\mathbf{V_n}|\,|\mathbf{Y_{in}}| \sin(\boldsymbol{\theta}_{\mathbf{in}} + \boldsymbol{\delta}_{\mathbf{n}} - \boldsymbol{\delta}_{\mathbf{i}}) = \mathbf{QI_i}$$

$$\text{for } \delta_i \quad i = 1,2,\ldots\ldots, N,$$

$$|V_i| \quad i = 1,2,\ldots\ldots, N,\ i \neq \text{PV buses}$$

2.1.3 Newton-Raphson (NR) Method

The NR method is used to solve the non linear equations. They are arranged as such way :

$$\mathbf{f_1\,(x_1, x_2, \ldots\ldots, x_n) = k_1}$$

$$\mathbf{f_2\,(x_1, x_2, \ldots\ldots, x_n) = k_2}$$

$$\vdots$$

$$\mathbf{f_n\,(x_1, x_2, \ldots\ldots, x_n) = k_n} \tag{10}$$

Then, the initial solutions are denoted as :

$$\mathbf{x_1^{(0)}, x_2^{(0)}, \cdots\ \cdots, x_n^{(0)}}$$

The initial solutions are then substituted into the matrix :

$$\begin{bmatrix} \mathbf{k_1 - f_1(x_1^{(0)}, x_2^{(0)}, \cdots\cdots, x_n^{(0)})} \\ \mathbf{k_2 - f_2(x_1^{(0)}, x_2^{(0)}, \cdots\cdots, x_n^{(0)})} \\ \vdots \\ \vdots \\ \mathbf{k_n - f_n(x_1^{(0)}, x_2^{(0)}, \cdots\cdots, x_n^{(0)})} \end{bmatrix} = \begin{bmatrix} \mathbf{0} \\ \mathbf{0} \\ \vdots \\ \vdots \\ \mathbf{0} \end{bmatrix} \tag{11}$$

Next the changes of *x* are also obtained.

$\mathbf{\Delta x_1, \Delta x_2, \cdots\cdots, \Delta x_n}$ are the corrections required on $\mathbf{x_1^{(0)}, x_2^{(0)}, \cdots\cdots, x_n^{(0)}}$

$$\mathbf{f_1\,[(x_1^{(0)} + \Delta x_1), (x_2^{(0)} + \Delta x_2), \cdots\cdots, (x_n^{(0)} + \Delta x_n)] = k_1}$$

$$\mathbf{f_2\,[(x_1^{(0)} + \Delta x_1), (x_2^{(0)} + \Delta x_2), \cdots\cdots, (x_n^{(0)} + \Delta x_n)] = k_2}$$

$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

$$\mathbf{f_n\,[(x_1^{(0)} + \Delta x_1), (x_2^{(0)} + \Delta x_2), \cdots\cdots, (x_n^{(0)} + \Delta x_n)] = k_n} \tag{12}$$

Each equation in the above set is then be expanded using Taylor's theorem :

$$\mathbf{f_1}\,(\mathbf{x_1^{(0)}}, \mathbf{x_2^{(0)}}, \cdots\cdots, \mathbf{x_n^{(0)}}) + \frac{\partial \mathbf{f_1}}{\partial \mathbf{x_1}}\Big|_{\circ} \Delta \mathbf{x_1} + \frac{\partial \mathbf{f_1}}{\partial \mathbf{x_2}}\Big|_{\circ} \Delta \mathbf{x_2} + \cdots\cdots + \frac{\partial \mathbf{f_1}}{\partial \mathbf{x_n}}\Big|_{\circ} \Delta \mathbf{x_n} + \boldsymbol{\varphi}_1 = \mathbf{k_1}$$

$$\mathbf{f_2}\,(\mathbf{x_1^{(0)}}, \mathbf{x_2^{(0)}}, \cdots\cdots, \mathbf{x_n^{(0)}}) + \frac{\partial \mathbf{f_2}}{\partial \mathbf{x_1}}\Big|_{0} \Delta \mathbf{x_1} + \frac{\partial \mathbf{f_2}}{\partial \mathbf{x_2}}\Big|_{0} \Delta \mathbf{x_2} + \cdots\cdots + \frac{\partial \mathbf{f_2}}{\partial \mathbf{x_n}}\Big|_{0} \Delta \mathbf{x_n} = \mathbf{k_2}$$

Next the Taylor series are written in the matrix form :

$$\begin{bmatrix} \frac{\partial \mathbf{f_1}}{\partial \mathbf{x_1}}\Big|_0 & \frac{\partial \mathbf{f_1}}{\partial \mathbf{x_2}}\Big|_0 & \cdots\cdots & \frac{\partial \mathbf{f_1}}{\partial \mathbf{x_n}}\Big|_0 \\ \frac{\partial \mathbf{f_2}}{\partial \mathbf{x_1}}\Big|_0 & \frac{\partial \mathbf{f_2}}{\partial \mathbf{x_2}}\Big|_0 & \cdots\cdots & \frac{\partial \mathbf{f_2}}{\partial \mathbf{x_n}}\Big|_0 \\ \vdots & \vdots & & \vdots \\ \vdots & \vdots & & \vdots \\ \frac{\partial \mathbf{f_n}}{\partial \mathbf{x_1}}\Big|_0 & \frac{\partial \mathbf{f_n}}{\partial \mathbf{x_2}}\Big|_0 & \cdots\cdots & \frac{\partial \mathbf{f_n}}{\partial \mathbf{x_n}}\Big|_0 \end{bmatrix} \begin{bmatrix} \Delta \mathbf{x_1} \\ \Delta \mathbf{x_2} \\ \vdots \\ \vdots \\ \Delta \mathbf{x_n} \end{bmatrix} = \begin{bmatrix} \mathbf{k_1} - \mathbf{f_1}(\mathbf{x_1^{(0)}}, \mathbf{x_2^{(0)}}, \cdots\cdots, \mathbf{x_n^{(0)}}) \\ \mathbf{k_2} - \mathbf{f_2}(\mathbf{x_1^{(0)}}, \mathbf{x_2^{(0)}}, \cdots\cdots, \mathbf{x_n^{(0)}}) \\ \vdots \\ \vdots \\ \mathbf{k_n} - \mathbf{f_n}(\mathbf{x_1^{(0)}}, \mathbf{x_2^{(0)}}, \cdots\cdots, \mathbf{x_n^{(0)}}) \end{bmatrix}$$

The above equation can be written in a compact form as:

$$\underbrace{\mathbf{F}'\,(\mathbf{X}^{(0)})}_{\text{JACOBIAN MATRIX}}\; \Delta \mathbf{X} = \mathbf{K} - \underbrace{\mathbf{F}\,(\mathbf{X}^{(0)})}_{\text{ERROR VECTOR}} \tag{13}$$

$$\Delta X = \left[F'(X^{(0)})\right]^{-1} \left[K - F(X^{(0)})\right]$$

$$X^{(1)} = X^{(0)} + \Delta X$$

For $(h+1)^{th}$ iteration :

$$X^{(h+1)} = X^{(h)} + \Delta X$$

$$\Delta X = \left[F'(X^{(h)})\right]^{-1} \left[K - F(X^{(h)})\right]$$

$$F'(X^{(h)})\,\Delta X = K - F(X^{(h)})$$

Procedure to solve $\boxed{F(X) = K}$

(i) Calculate the error vector $K - F(X^{(h)})$

If the error vector $\leq$ zero, convergence is reached, otherwise formulate

$$F'(X^{(h)})\,\Delta X = K - F(X^{(h)})$$

(ii) Solve for the correction vector ΔX

(iii) Update the solution as :

$$X^{(h+1)} = X^{(h)} + \Delta X$$

2.2 Flexible AC Transmission System (FACTS)

The need for more efficient electricity systems management has given rise to innovative technologies in power generation and transmission. FACTS are new devices that improve transmission systems. Flexible alternating-current transmission systems (FACTS) are defined by the IEEE as “ac transmission systems incorporating power electronics-based and other static controllers to enhance controllability and increase power transfer capability”. Worldwide transmission systems are undergoing continuous changes and restructuring. They are becoming more heavily loaded. Transmission systems must be flexible to react to more diverse generation and load patterns. The optimized use of transmission systems investments is also important to support industry. FACTS is a technology that responds to these needs. It significantly alters the way transmission systems are developed with objective of improving system steady state and dynamic performance.

