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APPLICATION OF AI TECHNIQUE FOR OPTIMAL LOCATION OF TCSC DEVICE

MOHD DAIM BIN MOHD DIAH

A thesis submitted in fulfillment of requirements for the award of the Bachelor of Electrical Engineering (Power System)

Faculty of Electrical & Electronic Engineering

Universiti Malaysia Pahang

NOVEMBER 2010

"I declare that this thesis entitled "Development of DC Power Supply Using Power Electronic Applications" is the result on my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidate of any of any other degree"

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DEDICATION

Specially dedicated To my beloved father Mohd Diah Bin Simu,
mother Samsunar Binti Muhammad and my sister for giving constant support and encouragement

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First of all, I would like to give my thanks to the Almighty Allah, for giving me the strength and the ability to complete the project wholeheartedly. Without it I possibly can not finish the project in a timely manner.

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ABSTRACT

This project is about how was to develop dc power supply using the applications of power electronic. In the power generation of most of electrical circuit, dc power supply is very required and demanded. It is familiarly to provide power for control and drive circuit within the main switchmode unit. Depending on the approaching of circuit design, the power supply will be common to either input or output of the circuit modeling. The design of DC power supply depends on the output of circuit design either single output or multiple output. There are different analysis to design the circuit based on the number of output. In this project, there are many applications of power electronics are applied such as transformer, AC to DC converter or rectifier, DC-DC converter, and semicondutor devices like power transistor. The circuit design approaching depends on the combination of these power electronic applications. The power supply designed is fully conversant with various combinations and its designer should be having capability to select the most appropriate for a particular application has indeed very powerful design tools.

ABSTRAK

Projek ini adalah mengenai bagaimana untuk mencipta pembekal kuasa arus terus dengan menggunakan aplikasi-aplikasi elektronik kuasa. Dalam penjanaan kuasa kebanyakan litar elektrik, pembekal kuasa arus terus sangat diperlukan dan mempunyai pemintaan yang tinggi. Ia biasanya membekalkan kuasa untuk litar kawalan dan kendalian. Bergantung dengan pendekatan rekaan litar, pembekal kuasa ini secara umum untuk sama ada kemasukan atau keluaran model litar. Model litar pembekal kuasa arus terus bergantung ke atas keluaran rekaan litar sama ada satu keluaran atau banyak keluaran. Terdapat analisis berbeza untuk merekacipta litar itu berdasarkan jumlah keluaran yang dikehendaki. Dalam projek ini, terdapat beberapa aplikasi elektronik kuasa diguna-pakai seperti penukar arust ulang-alik kepada arus terus, penukar arus terus kepada arus terus, dan komponen semikonduktor seperti transistor. Pendekatan model litar ini bergantung kepada kombinasi aplikasi-aplikasi elektronik kuasa. Pembekal kuasa arus terus direka sepenuhnya dengan pelbagai kombinasi dan pereka tersebut mempunyai kemampuan sewajarnya dengan menggunakan peralatan-peralatan yang berkualiti.

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LIST OF ABBREVIATIONS

TCSC	-	Thyristor Controlled Series Capacitor
PSO	-	Particle Swarm Optimization
TTC	-	Total Transfer Capability
FACTS	-	Flexible Alternative Current Transmission System
TCPS	-	Thyristor Controller Phase Shifter
SVC	-	Static VAR Compensator
TCR	-	Thyristor Controller reactor
UPFC	-	Unified power Flow Controller
SSSC	-	Static Synchronous Series Compensator
AC	-	Alternative Current
DC	-	Direct Current

CHAPTER 1

INTRODUCTION

1.1 Overview

Modern electric power utilities are facing many challenges due to ever-increasing complexity in their operation and structure. In the recent past, one of the problems that got wide attention is the power system instabilities [1]. With the lack of new generation and transmission facilities and over exploitation of the existing facilities geared by increase in load demand make these types of problems more imminent in modern power systems.

Demand of electrical power is continuously rising at a very high rate due to rapid industrial development. To meet this demand, it is essential to raise the transmitted power along with the existing transmission facilities. The need for the power flow control in electrical power systems is thus evident. With the increased loading of transmission lines, the problem of transient stability after a major fault can become a transmission power limiting factor. The power system should adapt to momentary system conditions, in other words, power system should be flexible. The idea of the so-called Flexible AC Transmission System (FACTS) has been introduced in 1980s. TCSC is the first generation of FACTS, which can control the line impedance through the introduction of a thyristor controlled capacitor in series with the transmission line [2].

Flexible AC Transmission Systems, called FACTS, got in the recent years a well-known term for higher controllability in power systems by means of power electronic devices. Several FACTS-devices have been introduced for various applications worldwide. A number of new types of devices are in the stage of being introduced in practice. In most of the applications the controllability is used to avoid cost intensive or landscape requiring extensions of power systems, for instance like upgrades or additions of substations and power lines. FACTS-devices provide a better adaptation to varying operational conditions and improve the usage of existing installations. There is several basic application of FACTS device [3]:

1. Power flow control.
2. Voltage control
3. Reactive power compensation
4. Stability improvement
5. Power quality improvement
6. Power conditioning

The project is using the application of Artificial Intelligent (AI) technique for optimal location of the FACTS device by using the Thyristor Controlled Series Capacitor (TCSC). The AI technique that will use is Particle Swarm Optimization (PSO) technique. This technique used to find optimal location of Flexible AC Transmission System (FACTS) devices to achieve the maximum system loadability.

1.2 Objectives

The objectives of this project are:

I. Using AI software (MATLAB) to find the parameter of FACTS device (TCSC).
II. Using the application of PSO (Particle Swarm Optimization) to find optimal location of FACTS device (TCSC) to reduce total losses.
III. Find the best location for the FACTS device TCSC (Thyristor Controlled Series Capacitor).

1.3 Scope of Project

The scopes of this project are:

a) Develop an algorithm by using MATLAB software to find the parameter of the FACTS device (TCSC).

b) Finding the optimal location for FACTS device (TCSC) using the application of Particle Swarm Optimization (PSO) technique.

c) Simulations are performed on IEEE 6 bus system for optimal location of TCSC device.

1.4 Problem Statement

The Electric supply industry is undergoing a profound transformation worldwide. Therefore sufficient transmission capacity for supporting transmission services is a great demand to transmission network's requirement. Transmission line need to transfer the power in efficiency state but is hard to get maximum power transfer capability. Total transfer capability (TTC) is a terminology that is used to define the amount of electric power that can be transferred over the interconnected transmission systems in a reliable manner [4]. If we can increases transfer capability between two areas of the grid might be more beneficial for increasing both reliability and economic. Present transmission line need to improve the ability to control the parameter and variable. By improving this ability, the existing transmission line will be more efficient and easy to control the variables depend on the demands.

1.5 Thesis Organization

Including this chapter, it consists of 5 chapters altogether. Chapter 1 will brief introduction about the project. Chapter 2 contained full description of the project, Chapter 3 consisting of the project methodology, mostly about the project flow and how it's organized. Chapter 4 will presenting the expected result, while the conclusions presented in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents an overview of the Particle Swam Optimization (PSO) and basic working principle of the Flexible AC Transmission System (FACTS) device will be discussed. It would also include brief overview of the continuous power flow analysis. Lastly, the principal of Matlab and the reviews of related work would also be included.

2.2 PSO Overview

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr.Ebehart and Dr. Kennedy in 1995, inspired by social behaviour of bird flocking or fish schooling [5]. PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. The detailed information will be given in following sections. Compared to GA, the advantages of PSO are that PSO is easy to implement and there are few parameters to adjust. PSO has been successfully applied in many areas: function optimization, artificial neural network training, fuzzy system control, and other areas where GA can be applied. Each particle of swarm has three features according to [6]:

(i) *Position* (this is the ith particle at time k, notice vector notation)

(ii) *Velocity* (similar to search direction, used to update the position)

(iii) *Fitness or objective* (determines which particle has the best value in the swarm and also determines the best position of each particle over time.

Every PSO uses a population of particles. The number of particle in a swarm is typically far less than the number of individuals in an evolutionary algorithm. A particle in this population is interconnected to other particles. This interconnection is called the neighbourhood topology. Neighbourhood refers to a communication structure rather than a geographical neighbourhood. To use these particles to explore the search space we need a so-called change rule. This rule moves the particles through the search space at a given moment t in time depending on its position at moment t_1 as well as the position of its previous best location. This is the cognitive aspect of the PSO. The social aspect is introduced by an interaction rule. A particles position is not only dependent on its own best position in history, but also on the best position in history of its neighbours.

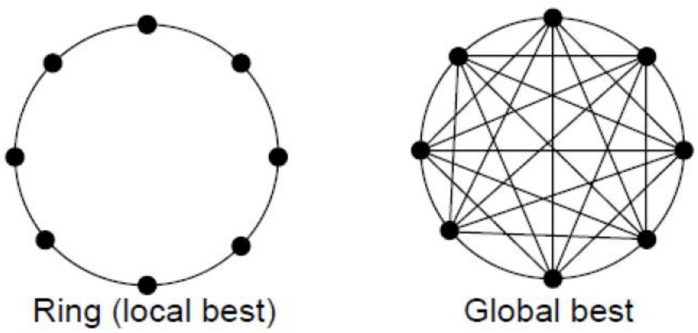

Fig 2.1: Two different neighbourhood topologies

2.3 FACTS Device

The Flexible Transmission Systems (FACTS) devices have been economically proved to be promising candidate for wide application for the purpose of power system stability enhancement. In 1988, Hingorani have initiated the concept of FACTS devices and their application for the following purposes: control of power routing, loading of transmission line near their steady-state, limiting the impact of multiple fault and, hence, containing cascaded outage. This can be performed through the use of thyristor-controlled phase shifter (TCPSs) which control the phase angle, thyristor-controlled series capacitors (TCSCs) which control the line impedance, static VAR compensators (SVCs) which controls the bus voltage, unified power flow controllers (UPFC), and other thyristor-controlled devices such as static compensator (STATCOMs), thyristor-controlled dynamic brake, etc [7-8].

2.4 Thyristor-controlled Series Capacitors (TCSC)

Thyristor-controlled series capacitors (TCSC) is also a type of series compensator, can provide many benefits for a power system including controlling power flow in the line, damping power oscillations, and mitigating sub synchronous resonance. The TCSC concept is that it uses an extremely simple main circuit. The capacitor is inserted directly in series with the transmission line and the thyristor-controlled inductor is mounted directly in parallel with the capacitor. Thus no interfacing equipment like e.g. high voltage transformers is required. This makes TCSC much more economic than some other competing FACTS technologies. Thus it makes TCSC simple and easy to understand the operation [9]. Figure 1 showed the simple diagram of TCSC.

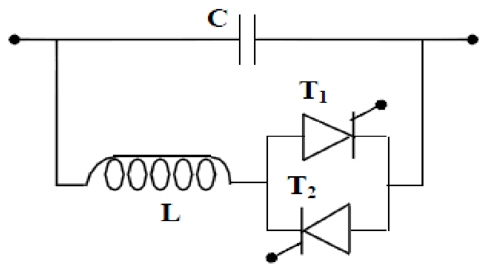

Fig 2.2: Basic TCSC circuit

The equivalent TCSC reactance is given by:

$$X_{TCSC} = X_C \frac{X_C^2}{X_C - X_P} \frac{2\beta \sin 2\beta}{\pi} + \frac{4X_C^2}{X_C - X_P} \frac{cos^2\beta}{(k^2-1)} \frac{(k \tan k\beta \tan \beta)}{\pi} \tag{2.1}$$

Where,

X_C = Nominal reactance of the fixed capacitor.

X_P = Reactance of inductor connected in parallel with fixed capacitor

β = Angle of advance

It is obvious that power transfer between areas can be affected by adjusting the net series impedance. One such conventional and established method of increasing transmission line capability is to install a series capacitor, which reduces the net series impedance, thus allowing additional power to be transferred. Although this method is well known, slow switching times is the limitation of its use. Thyristor controllers, on the other hand, are able to rapidly and continuously control the line compensation over a continuous range with resulting flexibility. Controller used for series compensation is the Thyristor Controlled Series Capacitor (TCSC).

