

APPLICATION OF AI TECHNIQUE FOR OPTIMAL LOCATION OF  
UPFC DEVICE

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**BORANG PENGESAHAN STATUS TESIS♦**

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UPFC DEVICE

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This thesis is submitted as partial fulfillment of the requirements for the award of the  
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**DEDICATION**

*Specially dedicated to  
My beloved family, and those who have guided and inspired me  
Throughout my journey of learning*

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## ABSTRAK

Thesis ini focus kepada peranti FACTS iaitu Unified Power Flow Controller (UPFC). Dengan kemampuan yang unik iaitu mengawal kuasa nyata dan kuasa aliran reaktif secara serentak pada saluran penghantaran serta menetapkan voltan pada bus yang disambungi, peranti ini juga menghasilkan impak yang berkualiti untuk menstabilkan sistem kuasa. Ciri-ciri ini menjadi lebih signifikan apabila diketahui UPFC dapat memberi bebanan kepada saluran penghantaran mendekati dengan batas terma, memaksa kuasa melalui arah yang dikehendaki. Ini akan memberi keluwesan kepada pembekal system kuasa untuk memenuhi permintaan sistem kuasa yang terderegulasi. Aplikasi teknik Particle Swarm Optimization (PSO) dilaksanakan untuk mencari lokasi optimum peranti Flexible AC Transmission System (FACTS) untuk mendapat maksimum beban kemampuan sistem. Semasa mencari optimum lokasi, batasan terma untuk saluran dan batasan voltan untuk bus juga diberi tumpuan. Peranti FACTS yang digunakan ialah UPFC. Pengoptimuman adalah dilakukan pada dua parameter iaitu lokasi UPFC dan tataranya. Simulasi dilakukan pada IEEE 6 bus system untuk mengoptimumkan lokasi UPFC.

## ABSTRACT

The focus of this thesis is a FACTS device known as the Unified Power Flow Controller (UPFC). With its unique capability to control simultaneously real and reactive power flows on a transmission line as well as to regulate voltage at the bus where it is connected, this device creates a tremendous quality impact on power system stability. These features become even more significant knowing that the UPFC can allow loading of the transmission lines close to their thermal limits, forcing the power to flow through the desired paths. This will give the power system operators much needed flexibility in order to satisfy the demands that the deregulated power system will impose. The application of Particle Swarm Optimization (PSO) technique is applied to find optimal location of Flexible AC Transmission System (FACTS) devices to achieve maximum system loadability. While finding the optimal location, thermal limit for the lines and voltage limit for the buses are taken as constraints. The type of FACTS devices Unified Power Flow Controller (UPFC) is considered. The optimizations are performed on three parameters namely the location of UPFC device and their setting. Simulations are performed on IEEE 6 bus system for optimal location of UPFC device and the results obtained are encouraging and will be useful in electrical restructuring.



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# **CHAPTER 1**

## **INTRODUCTION**

### **1.1 FACTS**

With the deregulation of the electricity market, the traditional practices of power systems have been changed a lot. Years of under investment in the transmission sector in many electricity markets has drawn attention to better utilize the existing transmission lines. The advent of Flexible AC Transmission System (FACTS) devices based on the advancement of semiconductor technology opens up new opportunities for increasing the capacities of the existing transmission systems [1, 2].

The Unified Power Flow Controller (UPFC) is one of the most promising FACTS devices in terms of its ability to control power system quantities. It can either simultaneously or selectively control the active and reactive power flow through the lines and also bus voltages [3-7]. The above mentioned salient features rendered by UPFCs depend on the configuration of UPFCs. Hence, for the practical

Implementation of UPFCs in a power system, a systematic procedure is needed in finding the optimal location and parameters of UPFCs. By optimally placing the UPFCs, it is possible to minimize transmission loss, minimize power generation cost, maximize the load ability of the transmission system etc.

## 1.2 Problem Statement

Some papers have been published on solving the optimal location of FACTS devices with respect to different purposes and methods [1, 8, 9]. In [1], Genetic Algorithm has been applied for the optimal placement of multi-type FACTS devices including Thyristor Control Series Compensator (TCSC), Thyristor Controlled Phase Angle Regulator (TCPSR), Thyristor Controlled Voltage Regulator (TCVR) and Static Var Compensators (SVC) to maximize the loadability of transmission lines. In [8], an approach based on augmented Lagrange multiplier method has been used to determine the optimal location of UPFCs to be installed. An improved evolutionary programming has been used to find the optimal location of UPFCs in [9] with the purpose of increasing the system loadability. A deterministic based method has been applied to evaluate the network losses. The present objective of this paper is to analyze, once more, the problem of system loadability maximization. However, the tool of analysis employed is particle swarm optimization (PSO) which is a new evolutionary computational stochastic technique.

Particle swarm optimization is a type of evolutionary algorithm developed by Kennedy and Eberhart [10]. The swarm initially has a population of random solutions. Each potential solution called particle, is given a random velocity and is flown through the problem space. The particles have memory and each particle keeps track of its previous best position and the corresponding fitness value.



The previous best value is called *pbest* and it is related to a particular particle. The swarm has another value called *gbest*, which is the best value of all the particles' *pbests* in the swarm. The main advantages of using PSO are that, it can generate high quality solutions within shorter calculation time and has more stable convergence characteristic compared to other stochastic methods [11]. The application of this tool to power system problems has been found in some papers [10-12]. For example, [10] focuses on the problem of fuel cost minimization.

Population based, cooperative and competitive stochastic search algorithms are very popular in the recent years in the research arena of computational intelligence. Some well established search algorithms such as (GA) [9] and Evolutionary Programming (EP) [10], [11] are successfully implemented to solve simple and complex problems efficiently and effectively. Most of the population based search approaches are motivated by evolution as seen in nature.

Particle swarm optimization (PSO), on the other hand, is motivated from the simulation of social behavior. Nevertheless, they all work in the same way that is, updating the position of individuals by applying some kinds of operators according to the fitness information obtained from the environment, so that the individuals of the population can be expected to move towards better solution areas. Instead of using evolutionary operators to manipulate the individuals, like in other evolutionary computational algorithms, each individual in PSO flies in the search space with a velocity which is dynamically adjusted according to its own flying experience and its companions' flying experience. Unlike in genetic algorithms, evolutionary programming, and evolution strategies, in PSO, the selection operation is not performed.

All particles in PSO are kept as members of the population through the course of the run (a run is defined as the total number of generations of the evolutionary algorithms prior to termination). It is the velocity of the particle which is updated according to its own previous best position and the previous best position of its

companions. The particles fly with the updated velocities. PSO is the only evolutionary algorithm that does not implement survival of the fittest. PSO is now applied for solving electrical engineering related problems [13].

Making use of this PSO technique, the proposed method can find high-quality solutions reliably with faster convergence characteristics in a reasonably good computation time. Finding the optimal placement and parameters of UPFCs for maximizing the system loadability is a large scale non-linear optimization problem. In this paper, a novel technique is proposed to increase the system loadability. PSO applied for optimal placement of UPFCs is evaluated on IEEE 6- bus power system.

### **1.3 Objectives**

- i) By using PSO to find optimal location of UPFC to achieve maximum system loadability.
- ii) Optimizations are performed based on :
  - Location and Setting of UPFC device
  - Distribution Power system (Simulations are performed on IEEE 6 bus system for optimal location of UPFC device )

### **1.4 Scope of Project**

The present objective of this paper is to analyze, once more, the problem of power loadability of the system. The main goal in this project is to find the optimal placement and parameters of UPFCs for maximizing the system load ability is a large scale non-linear optimization problem. PSO applied for optimal placement of UPFCs

is evaluated on IEEE 6- bus power systems. This project focus on power flow distribution power system.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Introduction**

Under such circumstances, FACTS (Flexible AC Transmission System) is an alternative for enhancing the transmission capability [1]. Originally, FACTS is useful for improving security and transmission losses as well as the transmission capability. Among the FACTS devices, UPFC is one of efficient FACTS devices. It has advantage to takes control of both active and reactive power at the same time flexibly [2, 3]. In this project, UPFC is used to maximize the transmission capability from generators to specified load buses. To install UPFC, it is necessary to determine the location and the control variables of UPFC.

The mathematical formulation for the optimal allocation of UPFC results in a nonlinear mixed integer problem that expresses the location in discrete number and the control variables in continuous one while satisfying the constraints. Since the optimal allocation has a local minimum, it is necessary to evaluate a global minimum

or its highly approximate solutions efficiently. So far, a lot of methods have been developed to deal with the optimal allocation of UPFC.

## **2.2 Method to Optimal Allocation of UPFC**

### **2.2.1 Hybrid Meta-heuristic Method**

Hiroyuki Mori has use Hybrid meta-heuristic method to determine the location of UPFCs with TS (Tabu Search) at Layer 1 and the control variables of UPFC with EPSO (Evolutionally Particle Swarm Optimization) at Layer 2[14]. After determining the location at Layer 1, the control variables are evaluated at Layer 2. The search process is repeated until the termination conditions are satisfied. This research proposes a new hybrid meta-heuristic method for determining the optimal allocation of UPFCs to maximize the transmission capability. The optimal allocation of UPFCs needs to evaluate the location and the control variables of UPFCs at the same time. Figure below shows the concept of the proposed method, where Layer 1 evaluates the optimal locations in discrete number and Layer 2 computes the optimal control variables in continuous number. The proposed method is based on two layered optimization. After creating the solution candidates of the location in the neighbourhood around the initial solution at Layer 1, Layer 2 optimizes the control variables and the incremental load rate (ILR) for each solution candidate at Layer 1. ILR is defined as initial load over load maximized by UPFC.

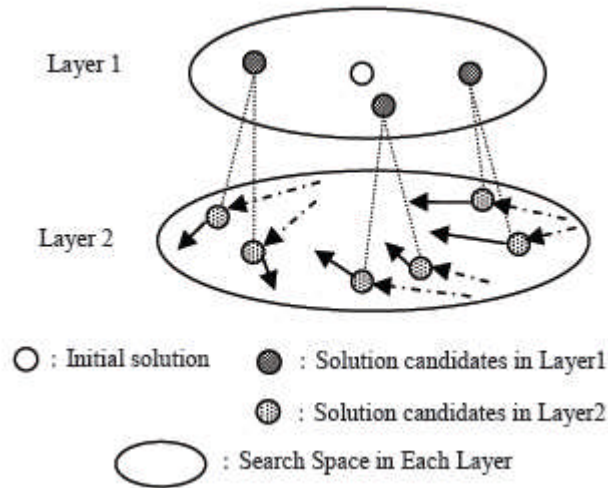


Figure 2.1: Layer Hybrid[14]

The second and the third terms mean the maximization of ILR and the minimization the transmission loss in (10), respectively. Equations (1)-(10) imply the constraints on the power flow equation, the upper and lower bounds of nodal voltage magnitudes, the line flows, the upper bound of apparent power for shunt and series inverters in UPFCs, the upper bound of voltage magnitude by UPFCs and the upper bound of reactive power by UPFCs.