2.2 Static Synchronous Compensator (STATCOM)

Examples of FACTS Controllers are Static VAR Compensator (SVC), Thyristor-Controlled Series Capacitor (TCSS), Unified Power Flow Controller (UPFC), Inter phase Power Controller and as well as STATCOM.

FACTS Controller is defined by IEEE as ‘a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters’. FACTS controllers are used for the dynamic control of voltage, impedance and phase angle of high voltage AC transmission lines.

The STATCOM has been defined as per CIGRE/IEEE with following three operating scenarios. First component is Static: based on solid state switching devices with no rotating components; second component is Synchronous: analogous to an ideal synchronous machine with 3 sinusoidal phase voltages at fundamental frequency; third component is Compensator: rendered with reactive compensation.

IEEE defines STATCOM as ‘A static synchronous generator operated as a shunt-connected SVC whose capacitive or inductive output current can be controlled independent of the AC system voltage.’ STATCOMs are GTO (gate turn-off type thyristor) based SVC.

GTO-based VSCs (GTO-VSC), commercially available with high power capacity, are employed in high power rating controllers with triggering once per cycle [fundamental frequency switching (FFS)]. Although insulated gate bipolar transistor (IGBT) and integrated gate commutated thyristor (IGCT) devices are available with reasonably good power ratings, these are being mainly used in low-to-medium rating compensators operated under pulse-width modulation (PWM) switching, that is, multiple switching (1–3 kHz) in a cycle of operation. Use of these switching devices in high power rating controllers is yet to be fully commercialized and therefore its use is limited. [2]

How the typical STATCOM is functioning is discussed in Figure 2 and Figure 3.

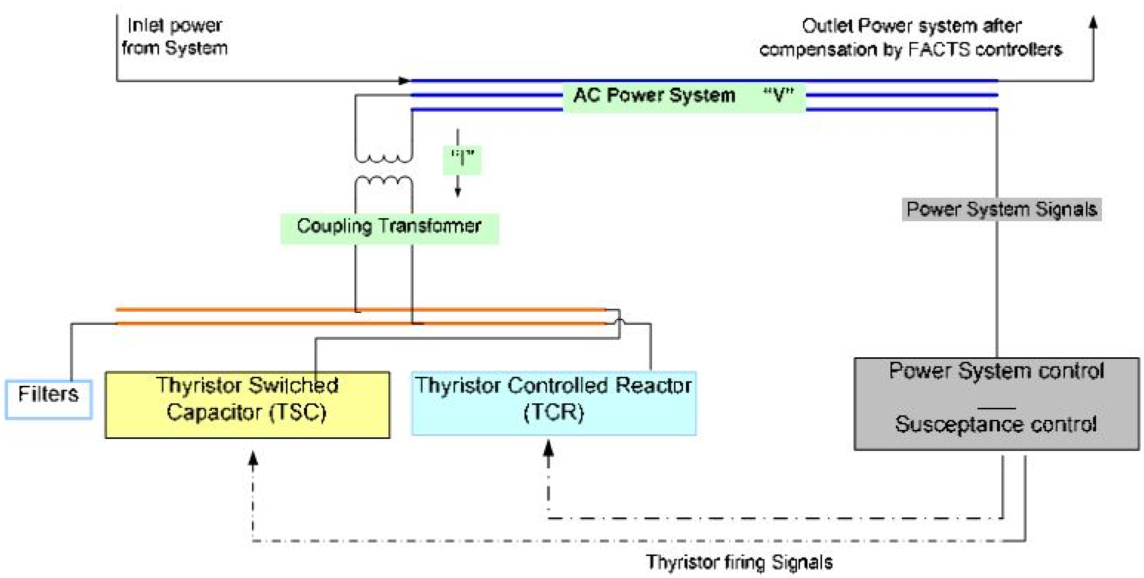


Figure 2 : Typical Static Var compensator (SVC) [3]

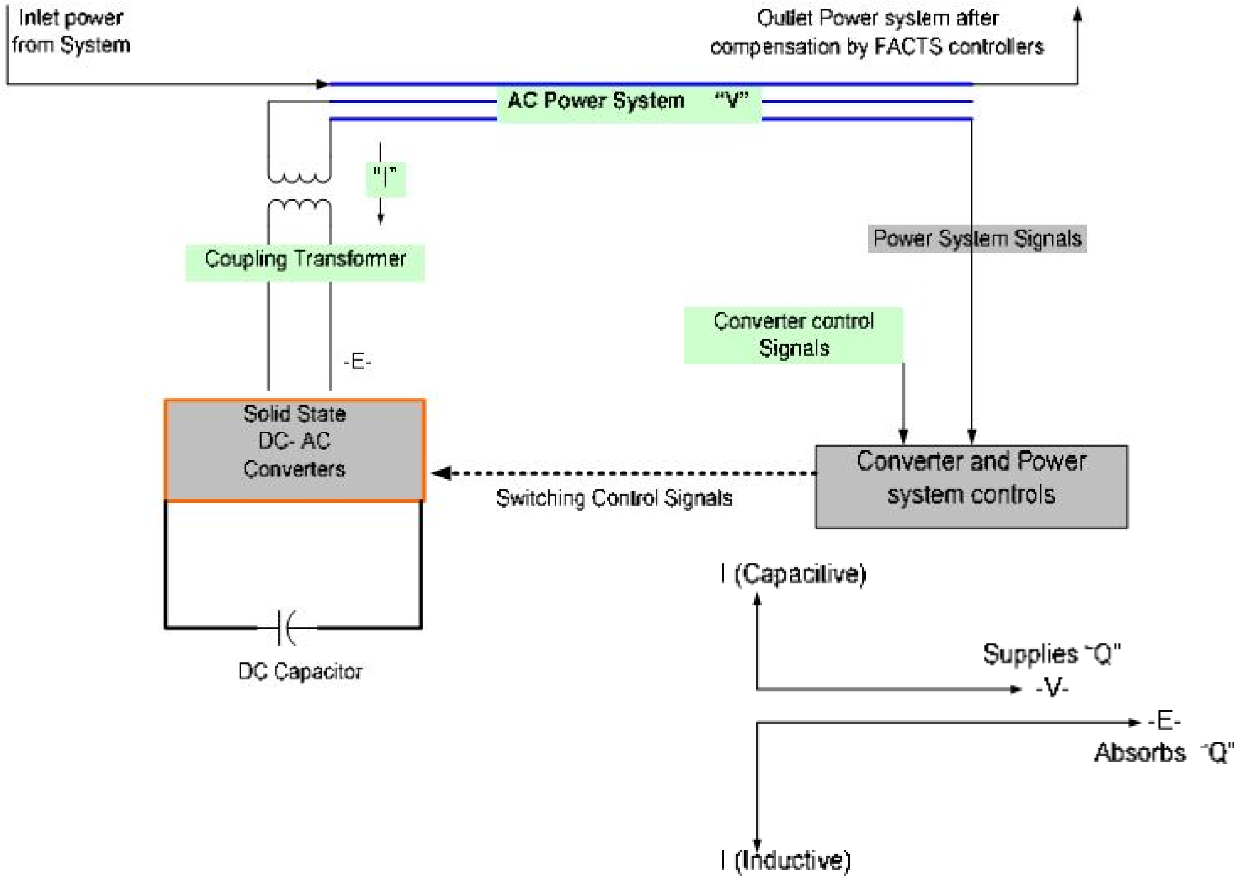
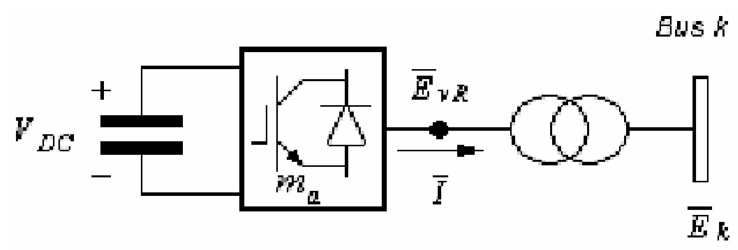


Figure 3 : Typical STATCOM Compensator [3]

Depending on the power rating of the STATCOM, different technologies are used for the power converter. High power STATCOMs (several hundreds of Mvars) normally use GTO-based, square-wave voltage-sourced converters (VSC), while lower power STATCOMs (tens of MVars) use IGBT-based or IGCT-based pulse-width modulation (PWM) VSC. [4]

STATCOM consists of one VSC and its associated shunt connected transformer. It is the static counterpart of the rotating synchronous condenser but it generates or absorbs reactive power at a faster rate because no moving parts are involved. In principle it performs the same voltage regulation function as the SVC but in a more robust manner because unlike the SVC, its operation is not impaired by the presence of low voltages [5]. Figure 4 represents Statcom's schematic diagram.