TCSC controllers use thyristor-controlled reactor (TCR) in parallel with capacitor segments of series capacitor bank (Figure 1). The combination of TCR and capacitor allow the capacitive reactance to be smoothly controlled over a wide range and switched upon command to a condition where the bi-directional thyristor pairs conduct continuously and insert an inductive reactance into the line.

TCSC is an effective and economical means of solving problems of transient stability, dynamic stability, steady state stability and voltage stability in long transmission lines. TCSC, the first generation of FACTS, can control the line impedance through the introduction of a thyristor controlled capacitor in series with the transmission line. A TCSC is a series controlled capacitive reactance that can provide continuous control of power on the ac line over a wide range.

2.5 TCSC in Transmission Line System

World's first 3 phase [10], 2 X 165 MVAR, TCSC was installed in 1992 in Kayenta substation, Arizona. It raised the transmission capacity of transmission line by 30%, but it was soon realized that the device is also a very effective means for providing damping of electromechanical power oscillations. A third possible application of TCSC emerged from the onsite observations that it can provide series compensation without causing the same risk for sub-synchronous resonance (SSR) as a fixed series capacitor. World's first TCSC for sub synchronous resonance (SSR) mitigation was installed in Stode, Sweden in 1998, by ABB. Specifically this period makes a valiant period for TCSC and makes the researchers to turn on to TCSC.

Other TCSC installations are in Brazil, they demonstrated their capability to stabilize a transmission system with a length of more than 1000 km, which could not be operated safe and stable without series compensation [11]. Another TCSC installation is in operation since one year in China, within a project to transfer electric power over a distance of more than 1000 km on parallel AC- and DC-lines [12]. Also in other countries with long distance power transmissions TCSCs are in commercial operation or under construction.

2.6 OPERATION OF TCSC

The basic operation of TCSC can be easily explained from circuit analysis. It consists of a series compensating capacitor shunted by a Thyristor controlled reactor (TCR). TCR is a variable inductive reactor X_L (figure 2) controlled by firing angle α. Here variation of XL with respect to α is given by

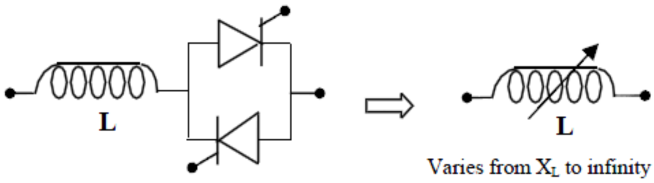

Fig 2.3: Simplify of TCSC Circuit

$$X_L(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - \sin 2\alpha} \tag{2.2}$$

For the range of 0 to 90 of α, $X_L(\alpha)$ start vary from actual reactance X_L to infinity. This controlled reactor is connected across the series capacitor, so that the variable capacitive reactance (figure 3) is possible across the TCSC to modify the transmission line impedance. Effective TCSC reactance X_{TCSC} with respect to alpha (α) is, [13, 14, 15,16].

$$\begin{aligned} X_{TCSC}(\alpha) &= -X_C + C_1(2(\pi - \alpha) + \sin(2(\pi - \alpha))) \\ &\quad - C_2\cos^2(\pi - \alpha)(w\tan(w(\pi - \alpha)) - \tan(\pi - \alpha)) \end{aligned} \tag{2.3}$$

Where,

$$X_{LC} = \frac{X_C X_L}{X_C - X_L}$$

$$C_1 = \frac{X_C + X_L}{\pi}$$

$$C_2 = 4\frac{X^2{}_{LC}}{X_L \pi}$$

$$w = \sqrt{\frac{X_C}{X_L}}$$

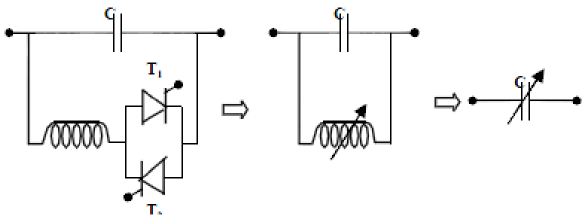

Fig 2.4: Equivalent circuit of TCSC

2.7 IMPEDANCE CHARACTERISTIC

Figure 4 shows the impedance characteristics curve of a TCSC device. It is drawn between effective reactance of TCSC and firing angle α [13, 16, 17, 18]

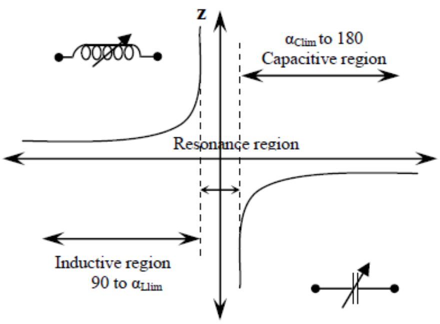

Fig 2.5: Impedance Vs firing angle characteristic curve

Net reactance of TCR, $X_L(\alpha)$ is varied from its minimum value X_L to maximum value infinity. Likewise effective reactance of TCSC starts increasing from TCR X_L value to till occurrence of parallel resonance condition $X_L(\alpha) = X_C$, theoretically X_{TCSC} is infinity. This region is inductive region. Further increasing of $X_L(\alpha)$ gives capacitive region, Starts decreasing from infinity point to minimum value of capacitive reactance X_C.

Thus, impedance characteristics of TCSC shows, both capacitive and inductive region are possible though varying firing angle (α).

From

$90 < \alpha < \alpha_L lim$ Inductive region.

$\alpha_L lim < \alpha < \alpha_C lim$ Capacitive region

Between

$\alpha_L lim < \alpha < \alpha_C lim$ Resonance region

While selecting inductance, X_L should be sufficiently smaller than that of the capacitor X_C to get both effective inductive and capacitive reactance across the device.

Suppose if X_C is smaller than the X_L, then only capacitive region is possible in impedance characteristics. In any shunt network, the effective value of reactance follows the lesser reactance present in the branch. So only one capacitive reactance region will appears.

Also X_L should not be equal to X_C value; or else a resonance develops that result in infinite impedance and unacceptable condition. Note that while varying $X_L(\alpha)$, a condition should not allow to occur $X_L(\alpha) = X_C$.

2.8 Current methods for solving the FACTS allocation problem

Since 1995, researchers have investigated the effects of FACTS devices in the power system. Steady state performance as well as dynamic and transient stability have been focus areas of study, but mainly for the purpose of finding appropriate controllers for these equipments.

The problem of optimal allocation of FACTS devices, considering technical criteria and cost functions, is still in a relatively early stage of investigation. Frequently, only technical criteria have been considered and the solutions found are not proven to be the global optimum.

This section presents current methods for allocating FACTS devices in the power system. These methods can be separated in three distinctive groups:
(i) Classical optimization methods, (ii) methods based on technical criteria and (iii) evolutionary computation techniques.

2.8.1 Classical Optimization Methods

Classical optimization theory has been applied in the literature to the FACTS allocation problem in the form of MILP and MINLP. In the MILP formulation, the approach is based on DC power flow that allows the power system to be represented in a linear manner [21]-[23]. The performance of the system is analyzed in steady state conditions considering maximum loadability of the system [21]-[23] and total transfer capability (TTC) [21]. The algorithms considered insolving the MILP problem are B&B, Gomory cuts [21], [22], and Bender’s decomposition [23].

The concluding remarks of the MILP approach indicate that the optimization process is performed in an efficient manner. However DC power flow is not suitable for performing transient analysis, therefore AC models should be considered and then the problem becomes non linear.

2.8.2 Method Base on Technical Criteria

Another group of methods that the literature have presented to solve the allocation of FACTS devices correspond to those based on pure technical criteria, in particular, sensitivity analysis for steady state performance and modal analysis for transient and dynamic conditions of the power system.

2.8.3 Evolutionary Computation Technique

A third group of methods to address the problem of optimally allocate FACTS devices corresponds to ECTs. In this case, the main objective is to find the optimal types, number, sizes, and locations for the FACTS devices in the system. To achieve this goal, several criteria are considered such as maximum loadability, minimum cost (installation and maintenance), transmission loss minimization, improvement of security margin, and maximization of TTC. Some studies also include N-1 contingency analysis [26] and the power generation and dispatch problem in deregulated markets [27]. The investigation mostly limited to steady state conditions; just two cases consider dynamic analysis of the power system. In one of these cases, the transient analysis is not used to allocate the FACTS device but to determine optimal control settings for power system stabilizers (PSS). The other study uses small signal analysis in order to determine the optimal location and types of FACTS devices.

The objective function is formulated based on three measurements: overshoot coefficient, damping ratio, and a penalty term for those unstable eigenvalues aligned in the right hand side plane. The results obtained for steady state analysis [24], [23], [27]-[28], are satisfactory in finding global optimum in reasonable computational time; however there is no clear indication that one algorithm outperforms all others. Several evolutionary computation techniques and hybrid versions can be used to address power system problems but the results are highly dependent on the nature of the problem and the implementation of the algorithm. In terms of transient analysis, results reported considering eigenvalue analysis are promising for small power systems (IEEE 14 bus system) [28].

In general the evolutionary computation techniques perform well in solving mixed integer non linear problems. However the scalability of these methods as well as their applications to dynamic and transient analysis requires further investigation.

2.9 MATLAB

Matlab is a commercial "Matrix Laboratory" package which operates as an interactive programming environment. It is a mainstay of the Mathematics Department software lineup and is also available for PC's and Macintoshes and may be found on the CIRCA VAXes. Matlab is well adapted to numerical experiments since the underlying algorithms for Matlab's builtin functions and supplied m-files are based on the standard libraries LINPACK and EISPACK.

Matlab program and script files always have filenames ending with ".m"; the programming language is exceptionally straightforward since almost every data object is assumed to be an array. Graphical output is available to supplement numerical results.

Matpower is a package of Matlab M-files for solving power flow and optimal power flow problems. It is intended as a simulation tool for researchers and educators that is easy to use and modify. Matpower is designed to give the best performance possible while keeping the code simple to understand and modify.

2.10 Reviews of Related Work

The paper by Yao et. al. (2005) is mainly about the application of SSSC in the purpose of congestion management and transfer capability of the power systems with high penetration of wind power. In order to verify their result, they have done some tests on modified IEEE 30 bus system, which consists of 6 generators (5 conventional generating plants and 1 wind farm). Based on the paper, they applying the continuous power flow analysis to compute the power transfer capability without the insertion SSSC. With the analysis, they obtained the maximum loading parameter, total generation and generation by wind. They also found out that the line that connecting bus 2 and 6 was congested. With this finding (the congested line) they eventually had determined the place for the insertion of SSSC in the system.

Then, they once again utilised the continuous power flow analysis in order to compute the power transfer capability after injecting SSSC in series with line 2-6. After the analysis had been made, they obtained the maximum loading parameter, total generation and generation by wind farm. Having the power flow results before and after the insertion of the SSSC, they made a comparison based on the acquired data, and it is shown that the maximum loading parameter, total generation and generation by wind farm increases. Therefore, based on the comparison made, they concluded that the power transfer capability of the network increase.

Mahdad et. al. (2006) basically presented method on how to choose the type of FACTS Controllers, the location (or the placement) and control the FACTS Controllers. They use 2 types of compensation, namely the SVC for shunt connected FACTS Controller and TCSC for series connected FACTS Controller. They have stated that they would use system loading ability and loss minimisation as a measure of power system performance. Similar with the preceding paper, they applied the continuous power flow method in order to determine the weak bus by comparing the voltage profiles of each bus in the system. With the data obtained, they have chosen the bus in which has the worst voltage profile (worst voltage collapse among other buses). Based on their finding, they placed SVC and again, they applied continuous power flow method to obtain the voltage profiles. After comparison made the maximum loading parameter and the voltage stability proven to be increased. For this project, the approach proposed by Mahdad et. al. (2006) would be used to compare the FACTS Controllers. The use of CPF is more reliable than the ordinary power flow method available for this case, since the power flow method simulate the increasing of load, and therefore the FACTS Controllers effects and performance are most likely could be studied.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Methodology can properly refer to the theoretical analysis of the methods appropriate to a field of study or to the body of methods and principles particular to a branch of knowledge. Flows of this project can be planned according to the methodology that already stated.