### 2.2.2 Bacteria Foraging Method

Optimal location and control of a unified power flow controller (UPFC) along with transformer taps are tuned with a view to simultaneously optimize the real power losses and voltage stability limit (VSL) of a mesh power network. This issue is formulated as a nonlinear equality and inequality constrained optimization problem with an objective function incorporating both the real power loss and VSLS. Tripathy, M. and Mishra, in (2007) have using a new evolutionary algorithm known as bacteria foraging is applied for solving the multi objective multivariable problem, with the UPFC location, its series injected voltage, and the transformer tap positions

as the variables [15]. For a single objective of only real power loss, the same problem is also solved with interior point successive linearization program (IPSLP) technique using the LINPROG command of MATLAB. A comparison between the two suggests the superiority of the proposed algorithm. A cost effectiveness analysis of UPFC installation vis-a-grave-vis loss reduction is carried out to establish the benefit of investment in a UPFC.

### **2.2.3 Optimal location and parameters setting of UPFC based on GA and PSO for enhancing power system security under single contingencies**

In 2008, T H. I. Shaheen, ,G. I. Rashed, and S. J. Cheng, their method is presents an approach to find out the optimal placement and the optimal parameters setting of UPFC for enhancing power system security under single contingencies (N-1 Contingency)[16]. Firstly, we perform a contingency analysis and ranking process to determine the severest line tripping contingencies considering line overloads and bus voltage violations as a performance index. Secondly, we apply genetic algorithm (GA) and particle swarm optimization (PSO) techniques to find out the optimal location and the optimal parameters setting of UPFC corresponding to the determined contingencies scenarios.

A contingency is considered to be the outage of a generator, a transformer or a line. The system may become unstable and enters an insecure state when a contingency event is occurred. Contingency analysis is one of the most important functions performed in power systems to establish appropriate preventive and / or corrective actions for each contingency. Contingency analysis procedure consists of line contingency analysis, contingency selection, detection of overloaded lines and bus voltage violations, and ranking of the severest contingencies cases. For each line outage contingency in the system, list the all overloaded lines and the buses which have voltage violations, and then the lines are ranked according to the severity of the

contingency, in other words, according to the number of the thermal and voltage violations limits. Then the most critical contingencies are determined. After determining the most critical contingencies scenarios, GA and PSO techniques are applied to find the optimal location and parameters setting of UPFC. Installing UPFC in such optimal location with such optimal parameters will eliminate or minimize the overloaded lines and the bus voltage violations under these critical contingencies.

For enhancing the system security level, UPFC should be located in order to eliminate or minimize the line overloads and to prevent the bus voltages violations.

#### **2.2.4 Evolutionary Optimization Techniques**

Optimal location of different types of FACTS devices in the power system has been attempted using different techniques such as Genetic Algorithm (GA), hybrid Tabu approach and simulated annealing (SA). The best location for a set of phase shifters was found by genetic algorithm to reduce the flows in heavily loaded lines resulting in an increased load ability of the network and reduced cost of production [17]. A hybrid tabu search and simulated annealing was proposed to minimize the generator fuel cost in optimal power flow control with multi-type FACTS devices [1,2].

The best location of UPFC to minimize the generation cost function and the investment cost on the UPFC device was found using steady state injection model of UPFC ,continuation power flow technique and OPF technique[18]. By using multiple UPFC, the real and reactive power are regulated in real time by a centralized optimal control scheme using evolutionary programming algorithm to provide best voltage profile and minimum overall transmission losses [10]. Power flow algorithm with the presence of TCSC and UPFC has been formulated and solved [19]. A hybrid GA approach to solve optimal power flow in a power system incorporating FACTS



devices has been reported. In this paper, applying PSO technique, find the optimal location and parameter setting of UPFC to achieve maximum system load ability.

## 2.3 System Modelling

It is necessary to model the complex real life power system with a set of equations that can describe the behaviour of a system to a satisfactory level of exactness. The modelling of transmission line as well as the representation of UPFC under static conditions can be described as under.

### 2.3.1 UPFC Power Flow Model

Fig. 1 shows the equivalent circuit of a UPFC power flow model, this circuit consists of two coordinated synchronous voltage sources represent the UPFC adequately for the purpose of fundamental steady-state analysis (Enrique et al., 2004), the UPFC voltage sources are:

$$E_{vR} = V_{vR} (\cos \delta_{vR} + j \sin \delta_{vR}) \quad (1)$$

$$E_{cR} = V_{cR} (\cos \delta_{cR} + j \sin \delta_{cR}) \quad (2)$$

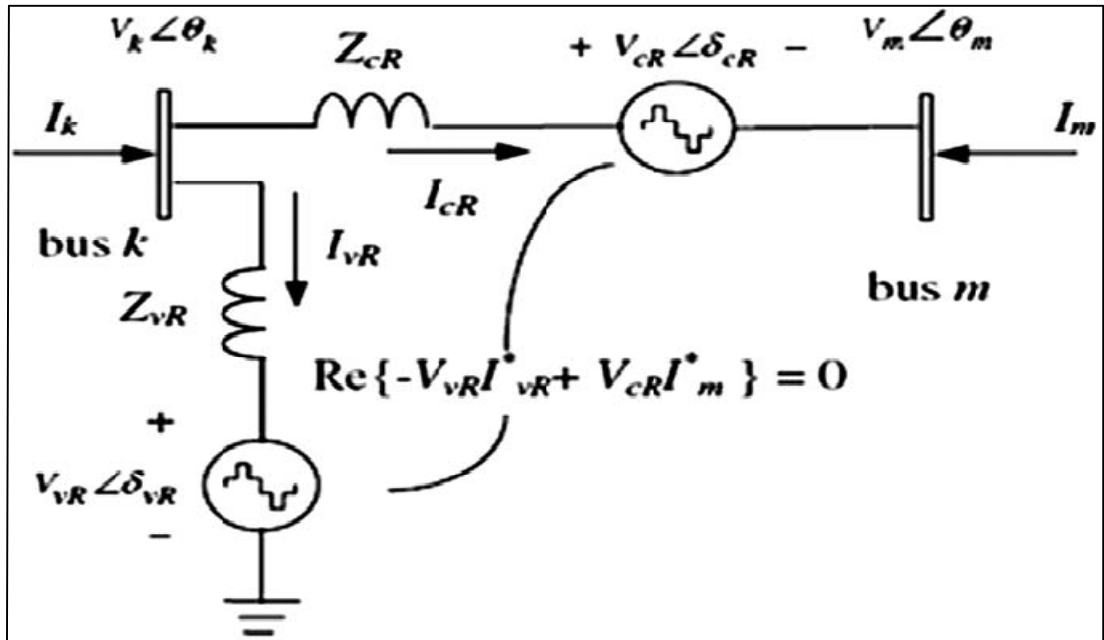


Figure 2.2: Unified power flow controller equivalent circuit

where  $V_{vR}$  is the shunt voltage source magnitude;  $\delta_{vR}$  is the shunt voltage source angle;  $V_{cR}$  is the series voltage source magnitude; and  $\delta_{cR}$  is the series voltage source angle.

The active power demanded by the series converter is drawn by the shunt converter from the AC network and supplied to bus  $m$  through the DC link. The output voltage of the series voltage source (series converter) is added to the nodal voltage, let say at bus  $k$ , to boost the nodal voltage at bus  $m$ . The voltage magnitude of the output voltage  $V_{cR}$  provides voltage regulation, and the phase angle  $\delta_{cR}$  determines the mode of power flow control. In addition to providing a supporting role in the active power exchange that takes place between the series converter and the AC system, the shunt converter may also generate or absorb reactive power in order to provide independent voltage magnitude regulation at its point of connection with the AC system.

Based on the equivalent circuit and on (1) and (2) the active and reactive power equations are:

At bus k:

$$\begin{aligned}
 P_k &= V_k^2 G_{kk} + V_k V_m [G_{km} \cos(\theta_k - \theta_m) + B_{km} \sin(\theta_k - \theta_m)] \\
 &+ V_k V_c R [G_{km} \cos(\theta_k - \delta_c R) + B_{km} \sin(\theta_k - \delta_c R)] \\
 &+ V_k V_v R [G_{vR} \cos(\theta_k - \delta_v R) + B_{vR} \sin(\theta_k - \delta_v R)]
 \end{aligned} \tag{3}$$

$$\begin{aligned}
 Q_k &= -V_k^2 B_{kk} - V_k V_m [G_{km} \sin(\theta_k - \theta_m) + B_{km} \cos(\theta_k - \theta_m)] \\
 &+ V_k V_c R [G_{km} \sin(\theta_k - \delta_c R) + B_{km} \cos(\theta_k - \delta_c R)] \\
 &+ V_k V_v R [G_{vR} \sin(\theta_k - \delta_v R) + B_{vR} \cos(\theta_k - \delta_v R)]
 \end{aligned} \tag{4}$$

At bus m:

$$\begin{aligned}
 P_m &= V_m^2 G_{mm} + V_m V_k [G_{km} \cos(\theta_m - \theta_k) + B_{km} \sin(\theta_m - \theta_k)] \\
 &+ V_m V_c R [G_{mm} \cos(\theta_m - \delta_c R) + B_{mm} \sin(\theta_m - \delta_c R)]
 \end{aligned} \tag{5}$$

$$\begin{aligned}
 Q_m &= -V_m^2 B_{mm} + V_m V_k [G_{km} \sin(\theta_m - \theta_k) - B_{km} \cos(\theta_m - \theta_k)] \\
 &+ V_m V_c R [G_{mm} \sin(\theta_m - \delta_c R) + B_{mm} \cos(\theta_m - \delta_c R)]
 \end{aligned} \tag{6}$$

Series converter:

$$\begin{aligned}
 P_{cR} &= V_c R^2 G_{mm} + V_c R V_k [G_{km} \cos(\theta_c R - \theta_k) + B_{km} \sin(\delta_c R - \theta_k)] \\
 &+ V_c R V_m [G_{mm} \cos(\delta_c R - \theta_m) + B_{mm} \cos(\delta_c R - \theta_m)]
 \end{aligned} \tag{7}$$

$$\begin{aligned}
 Q_{cR} &= -V_c R^2 B_{mm} + V_c R V_k [G_{km} \sin(\theta_c R - \theta_k) - B_{km} \cos(\delta_c R - \theta_k)] \\
 &+ V_c R V_m [G_{mm} \sin(\delta_c R - \theta_m) + B_{mm} \cos(\delta_c R - \theta_m)]
 \end{aligned} \tag{8}$$

Shunt converter:

$$P_{vR} = -V_v R^2 G_{vr} + V_v R V_k [G_{vr} \cos(\theta_v R - \theta_k) + B_{vr} \sin(\delta_v R - \theta_k)] \tag{9}$$

$$Q_{vR} = V_v R^2 B_{vr} + V_v R V_k [G_{vr} \sin(\theta_v R - \theta_k) - B_{vr} \cos(\delta_v R - \theta_k)] \tag{10}$$

where  $P_k$  and  $P_m$  are the active powers at bus k and bus m.  $Q_k$  and  $Q_m$  are the reactive powers at bus k and bus m.  $V_k$  and  $V_m$  are the voltage magnitudes at bus k

and bus  $m$ .  $\theta_k$  and  $\theta_m$  are the power angles at bus  $k$  and bus  $m$ .  $P_{cR}$  and  $Q_{cR}$  are the active and reactive power of UPFC series converter.  $P_{vR}$  and  $Q_{vR}$  are the active and reactive power of UPFC shunt converter.  $G_{kk}$  and  $G_{mm}$  are the conductance at bus  $k$  and bus  $m$ .  $G_{mk}$  and  $G_{km}$  are the conductance of the line between bus  $k$  and bus  $m$ .  $B_{kk}$  and  $B_{mm}$  are the susceptance at bus  $k$  and bus  $m$ .  $B_{mk}$  and  $B_{km}$  are the susceptance of the line between bus  $k$  and bus  $m$ .  $G_{vR}$  and  $B_{vR}$  are the conductance and the susceptance of the shunt voltage source of UPFC. The UPFC power flow equations, in linearized form, are combined with those of the AC network.