EvR = voltage in the STATCOM's terminals

Ek = voltage in the power system bus

Figure 4 : STATCOM Schematic Diagram [6]

STATCOM is a controlled reactive-power source. It provides voltage support by generating or absorbing reactive power at the point of common coupling without the need of large external reactors or capacitor banks. The basic voltage-source converter scheme is shown in Figure 5. Compared with conventional SVC in Figure 6, they do not require large inductive and capacitive components to provide inductive or capacitive reactive power to high voltage transmission systems. This results in smaller space requirements. An additional advantage is the higher reactive output at low system voltages where a STATCOM can be considered as a current source independent from the system voltage.

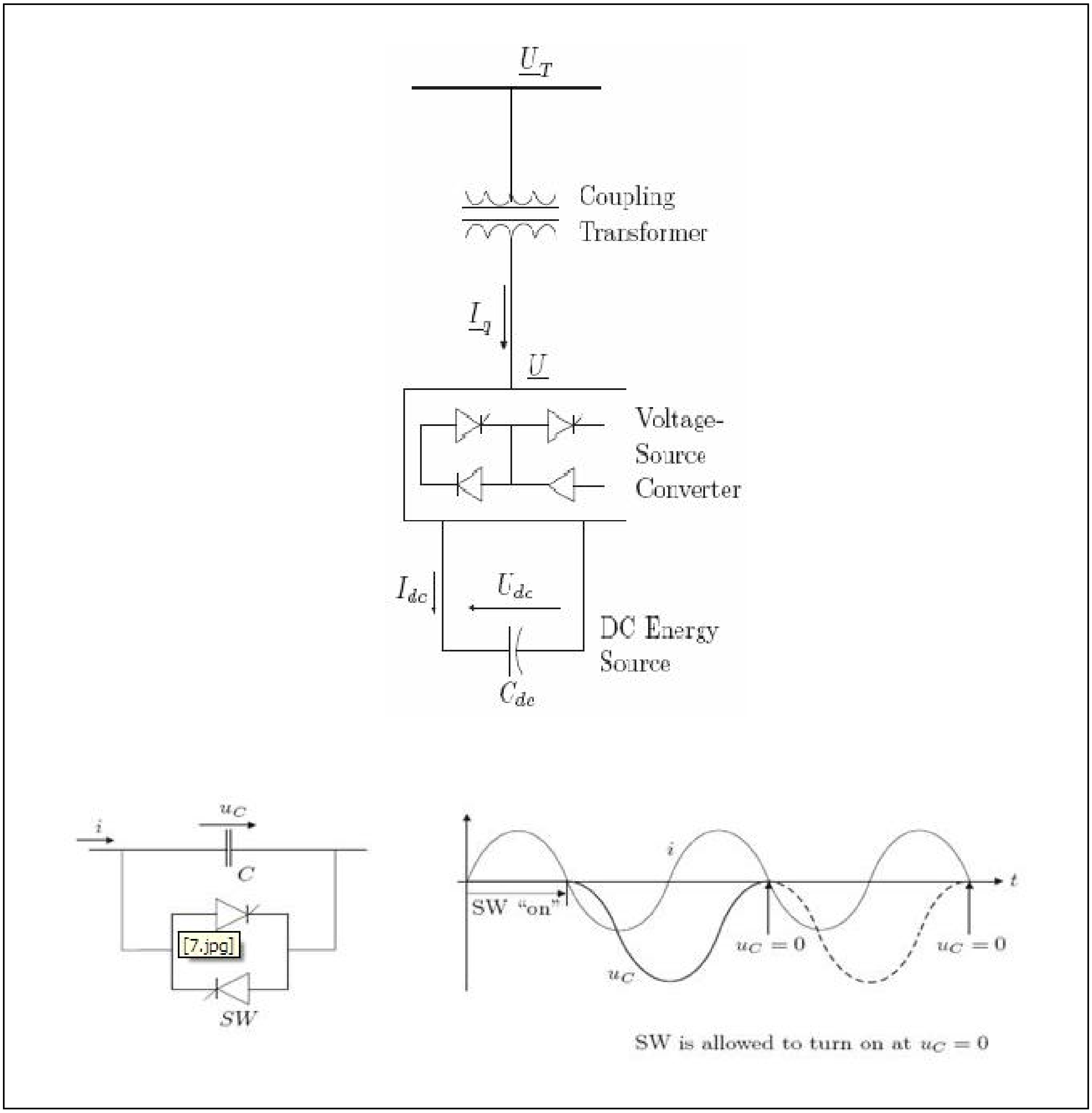


Figure 5 **:** Basic voltage-source converter scheme. [7]

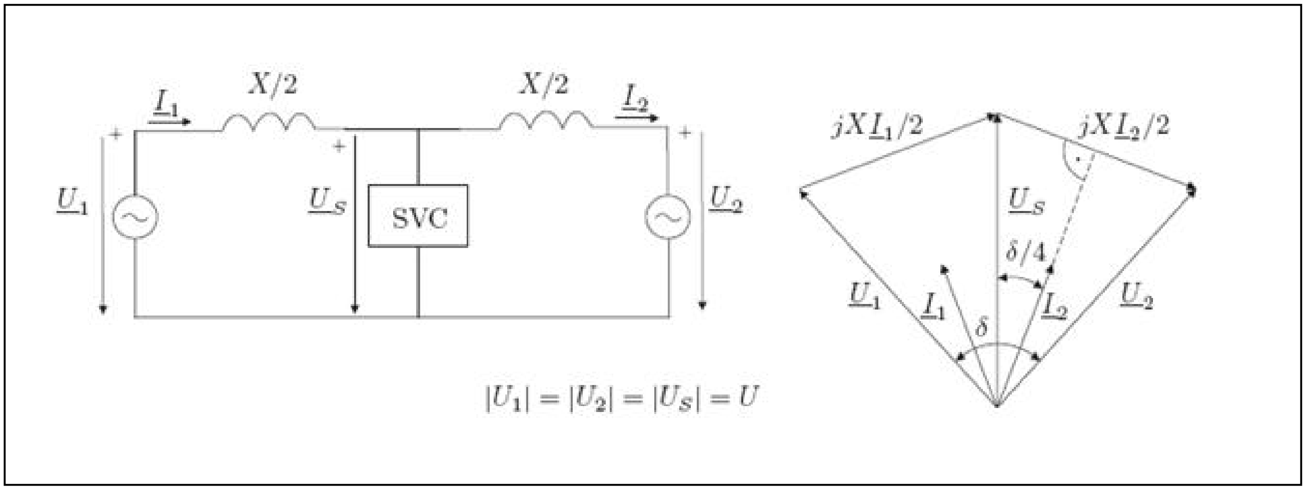


Figure 6 : Conventional SVC [7]

On the other hand, the phasor diagrams on the operating principle of STATCOM are illustrated in Figure 7. The STATCOM injects an almost sinusoidal current (I) in quadrature (lagging or leading) with the line voltage (Vs), and become inductive or a capacitive reactance at the connection point with the electrical system for reactive power control [2]. The situation is described when amplitude of Vs is controlled from full leading (capacitive) to full lagging (inductive) for (α) equals to zero which occurs when both Vc and Vs are in the same phase. The magnitude and phase angle of the injected current (I) are determined by the magnitude and phase difference (α) between Vc and Vs across the leakage inductance (L), this will control the reactive power flow and DC voltage, Vdc across the capacitor. STATCOM absorbs or delivers reactive power to the system with compensation purposes. The operating modes of STATCOM are based on the following conditions:

i) When Vc > Vs, it is considered to be operating in a capacitive mode.
ii) When Vc < Vs, it is operating in an inductive mode and
iii) when Vc = Vs, no reactive power exchange takes place.