This project would demonstrate the effects and the performance of implementing Thyristor Controller Series Capacitor (TCSC) in the power system. Before the performance and the effect of TCSC in power system were evaluated, firstly the power flow using the Newton-Raphson method to analysis the 6-bus system used before installing the TCSC and the data was collected, then location or the placement and the parameter of the TCSC were determined and use the same method to analysis the bus system with TCSC installed. Finally, by using the application of Particle Swarm Optimization (PSO), it will find the best location and parameter for the TCSC. The results are used to evaluate the line or transformer loading, the acceptability of bus voltages and the total power losses.

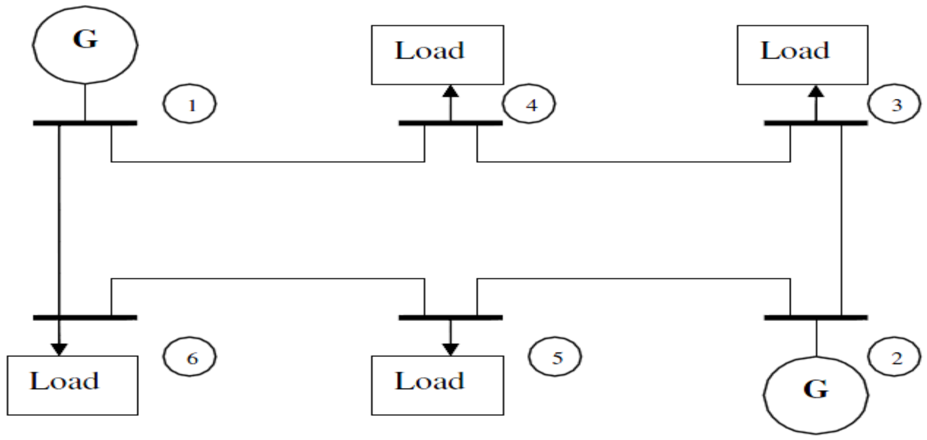

Fig 3.1: 6-bus test system diagram

The technique for this project is tested on a six bus test system which was obtained from IEEE as shown in Figure 3.1. The bus consists of four load buses, one slack bus and one generator bus which can be seen from Figure 3.2 and Figure 3.3 that is the bus data and line data for six bus system.

Table 3.1: Busdata of 6-bus test system

Bus	Code	Voltage	Angle	Load		Generator		Injected		
		(pu)	(θ)	MW	Mvar	MW	Mvar	Qmin	Qmax	Mvar
1	1	1.0	0.0	0.00	000	0.00	0.00	0.00	0.00	0
2	2	1.0	0.0	0.00	000	40.0	0.00	-40.0	40.0	0
3	0	1.0	0.0	38.0	2.00	0.00	0.00	0.00	0.00	0
4	0	1.0	0.0	10.0	2.00	0.00	0.00	0.00	0.00	0
5	0	1.0	0.0	20.0	2.00	0.00	0.00	0.00	0.00	0
6	0	1.0	0.0	30.0	3.00	0.00	0.00	0.00	0.00	0

Table 3.2: Linedata of 6-bus test system

Bus		Resistance	Reactance	Shunt Conductance	Shunt Susceptance	Tap Setting
Send	Rec					
1	6	0.102	0.413	0.0	0.0	1.00
1	4	0.110	0.480	0.0	0.0	1.00
4	6	0.120	0.516	0.0	0.0	1.00
6	5	0.190	0.820	0.0	0.0	1.09
2	5	0.368	1.490	0.0	0.0	1.00
2	3	0.115	0.510	0.0	0.0	1.00
4	3	0.080	0.360	0.0	0.0	1.00

3.2 Analysis 6-bus system using Newton Raphson Method

The EEE 6-bus system is shown in Figure 6. Bus 1 is the swing bus, bus 2 is a PV bus, while Bus 3 and 6 are reactive power installation buses. The IEEE 6-bus system is used to show the practicability of the proposed algorithm and to find the optimal settings for generator voltages, transformer taps and switch-able VAR sources while maintain the allowable limit for previously mentioned constraints.

The power flow analysis performed using the Newton-Raphson without installing the TCSC. Newton-Raphson method is more efficient and practical compare with other method. The simulation performed in Matlab software by referring the programming in Hadi Saadat book. The result obtained will be used to compare between the power flows while installing the TCSC. The data that obtained show the total loss of the 6-bus system without installing the TCSC.

3.3 Load Flow Programs Newton-Raphson Method

Load flow programs are the programs that have been developed for the power flow solution of practical system. The load flow consists of the calculation of power flows and voltages of a network for specified bus conditions. Associated with each bus are four quantities: the real and reactive power, the voltage magnitude and the phase angle. Three types of buses are represented in the load flow calculation and two of the four quantities mentioned above should be specified at every bus. It is necessary to select one bus, called the slack bus, to provide the additional real and reactive power to supply the transmission losses, since these are unknown until the final solution is obtained. At this bus the voltage magnitude and phase angle are specified. The remaining buses of the system are designated either as voltage controlled buses (PV) or load buses (PQ). The real power and voltage magnitude are specified at PV buses. The real and reactive powers are specified at PQ buses.

The mathematical formulation of the load flow problem results in a system of algebraic nonlinear equations. These equations can be established by using the bus analysis that results in voltages as independent variables. Thus, the admittance network matrix should be used.

3.4 Calculation for Newton-Raphson Method

The Newton-Raphson method begins with initial guesses of all unknown variables (voltage magnitude and angles at Load Buses and voltage angles at Generator Buses). Next, a Taylor Series is written, with the higher order terms ignored, for each of the power balance equations included in the system of equations. This equation needed to put in the calculation method. The result is a linear system of equations that can be expressed as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\theta \\ \Delta|V| \end{bmatrix}$$

Where ΔP and ΔQ are called the mismatch equations:

$$\Delta P_i = -P_1 + \sum_{k=1}^{N} |V_i||V_k|(G_{ik} \cos\theta_{ik} + B_{ik} sin\theta_{ik}) \tag{3.1}$$

$$\Delta Q_i = -Q_1 + \sum_{k=1}^{N} |V_i||V_k|(G_{ik} \sin\theta_{ik} + B_{ik} cos\theta_{ik}) \tag{3.2}$$

J is a matrix of partial derivatives known as a Jacobian:

$$J = \begin{bmatrix} \frac{\delta P}{\delta\theta} & \frac{\delta P}{\delta|V|} \\ \frac{\delta Q}{\delta\theta} & \frac{\delta Q}{\delta|V|} \end{bmatrix}$$

The diagonal and off-diagonal elements of J_1 are:

$$\frac{\delta P_i}{\delta\theta_i} = \sum_{j\neq 1} |V_i||V_k||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \tag{3.3}$$

$$\frac{\delta P_i}{\delta\theta_j} = -|V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \tag{3.4}$$

The diagonal and the off-diagonal elements of J_2 are:

$$\frac{\partial P_i}{\partial|V_i|} = 2|V_i||Y_{ij}| \cos\theta_{ii} + \sum_{j\neq 1} |V_i||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \tag{3.5}$$

$$\frac{\partial P_i}{\partial|V_j|} = |V_i||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \tag{3.6}$$

The diagonal and the off-diagonal elements of J_3 are:

$$\frac{\partial Q_i}{\partial\delta_i} = \sum_{j\neq 1} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \tag{3.7}$$

$$\frac{\partial Q_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) \tag{3.8}$$

The diagonal and the off-diagonal elements of J_4 are:

$$\frac{\partial Q_i}{\partial |V_i|} = -2|V_i||Y_{ii}|\sin\theta_{ii} + \sum_{j\neq 1}|V_i||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) \tag{3.9}$$

$$\frac{\partial P_i}{\partial |V_j|} = -|V_i||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) \tag{3.10}$$

The term $\Delta P^{(k)}$ and $\Delta Q^{(k)}$ are the difference between the scheduled and calculated value, known as the power residuals, given by:

$$\Delta P_i^{(k)} = P_i^{sch} - P_i^{(k)} \tag{3.11}$$

$$\Delta Q_i^{(k)} = Q_i^{sch} - Q_i^{(k)} \tag{3.12}$$

The new estimates for bus voltages are:

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \tag{3.13}$$

$$|V_i^{(k+1)} = |V_i^{(k)}| + |\Delta V_i^{(k)}| \tag{3.14}$$

The process continues until a stopping condition is met. A common stopping condition is to terminate if the norm of the mismatch equations are below a specified tolerance. All the equation above will be used for programming in the Matlab software.

3.5 Load Flow Programs Using TCSC

The load flow program with installing the TCSC is the same like the Newton–Raphson method and only need some modification of the program. The load flow program for this method needs some additional calculation equation. This calculation need because the TCSC was included to the program.

3.6 Calculation for Newton-Raphson Method with TCSC

This calculation begin with added the TCSC data. The TCSC data include the TCSC reactance and TCSC variable. It also added with number of TCSC included at the system, the sending bus and receiving bus of installed TCSC and the range of the TCSC reactance.

3.6.1 Calculate TCSC Power

This TCSC calculation method use to calculate TCSC active and reactive power and to determine the TCSC model Parameter. It also used to calculate the power mismatch of the TCSC.

$$\theta = \theta_i - \theta_j \tag{3.15}$$

Where

θ = Voltage angle

θ_i = Voltage angle sending bus

θ_j = Voltage angle receiving bus

$$P_{cal} = V_i V_j \frac{1}{X_{TCSC}} \sin\theta \tag{3.16}$$

$$Q_{cal} = (V_i^2)\left(-\frac{1}{X_{TCSC}}\right) - V_i V_j \frac{1}{X_{TCSC}} \sin\theta \tag{3.17}$$

Where

V_i = Sending Voltage Magnitude

V_j = Receiving Voltage Magnitude

X_{TCSC} = TCSC Reactance

$$P_i^{(k+1)} = \Delta P_i^{(k)} + P_{cal} \tag{3.18}$$

$$Q_i^{(k+1)} = \Delta Q_i^{(k)} + Q_{cal} \tag{3.19}$$

Where

$P_i^{(k+1)} \; = TCSC\ Active\ Power$

$Q_i^{(k+1)} = TCSC\ Reactive\ Power$

Series Reactance Power Flow Mismatch:

$$\Delta X_{TCSC} = X_{TCSC}^{(i)} - X_{TCSC}^{(i-1)} \tag{3.20}$$

$$DPQ = Psp - P_i^{(k+1)} \tag{3.21}$$

Where

$Psp = Active\ power\ flow\ to\ be\ control$

The state variable X_{TCSC} of the series controller is updated at the end of each iterative step according to

$$X_{TCSC}^{(i)} = X_{TCSC}^{(i-1)} + \left(\frac{\Delta X_{TCSC}}{X_{TCSC}}\right)^{(i)} X_{TCSC}^{(i-1)} \tag{3.22}$$

This reactance of TCSC changes due to the active power of TCSC change.