## **CHAPTER 3**

### **METHODOLOGY**

#### **3.1 Introduction**

For this project, it can be divided into five major parts.

- i. Create IEEE 6-Bus System by MATLAB programming
- ii. Implementation of UPFC in Newton Raphson Power Flow Algorithm
- iii. Develop software based on PSO under environment of MATLAB
- iv. Implementation PSO in the UPFCNewtonRaphson
- v. Simulation the software using MATLAB programming

### 3.2 Create IEEE 6-Bus System by MATLAB programming

The IEEE 6-bus system is used to show the practicability of the proposed algorithm and to find the optimal settings for source voltage parameter and the best location of UPFC with minimum losses to the system while maintain the allowable limit for previously mentioned constraints.

The IEEE 6-bus system with 11 transmission line is shown in Figure 3.1. Bus 1 is the swing bus, Bus 2 and Bus 3 is a PV bus, while Bus 4 to Bus 6 are reactive power installation buses. The line data, the load buses for the IEEE 6-Bus system are shown in Tables 1,2 and 3.

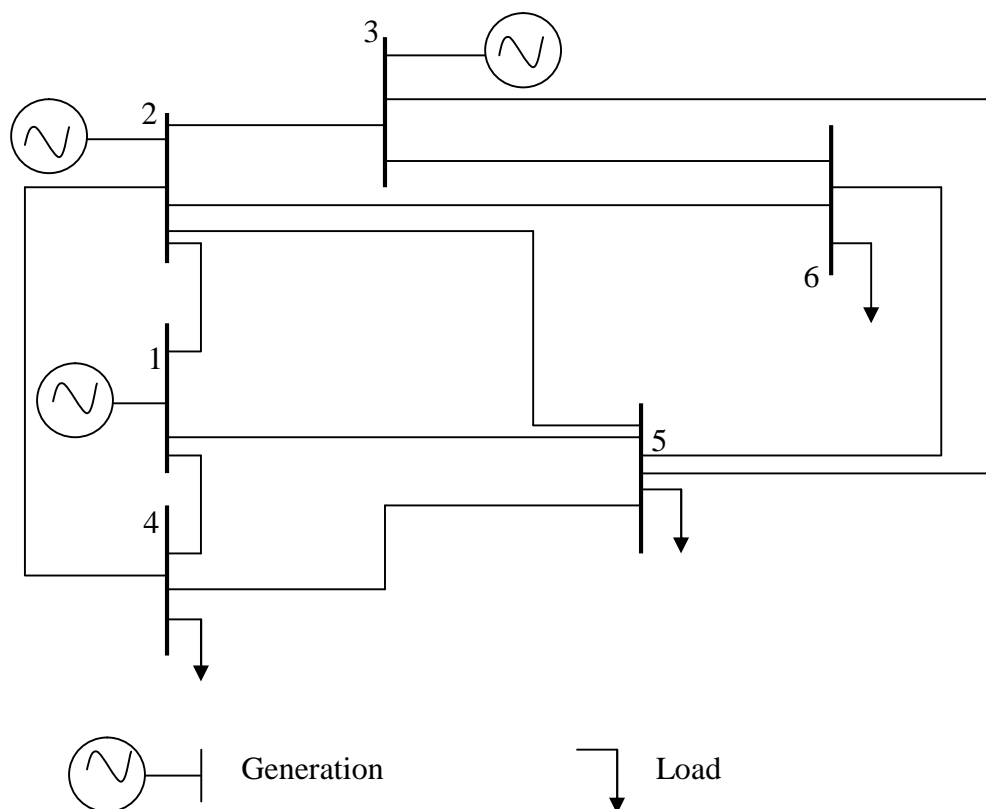


Figure 3.1: IEEE 6-Bus Diagram

Bus Number	Bus Type	Voltage Schedule (pu V)	$P_{gen}$ (pu MW)	$P_{load}$ (pu MW)	$Q_{load}$ (pu MVAR)
1	Swing	1.05			
2	Gen.	1.05	0.50	0.0	0.0
3	Gen.	1.07	0.60	0.0	0.0
4	Load		0.0	0.7	0.7
5	Load		0.0	0.7	0.7
6	Load		0.0	0.7	0.7

Table 3.1: Input Data for IEEE 6-Bus System Data

From bus	To Bus	$R(\text{pu})$	$X(\text{pu})$	Shunt suseptance
1	2	0.10	0.20	0.02
1	4	0.05	0.20	0.02
1	5	0.08	0.30	0.03
2	3	0.05	0.25	0.03
2	4	0.05	0.10	0.01
2	5	0.10	0.30	0.02
2	6	0.07	0.20	0.025
3	5	0.12	0.26	0.025
3	6	0.02	0.10	0.01
4	5	0.20	0.40	0.04
5	6	0.10	0.30	0.03

Table 3.2 Line Data

### 3.3 Implementation of UPFC in Newton Raphson Power Flow Algorithm

The algorithm for solving a power flow problem embedded with UPFC is implemented by using the MATLAB programming.

The Newton Raphson load flow algorithm incorporating the UPFC is shown by flow chart in Fig. 3. The input system data includes the basic system data needed for conventional power flow calculation consisting of the number and types of buses, transmission line data, generation and load data, location of UPFC and the control variables of UPFC for example the magnitude and angles of voltage output  $V_{se}$  and  $V_{sh}$  of two converters. The inclusion of the UPFC increases one bus in the system. The UPFC power equations are combined with the network equations to give equation (12).

$$P_i + jQ_i = \sum_{j=1}^n V_i V_j Y_{ij} \angle(\theta_{ij} - \delta_i + \delta_j) + P_i' + jQ_i' \quad (12)$$

$P_i' + jQ_i'$  = active and reactive power due to UPFC between the bus  $k$  and  $m$

$P_i + jQ_i$  = active and reactive power at the  $i$ th bus

$V_i \angle \delta_i$  = voltage and angle of  $i$ th bus

$V_j \angle \delta_j$  = voltage and angle of  $j$ th bus

$Y_{ij}$  = admittance of the transmission line between the bus  $i$  and bus  $j$ .



Equation (8) is linearised with respect to the variables of the network and the UPFC. The power flow constraint of the UPFC is included in the Jacobian. The inclusion of these variables increases the dimension of the Jacobian. The power equations are mismatched until convergence is achieved. A scalar multiplier is used to control the updating of variables to ensure that they converge in an optimal way to the solution point.

Flow Chart for power load flow by Newton Raphson with UPFC

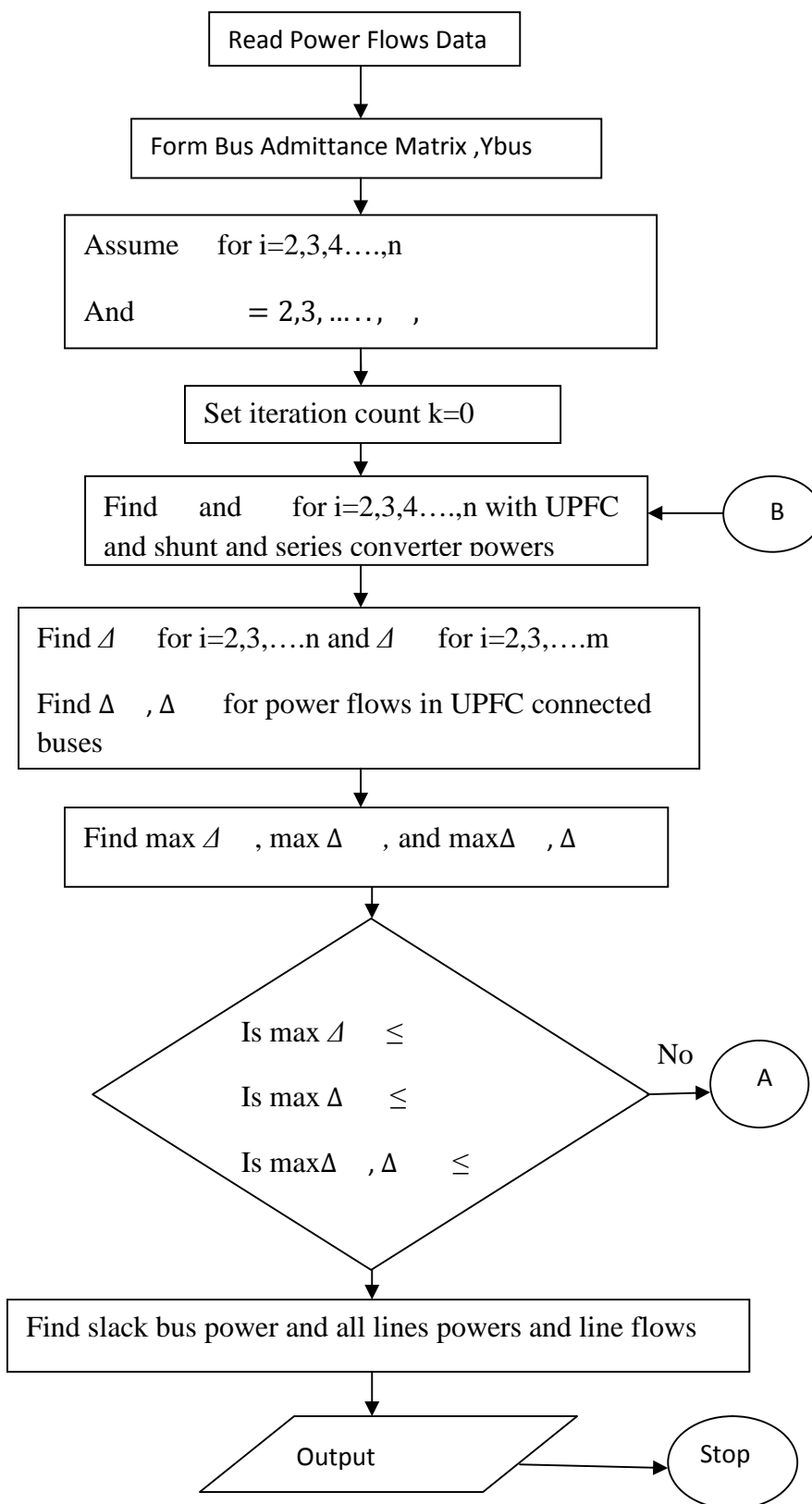


Figure 3.2: Flow Chart for power load flow by Newton Raphson with UPFC (1)