During high rating STATCOM operated under fundamental frequency switching, the principle of phase angle control is adopted in control algorithm to compensate converter losses by active power drawn from AC system as well as for power flow in or out of the VSC. This will enable indirect control of the magnitude of DC voltage with charging or discharging of DC bus capacitor. Hence, control of reactive power flow into the system is enabled.[8]

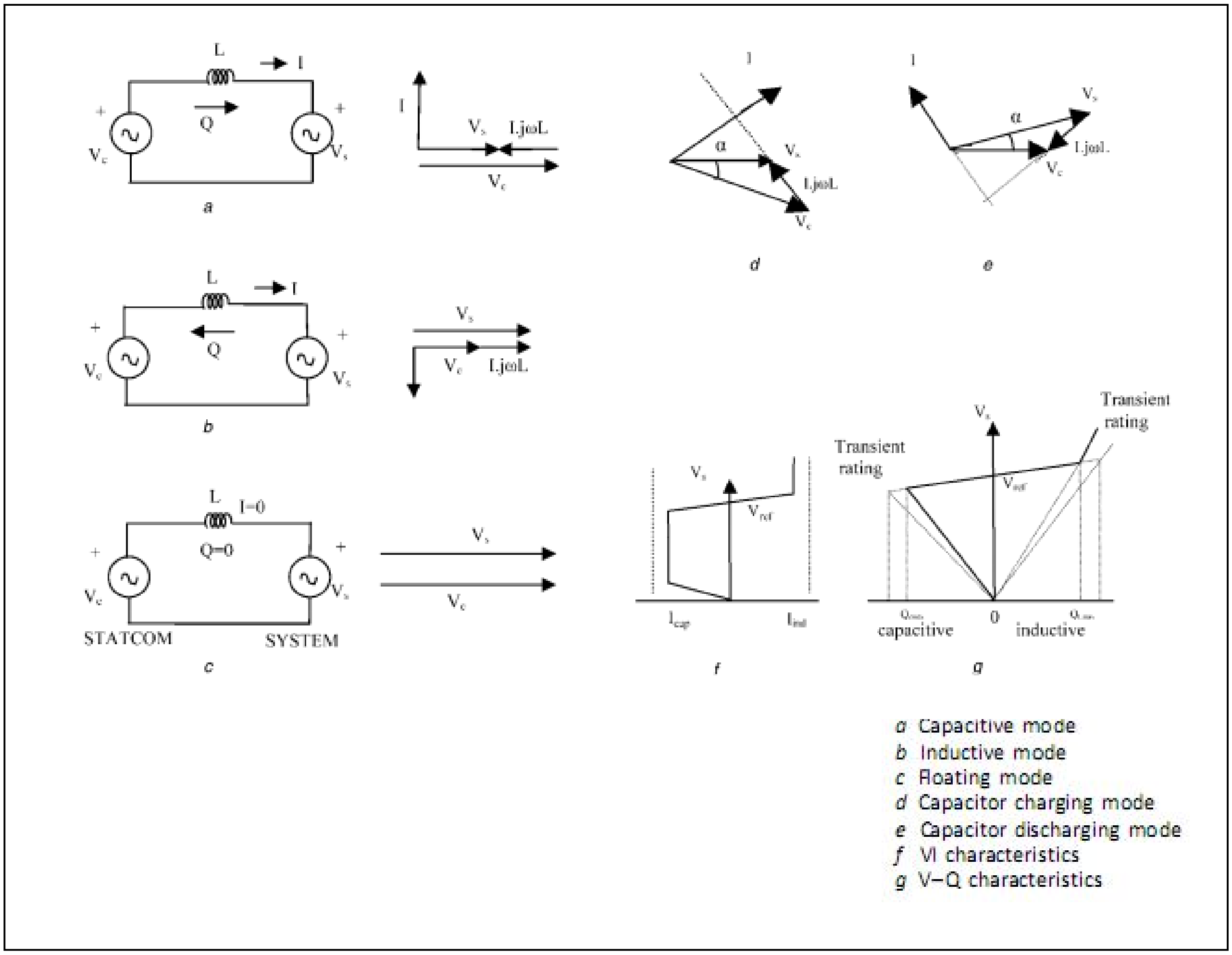


Figure 7 : STATCOM Operating Principle and Control Characteristics [2]

Summing up, STATCOMs are fast responding generators of reactive power with leading VAr or lagging VAr capability which can provide steady state reactive compensation as well as dynamic compensation during power system transients, sags, swells and flicker. Thereby they can contribute significantly to enhancement of power quality. [9]

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

In order to complete my project, the following procedure will be implemented:

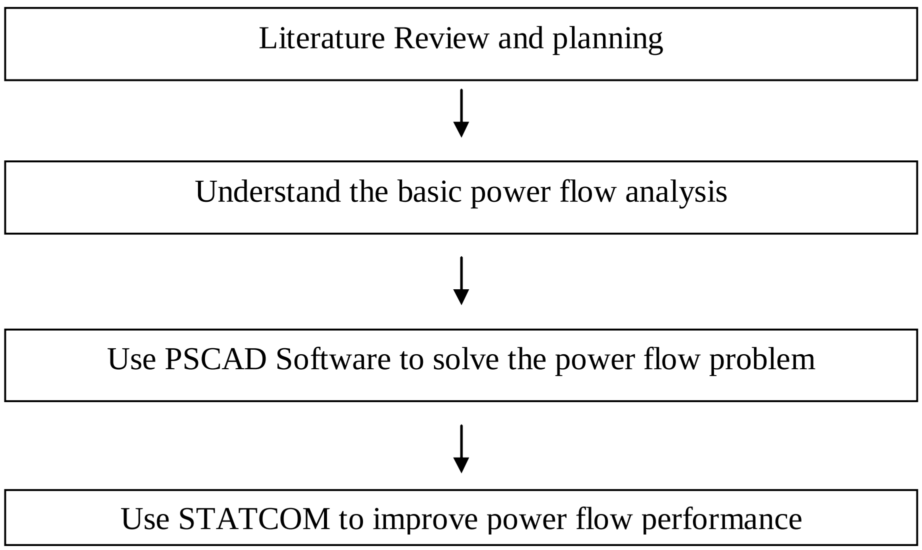


Figure 8: Sequential procedures to be followed throughout the project

Please refer APPENDIX A to view project Gantt chart.