3.6.2 Modification of the Jacobian Matrix

The structure of the Jacobian matrix must be modified in the presence of FACTS devices. Jacobian matrix needed the some modification to meet the result after installing the TCSC to the system to obtain the load flow by simulating using the Matlab. This modification required to replace the standard Jacobian matrix because the element of TCSC already inserted to the calculation. For each row and column of the Jacobian matrix due to a FACTS device, there is a corresponding additional power mismatch equation that must be satisfied in order for the power flow study to converge to the solution. The modified Jacobian matrix as follow:

$$\begin{bmatrix} \Delta P_1 \\ \vdots \\ \Delta P_k \\ \vdots \\ \Delta P_n \\ \vdots \\ \Delta Q_1 \\ \vdots \\ \Delta Q_k \\ \vdots \\ \Delta Q_n \end{bmatrix} = \begin{bmatrix} \frac{\partial P_1}{\partial \delta_1} & \cdots & \frac{\partial P_1}{\partial \delta_k} & \cdots & \frac{\partial P_1}{\partial \delta_n} & \frac{\partial P_1}{\partial V_1} & \cdots & 0 & \cdots & \frac{\partial P_1}{\partial V_n} \\ \vdots & & \vdots & \vdots & \vdots & \vdots & \vdots & & & \vdots \\ \frac{\partial P_k}{\partial \delta_1} & \cdots & \frac{\partial P_k}{\partial \delta_k} & \cdots & \frac{\partial P_k}{\partial \delta_n} & \frac{\partial P_k}{\partial V_1} & \cdots & 0 & \cdots & \frac{\partial P_k}{\partial V_n} \\ \vdots & & \vdots & & \vdots & \vdots & \vdots & & & \vdots \\ \frac{\partial P_n}{\partial \delta_1} & \cdots & \frac{\partial P_n}{\partial \delta_k} & \cdots & \frac{\partial P_n}{\partial \delta_n} & \frac{\partial P_n}{\partial V_1} & \cdots & 0 & \cdots & \frac{\partial P_n}{\partial V_n} \\ \frac{\partial Q_1}{\partial \delta_1} & \cdots & \frac{\partial Q_1}{\partial \delta_k} & \cdots & \frac{\partial Q_1}{\partial \delta_n} & \frac{\partial Q_1}{\partial V_1} & \cdots & 0 & \cdots & \frac{\partial Q_1}{\partial V_n} \\ \vdots & & \vdots & & \vdots & \vdots & \vdots & & & \vdots \\ \frac{\partial Q_k}{\partial \delta_1} & \cdots & \frac{\partial Q_k}{\partial \delta_k} & \cdots & \frac{\partial Q_k}{\partial \delta_n} & \frac{\partial Q_k}{\partial V_1} & \cdots & \frac{\partial Q_k}{\partial_\alpha} & \cdots & \frac{\partial Q_k}{\partial V_n} \\ \vdots & & \vdots & & \vdots & \vdots & \vdots & & & \vdots \\ \frac{\partial Q_n}{\partial \delta_1} & \cdots & \frac{\partial Q_n}{\partial \delta_k} & \cdots & \frac{\partial Q_n}{\partial \delta_n} & \frac{\partial Q_n}{\partial V_1} & \cdots & 0 & \cdots & \frac{\partial Q_n}{\partial V_n} \end{bmatrix} \begin{bmatrix} \Delta \delta_1 \\ \vdots \\ \Delta \delta_k \\ \vdots \\ \Delta \delta_n \\ \vdots \\ \Delta \delta_1 \\ \vdots \\ \Delta \alpha \\ \vdots \\ \Delta \delta_n \end{bmatrix}$$

3.6.3 Check the TCSC Impedance Limit

The TCSC can serve as the capacitive or inductive compensation respectively by modifying the reactance of the transmission line. The rated value of TCSC is a function of the reactance of the transmission line where the TCSC is located.

$$X_{ij} = X_{Line} + X_{TCSC} \tag{3.33}$$

To avoid overcompensation, the working range of the TCSC is between –0.7 X_{Line} and 0.2 X_{Line} [6], [7].

3.7 TCSC Newton-Raphson Load Flow Flowchart

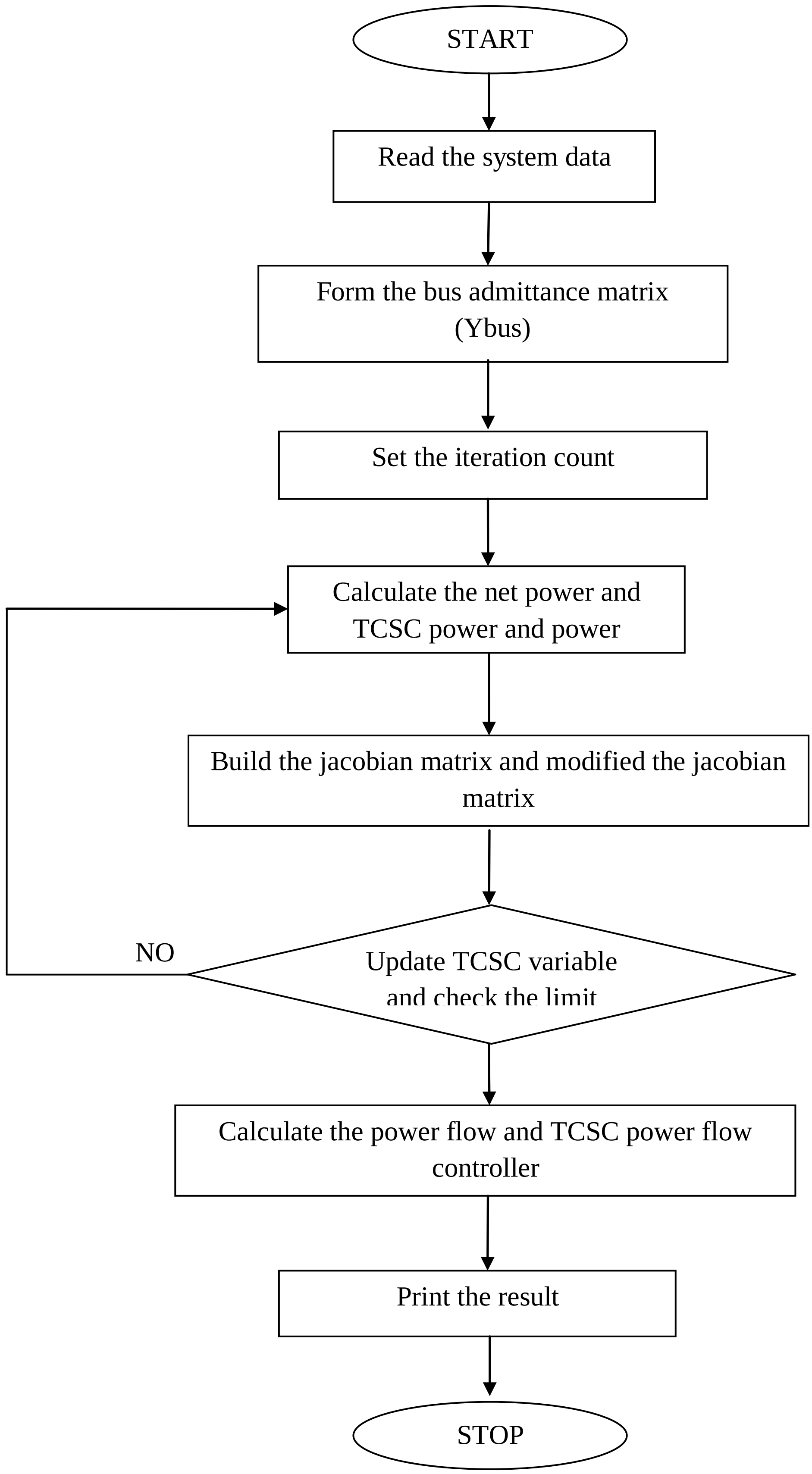

Fig 3.2: TCSC Newton-Raphson Flowchart

3.8 Algorithm to Solve Optimal Location of TCSC with PSO

In the PSO algorithm each individual is called a "particle", and is subject to a movement in a multidimensional space that represents the belief space. Particles have memory, thus retaining part of their previous state. There is no restriction for particles to share the same point in belief space, but in any case their individuality is preserved. Each particle's movement is the composition of an initial random velocity and two randomly weighted influences: individuality, the tendency to return to the particle's best previous position, and sociality, the tendency to move towards the neighbourhood's best previous position. The various steps to solve the optimal location of TCSC with the PSO are given below.

3.9 Basic PSO Algorithm

The basic algorithm of the canonical PSO can be described as follow:

Step 1: Initialize *n* particles $x_1 \in R^{N_{dim}}$ and velocities $v_1 \in R^{N_{dim}}$

Step 2: Compute fitness function f (i) for each particle;

Step 3: Find current best position *for* each pbest and gbest

Step 4: For each particle, update the particle velocities and positions:

Step 5: If the stop criterion is satisfied, gbest is the final optimal solution with fitness f (g); Otherwise, return to Step 2.

3.10 BASIC PSO FLOWCHART

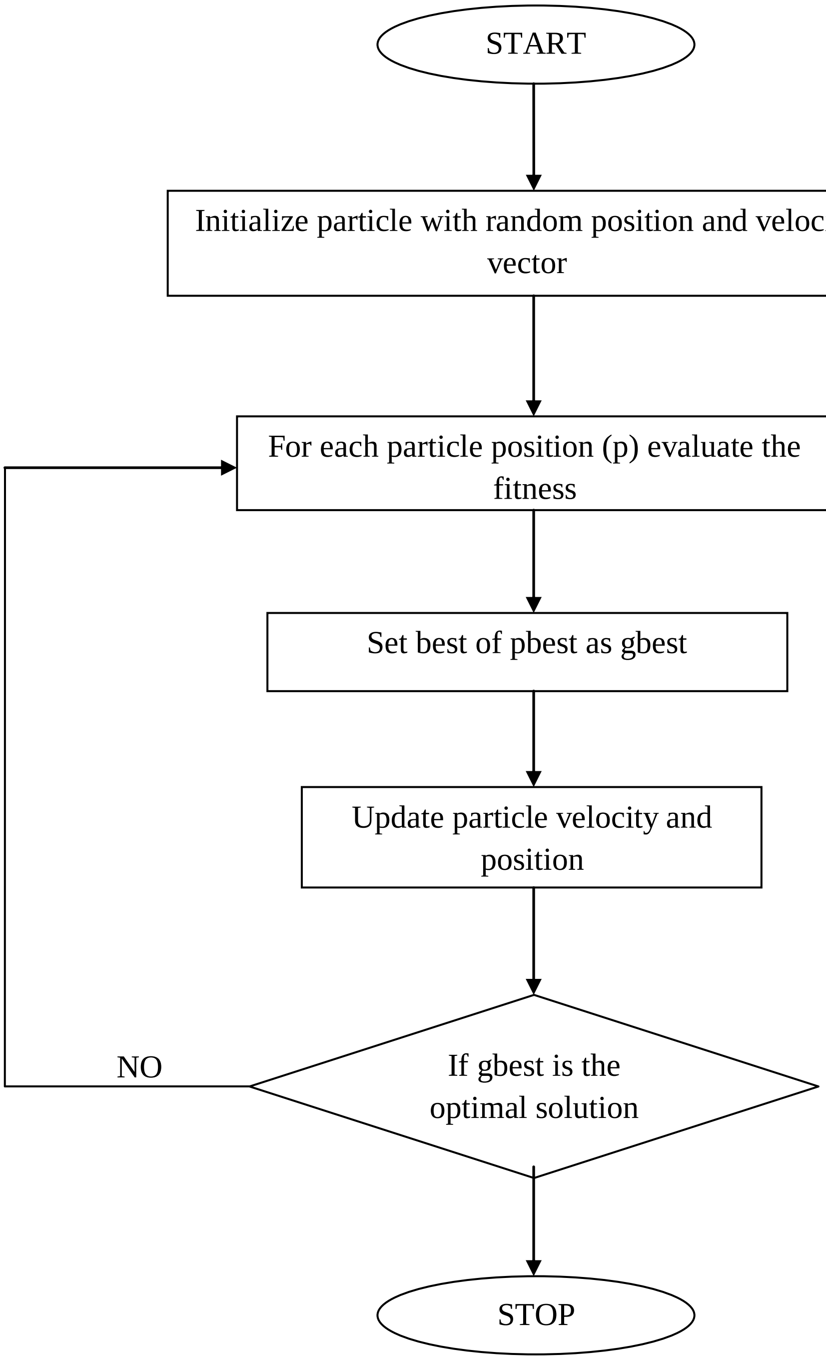

Fig 3.3: PSO Flowchart

This PSO algorithm needed the modification in order to find the optimal location of FACTS device (TCSC). The modification will modify the PSO and integrated with the FACTS device. The step by step algorithm for the proposed optimal placement of TCSC devices using PSO is given below:

3.11 TCSC with PSO Algorithm

Step 1: The number of devices to be placed is declared. The load flow is performed.