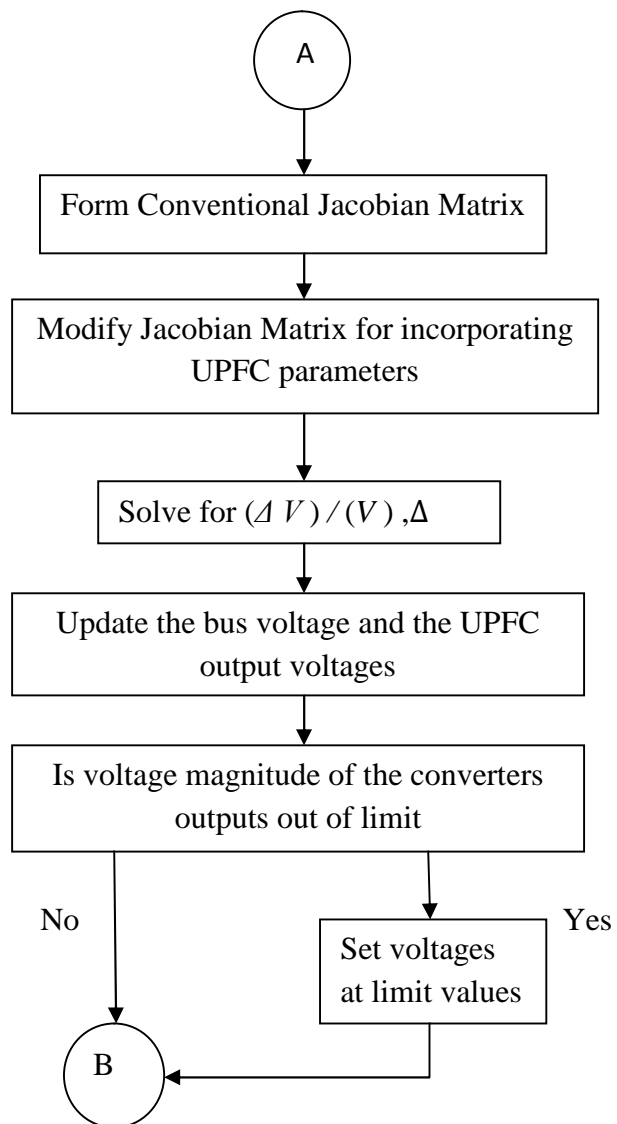


Figure 3.3: Flow Chart for power load flow by Newton Raphson with UPFC (2)

### 3.4 Develop software based on PSO under environment of MATLAB

Below are the procedures of PSO algorithm [10],

**Step 1:** Define the problem space and set the boundaries, i.e. the acceptable limits of the controller parameters.

**Step 2:** Initialize an array of particles with random positions and their associated velocities inside the problem space. These particle positions represent the initial set of solutions.

**Step 3:** Check if the current position is inside the problem space or not. If not, adjust the positions so as to be inside the problem space.

**Step 4:** Evaluate the fitness value of each particle.

**Step 5:** Compare the current fitness value with the particles' previous best value (*pbesti*). If the current fitness value is better, then assign the current fitness value to *pbesti* and assign the current coordinates to *pbestxi* coordinates.

**Step 6:** Determine the current global minimum among particle's best position.

**Step 7:** If the current global minimum is better than *gbest*, then assign the current global minimum to *gbest* and assign the current coordinates to *gbestx* coordinates.

**Step 8:** Change the velocities according to equation.

**Step 9:** Move each particle to the new position according to equation and return to Step 3.

**Step 10:** Repeat **Step 3- Step 9** until a stopping criteria is satisfied.

$v_{id}$  and  $x_{id}$  represent the velocity and position of the  $i^{th}$  particle's dimension  $d$  respectively and  $rand1$  and  $rand2$  are two uniform random functions between 0 and 1.  $\omega$  is the inertia weight that controls the exploration and exploitation of the search space as it dynamically reduces the velocity with increasing number of iterations.  $c_1$  and  $c_2$  are the acceleration constants of cognitive and social components, respectively.

## Flow Chart PSO

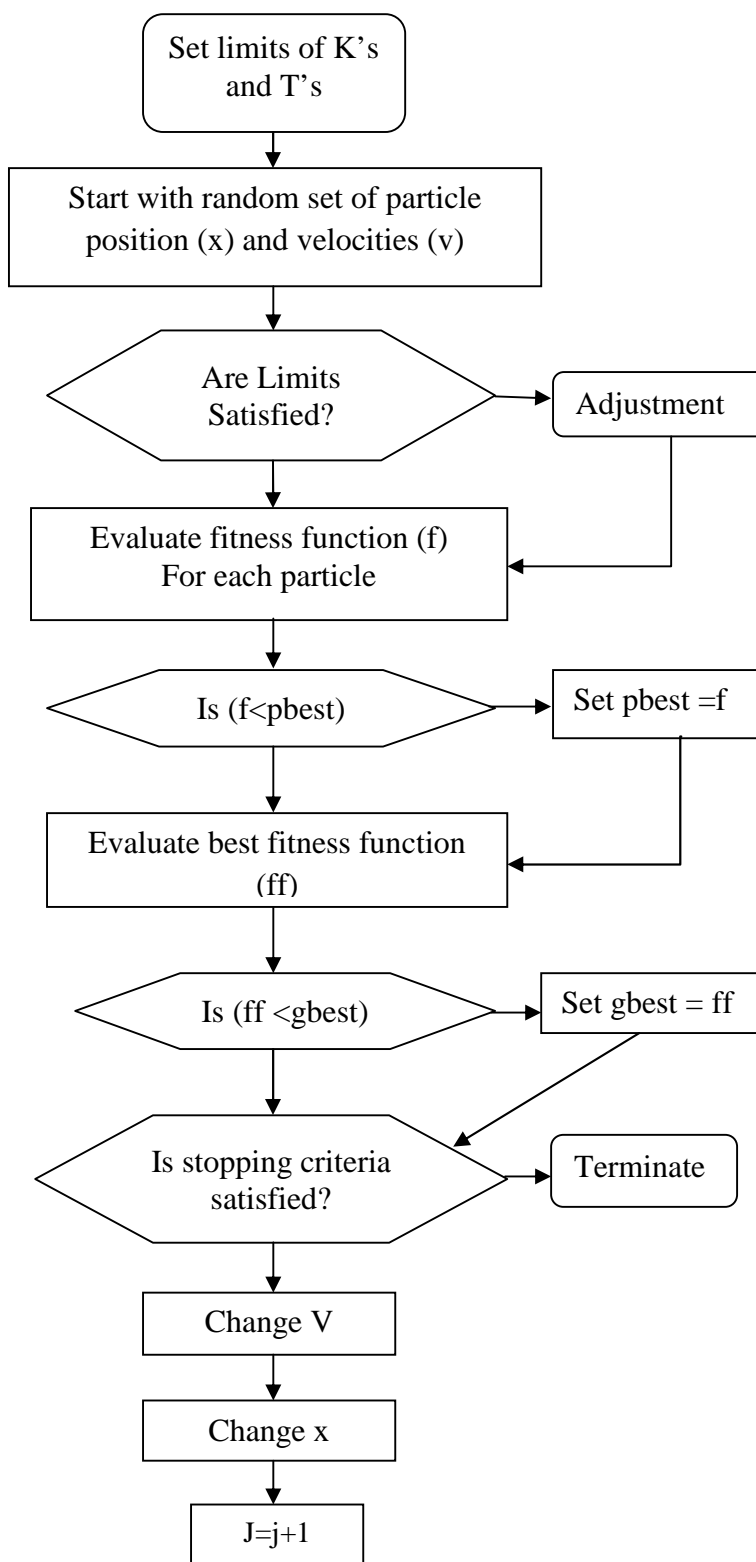


Figure 3.4: Flow Chart PSO

### 3.5 Implementation PSO in the UPFC Newton Raphson

#### 1. Initialisation

The initial population of particles  $P_i = X, T, \varphi$ ,  $i=1,2,\dots,n$ , where  $n$  is population size, are generated randomly, such that the variables of each particle are in normalised form (i.e between 0 to 1). The variables of each particle in the population corresponds to the series compensator setting, tap settings and phase shifter angles.

#### 2. Calculation of Fitness function

The constrained optimization problem of power flow control using FACTS is converted into unconstrained optimisation problem using penalty factor (PF) as given in (8), which becomes the Fitness function in PSO technique. To calculate the fitness function for each particle, the normalised value of each variable ( $X_{norm}$ ) in the particle are first denormalised to actual value ( $X_{actual}$ ) according to (12)

$$X_{actual} = X_{min} + (X_{max} - X_{min}) \times X_{norm} \quad (12)$$

$X_{min}$  = minimum value of the variable

$X_{max}$  = maximum value of the variable

For each particle, the line data updated according to its FACTS device setting. Load flow is performed using Newton Raphson method, from that line flow through the branches; voltage and angle at buses are obtained. Using these values, the active power losses is found out and the fitness function of each particle is calculated using

(8). The particle that gives minimum value for the fitness function in the population is considered as gbest particle.

### 3. Generation of new population

The new velocity is calculated using (10) and the new position of each particle is found using (11). Step 2 and 3 are repeated until maximum number of iterations are reached.



## **CHAPTER 4**

### **RESULTS AND DISCUSSION**

#### **4.1 Introduction**

The IEEE 6-Bus System is modified to include one UPFC to compensate the transmission line linking between buses. The modified network is shown in Figure 4.1. The UPFC series converter is used to maintain active and reactive powers leaving the UPFC, towards the receiving buses. Active and reactive powers are depend on the UPFC parameter. Moreover the UPFC shunt converter is set to regulate the nodal voltage magnitude or sending buses at 1 per unit. The data given in Table 3.1 is modified to inclusion of the UPFC. The bus system is become 7 buses each time inclusion of UPFC. One of the original transmission line originally connected between buses is now connected between UPFC.