3.2 Tools/Equipment Required

- PSCAD EMTDC software

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Simple Six Pulse STATCOM

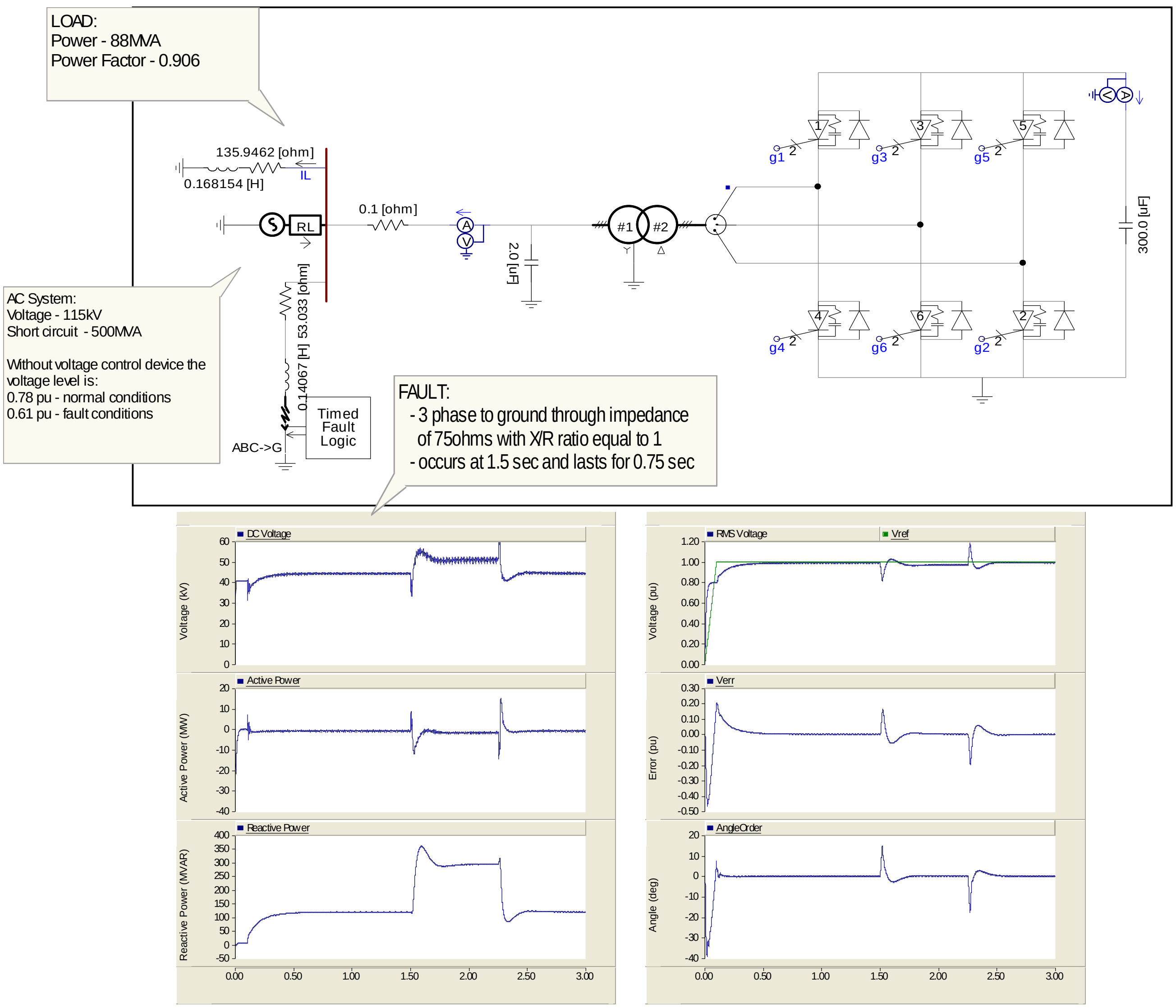


Figure 9 : Simple Six Pulse Statcom and its characteristics

Please refer APPENDIX B for full schematic diagram

4.2 5-Bus Network Simulation using PSCAD Software

The 5-Bus system without STATCOM is constructed and simulated to obtain the power flow result of voltage magnitude and phase angle.

Case 1 : A 5-Bus System Without STATCOM

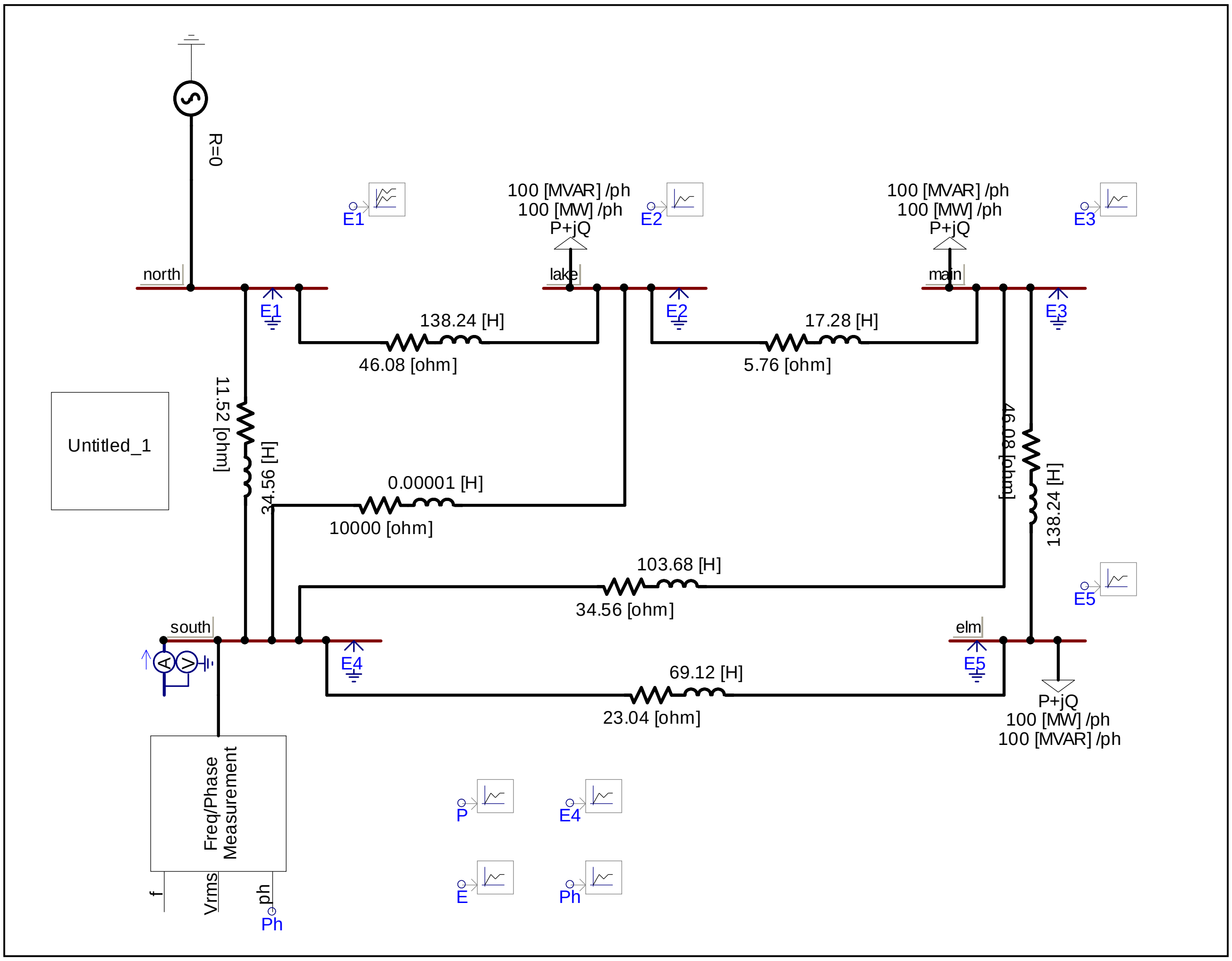


Figure 10 : A 5-Bus System Without STATCOM

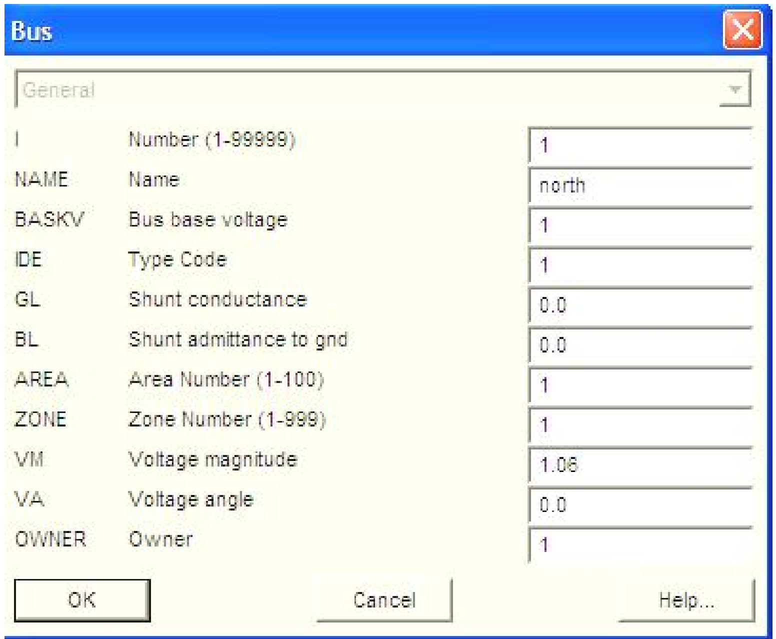


Figure 11 : Bus E1 parameters setting

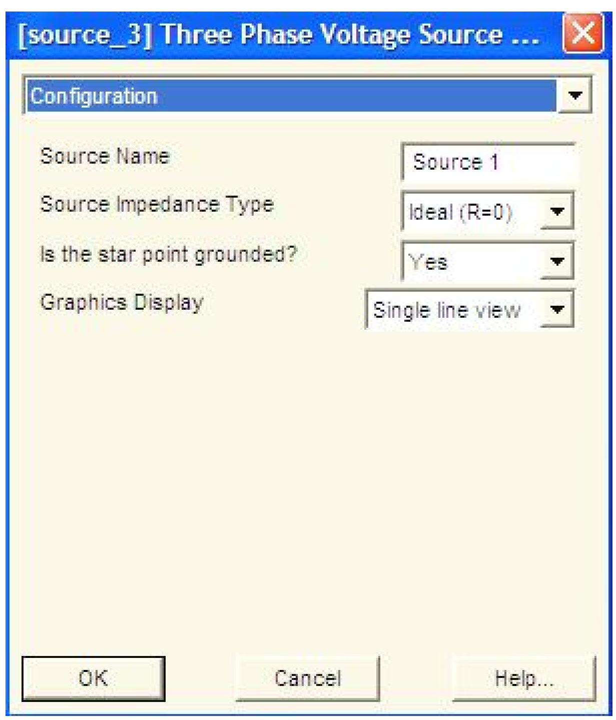


Figure 12 : Source Voltage parameters setting

Figures below display the output obtained for E1.