Step 2: The initial population of individuals is created satisfying the TCSC device's constraints and it is verified that only one device is placed in each line.

Step 3: For each individual in the population, the fitness function is evaluated after running load flow.

Step 4: The velocity is updated and new population is created.

Step 5: If maximum iteration number is reached, then go to next step else go to step 3

Step 6: Print the previous best individual's location and its settings.

Step 7: Stop.

3.12 TCSC with PSO Flowchart

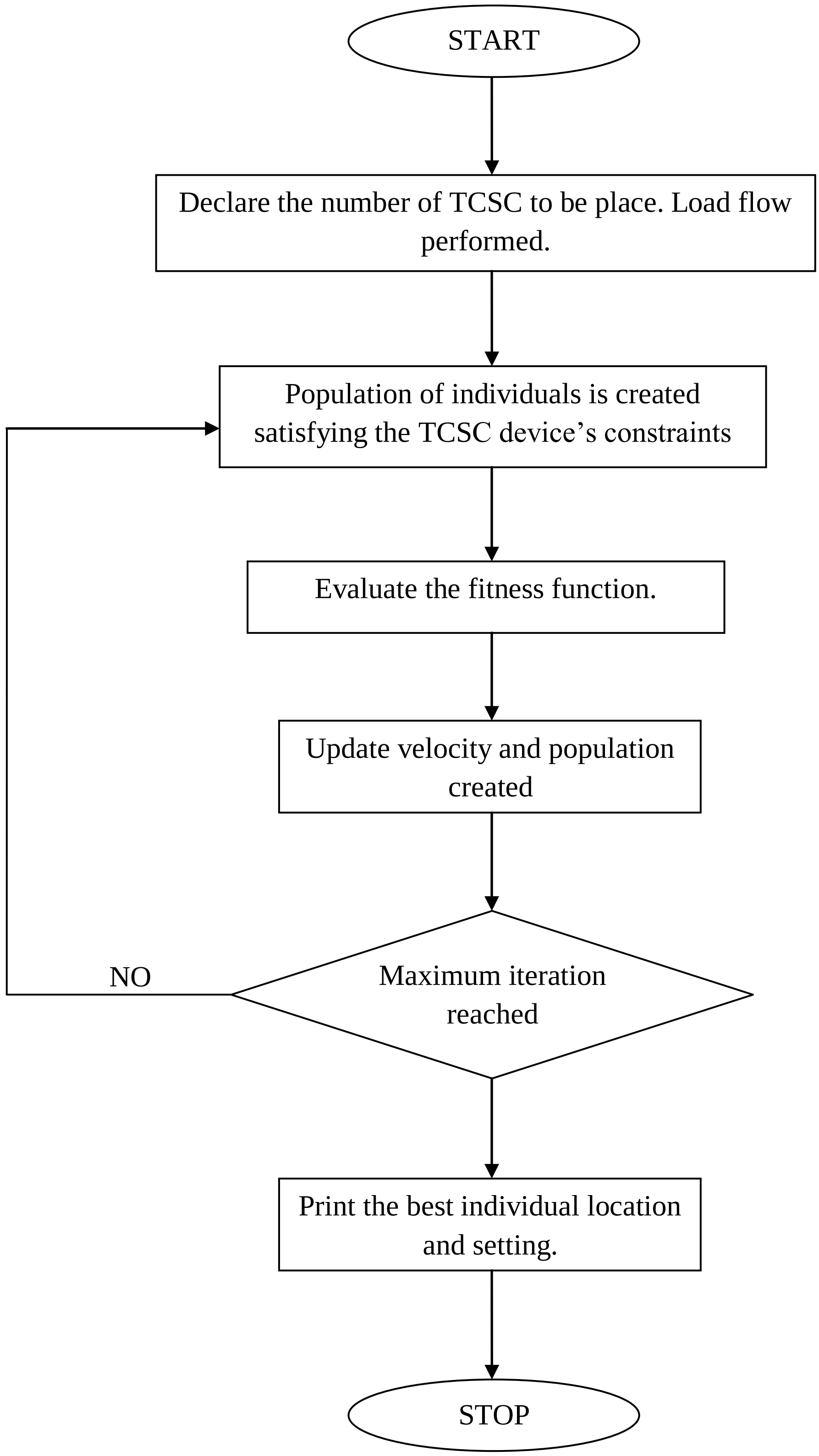

Fig 3.4: TCSC with PSO Flowchart

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In order to analyse the TCSC, some simulations are done to complete this project. The first simulation was involving the 6-bus system without the installation of the TCSC, meaning it was just to measure the system performance without the TCSC effect. Then, the system performance was measured with TCSC installed to the system to see the effect at the system simulated with PSO application. Lastly, the analysis of the system with TCSC will be discussed.

4.2 Simulation without Installation of TCSC (Base Case)

For the Base Case, the simulation is not inclusive of FACTS device (TCSC) This is to measure the performance of the system itself, without the consideration of TCSC installation. The simulation was performed with the Newton-Raphson method by using MATLAB environment.

The 6-bus test system consists of six buses in total, four load buses, one slack bus and one generator bus. The total generation and load for the system is 102.04MVA and 98.00 MVA respectively after ran the simulation by using MATLAB environment. The simulation ran with 7 iterations and shows the total loss of the system. The result obtained was recorded at the Table 4.1.

Table 4.1: Result before installing TCSC

Bus No.	Angle (Degree)	Voltage Mag.	Load		Generation		Injected
			MW	Mvar	MW	Mvar	Mvar
1	0.0000	1.0000	0.000	0.000	62.04	15.06	0.000
2	-1.9134	1.0000	0.000	0.000	40.000	11.00	0.000
3	-9.9581	0.9416	38.000	2.000	0.000	0.000	0.000
4	-7.2532	0.9486	10.000	2.000	0.000	0.000	0.000
5	-12.8369	0.9120	20.000	2.000	0.000	0.000	0.000
6	-8.4814	0.9375	30.000	3.000	0.000	0.000	0.000
Total			98.000	9.000	102.04	26.06	0.000

From the result, we can see the total generation of the IEEE 6-bus system equal to 102.24MW of real power and 26.06Mvar for the reactive power. The total load of the system is 98.00MW for real power and 9.00Mvar for the reactive power. The total load of the system needed to be improving in order to maximize the total transfer loadability. To do so, installing the TCSC to the system is important to increase the loadability of the system.

4.3 Simulations of System with Installation of TCSC

In this case, the system was simulated together with the TCSC. In order to simulate the system, the series of PSO application used to find the optimal location and best parameter for the TCSC. The simulation ran and the best location of installed TCSC will be obtained. The data recorded as in Table below.

Table 4.2: Result after installing TCSC (Between bus 4 and bus 6)

Bus No.	Angle (Degree)	Voltage Mag.	Load		Generation	
			MW	Mvar	MW	Mvar
1	0.0000	1.0000	0.000	0.000	62.04	14.55
2	-1.9345	1.0000	0.000	0.000	40.000	11.01
3	-9.9915	0.9415	38.00	2.000	0.000	0.000
4	-7.2941	0.9484	14.13	3.16	0.000	0.000
5	-12.82	0.9121	20.00	2.000	0.000	0.000
6	-8.4458	0.9377	30.00	3.000	0.000	0.000
7	-7.1625	0.9490	0.00	0.00	4.13	1.17
Total			102.13	10.16	106.17	26.73

Table 4.3: Result after installing TCSC (Between bus 6 and bus 5)

Bus No.	Angle (Degree)	Voltage Mag.	Load		Generation	
			MW	Mvar	MW	Mvar
1	0.0000	1.0000	0.000	0.000	62.04	15.05
2	-1.8305	1.0000	0.000	0.000	40.000	10.96
3	-9.9149	0.9416	38.00	2.000	0.000	0.000
4	-7.2392	0.9486	10.00	2.000	0.000	0.000
5	-12.6355	0.9125	20.00	2.000	0.000	0.000
6	-8.4934	0.9375	38.34	4.270	0.000	0.000
7	-8.2218	0.9382	0.00	0.000	8.34	1.31
Total			106.34	10.27	110.38	27.32

Table 4.4: Result after installing TCSC (Between bus 4 and bus 3)

Bus No.	Angle (Degree)	Voltage Mag.	Load		Generation	
			MW	Mvar	MW	Mvar
1	0.0000	1.0000	0.000	0.000	62.04	14.98
2	-1.6495	1.0000	0.000	0.000	40.000	11.00
3	-9.6422	0.9416	38.00	2.000	0.000	0.000
4	-7.2736	0.9489	21.76	2.430	0.000	0.000
5	-12.7307	0.9119	20.00	2.000	0.000	0.000
6	-8.4657	0.9376	30.00	3.000	0.000	0.000
7	-6.8991	0.9486	0.00	0.000	11.74	0.49
Total			109.76	9.430	114.14	26.47

From the Tables above, we can see the total loadability of the system increased due to installing of the TCSC to the system bus. As we see at the data that obtained form Table 4.2, the TCSC was installed between the bus 4 and 6. The resulting of installed at the location, the total load at that bus has been increase, at the bus 4 load increased from 10 MW to the 14.13 MW. This increase makes the total load of the system from 98.00MW to 102.13 MW. The percentage of increasing the total load is 4.21% respectively.

The data form Table 4.3, the TCSC was installed between the bus 6 and 5, it resulting the increasing of the load at bus 6 from 30 MW to 38.34 MW. The total load of the system increase to 106.34 MW and the percentage of the increasing is 8.51% respectively.

For the data at Table 4.4, TCSC installed between the bus 4 and 3. The result show that the increasing of the load at bus 4 from 10 MW to 21.76 MW. This increasing dramatically improved the total load of the system. The percentage of this increasing is 12%. It shows this location of installed TCSC is the optimal location and the best location to improve the total loadability of the system.

4.4 Others Result From the Simulation

The table show the result that obtained after the simulation. This result need to compare between the best location and the other location of installed TCSC in the system.

Table 4.5: Result after installing TCSC (Between bus 2 and bus 3)

Bus No.	Angle (Degree)	Voltage Mag.	Load		Generation	
			MW	Mvar	MW	Mvar
1	0.0000	1.000	0.000	0.000	64.39	42.48
2	4.9548	0.7837	0.000	0.000	12.56	-1.21
3	-9.6911	0.8018	38.00	2.000	0.000	0.000
4	-7.0503	0.8757	10.00	2.000	0.000	0.000
5	-13.1457	0.7866	20.00	2.000	0.000	0.000
6	-8.5707	0.8834	30.00	3.000	0.000	0.000
7	-3.6796	0.7868	0.000	0.000	27.44	-5.16
Total			98.00	9.000	104.39	36.11

Table 4.5 showed the other result after ran the simulation. The result obtained after the simulation run for several iterations. The result shows the total ladability of the system is still the same. It because, the location of installation TCSC not suitable at that location. For information, the purpose of installation of TCSC is to increase the total loadability to the system and if nothing changes at that installed location, it mean that not a best location to install the TCSC.

4.5 Discussion

From the result, after simulation the load flow of 6-bus test system, it shows that the optimal location for TCSC placement is between bus 4 and bus 3. The location was determined by using the PSO application and also shows the optimal parameter for placing the TCSC at that position is X_{TCSC} = -0.05 pu. The negative sign of TCSC impedance mean the TCSC will operated in capacitive mode. The result shows the total system loadability is 109.76 MW compared to the result before installing the TCSC is 98 MW. The percentage of the increasing is 12%.

It mean, the effect of installing the TCSC to the transmission system will help the existence transmission line to improve the system loadability to the maximum. If TCSC placement of installation in the transmission system not suitable, it will result of no changing in total loadability of the system. For example of the result while installing the TCSC between bus 2 and bus 3, there is no sign of changing of the total loadability to the system.

CHAPTER 5

CONCLUSIONS AND SUGGESTIONS FOR FUTURE STUDY

5.1 Conclusions

The simulations have been run, and the performance of FACTS controllers (TCSC) used have been evaluated. Therefore, it could be concluded that specific location and parameter would improves some of the power system parameters. Based on the results obtained, the TCSC improved the total system loss which is reduced the total losses of the system. Also from the results, the series FACTS controllers could increase the power transfer capability of the line, even though not much different from the base case.