## 4.2 Modified IEEE Bus System

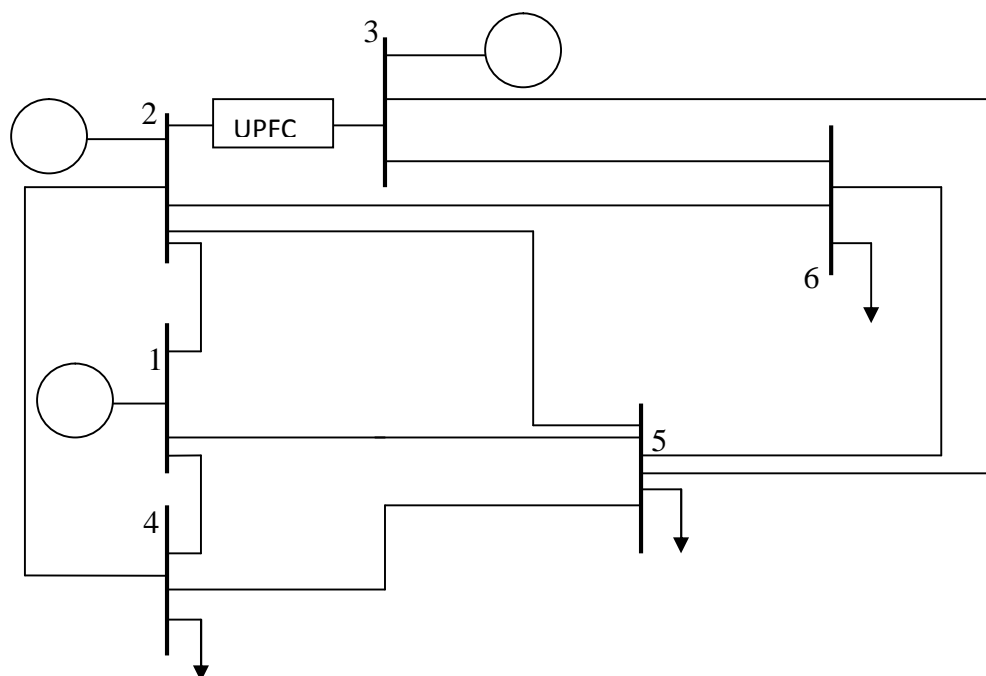


Figure 4.1: Modified IEEE 6-Bus System

For an example, the IEEE 6-Bus System is modified to include one UPFC to compensate the transmission line linking Bus 2 and Bus 3. The modified network is shown in Figure 4.1. The UPFC is used to maintain active and reactive powers leaving the UPFC, towards Bus 3, at 70MW and 2MVAR, respectively. Moreover the UPFC shunt converter is set to regulate the nodal voltage magnitude at 1.07 per unit. The data given in Table 3.1 is modified to inclusion of the UPFC. The bus system is become 7 buses. The transmission line originally connected between Bus 2 and Bus 3 is now connected between UPFC (Bus 7) and Bus 3.

The line data is modified each time the location of UPFC is changing. The modified line data is shown by Table 4.1.

UPFC(Send)	UPFC(Receive)	Original Line Data	Modified Line Data
2	7	2-3	7-3
2	7	2-4	7-4
2	7	2-5	7-5
2	7	2-6	7-6
3	7	3-5	7-5
3	7	3-6	7-6
4	7	4-5	7-5
5	7	5-6	7-6

Table 4.1 Modified UPFC Line Data

UPFC shunt converter is set to regulate the nodal voltage magnitude and UPFC series converter is used to maintain active and reactive powers leaving the UPFC. The targeted magnitude and angle is showed in Table 4.2. Reactive power of the bus is always smaller than the original value. For an example, if UPFC is injected between Bus 1 and Bus 5, shunt converter will regulate nodal voltage magnitude equal to 1.06p.u. Series converter will try to maintain the active and reactive power at Bus 5.

Targeted Bus	VvrTar	Psp	Qsp
2-3	1.07	0.70	0.02
2-4	1.00	0.70	0.02
2-5	1.00	0.70	0.02
2-6	1.00	0.70	0.02
3-5	1.00	0.70	0.02
3-6	1.00	0.70	0.02
4-5	1.00	0.70	0.02
5-6	1.00	0.70	0.02

Table 4.2 Targeted Values

VvrTar: Target nodal voltage magnitude to be controlled by UPFC shunt converter

Psp: Target active power flow

Qsp: Target reactive power flow

### 4.3 Optimal location and parameter setting of UPFC

The following variables are considered as the optimization variables:

- a) The series voltage source magnitude ( $V_{cR}$ ) of the UPFC is considered as the second variable to be optimized, and the working range for this variable is 0.001 to 0.2.
- b) The series voltage source phase angle ( $\delta_{cR}$ ) of the UPFC is considered as the third variable to be optimized, and the working range for this variable is  $0-2\pi$
- c) The shunt voltage source magnitude ( $V_{vR}$ ) of the UPFC is considered as the fourth variable to be optimized, and the working range for this variable is 0.9 to 1.1.
- d) The shunt voltage source phase angle ( $\delta_{vR}$ ) of the UPFC is considered as the fifth variable to be optimized, and the working range for this variable is 0 to  $2\pi$ .

## 4.4 Result

### 4.4.1 Simulation without UPFC by Newton Raphson Method

Bus	1	2	3	4	5	6
VM	1.0500	1.0500	1.0700	0.9881	0.9788	0.9986
VA	0	-7.5388	-11.6157	-6.8581	-9.2837	-11.7983

it	Vcr	Tcr	Vvr	Tvr	UPFC_PQsend	UPFC_PQrec
6	0.3130	-84.1483	0.9609	-15.2693	0.7000+0.2354i	-0.7000 -0.0200i

Line	PQsend	PQrec
1-2	0.5976 - 0.2622i	-0.5595 + 0.3164i
1-4	0.6682 + 0.1840i	-0.6462 - 0.1169i
1-5	0.5892 + 0.1205i	-0.5626 - 0.0518i
2-3	0.2933 - 0.1478i	-0.2886 + 0.1375i
2-4	0.1616 + 0.5643i	-0.1457 - 0.5428i
2-5	0.1691 + 0.1835i	0.1631 - 0.1860i
2-6	0.4355 + 0.1179i	-0.4224 - 0.1066i
3-5	0.0090 + 0.3603i	0.0057 - 0.3547i
3-6	0.1796 + 0.7220i	-0.1698 - 0.6836i
4-5	0.0919 - 0.0403i	-0.0901 + 0.0052i
5-6	0.1102 - 0.1127i	0.1079 + 0.0902i
Total Losses		0.1550 + 0.1963i

Table 4.3: Result without UPFC

#### 4.4.2 Simulation with UPFC by Newton Raphson Method

UPFC inserted between Bus 2 and Bus 3

Bus	1	2	3	4	5	6	7
VM	1.0500	1.0000	1.0700	0.9552	0.9594	0.9830	1.0989
VA	0	-7.2708	-8.4936	-6.6909	-8.1282	-9.8966	-0.0280

it	Vcr	Tcr	Vvr	Tvr	UPFC_PQsend	UPFC_PQrec
11	0.2187	-119.823	1.0999	-7.6134	0.7000-1.0613i	-0.7000 -0.0200i

Line	PQsend	PQrec
1-2	0.6534 - 0.0330i	-0.6147 + 0.0895i
1-4	0.6751 + 0.3523i	-0.6484 - 0.2658i
1-5	0.5306 + 0.1929i	-0.5070 - 0.1347i
<b>7-3</b>	0.7000 + 0.0200i	-0.6797 + 0.0465i
2-4	0.1022 + 0.3928i	-0.0938 - 0.3855i
2-5	0.0838 + 0.0978i	-0.0819 - 0.1114i
2-6	0.2286 - 0.0026i	-0.2250 - 0.0115i
3-5	0.1525 + 0.3706i	-0.1345 - 0.3575i
3-6	0.4272 + 0.8424i	-0.4114 - 0.7742i
4-5	0.0422 - 0.0487i	-0.0416 + 0.0133i
5-6	0.0651 - 0.1097i	-0.0636 + 0.0857i
Total Losses		0.1591 + 0.2692i

Table 4.4: Result with UPFC (Bus 2- Bus 3)

UPFC inserted between Bus 2 and Bus 4

Bus	1	2	3	4	5	6	7
VM	1.0500	1.0000	1.0700	0.9237	0.9508	0.9787	0.9550
VA	0	-13.449	-17.908	-11.816	-14.014	-17.912	-2.779

it	Vcr	Tcr	Vvr	Tvr	UPFC_PQsend	UPFC_PQrec
7	-0.2597	-92.888	0.9011	-13.295	0.7000+0.8739i	-0.7000 -0.0200i

Line	PQsend	PQrec
1-2	1.1395 - 0.1743i	-1.0193 + 0.3936i
1-4	0.7000 + 0.0200i	-0.6731 + 0.0700i
1-5	0.8635 + 0.1996i	-0.8060 - 0.0141i
2-3	0.2686 - 0.3358i	-0.2598 + 0.3473i
<b>7-4</b>	0.0962 + 0.7138i	-0.0699 - 0.6705i
2-5	0.0774 + 0.1285i	-0.0749 - 0.1400i
2-6	0.3771 - 0.0229i	-0.3671 + 0.0269i
3-5	-0.0289 + 0.4988i	0.0565 - 0.4644i
3-6	0.1887 + 0.9339i	-0.1726 - 0.8642i
4-5	0.0430 - 0.0995i	-0.0410 + 0.0684i
5-6	0.1653 - 0.1499i	-0.1603 + 0.1372i
Total Losses		0.3029 + 0.6025i

Table 4.5: Result with UPFC (Bus 2 – Bus 4)



UPFC inserted between Bus 2 and Bus 5

Bus	1	2	3	4	5	6	7
VM	1.0500	1.0000	1.0700	0.9532	0.9404	0.9765	0.9839
VA	0	-12.011	-16.816	-9.9730	-13.091	-16.775	-0.1486

it	Vcr	Tcr	Vvr	Tvr	UPFC_PQsend	UPFC_PQrec
6	-0.2768	88.3405	0.9962	-12.0092	0.7000-0.0883i	-0.7000 -0.0200i

Line	PQsend	PQrec
1-2	1.0250 - 0.1461i	-0.9281 + 0.3190i
1-4	0.9531 + 0.3344i	-0.9064 - 0.1681i
1-5	0.7000 + 0.0200i	-0.6594 + 0.1044i
2-3	0.2937 - 0.3387i	-0.2842 + 0.3543i
2-4	-0.0817 + 0.5097i	0.0953 - 0.4921i
<b>7-5</b>	0.1130 + 0.1517i	-0.1091 - 0.1589i
2-6	0.4031 - 0.0194i	-0.3917 + 0.0275i
3-5	-0.0011 + 0.5279i	0.0319 - 0.4865i
3-6	0.1853 + 0.9573i	-0.1685 - 0.8838i
4-5	0.1111 - 0.0398i	-0.1083 + 0.0096i
5-6	0.1449 - 0.1686i	-0.1398 + 0.1564i
Total Losses		0.2781 + 0.5702i