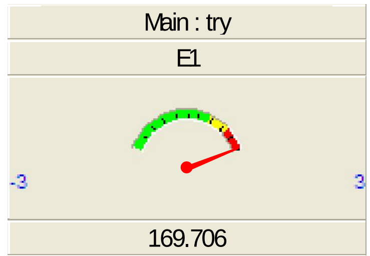


Figure 13 : Voltmeter reading at E1

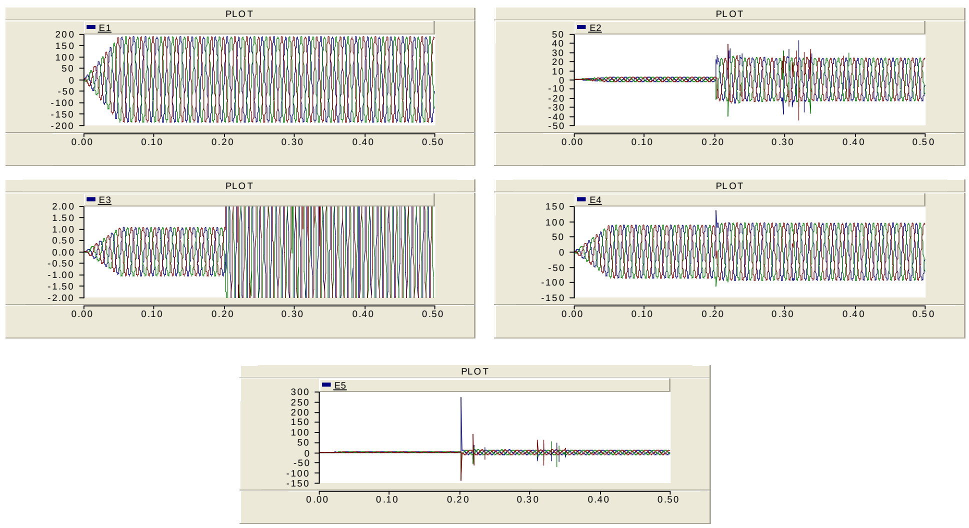


Figure 14: Plot of Voltage versus time of the 5-Bus System

From the graphs in Figure 14, Bus 1 or E1 displays a smooth graph because only pure source is presence. While E2, E3, E4 and E5 show unsmooth graphs with spikes because reactance is attached at each of the buses. STATCOM's role in regulating voltage is expected to minimize this problem.

4.3 5-Bus Network With Statcom Simulation using PSCAD Software

The 5-Bus system with STATCOM is constructed and simulated to obtain the power flow result of voltage magnitude and phase angle.

Case 2 : A 5-Bus System With STATCOM At Bus 2

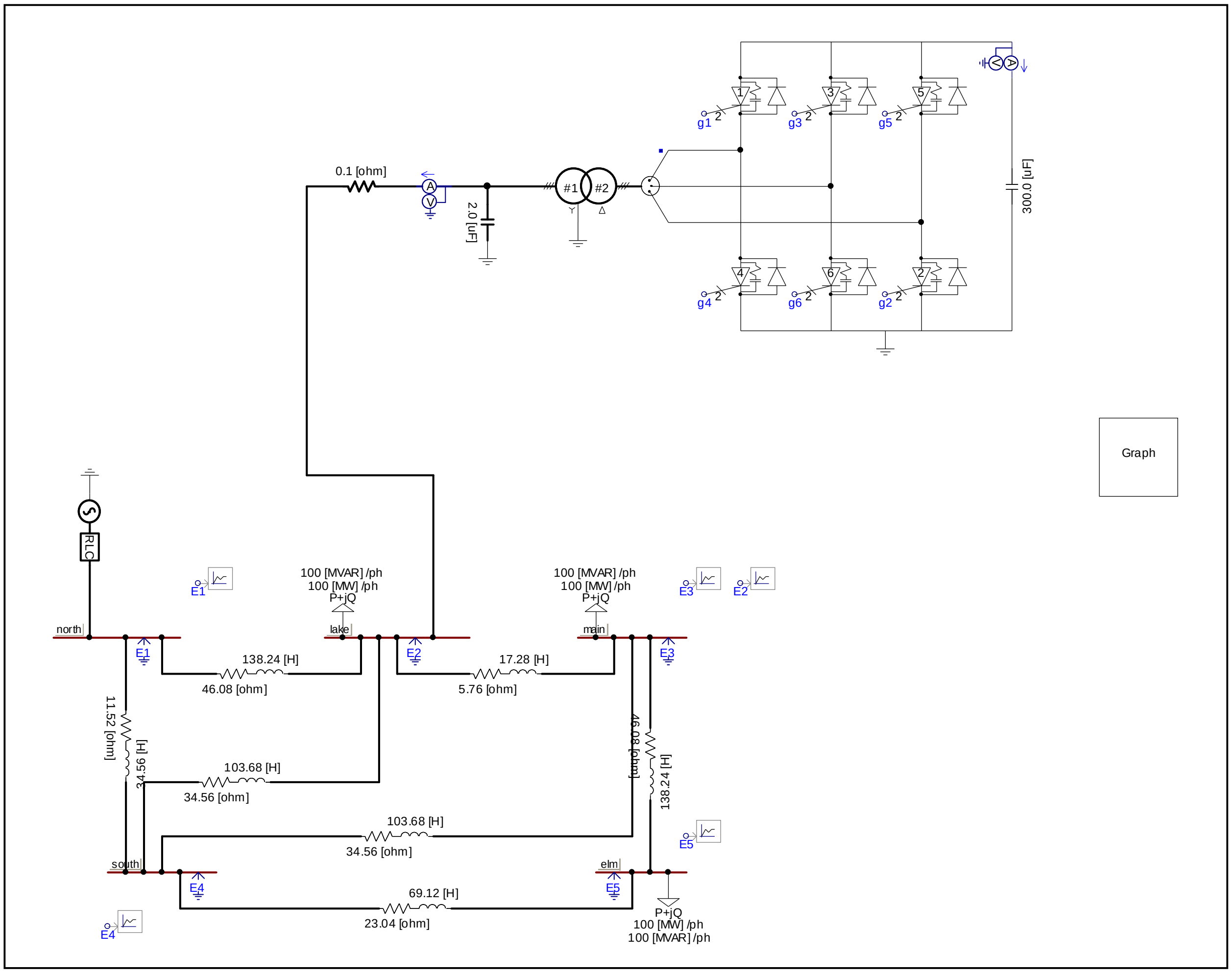


Figure 15 : A 5-Bus System With STATCOM At Bus 2

In Figure 15, Statcom is attached to the prior constructed 5-bus system at Bus 2 to enhance power transfer capability by using Facts devices.