The project proposed PSO based algorithm to find optimal location and setting of TCSC for maximizing TTC and minimizing total real power losses of the system. Simulations were performed on IEEE 6-bus system and the results indicate that optimally placed TCSC by PSO could significantly increase TTC, reduce real power losses and reactive power losses under normal and contingency conditions. In addition, PSO exhibits robust convergence characteristic so it can be used to effectively calculate TTC.

5.2 Suggestions for Future Study

There are several suggestions for future study, and these are:

i. The FACTS Controller should be tested on a very large network, to view its capability handling complex network.

ii. The FACTS Controller should be tested with respect to dynamic machine, to observe its effect to machine dynamic performance.

iii. More type and numbers of FACTS Controllers should be used, and hence could observe and compare the difference of the FACTS Controllers.

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APPENDIX A

Source Code for Optimal Location of TCSC

```
%        Bus Bus   Voltage Angle     --Load--    --Generator--     --Injected--
%        No  Code    Mag.   Degree    MW     Mvar    MW     Mvar    Qmin    Qmax    Mvar
Busdata = [1    1     1.00    0.0        0.00   0.00   0.00    0.00     0.00    0.00      0;
               2    2     1.00    0.0        0.00   0.00   40.0    0.00    -40.0    40.0     0;
               3    3     1.00    0.0        38.0   2.00   0.00    0.00    0.00    0.00     0;
               4    3     1.00    0.0        10.0   2.00   0.00    0.00    0.00    0.00     0;
               5    3     1.00    0.0        20.0   2.00   0.00    0.00    0.00    0.00     0;
               6    3     1.00    0.0        30.0   3.00   0.00    0.00    0.00    0.00     0;
               7    3     1.00    0.0        0.00   0.00   0.00    0.00    0.00    0.00     0]
%   Line Data
%          Bus  Bus   R        X      shunt       shunt       for Line code  or
%          n1   nr    pu       pu   conductance  susceptance   tap setting value
 linedata= [1    6   0.102    0.413       0.0         0.0            1.00;
               1    4   0.110    0.480       0.0         0.0            1.00;
               4    6   0.120    0.516       0.0         0.0            1.00;
               6    5   0.190    0.820       0.0         0.0            1.00;
               2    5   0.368    1.490       0.0         0.0            1.00;
               2    3   0.115    0.510       0.0         0.0            1.00;
               4    3   0.080    0.360       0.0         0.0            1.00]

%        between   TCSC placed in linedata  VvrTar  Psp   Qsp
 update=   [4   6     4   7     7   6      1     0.21    0.02;
              6   5     6   7     7   5      1     0.21    0.02;
              2   5     2   7     7   5      1     0.21    0.02;
              2   3     2   7     7   3      1     0.21    0.02;
              4   3     4   7     7   3      1     0.21    0.02]

%Choosing which transmission line want to change

X = 5
change_line = X
btw=update(X,:)
linedata(X+2,1)=7

%nbus = length(busdata(:,1));% nO. OF tRAMSMISSION LINE
%nbr=length(linedata(:,1)); %No.o ftramsmission line
%The following convention is used for the four types of buses available
%in conventional power flow studies:
%bustype = 1 is slack or swing bus
%bustype = 2 is generator bus
%bustype = 3 or 0 is load bus
%The IEEE-6 buses in the network shown in above are numbered for the
% purpose of the power flow solution, as follows:
%Bus data
```

```
%nbb = number of buses
%bustype = type of bus
%VM = nodal voltage magnitude
%VA = nodal voltage phase angle
nbb = 7 ;
bustype = busdata(:,2)';
VM= busdata(:,3)';
VA=busdata(:,4)';
%Generator data
%ngn = number of generators
%genbus = generator bus number
%PGEN = scheduled active power contributed by the generator
%QGEN = scheduled reactive power contributed by the generator
%QMAX = generator reactive power upper limit
%QMIN = generator reactive power lower limit
ngn = 2 ;
genbus(1) = 1 ; PGEN(1) = 0 ; QGEN(1) = 0 ; QMAX(1) = 0 ; QMIN(1) = 0 ;
genbus(2) = 2 ; PGEN(2) = 0.4 ; QGEN(2) = 0 ; QMAX(2) = 0.4 ; QMIN(2) = -0.4 ;

%Transmission line data
%ntl = number of transmission lines
%tlsend = sending end of transmission line
%tlrec = receiving end of transmission line
%tlresis = series resistance of transmission line
%tlreac = series reactance of transmission line
%tlcond = shunt conductance of transmission line
%tlsuscep = shunt susceptance of transmission line
ntl = 7 ;
tlsend=linedata(:,1)';
tlrec=linedata(:,2)';
tlresis=linedata(:,3)';
tlreac=linedata(:,4)';
tlcond=linedata(:,5)';
tlsuscep=linedata(:,6)';
%Shunt data
%nsh = number of shunt elements
%shbus = shunt element bus number
%shresis = resistance of shunt element
%shreac = reactance of shunt element:
%+ve for inductive reactance and –ve for capacitive reactance
nsh = 0 ;
shbus(1) = 0 ; shresis(1) = 0 ; shreac(1) = 0 ;
%Load data
%nld = number of load elements
%loadbus = load element bus number
%PLOAD = scheduled active power consumed at the bus
%QLOAD = scheduled reactive power consumed at the bus
nld = 4 ;
loadbus(1) = 3 ; PLOAD(1) = 0.38 ; QLOAD(1) = 0.02 ;
loadbus(2) = 4 ; PLOAD(2) = 0.10 ; QLOAD(2) = 0.02 ;
loadbus(3) = 5 ; PLOAD(3) = 0.20 ; QLOAD(3) = 0.02 ;
loadbus(4) = 6 ; PLOAD(4) = 0.30 ; QLOAD(4) = 0.03 ;
```

```
%General parameters
%itmax = maximum number of iterations permitted before the iterative
%process is terminated – protection against infinite iterative loops
%tol = criterion tolerance to be met before the iterative solution is
%successfully brought to an end
itmax = 100;
tol = 1e-12;
nmax = 2*nbb;
%End of function PowerFlowsData
```

```
% This function is used exclusively to enter data for:
% THYRISTOR CONTROLLED SERIES COMPENSATOR reactance variable
% NTCSC : Number of TCSC's
% TCSCsend : Sending bus
% TCSCrec : Receiving bus
% X : TCSC's reactance
% XLo : Lower reactance limit
% XHi : Higher reactance limit
% Flow : Power flow direction: 1 is for sending to receiving bus; -1
% indicates opposite direction
% Psp : Active power flow to be controlled
% PSta : Indicates control status for active power: 1 is on and 0 is off
NTCSC=1;
TCSCsend(1)=btw (1,3); TCSCrec(1)=btw(1,4); X(1)=-0.015; XLo(1)=-0.05;
XHi(1)=0.05;
Flow(1)=1; Psp(1)=btw(1,8); PSta(1)=1;
```

```
%Build up admittance matrix
YR=zeros(nbb,nbb);
YI=zeros(nbb,nbb);
% Transmission lines contribution
for kk = 1: ntl
ii = tlsend(kk);
jj = tlrec(kk);
denom = tlresis(kk)^2+tlreac(kk)^2;
YR(ii,ii) = YR(ii,ii) + tlresis(kk)/denom + 0.5*tlcond(kk);
YI(ii,ii) = YI(ii,ii) - tlreac(kk)/denom + 0.5*tlsuscep(kk);
YR(ii,jj) = YR(ii,jj) - tlresis(kk)/denom;
YI(ii,jj) = YI(ii,jj) + tlreac(kk)/denom;
YR(jj,ii) = YR(jj,ii) - tlresis(kk)/denom;
YI(jj,ii) = YI(jj,ii) + tlreac(kk)/denom;
YR(jj,jj) = YR(jj,jj) + tlresis(kk)/denom + 0.5*tlcond(kk);
YI(jj,jj) = YI(jj,jj) - tlreac(kk)/denom + 0.5*tlsuscep(kk);
end
% Shunt elements contribution
for kk = 1: nsh
ii = shbus(kk);
denom = shresis(kk)^2+shreac(kk)^2;
YR(ii,ii) = YR(ii,ii) + shresis(kk)/denom;
YI(ii,ii) = YI(ii,ii) - shreac(kk)/denom;
```

```
end
% End of function YBus


%Carry out iterative solution using the Newton–Raphson method
% GENERAL SETTINGS
flag = 0;
it = 1;


% CALCULATE NET POWERS
%Function to calculate the net scheduled powers
% CALCULATE NET POWERS
PNET = zeros(1,nbb);
QNET = zeros(1,nbb);
for ii = 1: ngn
PNET(genbus(ii)) = PNET(genbus(ii)) + PGEN(ii);