Table 4.6: Result with UPFC (Bus 2 – Bus 5)

UPFC inserted between Bus 2 and Bus 6

Bus	1	2	3	4	5	6	7
VM	1.0500	1.0000	1.0700	0.9552	0.9594	0.9830	1.0989
VA	0	-7.2708	-8.4936	-6.6909	-8.1282	-9.8966	-0.0280

it	Vcr	Tcr	Vvr	Tvr	UPFC_PQsend	UPFC_PQrec
11	0.2187	-119.823	1.0999	-7.6134	0.7000-1.0613i	-0.7000 -0.0200i

Line	PQsend	PQrec
1-2	0.6534 - 0.0330i	-0.6147 + 0.0895i
1-4	0.6751 + 0.3523i	-0.6484 - 0.2658i
1-5	0.5306 + 0.1929i	-0.5070 - 0.1347i
2-3	0.7000 + 0.0200i	-0.6797 + 0.0465i
2-4	0.1022 + 0.3928i	-0.0938 - 0.3855i
2-5	0.0838 + 0.0978i	-0.0819 - 0.1114i
<b>7-6</b>	0.2286 - 0.0026i	-0.2250 - 0.0115i
3-5	0.1525 + 0.3706i	-0.1345 - 0.3575i
3-6	0.4272 + 0.8424i	-0.4114 - 0.7742i
4-5	0.0422 - 0.0487i	-0.0416 + 0.0133i
5-6	0.0651 - 0.1097i	-0.0636 + 0.0857i
Total Losses		0.1591 + 0.2692i

Table 4.7: Result with UPFC (Bus 2 – Bus 6)

UPFC inserted between Bus 3 and Bus 5

Bus	1	2	3	4	5	6	7
VM	1.0500	1.0000	1.0000	0.9127	0.9321	0.9458	0.9493
VA	0	-11.234	-18.111	-2.1661	-12.139	-16.927	2.3866

it	Vcr	Tcr	Vvr	Tvr	UPFC_PQsend	UPFC_PQrec
10	-0.424	-89.6013	0.9000	-18.1233	0.4709+0.8382i	-0.4708 -0.0120i

Line	PQsend	PQrec
1-2	0.9015 - 0.3561i	-0.8170 + 0.5031i
1-4	0.3408 + 0.6279i	-0.3171 - 0.5521i
1-5	0.7614 + 0.2660i	-0.7135 - 0.1161i
2-3	0.5297 + 0.1177i	-0.5161 - 0.0816i
2-4	0.7000 + 0.0200i	-0.6728 + 0.0258i
2-5	0.1702 + 0.3453i	-0.1561 - 0.3226i
2-6	0.6170 + 0.3420i	-0.5848 - 0.2749i
<b>7-5</b>	-0.2007 + 0.3608i	0.2223 - 0.3374i
3-6	-0.0831 + 0.5560i	0.0896 - 0.5333i
4-5	0.2898 - 0.1736i	-0.2638 + 0.1918i
5-6	0.2111 - 0.1156i	-0.2048 + 0.1082i
Total Losses		0.3037 + 0.6011i

Table 4.8: Result with UPFC (Bus 3 – Bus 5)

UPFC inserted between Bus 3 and Bus 6

Bus	1	2	3	4	5	6	7
VM	1.0500	1.0500	1.0000	0.9811	0.9297	0.9454	0.9857
VA	0	-8.8072	-15.064	-7.4445	-8.0832	-13.890	4.9734

It	Vcr	Tcr	Vvr	Tvr	UPFC_PQsend	UPFC_PQrec
6	-0.4165	-88.316	0.9594	-15.2194	0.7000-0.1822i	-0.7000 -0.0200i

Line	PQsend	PQrec
1-2	0.7012 - 0.2966i	-0.6492 + 0.3786i
1-4	0.7235 + 0.2134i	-0.6974 - 0.1300i
1-5	0.5400 + 0.2929i	-0.5119 - 0.2170i
2-3	0.4854 + 0.1214i	-0.4738 - 0.0952i
2-4	0.0947 + 0.6739i	-0.0734 - 0.6415i
2-5	0.7000 + 0.0200i	-0.6495 + 0.1132i
2-6	0.5691 + 0.3558i	-0.5399 - 0.2972i
3-5	-0.2453 + 0.3977i	0.2727 - 0.3616i
<b>7-6</b>	-0.0808 + 0.5594i	0.0873 - 0.5363i
4-5	0.0708 + 0.0715i	-0.0680 - 0.1025i
5-6	0.2567 - 0.1321i	-0.2475 + 0.1336i
Total Losses		0.2647 + 0.5212i

Table 4.9: Result with UPFC (Bus 3 – Bus 6)

UPFC inserted between Bus 4 and Bus 5

Bus	1	2	3	4	5	6	7
VM	1.0500	1.0500	1.0700	1.0000	0.9808	0.9921	1.0369
VA	0	-6.3299	-9.2723	-8.9429	-8.1009	-8.5530	-0.8634

it	Vcr	Tcr	Vvr	Tvr	UPFC_PQsend	UPFC_PQrec
8	-0.213	75.9397	1.0459	-9.1013	0.7000-0.5351i	-0.7000 -0.0200i

Line	PQsend	PQrec
1-2	0.4997 - 0.2272i	-0.4728 + 0.2590i
1-4	0.8449 + 0.1041i	-0.8119 + 0.0068i
1-5	0.5205 + 0.1212i	-0.4994 - 0.0733i
2-3	0.2068 - 0.1360i	-0.2042 + 0.1152i
2-4	0.5973 + 0.2317i	-0.5786 - 0.2048i
2-5	0.1686 + 0.1767i	-0.1629 - 0.1800i
2-6	0.7000 + 0.0200i	-0.6680 + 0.0456i
3-5	0.0720 + 0.3205i	-0.0597 - 0.3202i
3-6	0.0322 + 0.8217i	-0.0202 - 0.7724i
<b>7-5</b>	-0.0095 + 0.0331i	0.0101 - 0.0711i
5-6	0.0119 - 0.0555i	-0.0117 + 0.0268i
Total Losses		0.1650 + 0.2418i

Table 4.10: Result with UPFC (Bus 4 – Bus 5)

UPFC inserted between Bus 5 and Bus 6

Bus	1	2	3	4	5	6	7
VM	1.0500	1.0500	1.0700	0.9913	1.0000	1.0028	1.0728
VA	0	-7.5558	-11.595	-6.9361	-9.8542	-11.859	-0.3103

it	Vcr	Tcr	Vvr	Tvr	UPFC_PQsend	UPFC_Pqrec
8	-0.002	8.7078	0.0011	-0.0101	0.7000-0.6693i	-0.7000 -0.0200i

Line	PQsend	PQrec
1-2	0.5990 – 0.2627i	-0.5607 + 0.3172i
1-4	0.6730 + 0.1671i	-0.6510 – 0.1000i
1-5	0.6157 + 0.0459i	-0.5879 + 0.0267i
2-3	0.2904 – 0.1475i	-0.2858 + 0.1368i
2-4	0.1568 + 0.5333i	-0.1425 – 0.5151i
2-5	0.1797 + 0.1069i	-0.1755 – 0.1154i
2-6	0.4338 + 0.0970i	-0.4211 – 0.0870i
3-5	0.7000 + 0.0200i	-0.6488 + 0.0641i
3-6	0.1858 + 0.6762i	-0.1771 – 0.6433i
4-5	0.0936 – 0.0848i	-0.0909 + 0.0505i
<b>7-6</b>	0.1031 – 0.0567i	-0.1018 + 0.0303i
Total Losses		0.1877 + 0.2595i

Table 4.11: Result with UPFC (Bus 5 – Bus 6)

## 4.5 Discussion

When the transmission line is without UPFC, the real and reactive power flow cannot be controlled. Table 4.3 shows the active power through the line without UPFC. Table 4.4 to 4.11 shows the active power flow through line which is controlled by UPFC. Transmission capability of the existing transmission line is highly improved with the presence of UPFC. But the difference between the sending-end real power and receiving end real power is high in the transmission line with UPFC. This is due to the increase in transmission losses, which include losses in the both converters and coupling transformers. No matter how from table 4.4 to 4.11, results showed that difference between the locations of the UPFC will affect the maximum loadability of the transmission line and the losses of the system. Active power of each location is showed by table 4.12. From the table, we can notice that inclusion UPFC between Bus 5 and Bus 6 has the largest increment of loadability.

Location UPFC	Total Active Power	Increment of Loadability (%)
2-3	366	10.9
2-4	383	16.0
2-5	384	16.3
2-6	366	10.9
3-5	423	30.9
3-6	381	15.4
4-5	364	10.3
5-6	403	22.1

Table 4.12: Increment Loadability

Location UPFC	Total Losses (MW)
2-3	15.91
2-4	30.39
2-5	27.81
2-6	15.91
3-5	30.37
3-6	26.47
4-5	16.50
5-6	18.77

Table 4.13: Total Losses

Although increment of load ability is the main objective of this project, the losses of the bus system also considered as the main factor to choose the best location of UPFC. Judging from Table 4.13, the line 5-6 is the best location to install UPFC. Although the losses at the line is slightly higher than 2-3, but the ratio for line 5-6 is the least among all. The parameters of UPFC for line 5-6 have showed in Table 4



## **CHAPTER 5**

### **CONCLUSION**

#### **5.1 Conclusion**

This paper investigates one of the most promising FACTS devices, namely UPFC as control agent in a power system. Here, particle swarm optimization is used to determine the optimal location and parameters of UPFCs. The system loadability was employed as a measure of power system performance. Simulation results validate the efficiency of this new approach in maximizing the loadability of the system. Furthermore, the location of UPFCs and their parameters are optimized simultaneously. Results have shown that, as the UPFCs is added to the system, the system loadability also increases up to a limit. The performance of the proposed method demonstrated through its evaluation on the IEEE 6-bus power system and shows that PSO is able to undertake global search with a fast convergence rate and a feature of robust computation.

## **5.2 Recommendation**

A new power market structure is proposed. The significance of this research is that it provides a scheme that could dramatically reduce the power market operation cost, and improve the market efficiency; meanwhile the welfare of society is guaranteed. This proposed market structure eliminates the need for iterative bidding, and the settles solution is optimal in the sense that is the best solution possible had the iterative bidding process really taken place. The solution in the research is obtained without considering system physical conditions, such as system stability, margin, overheating of transmission lines, and so on. One step further along this line of research is to include all these concerns in the problem formulation. A solution to such a problem will eventually give a more comprehensive result to the situation in question.