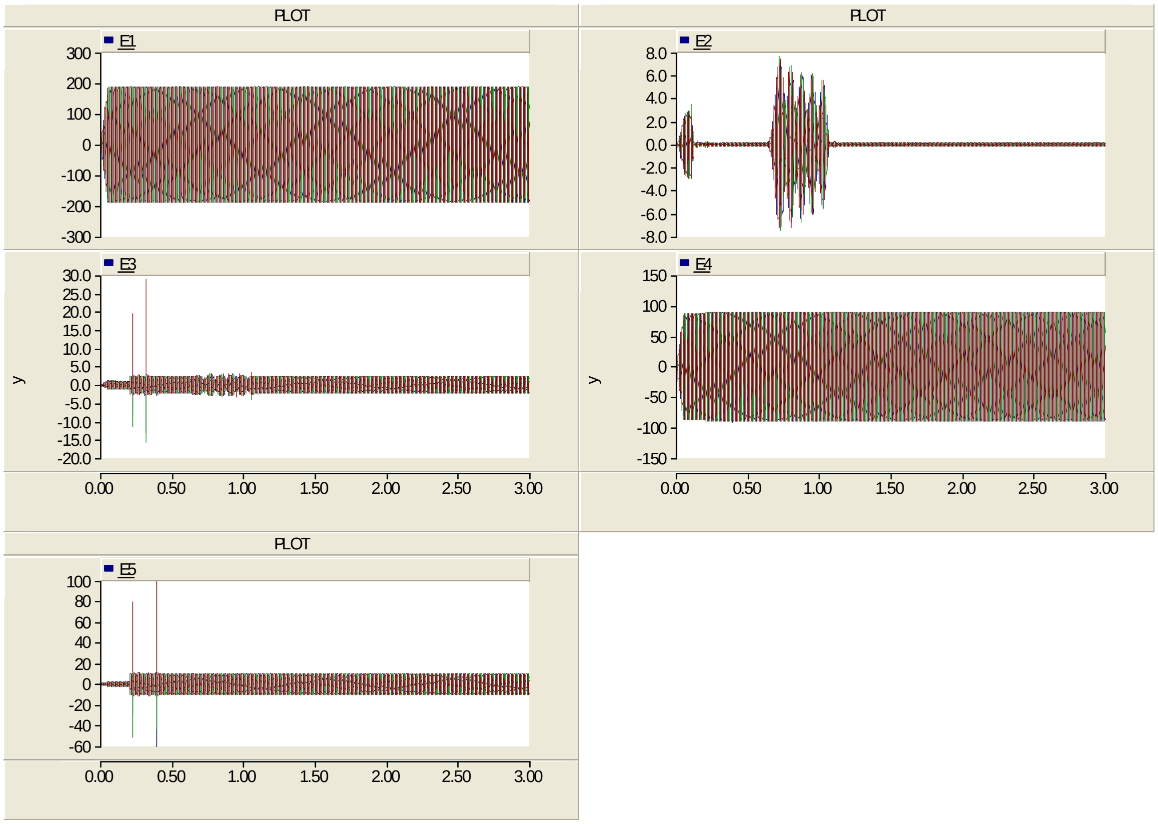


Figure 16 : Plot of Voltage versus time of the 5-bus System
With STATCOM At Bus 2

The resultant graphs in Figure 16 imply that plots of E1, E4 and E5 are stable although spikes still occur at E2 and E3. Overall, voltage stability has increased at the 5-bus system with STATCOM.

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Table 1: Expected Values of 5-bus System Without STATCOM

Nodal Voltage	BUS 1	BUS 2	BUS 3	BUS 4	BUS 5
Magnitude (p.u)	1.06	1.00	0.987	0.984	0.972
Phase angle (degree)	0.00	-2.06	-4.64	-4.96	-5.77

Table 2: Expected Values of 5-bus System With STATCOM

Nodal Voltage	BUS 1	BUS 2	BUS 3	BUS 4	BUS 5
Magnitude (p.u)	1.06	1.00	1.00	0.994	0.975
Phase angle (degree)	0.00	-2.05	-4.83	-5.11	-5.8

Comparing the voltage magnitude in table 1 and table 2, the voltage magnitudes at Bus 3, Bus 4 and Bus 5 in the five-bus system have increased towards the ideal value which is 1 p.u.

Next, power flow analysis has been performed on another two test cases. These are to compare result when STATCOM is placed at different buses in the system. The cases are presented as follows:

i) Case 3 : A 5-Bus System With Statcom at Bus 3

ii) Case 4 : A 5-Bus System With Statcom at Bus 5

Case 3 : A 5-Bus System With Statcom at Bus 3

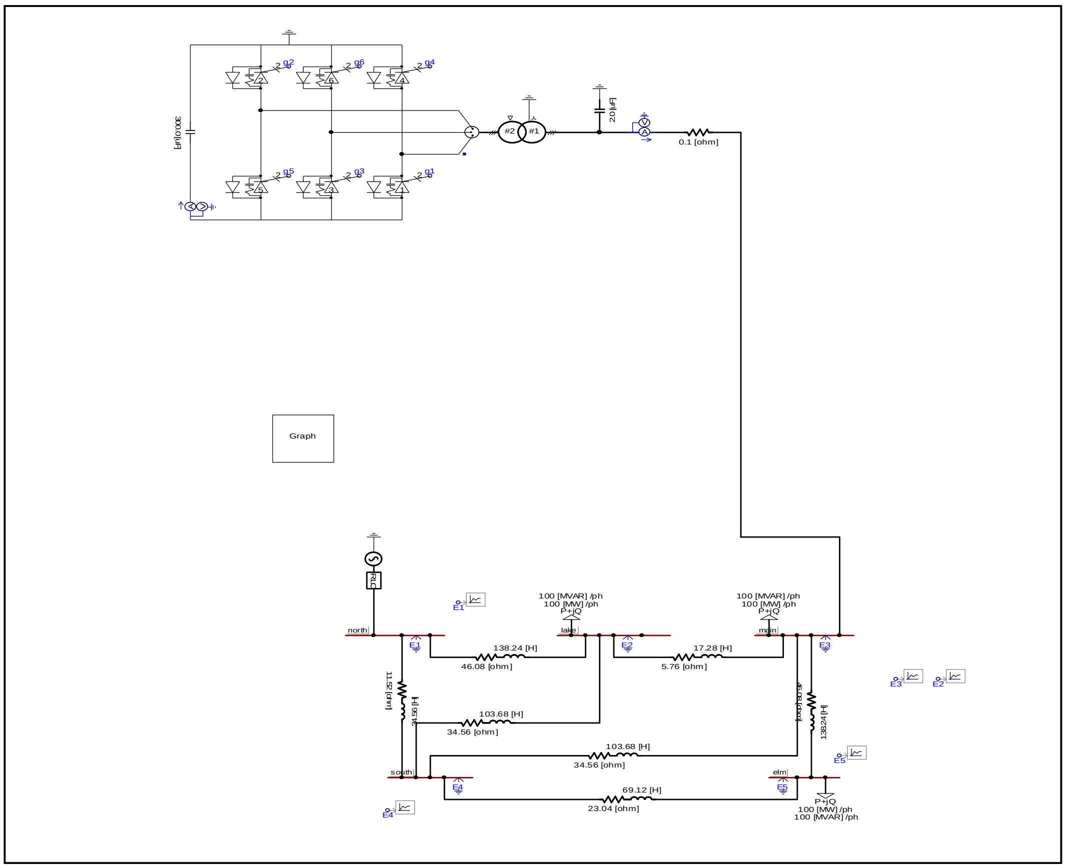

Figure 17 : A 5-Bus System With Statcom at Bus 3

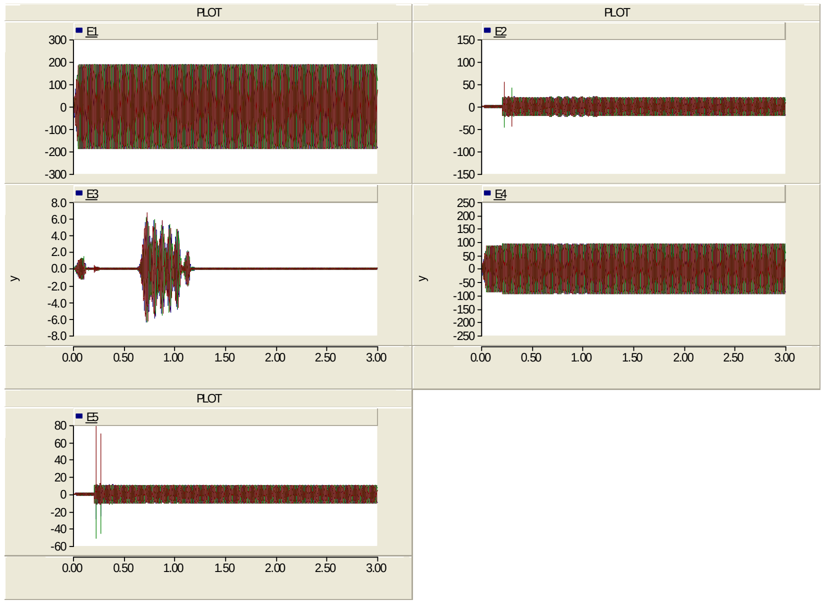

Figure 18 : Plot of Voltage versus time of the 5-bus System
With STATCOM At Bus 3

From Figure 18, the graph of E3 which represents Bus 3 does not have the same pattern with others because Statcom is attached at Bus 3. It functions to regulate the reactive power to meet the voltage requirement at the bus.