QNET(genbus(ii)) = QNET(genbus(ii)) + QGEN(ii);
end
for ii = 1: nld
PNET(loadbus(ii)) = PNET(loadbus(ii)) - PLOAD(ii);
QNET(loadbus(ii)) = QNET(loadbus(ii)) - QLOAD(ii);
end
%End function NetPowers

while ( it < itmax & flag==0 )

% CALCULATED POWERS
%Function to calculate injected bus powers
% Include all entries
PCAL = zeros(1,nbb);
QCAL = zeros(1,nbb);
for ii = 1: nbb
PSUM = 0;
QSUM = 0;
for jj = 1: nbb
PSUM = PSUM + VM(ii)*VM(jj)*(YR(ii,jj)*cos(VA(ii)-VA(jj)) +YI(ii,jj)*sin(VA(ii)-
VA(jj)));
QSUM = QSUM + VM(ii)*VM(jj)*(YR(ii,jj)*sin(VA(ii)-VA(jj)) - YI(ii,jj)*cos(VA(ii)-
VA(jj)));
end
PCAL(ii) = PSUM;
QCAL(ii) = QSUM;
end
%End of functionCalculatePowers


% CALCULATED TCSC POWERS
%Function to calculate injected bus powers by the TCSC
for ii = 1 : NTCSC
Bmm = - 1/X(ii);
Bmk = 1/X(ii);
```

```
for kk = 1 : 2
A = VA(TCSCsend(ii))-VA(TCSCrec(ii));
Pcal = VM(TCSCsend(ii))*VM(TCSCrec(ii))*Bmk*sin(A);
Qcal = - VM(TCSCsend(ii))^2*Bmm -
VM(TCSCsend(ii))*VM(TCSCrec(ii))*Bmk*cos(A);
PCAL(TCSCsend(ii)) = PCAL(TCSCsend(ii)) + Pcal;
QCAL(TCSCsend(ii)) = QCAL(TCSCsend(ii)) + Qcal;
if kk == 1
TCSC_PQsend(ii) = Pcal + j*Qcal;
else
TCSC_PQrec(ii) = Pcal + j*Qcal;
end
send = TCSCsend(ii);
TCSCsend(ii) = TCSCrec(ii);
TCSCrec(ii) = send;
end
end


% POWER MISMATCHES
%Function to compute power mismatches
% POWER MISMATCHES
DPQ = zeros(1,nmax);
DP = zeros(1,nbb);
DQ = zeros(1,nbb);
DP = PNET - PCAL;
DQ = QNET - QCAL;
% To remove the active and reactive powers contributions of the slack
% bus and reactive power of all PV buses
for ii = 1: nbb
if (bustype(ii) == 1 )
DP(ii) = 0;
DQ(ii) = 0;
elseif (bustype(ii) == 2 )
DQ(ii) = 0;
end
end
% Re-arrange mismatch entries
kk = 1;
for ii = 1: nbb
DPQ(kk) = DP(ii);
DPQ(kk+1) = DQ(ii);
kk = kk + 2;
end
% Check for convergence
for ii = 1: nbb*2
if ( abs(DPQ) < tol)
flag = 1;
end
end
%End function PowerMismatches
```

```
% TCSC POWER MISMATCHES
%Function to compute power mismatches with TCSC
if it > 1
for ii = 1 : NTCSC
if PSta(ii) == 1
Bmk = 1/X(ii);
for kk = 1 : 2
A = VA(TCSCsend(ii)) - VA(TCSCrec(ii));
Pcal = VM(TCSCsend(ii))*VM(TCSCrec(ii))*Bmk*sin(A);
if (Flow(ii) == 1 & kk == 1) | (Flow(ii) == -1 & kk == 2)
DPQ(1, 2*nbb + ii) = Psp(ii) - Pcal;
break;
end
send = TCSCsend(ii);
TCSCsend(ii) = TCSCrec(ii);
TCSCrec(ii) = send;
end
else
DPQ(1, 2*nbb + ii)= 0;
end
end
end


%Check for convergence
if flag == 1
break
end


% JACOBIAN FORMATION
%Function to built the Jacobian matrix
% JACOBIAN FORMATION
% Include all entries
JAC = zeros(nmax,nmax);
iii = 1;
for ii = 1: nbb
jjj = 1;
for jj = 1: nbb
if ii == jj
JAC(iii,jjj) = -QCAL(ii) - VM(ii)^2*YI(ii,ii);
JAC(iii,jjj+1) = PCAL(ii) + VM(ii)^2*YR(ii,ii);
JAC(iii+1,jjj) = PCAL(ii) - VM(ii)^2*YR(ii,ii);
JAC(iii+1,jjj+1) = QCAL(ii) - VM(ii)^2*YI(ii,ii);
else
JAC(iii,jjj) = VM(ii)*VM(jj)*(YR(ii,jj)*sin(VA(ii)-VA(jj))-YI(ii,jj)*cos(VA(ii)-
VA(jj)));
JAC(iii+1,jjj) = -VM(ii)*VM(jj)*(YI(ii,jj)*sin(VA(ii)-VA(jj))+YR(ii,jj)*cos(VA(ii)-
VA(jj)));
JAC(iii,jjj+1) = -JAC(iii+1,jjj);
JAC(iii+1,jjj+1) = JAC(iii,jjj);
end
```

```
jjj = jjj + 2;
end
iii = iii + 2;
end
% Delete the voltage magnitude and phase angle equations of the slack
% bus and voltage magnitude equations corresponding to PV buses
for kk = 1: nbb
if (bustype(kk) == 1)
ii = kk*2-1;
for jj = 1: 2*nbb
if ii == jj
JAC(ii,ii) = 1;
else
JAC(ii,jj) = 0;
JAC(jj,ii) = 0;
end
end
end
if (bustype(kk) == 1) | (bustype(kk) == 2)
ii = kk*2;
for jj = 1: 2*nbb
if ii == jj
JAC(ii,ii) = 1;
else
JAC(ii,jj) = 0;
JAC(jj,ii) = 0;
end
end
end
end
%End of function NewtonRaphsonJacobian


% MODIFICATION THE JACOBIAN FOR TCSC
%Function to add the TCSC elements to Jacobian matrix
for ii = 1 : NTCSC
Bmm = - 1/X(ii);
Bmk = 1/X(ii);
for kk = 1 : 2
A = VA(TCSCsend(ii))-VA(TCSCrec(ii));
Hkm = - VM(TCSCsend(ii))*VM(TCSCrec(ii))*Bmm*cos(A);
Nkm = VM(TCSCsend(ii))*VM(TCSCrec(ii))*Bmm*sin(A);
JAC(2*TCSCsend(ii)-1, 2*TCSCsend(ii)-1) = JAC(2*TCSCsend(ii)-1,2*TCSCsend(ii)-
1) - VM(TCSCsend(ii))^2*Bmm;
JAC(2*TCSCsend(ii)-1, 2*TCSCrec(ii)-1) = JAC(2*TCSCsend(ii)-1,2*TCSCrec(ii)-1) -
Hkm;
JAC(2*TCSCsend(ii)-1, 2*TCSCrec(ii)) = JAC(2*TCSCsend(ii)-1,2*TCSCrec(ii)) -
Nkm;
JAC(2*TCSCsend(ii), 2*TCSCsend(ii)) = JAC(2*TCSCsend(ii),2*TCSCsend(ii)) -
VM(TCSCsend(ii))^2*Bmm;
JAC(2*TCSCsend(ii), 2*TCSCrec(ii)-1) = JAC(2*TCSCsend(ii),2*TCSCrec(ii)-1) +
Nkm;
```

```
JAC(2*TCSCsend(ii), 2*TCSCrec(ii)) = JAC(2*TCSCsend(ii),2*TCSCrec(ii)) - Hkm;
if it > 1
if PSta(ii) == 1
if (Flow(ii) == 1 & kk == 1 )|(Flow(ii) == -1 & kk == 2)
JAC(2*nbb + ii, 2*TCSCsend(ii)-1) = Hkm;
JAC(2*nbb + ii, 2*TCSCsend(ii)) = - Nkm;
JAC(2*nbb + ii, 2*TCSCrec(ii)-1) = - Hkm;
JAC(2*nbb + ii, 2*TCSCrec(ii)) = - Nkm;
JAC(2*nbb + ii, 2*nbb + ii) = + Nkm;
end
JAC(2*TCSCsend(ii)-1, 2*nbb + ii) = Nkm;
JAC(2*TCSCsend(ii), 2*nbb + ii) = Hkm - VM(TCSCsend(ii))^2*Bmk;
else
JAC(2*nbb + ii, 2*nbb + ii) = 1;
end
end
send = TCSCsend(ii);
TCSCsend(ii) = TCSCrec(ii);
TCSCrec(ii) = send;
end
end


% SOLVE JOCOBIAN
D = JAC\DPQ';


% UPDATE THE STATE VARIABLES VALUES, WITH TRUNCATED
CORRECTIONS IF
% NECESSARY (VM increments < +-0.1 p.u. and VA inrements < +- 5 deg)
%Function to update state variables
iii = 1;
for ii = 1: nbb
VA(ii) = VA(ii) + D(iii);
VM(ii) = VM(ii) + D(iii+1)*VM(ii);
iii = iii + 2;
end
%End function StateVariableUpdating


% UPDATE THE TCSC VARIABLES
%Function to update TCSC state variable
if it > 1
for ii = 1 : NTCSC
if PSta(ii) == 1
X(ii) = X(ii) + D(2*nbb + ii,1)*X(ii);
end
end
end
```

```
%CHECK IMPEDANCE FOR LIMITS
%Function to check the impedance limits
for ii = 1 : NTCSC
% Check impedance Limits
if X(ii) < XLo(ii) | X(ii) > XHi(ii)
PSta(ii) = 0;
if X(ii) < XLo(ii)
X(ii) = XLo(ii);
elseif X(ii) > XHi(ii)
X(ii) = XHi(ii);
end
end
end


it = it + 1;
end


%Function to calculate the power flows
PQsend = zeros(1,ntl);
PQrec = zeros(1,ntl);
% Calculate active and reactive powers at the sending and receiving
% ends of tranmsission lines
for ii = 1: ntl
Vsend = ( VM(tlsend(ii))*cos(VA(tlsend(ii))) + VM(tlsend(ii))*sin(VA(tlsend(ii)))*i );
Vrec = ( VM(tlrec(ii))*cos(VA(tlrec(ii))) + VM(tlrec(ii))*sin(VA(tlrec(ii)))*i );
tlimped = tlresis(ii) + tlreac(ii)*i;
current =(Vsend - Vrec) / tlimped + Vsend*( tlcond(ii) + tlsuscep(ii)*i )*0.5 ;
PQsend(ii) = Vsend*conj(current);
current =(Vrec - Vsend) / tlimped + Vrec*( tlcond(ii) + tlsuscep(ii)*i )*0.5 ;
PQrec(ii) = Vrec*conj(current);
PQloss(ii) = PQsend(ii) + PQrec(ii);
end
% Calculate active and reactive powers injections at buses
PQbus = zeros(1,nbb);
for ii = 1: ntl
PQbus(tlsend(ii)) = PQbus(tlsend(ii)) + PQsend(ii);
PQbus(tlrec(ii)) = PQbus(tlrec(ii)) + PQrec(ii);
end
% Make corrections at generator buses, where there is load, in order to
% get correct generators contributions
for ii = 1: nld
jj = loadbus(ii);
for kk = 1: ngn
ll = genbus(kk);
if jj == ll
PQbus(jj) = PQbus(jj) + ( PLOAD(ii) + QLOAD(ii)*i );
end
end
end
%End function PQflows
```

```
%Function to calculate power flows in TCSC controller
for ii = 1 : NTCSC
Bmk = 1/X(ii);
Bmm = -1/X(ii);
for kk = 1 : 2
A = VA(TCSCsend(ii)) - VA(TCSCrec(ii));
Ptcsc(ii,kk) = VM(TCSCsend(ii))*VM(TCSCrec(ii))*Bmk*sin(A);
Qtcsc(ii,kk) = - VM(TCSCsend(ii))^2*Bmm -
VM(TCSCsend(ii))*VM(TCSCrec(ii))*Bmk*cos(A);
send = TCSCsend(ii);
TCSCsend(ii) = TCSCrec(ii);
TCSCrec(ii) = send;
end
end


%Print results
it %Number of iterations
VM %Nodal voltage magnitude (p.u)
VA=VA*180/pi %Nodal voltage phase angles (Deg)
Ptcsc %Active power flow in TCSC (p.u.)
Qtcsc %Reactive power flow in TCSC (p.u.)
X %Final reactance value (p.u.)
sum (PQsend + PQrec)
```