A scheme is developed to solve the load flow problem such that the loadability factor for the system can be maximized. Following the deregulation of the power industry, greater flexibility of the transmission system demanded to satisfy the ever-changing market situation. A load flow solution that leaves the biggest room to accommodate market changes very appealing to the market operators. Simulation results show that the proposed scheme works well for a realistic power system.

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# APPENDIX A

## M-File

## Appendix-Power Flow Data

```

%          Bus Bus   Voltage Angle      --Load--      --Generator--      --
Injected--
%          No  Code   Mag.   Degree   MW   Mvar   MW   Mvar   Qmin
Qmax     Mvar
busdata=[ 1   1   1.05   0.0   0.00  0.00  0.00  0.00  0.00
0.00      0;
          2   2   1.05   0.0   0.00  0.00  50.0  0.00 -40.0
40.0     0;
          3   2   1.07   0.0   0.00  0.00  60.0  0.00  0.00
0.00     0;
          4   3   1.00   0.0   70.0  70.00  0.00  0.00  0.00
0.00     0;
          5   3   1.00   0.0   70.0  70.00  0.00  0.00  0.00
0.00     0;
          6   3   1.00   0.0   70.0  70.00  0.00  0.00  0.00
0.00     0;
          7   3   1.00   0.0   0.0   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   2   0.100   0.200   0.0       0.02
1.00;
          1   4   0.050   0.200   0.0       0.02
1.00;
          1   5   0.080   0.300   0.0       0.03
1.00;
          2   3   0.050   0.250   0.0       0.03
1.00;
          2   4   0.050   0.100   0.0       0.01
1.00;
          2   5   0.100   0.300   0.0       0.02
1.00;
          2   6   0.070   0.200   0.0       0.025
1.00;
          3   5   0.120   0.260   0.0       0.025
1.00;
          3   6   0.020   0.100   0.0       0.01
1.00;
          4   5   0.200   0.400   0.0       0.04
1.00;
          5   6   0.100   0.300   0.0       0.03
1.00]

```

```

%          btw          UPFC      linedata  VvrTar  Psp  Qsp
update=[2  3    2  7    7  3    1.07    0.70  0.02;
        2  4    2  7    7  4     1     0.70  0.02;
        2  5    2  7    7  5     1     0.70  0.02;
        2  6    2  7    7  6     1     0.70  0.02;
        3  5    3  7    7  5     1     0.70  0.02;
        3  6    3  7    7  6     1     0.70  0.02;
        4  5    4  7    7  5     1     0.70  0.02;
        5  6    5  7    7  6     1     0.70  0.02]

%Choosing which transmission line want to change
change=8
btw=update(change,:)
linedata(change,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 = 3
genbus(1) = 1 ; PGEN(1) = 0 ; QGEN(1) = 0 ; QMAX(1) = 5 ; QMIN(1) = -5 ;
genbus(2) = 2 ; PGEN(2) = 0.5 ; QGEN(2) = 0 ; QMAX(2) = 3 ; QMIN(2) = -
3 ;

```



```
genbus(3) = 3 ; PGEN(3) = 0.6 ; QGEN(3) = 0 ; QMAX(3) = 3 ; QMIN(3) = -
3
```

```
%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 = 11 ;
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) = 0.70 ; QLOAD(1) = 0.70 ;
loadbus(2) = 4 ; PLOAD(2) = 0.70 ; QLOAD(2) = 0.70 ;
loadbus(3) = 5 ; PLOAD(3) = 0.70 ; QLOAD(3) = 0.70 ;
loadbus(4) = 6 ; PLOAD(4) = 0.70 ; QLOAD(4) = 0.70 ;
```

```
%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
```

## Appendix-data UPFC

```

% UNIFIED POWER FLOW CONTROLLER
% NUPFC : Number of UPFC's
% UPFCsend : Shunt converter's bus and series converter' sending bus
% UPFCrec : Series converter' receiving bus
% Xcr : Inductive reactance of Shunt impedance (p.u.)
% Xvr : Inductive reactance of Series impedance (p.u.)
% Flow : Power flow direction : 1 is for sending to receiving bus
% -1 indicates opposite direction
% Psp : Target active power flow (p.u.)
% PSta : control status for active power : 1 is on; 0 is off
% Qsp : Target reactive power flow (p.u.)
% QSta : control status for reactive power : 1 is on; 0 is off
% Vcr : Initial condition for the series source voltage magnitude (p.u.)
% Tcr : Initial condition for the series source voltage angle (rad.)
% VcrLo : Lower limit of series source voltage magnitude (p.u.)
% VcrHi : Higher limit of series source voltage magnitude (p.u.)
% Vvr : Initial condition to the shunt source voltage magnitude (p.u.)
% Tvr : Initial condition to the shunt source voltage angle (rad.)
% VvrLo : Lower limit of shunt source voltage magnitude (p.u.)
% VvrHi : Higher limit of shunt source voltage magnitude (p.u.)
% VvrTar : Target nodal voltage magnitude to be controlled by shunt ...
% branch (p.u.)
% VvrSta : Control status for nodal voltage magnitude: 1 is on; 0 is
off
% d : Numbers of Parameter
NUPFC=1;
UPFCsend(1)=btw(1,3); UPFCrec(1)=btw(1,4);
Xcr(1)=0.1; Xvr(1)=0.1;
Flow(1)=-1;
PSta(1)=1; QSta(1)=1;
Psp(1)=btw(1,8); Qsp(1)=btw(1,9);
%SeriesVoltageMagnitude
Vcr(1)=Xcr(1)*((Psp(1)^2+Qsp(1)^2)^0.5); Tcr(1)=atan(Psp(1)/Qsp(1));
VcrLo(1)=0.001; VcrHi(1)=0.7;
%ShuntVoltageMagnitude
Vvr(1)=1.0; Tvr(1)=0; VvrLo(1)=0.9; VvrHi(1)=1.1;
VvrTar(1)=btw(1,7); VvrSta(1)=1;

%end of UPFC data

```

## Appendix- Ybus

```

% [YR,YI]
=YBus(tlsend,tlrec,tlresis,tlreac,tl suscep,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*tl suscep(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*tl susceptible(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

```

## Appendix-UPFC Newton Raphson Method

```

%General Settings
flag = 0;
it = 1;

%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 )
% 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 UPFC POWERS
for ii = 1 : NUPFC
Bkk = - 1/Xcr(ii)-1/Xvr(ii);
Bmm = -1/Xcr(ii);
Bmk = 1/Xcr(ii);
Bvr = 1/Xvr(ii);
for kk = 1 : 2
A1 = VA(UPFCsend(ii))-VA(UPFCrec(ii));

```

```

A2 = VA(UPFCsend(ii))-Tcr(ii);
A3 = VA(UPFCsend(ii))-Tvr(ii);
% Computation of Conventional Terms
Pkm = VM(UPFCsend(ii))*VM(UPFCrec(ii))*Bmk*sin(A1);
Qkm = - VM(UPFCsend(ii))^2*Bkk - VM(UPFCsend(ii))*VM(UPFCrec(ii))...
*Bmk*cos(A1);
% Computation of Shunt Converters Terms
Pvrk = VM(UPFCsend(ii))*Vvr(ii)*Bvr*sin(A3);
Qvrk = - VM(UPFCsend(ii))*Vvr(ii)*Bvr*cos(A3);
if kk == 1
% Computation of Series Converters Terms
Pcrk = VM(UPFCsend(ii))*Vcr(ii)*Bmk*sin(A2);
Qcrk = - VM(UPFCsend(ii))*Vcr(ii)*Bmk*cos(A2);
%Power in bus k
Pk = Pkm + Pcrk + Pvrk;
Qk = Qkm + Qcrk + Qvrk;
UPFC_PQsend(ii) = Pk + Qk*i;
PCAL(UPFCsend(ii)) = PCAL(UPFCsend(ii)) + Pk;
QCAL(UPFCsend(ii)) = QCAL(UPFCsend(ii)) + Qk;
%Power in Series Converter
Pcr = Vcr(ii)*VM(UPFCsend(ii))*Bmk*sin(-A2);
Qcr = - Vcr(ii)^2*Bmm - Vcr(ii)*VM(UPFCsend(ii))*Bmk*cos(-A2);
%Power in Shunt Converter
Pvr = Vvr(ii)*VM(UPFCsend(ii))*Bvr*sin(-A3);
Qvr = Vvr(ii)^2*Bvr - Vvr(ii)*VM(UPFCsend(ii))*Bvr*cos(-A3);
PQvr(ii) = Pvr + Qvr*i;
else
% Computation of Series Converters Terms
Pcrk = VM(UPFCsend(ii))*Vcr(ii)*Bkk*sin(A2);
Qcrk = - VM(UPFCsend(ii))*Vcr(ii)*Bkk*cos(A2);
%Power in bus m
Pcal = Pkm + Pcrk;
Qcal = Qkm + Qcrk;
UPFC_PQrec(ii) = Pcal + Qcal*i;
PCAL(UPFCsend(ii)) = PCAL(UPFCsend(ii)) + Pcal;
QCAL(UPFCsend(ii)) = QCAL(UPFCsend(ii)) + Qcal;
%Power in Series Converter
Pcr = Pcr + Vcr(ii)*VM(UPFCsend(ii))*Bkk*sin(-A2);
Qcr = Qcr - VM(UPFCsend(ii))*Vcr(ii)*Bkk*cos(-A2);
PQcr(ii) = Pcr + Qcr*i;
end
send = UPFCsend(ii);
UPFCsend(ii) = UPFCrec(ii);
UPFCrec(ii) = send;
Beq = Bmm;
Bmm = Bkk;
Bkk = Beq;
end
end
%END UPFC CALCULATED POWERS

%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

%UPFCPowerMismatches
iii = 0;
for ii = 1 : NUPFC
index = 2*(nbb + ii) + iii;
if PSta(ii) == 1
if Flow(ii) == 1
DPQ(index-1) = Psp(ii) - real(UPFC_PQsend(ii));
else
DPQ(index-1) = - Psp(ii) - real(UPFC_PQrec(ii));
end
else
DPQ(index-1) = 0;
end
if QSta(ii) == 1
if Flow(ii) == 1
DPQ(index) = Qsp(ii) - imag(UPFC_PQrec(ii));
else
DPQ(index) = - Qsp(ii) - imag(UPFC_PQrec(ii));
end
else
DPQ(index) = 0;
end
DPQ(index + 1) = - real(PQcr(ii) + PQvr(ii));
iii=iii+1;
end
% Check for convergence