Case 4 : A 5-Bus System With Statcom at Bus 5

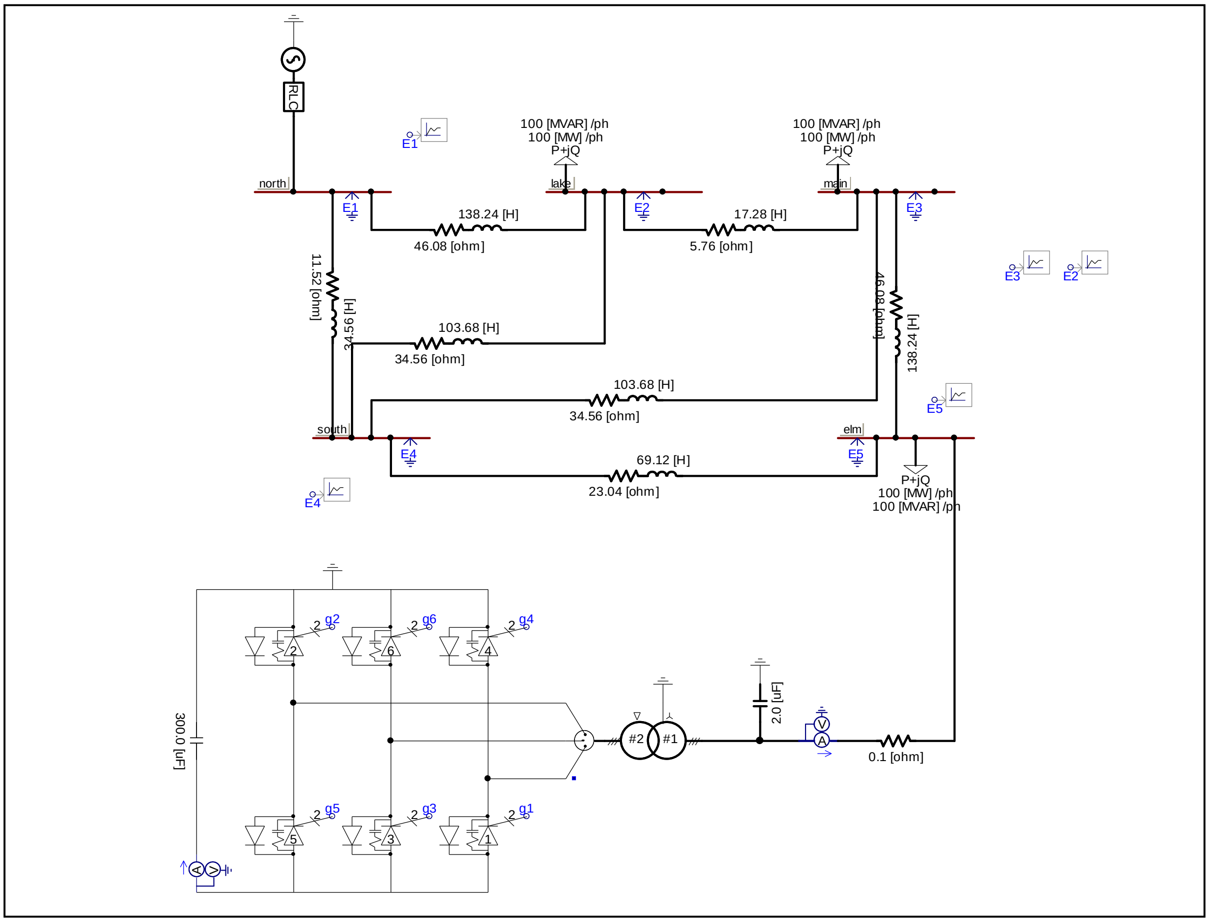

Figure 19 : A 5-Bus System With Statcom at Bus 5

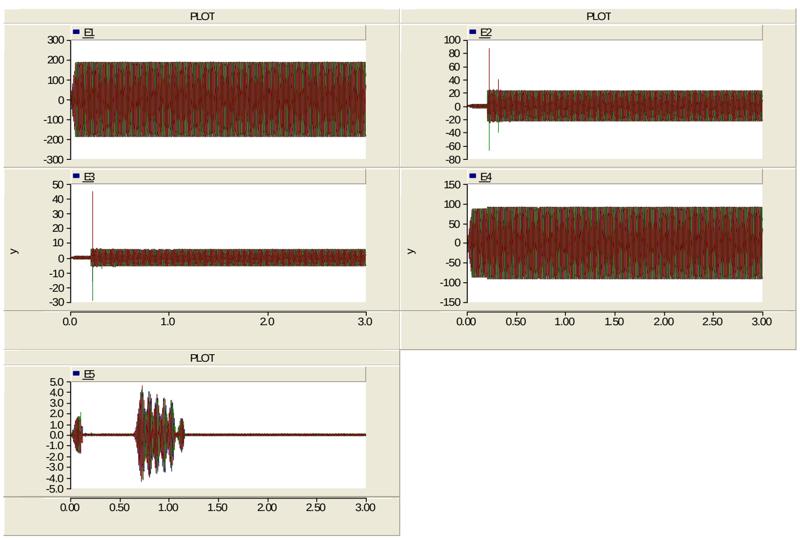

Figure 20 : Plot of Voltage versus time of the 5-bus System

With STATCOM At Bus 4

From Figure 20, the graph of E5 which represents Bus 5 also does not have the same pattern with others because Statcom is attached at the bus. It functions to regulate the reactive power to meet the voltage requirement at that bus hence it provides voltage stability.

To summarize the results and discussions of all the four cases of Statcom, Table 3 indicates the value of real power, P and reactive power, Q of Case 1 while Table 4 compares the value of P and Q at the transmission lines connected to the corresponding bus of interest. In Case 1 a 5-bus system without STATCOM is discussed whereas Case 2, Case 3 and Case 4 discuss 5-bus systems with STATCOM.

Table 3 : P and Q of Case 1

Transmission Lines	P (p.u)	Q (p.u)
Bus 2 – Bus 3	5.338e-005	0.0001403
Bus 3 – Bus 5	4.075e-007	7.764e-007
Bus 4 – Bus 5	0.0003006	0.02661

Table 4 : Comparison of P and Q of Test Cases

CASE	P (p.u)	Q (p.u)
Case 2	0.2611	0.0368
Case 3	0.2545	0.03591
Case 4	0.2119	0.0299

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.1 Conclusion

This project focuses on STATCOM which provides instantaneous and continuous variable reactive power to increase voltage stability in a system. STATCOM produces or absorbs reactive power using a combination of capacitors, reactors and power electronic switches. The power flow simulation result of both bus system with and without STATCOM shall justify the role of STATCOM in enhancing the power transmission network.

Voltage stability in a network is very important to minimize power loss. From the result obtained, voltage magnitudes at buses with Statcom attached to it, increase. This is because Statcom regulates the reactive power to maintain whatever value of voltage magnitude required to increase system stability.

STATCOM absorbs or delivers reactive power to the system with compensation purposes. This project helps to understand the role of STATCOM and implement it in a power flow system. Hence improve the performance of power transmission network.

5.2 Recommendation

This project is intended to improve the power flow performance in a transmission network employing PSCAD EMTDC software. 5-Bus system with different cases had been constructed and analyzed to study the power flow and FACTS controller-Statcom. With objective to add improvement on the output data, simulations can be carried on with larger system containing more number of buses. This will allow more data manipulations hence produce variation of resultant data to be discussed. Other than that, it is also recommended to run actual experiments for the power system.

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APPENDICES

APPENDIX A

PROJECT GANTT CHART

APPENDIX B

STATCOM & ITS CHARACTERISTICS

APPENDIX C

Statcom Characteristics In A 5-Bus System