APPENDIX B

Source Code for Newton-Raphson Power Flow

```
%***- - - Main Program
% PowerFlowsData; %Read system data

%        Bus Bus   Voltage Angle     --Load--    --Generator--    --Injected--
%        No  Code   Mag.   Degree   MW    Mvar    MW     Mvar    Qmin    Qmax    Mvar
busdata=[ 1    1     1.00    0.0     0.00   0.00   0.00   0.00    0.00    0.00       0;
          2    2     1.00    0.0     0.00   0.00   40.0   0.00    -40.0   40.0       0;
          3    3     1.00    0.0     38.0   2.00   0.00   0.00    0.00    0.00       0;
          4    3     1.00    0.0     10.0   2.00   0.00   0.00    0.00    0.00       0;
          5    3     1.00    0.0     20.0   2.00   0.00   0.00    0.00    0.00       0;
          6    3     1.00    0.0     30.0   3.00   0.00   0.00    0.00    0.00       0]
%   Line Data
%          Bus  Bus   R       X      shunt        shunt       for Line code  or
%          n1   nr    pu      pu   conductance   susceptance   tap setting value
 linedata=[1    6   0.102    0.413      0.0          0.0          1.00;
           1    4   0.110    0.480      0.0          0.0          1.00;
           4    6   0.120    0.516      0.0          0.0          1.00;
           6    5   0.190    0.820      0.0          0.0          1.09;
           2    5   0.368    1.490      0.0          0.0          1.00;
           2    3   0.115    0.510      0.0          0.0          1.00;
           4    3   0.080    0.360      0.0          0.0          1.00]

%nbus = length(busdata(:,1));% nO. OF tRAMSMISSION LINE
%nbr=length(linedata(:,1)); %No.o ftramsmission line
%The following convention is used for the four types of buses available
%in conventional power flow studies:
%bustype = 1 is slack or swing bus
%bustype = 2 is generator bus
%bustype = 3 or 0 is load bus
%The IEEE-6 buses in the network shown in above are numbered for the
% purpose of the power flow solution, as follows:
%Bus data
%nbb = number of buses
%bustype = type of bus
%VM = nodal voltage magnitude
%VA = nodal voltage phase angle
nbb = 6 ;
bustype = busdata(:,2)';
VM= busdata(:,3)';
```

```
VA=busdata(:,4)';

%Generator data
%ngn = number of generators
%genbus = generator bus number
%PGEN = scheduled active power contributed by the generator
%QGEN = scheduled reactive power contributed by the generator
%QMAX = generator reactive power upper limit
%QMIN = generator reactive power lower limit
ngn = 2 ;
genbus(1) = 1 ; PGEN(1) = 0 ; QGEN(1) = 0 ; QMAX(1) = 0 ; QMIN(1) = 0 ;
genbus(2) = 2 ; PGEN(2) = 0.4 ; QGEN(2) = 0 ; QMAX(2) = 0.4 ; QMIN(2) = -0.4 ;

%Transmission line data
%ntl = number of transmission lines
%tlsend = sending end of transmission line
%tlrec = receiving end of transmission line
%tlresis = series resistance of transmission line
%tlreac = series reactance of transmission line
%tlcond = shunt conductance of transmission line
%tlsuscep = shunt susceptance of transmission line
ntl = 7 ;
tlsend=linedata(:,1)';
tlrec=linedata(:,2)';
tlresis=linedata(:,3)';
tlreac=linedata(:,4)';
tlcond=linedata(:,5)';
tlsuscep=linedata(:,6)';
%
%Shunt data
%nsh = number of shunt elements
%shbus = shunt element bus number
%shresis = resistance of shunt element
%shreac = reactance of shunt element:
%+ve for inductive reactance and –ve for capacitive reactance
nsh = 0 ;
shbus(1) = 0 ; shresis(1) = 0 ; shreac(1) = 0 ;
%
%Load data
%nld = number of load elements
%loadbus = load element bus number
%PLOAD = scheduled active power consumed at the bus
%QLOAD = scheduled reactive power consumed at the bus
nld = 4 ;
loadbus(1) = 3 ; PLOAD(1) = 0.38 ; QLOAD(1) = 0.02 ;
loadbus(2) = 4 ; PLOAD(2) = 0.10 ; QLOAD(2) = 0.02 ;
loadbus(3) = 5 ; PLOAD(3) = 0.20 ; QLOAD(3) = 0.02 ;
loadbus(4) = 6 ; PLOAD(4) = 0.30 ; QLOAD(4) = 0.03 ;
```

```
%General parameters
%itmax = maximum number of iterations permitted before the iterative
%process is terminated – protection against infinite iterative loops
%tol = criterion tolerance to be met before the iterative solution is
%successfully brought to an end
itmax = 100;
tol = 1e-12;
nmax = 2*nbb;
%End of function PowerFlowsData


% [YR,YI]
=YBus(tlsend,tlrec,tlresis,tlreac,tlsuscep,tlcond,shbus,shresis,shreac,ntl,nbb,nsh);
YR=zeros(nbb,nbb);
YI=zeros(nbb,nbb);
% Transmission lines contribution
for kk = 1: ntl
ii = tlsend(kk);
jj = tlrec(kk);
denom = tlresis(kk)^2+tlreac(kk)^2;
YR(ii,ii) = YR(ii,ii) + tlresis(kk)/denom + 0.5*tlcond(kk);
YI(ii,ii) = YI(ii,ii) - tlreac(kk)/denom + 0.5*tlsuscep(kk);
YR(ii,jj) = YR(ii,jj) - tlresis(kk)/denom;
YI(ii,jj) = YI(ii,jj) + tlreac(kk)/denom;
YR(jj,ii) = YR(jj,ii) - tlresis(kk)/denom;
YI(jj,ii) = YI(jj,ii) + tlreac(kk)/denom;
YR(jj,jj) = YR(jj,jj) + tlresis(kk)/denom + 0.5*tlcond(kk);
YI(jj,jj) = YI(jj,jj) - tlreac(kk)/denom + 0.5*tlsuscep(kk);
end
% Shunt elements contribution
for kk = 1: nsh
ii = shbus(kk);
denom = shresis(kk)^2+shreac(kk)^2;
YR(ii,ii) = YR(ii,ii) + shresis(kk)/denom;
YI(ii,ii) = YI(ii,ii) - shreac(kk)/denom;
end
% End of function YBus

%
NewtonRaphson(nmax,tol,itmax,ngn,nld,nbb,bustype,genbus,loadbus,PGEN,QGEN,QMAX
,QMIN,PLOAD,QLOAD,YR,YI,VM,VA);
D = zeros(1,nmax);
flag = 0;
it = 1;

% CALCULATE NET POWERS
% NetPowers(nbb,ngn,nld,genbus,loadbus,PGEN,QGEN,PLOAD,QLOAD);
PNET = zeros(1,nbb);
QNET = zeros(1,nbb);
```

```
for ii = 1: ngn
PNET(genbus(ii)) = PNET(genbus(ii)) + PGEN(ii);
QNET(genbus(ii)) = QNET(genbus(ii)) + QGEN(ii);
end
for ii = 1: nld
PNET(loadbus(ii)) = PNET(loadbus(ii)) - PLOAD(ii);
QNET(loadbus(ii)) = QNET(loadbus(ii)) - QLOAD(ii);
end
%End function NetPowers


while ( it < itmax & flag==0 )


% CALCULATED POWERS
% [PCAL,QCAL] = CalculatedPowers(nbb,VM,VA,YR,YI);
PCAL = zeros(1,nbb);
QCAL = zeros(1,nbb);
for ii = 1: nbb
PSUM = 0;
QSUM = 0;
for jj = 1: nbb
PSUM = PSUM + VM(ii)*VM(jj)*(YR(ii,jj)*cos(VA(ii)-VA(jj)) +...
YI(ii,jj)*sin(VA(ii)-VA(jj)));
QSUM = QSUM + VM(ii)*VM(jj)*(YR(ii,jj)*sin(VA(ii)-VA(jj)) -...
YI(ii,jj)*cos(VA(ii)-VA(jj)));
end
PCAL(ii) = PSUM;
QCAL(ii) = QSUM;
end
%End of functionCalculatePowers

% CHECK FOR POSSIBLE GENERATOR'S REACTIVE POWERS LIMITS
VIOLATIONS
% GeneratorsLimits(ngn,genbus,bustype,QGEN,QMAX,QMIN,QCAL,QNET, QLOAD, it,
VM, nld, loadbus);
if it > 2
flag2 = 0;
for ii = 1: ngn
jj = genbus(ii);
if (bustype(jj) == 2)
if ( QCAL(jj) > QMAX(ii) )
QNET(genbus(ii)) = QMAX(ii);
bustype(jj) = 3;
flag2 = 1;
elseif ( QCAL(jj) < QMIN(ii) )
QNET(genbus(ii)) = QMIN(ii);
bustype(jj) = 3;
flag2 = 1;
```

```
end
if flag2 == 1
for ii = 1:nld
if loadbus(ii) == jj
QNET(loadbus(ii)) = QNET(loadbus(ii)) - QLOAD(ii)
end
end
end
end
end
end
%End function Generatorslimits

% POWER MISMATCHES
% [DPQ,DP,DQ,flag] =
PowerMismatches(nmax,nbb,tol,bustype,flag,PNET,QNET,PCAL,QCAL);
DPQ = zeros(1,nmax);
DP = zeros(1,nbb);
DQ = zeros(1,nbb);
DP = PNET - PCAL;
DQ = QNET - QCAL;
% To remove the active and reactive powers contributions of the slack
% bus and reactive power of all PV buses
for ii = 1: nbb
if (bustype(ii) == 1 )
DP(ii) = 0;
DQ(ii) = 0;
elseif (bustype(ii) == 2 )
DQ(ii) = 0;
end
end
% Re-arrange mismatch entries
kk = 1;
for ii = 1: nbb
DPQ(kk) = DP(ii);
DPQ(kk+1) = DQ(ii);
kk = kk + 2;
end
% Check for convergence
for ii = 1: nbb*2
if ( abs(DPQ) < tol)
flag = 1;
end
end
%End function PowerMismatches

% JACOBIAN FORMATION
% [JAC] = NewtonRaphsonJacobian(nmax,nbb,bustype,PCAL,QCAL,VM,VA,YR,YI);
JAC = zeros(nmax,nmax);
```

```
iii = 1;
for ii = 1: nbb
jjj = 1;
for jj = 1: nbb
if ii == jj
JAC(iii,jjj) = -QCAL(ii) - VM(ii)^2*YI(ii,ii);
JAC(iii,jjj+1) = PCAL(ii) + VM(ii)^2*YR(ii,ii);
JAC(iii+1,jjj) = PCAL(ii) - VM(ii)^2*YR(ii,ii);
JAC(iii+1,jjj+1) = QCAL(ii) - VM(ii)^2*YI(ii,ii);
else
JAC(iii,jjj) = VM(ii)*VM(jj)*(YR(ii,jj)*sin(VA(ii)-VA(jj))...
-YI(ii,jj)*cos(VA(ii)-VA(jj)));
JAC(iii+1,jjj) = -VM(ii)*VM(jj)*(YI(ii,jj)*sin(VA(ii)...
-VA(jj))+YR(ii,jj)*cos(VA(ii)-VA(jj)));
JAC(iii,jjj+1) = -JAC(iii+1,jjj);
JAC(iii+1,jjj+1) = JAC(iii,jjj);
end
jjj = jjj + 2;
end
iii = iii + 2;
end
% Delete the voltage magnitude and phase angle equations of the slack
% bus and voltage magnitude equations corresponding to PV buses
for kk = 1: nbb
if (bustype(kk) == 1)
ii = kk*2-1;
for jj = 1: 2*nbb
if ii == jj
JAC(ii,ii) = 1;
else
JAC(ii,jj) = 0;
JAC(jj,ii) = 0;
end
end
end
if (bustype(kk) == 1) | (bustype(kk) == 2)
ii = kk*2;
for jj = 1: 2*nbb
if ii == jj
JAC(ii,ii) = 1;
else
JAC(ii,jj) = 0;
JAC(jj,ii) = 0;
end
end
end
end
%End of function NewtonRaphsonJacobian
```

```
% SOLVE FOR THE STATE VARIABLES VECTOR
D = JAC\DPQ';
% UPDATE STATE VARIABLES

% [VA,VM] = StateVariablesUpdates(nbb,D,VA,VM);
iii = 1;
for ii = 1: nbb
VA(ii) = VA(ii) + D(iii);
VM(ii) = VM(ii) + D(iii+1)*VM(ii);
iii = iii + 2;
end
%End function StateVariableUpdating
it = it + 1;
end
% End function Newton-Raphson

%
PQflows(nbb,ngn,ntl,nld,genbus,loadbus,tlsend,tlrec,tlresis,tlreac,tlcond,tlsuscep,PLOAD,Q
LOAD,VM,VA);
PQsend = zeros(1,ntl);
PQrec = zeros(1,ntl);
% Calculate active and reactive powers at the sending and receiving
% ends of tranmsission lines
for ii = 1: ntl
Vsend = ( VM(tlsend(ii))*cos(VA(tlsend(ii))) + ...
VM(tlsend(ii))*sin(VA(tlsend(ii)))*i );
Vrec = ( VM(tlrec(ii))*cos(VA(tlrec(ii))) + ...
VM(tlrec(ii))*sin(VA(tlrec(ii)))*i );
tlimped = tlresis(ii) + tlreac(ii)*i;
current =(Vsend - Vrec) / tlimped + Vsend*( tlcond(ii) + ...
tlsuscep(ii)*i )*0.5 ;
PQsend(ii) = Vsend*conj(current);
current =(Vrec - Vsend) / tlimped + Vrec*( tlcond(ii) + ...
tlsuscep(ii)*i )*0.5 ;
PQrec(ii) = Vrec*conj(current);
PQloss(ii) = PQsend(ii) + PQrec(ii);
end
% Calculate active and reactive powers injections at buses
PQbus = zeros(1,nbb);
for ii = 1: ntl
PQbus(tlsend(ii)) = PQbus(tlsend(ii)) + PQsend(ii);
PQbus(tlrec(ii)) = PQbus(tlrec(ii)) + PQrec(ii);
end
% Make corrections at generator buses, where there is load, in order to
% get correct generators contributions
for ii = 1: nld
jj = loadbus(ii);
for kk = 1: ngn
ll = genbus(kk);
```

```
 if jj == ll
PQbus(jj) = PQbus(jj) + ( PLOAD(ii) + QLOAD(ii)*i );
end
end
end
%End function PQflows

Send = sum (PQsend);
Rec = sum (PQrec);
VA = VA*180/pi; %Nodal voltage phase angle(Deg)
Iteration = it
Voltage = VM
Angle = VA
Power_Bus = PQbus
sum (PQloss)
%End Main Program
```