```

```

if ( abs(DPQ) < tol )
flag = 1;
end

%End Power Mismatches

if flag == 1
break
end

%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 OF THE JACOBIAN FOR UPFC
iii = 0;
for ii = 1 : NUPFC
indexQ=2*(nbb + ii) + iii;
indexP=indexQ-1;
indexL=indexQ + 1;
if VvrSta(ii) == 1
JAC(:,2*UPFCsend(ii)) = 0.0;
end
Bmm = - 1/Xcr(ii)-1/Xvr(ii);
Bkk = -1/Xcr(ii);
Bmk = 1/Xcr(ii);
Bvr = 1/Xvr(ii);
for kk = 1 : 2
A1 = VA(UPFCsend(ii))-VA(UPFCrec(ii));
A2 = VA(UPFCsend(ii))-Tcr(ii);
A3 = VA(UPFCsend(ii))-Tvr(ii);
% Computation of Conventional Terms
Hkm = - VM(UPFCsend(ii))*VM(UPFCrec(ii))*Bmk*cos(A1);
Nkm = VM(UPFCsend(ii))*VM(UPFCrec(ii))*Bmk*sin(A1);
% Computation of Shunt Converters Terms
Hvr = -VM(UPFCsend(ii))*Vvr(ii)*Bvr*cos(A3);
Nvr = VM(UPFCsend(ii))*Vvr(ii)*Bvr*sin(A3);
% Computation of Series Converters Terms
if kk == 1
Hcr = - VM(UPFCsend(ii))*Vcr(ii)*Bmk*cos(A2);
Ncr = VM(UPFCsend(ii))*Vcr(ii)*Bmk*sin(A2);
else
Hcr = - VM(UPFCsend(ii))*Vcr(ii)*Bkk*cos(A2);
Ncr = VM(UPFCsend(ii))*Vcr(ii)*Bkk*sin(A2);
end
if kk == 1
JAC(2*UPFCsend(ii)-1,2*UPFCsend(ii)-1) = JAC(2*UPFCsend...
(ii)-1, 2*UPFCsend(ii)-1) - VM(UPFCsend(ii))^2*Bmm;
if VvrSta(ii) == 1
JAC(2*UPFCsend(ii)-1,2*UPFCsend(ii)) = Nvr;
JAC(2*UPFCsend(ii),2*UPFCsend(ii)) = Hvr;
else
JAC(2*UPFCsend(ii)-1,2*UPFCsend(ii)) = JAC(2*UPFCsend(ii)-1,...
2*UPFCsend(ii)) - Nkm + Nvr;
JAC(2*UPFCsend(ii),2*UPFCsend(ii)) = JAC(2*UPFCsend...
(ii),2*UPFCsend(ii)) - Hkm + Hvr + 2*VM(UPFCsend(ii))^2*Bmk;

```

```

end
JAC(2*UPFCsend(ii)-1,indexL) = Hvr;
JAC(2*UPFCsend(ii),indexL) = - Nvr;
else
JAC(2*UPFCsend(ii)-1,2*UPFCsend(ii)-1) = JAC(2*UPFCsend...
(ii)-1,2*UPFCsend(ii)-1) + VM(UPFCsend(ii))^2*Bmk;
JAC(2*UPFCsend(ii),2*UPFCsend(ii)) = JAC(2*UPFCsend(ii),...
2*UPFCsend(ii)) + VM(UPFCsend(ii))^2*Bmk;
JAC(2*UPFCsend(ii)-1,indexL) = 0.0;
JAC(2*UPFCsend(ii),indexL) = 0.0;
end
JAC(2*UPFCsend(ii)-1,2*UPFCrec(ii)-1) = JAC(2*UPFCsend(ii)-1,...
2*UPFCrec(ii)-1) + Hkm;
JAC(2*UPFCsend(ii),2*UPFCrec(ii)-1) = JAC(2*UPFCsend(ii),...
2*UPFCrec(ii)-1) - Nkm;
if VvrSta(ii) == 1 & kk == 2
JAC(2*UPFCsend(ii)-1,2*UPFCrec(ii)) = 0.0;
JAC(2*UPFCsend(ii),2*UPFCrec(ii)) = 0.0;
else
JAC(2*UPFCsend(ii)-1,2*UPFCrec(ii)) = JAC(2*UPFCsend(ii)-1,...
2*UPFCrec(ii)) + Nkm;
JAC(2*UPFCsend(ii),2*UPFCrec(ii)) = JAC(2*UPFCsend(ii),...
2*UPFCrec(ii)) + Hkm;
end
end
% Computation of Active Power Controlled Jacobian's Terms
if PSta(ii) == 1
if (Flow(ii) == 1 & kk == 1) | (Flow(ii) == -1 & kk == 2)
if kk == 1
JAC(indexP, 2*UPFCsend(ii)-1) = - Hkm - Hcr - Hvr;
JAC(indexP, 2*UPFCsend(ii)) = - Nkm + Ncr;
JAC(indexP, 2*UPFCrec(ii)-1) = - Hkm;
if VvrSta(ii) == 1
JAC(indexP, 2*UPFCrec(ii)) = 0.0;
else
JAC(indexP, 2*UPFCrec(ii)) = Nkm;
end
end
JAC(indexP, indexP) = Hcr;
if QSta(ii) == 1
JAC(indexP, indexQ) = Ncr;
else
JAC(indexP, indexQ) = 0.0;
end
end
else
JAC(indexP, 2*UPFCsend(ii)-1) = - Hkm - Hcr;
JAC(indexP, 2*UPFCsend(ii)) = Nkm + Ncr;
JAC(indexP, 2*UPFCrec(ii)-1) = Hkm;
if VvrSta(ii) == 1
JAC(indexP, 2*UPFCrec(ii)) = 0.0;
else
JAC(indexP, 2*UPFCrec(ii)) = Nkm;
end
end
JAC(indexP, indexP) = Hcr;
if QSta(ii) == 1
JAC(indexP, indexQ) = Ncr;
else

```

```

JAC(indexP, indexQ) = 0.0;
end
JAC(indexP, indexL) = 0.0;
end
end
JAC(2*UPFCsend(ii)-1, indexP) = + Hcr;
JAC(2*UPFCsend(ii), indexP) = - Ncr;
else
JAC(indexP, indexP) = 1.0;
end
end
% Computation of Rective Power Controlled Jacobian's Terms
if QSta(ii) == 1
if (Flow(ii) == 1 & kk == 1) | (Flow(ii) == -1 & kk == 2)
if kk == 1
JAC(indexQ, 2*UPFCsend(ii)-1) = - Nkm + Ncr;
JAC(indexQ, 2*UPFCsend(ii)) = - 2*VM(UPFCsend(ii))^2*Bmm - ...
Hkm + Hcr;
JAC(indexQ, 2*UPFCrec(ii)-1) = Nkm;
JAC(indexQ, indexQ) = Hcr;
if VvrSta(ii) == 1
JAC(indexQ, 2*UPFCrec(ii)) = 0.0;
else
JAC(indexQ, 2*UPFCrec(ii)) = Hkm;
end
if PSta(ii) == 1
JAC(indexQ, indexP) = - Ncr;
else
JAC(indexQ, indexP) = 0.0;
end
else
JAC(indexQ, 2*UPFCsend(ii)-1) = Nkm + Ncr;
JAC(indexQ, 2*UPFCsend(ii)) = - 2*VM(UPFCsend(ii)) ...
^2*Bkk + Hkm + Hcr;
JAC(indexQ, 2*UPFCrec(ii)-1) = - Nkm;
JAC(indexQ, indexQ) = Hcr;
if VvrSta(ii) == 1
JAC(indexQ, 2*UPFCrec(ii)) = 0.0;
else
JAC(indexQ, 2*UPFCrec(ii)) = Hkm;
end
if PSta(ii) == 1
JAC(indexQ, indexP) = - Ncr;
else
JAC(indexQ, indexP) = 0.0;
end
end
end
JAC(2*UPFCsend(ii)-1, indexQ) = Ncr;
JAC(2*UPFCsend(ii), indexQ) = Hcr;
else
JAC(indexQ, indexQ) = 1.0;
end
end
temp = UPFCsend(ii);
UPFCsend(ii) = UPFCrec(ii);
UPFCrec(ii) = temp;

```

```

end
A1 = Tcr(ii) - VA(UPFCsend(ii));
A2 = Tcr(ii) - VA(UPFCrec(ii));
A3 = Tvr(ii) - VA(UPFCsend(ii));
Hcrk = - Vcr(ii)*VM(UPFCsend(ii))*Bmk*cos(A1);
Ncrk = Vcr(ii)*VM(UPFCsend(ii))*Bmk*sin(A1);
Hcrm = Vcr(ii)*VM(UPFCrec(ii))*Bmk*cos(A2);
Ncrm = - Vcr(ii)*VM(UPFCrec(ii))*Bmk*sin(A2);
Hvrk = - Vvr(ii)*VM(UPFCsend(ii))*Bvr*cos(A3);
Nvrk = Vvr(ii)*VM(UPFCsend(ii))*Bvr*sin(A3);
JAC(indexL, 2*UPFCsend(ii)-1) = Hcrk + Hvrk;
if VvrSta == 1
JAC(indexL, 2*UPFCsend(ii)) = Nvrk;
else
JAC(indexL, 2*UPFCsend(ii)) = Nvrk + Ncrk;
end
JAC(indexL, 2*UPFCrec(ii)-1) = Hcrm;
JAC(indexL, 2*UPFCrec(ii)) = Ncrm;
JAC(indexL, indexL) = - Hvrk;
if PSta == 1
JAC(indexL, indexP) = - Hcrk - Hcrm;
else
JAC(indexL, indexP) = 0.0;
end
if QSta == 1
JAC(indexL, indexQ) = Ncrk + Ncrm;
else
JAC(indexL, indexP) = 0.0;
end
iii = iii + 1;
end

%End of UPFCjacobian

% SOLVE JOCOBIAN
Z=DPQ'
D = pinv(JAC)*Z

```

```

% UPDATE THE STATE VARIABLES VALUES
%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

%Function to update the UPFC state variables
iii = 0;
for ii = 1 : NUPFC
indexQ=2*(nbb + ii) + iii;
indexP=indexQ-1;
indexL=indexQ + 1;
if PSta(ii) == 1
Tcr(ii) = Tcr(ii) + D(indexP);
end
if QSta(ii) == 1
Vcr(ii) = Vcr(ii) + D(indexQ)*Vcr(ii);
end
if VvrSta(ii) == 1
Vvr(ii) = Vvr(ii) + D(2*UPFCsend(ii),1)*Vvr(ii);
VM(UPFCsend(ii)) = VvrTar(ii);
end
Tvr(ii) = Tvr(ii) + D(indexL);
iii = iii +1;
end

%END Function update the UPFC state variables

```

```

%Global PSO (to check the voltage sources limits in the UPFC)
for ii = 1 : NUPFC

% Check Magnitude Voltage Limits
if abs(Vcr(ii)) < VcrLo(ii) | abs(Vcr(ii)) > VcrHi(ii)
if abs(Vcr(ii)) < VcrLo(ii)
Vcr(ii) = VcrLo(ii);
elseif abs(Vcr(ii)) > VcrHi(ii)
Vcr(ii) = VcrHi(ii);
end
end
if abs(Vvr(ii)) < VvrLo(ii) | abs(Vvr(ii)) > VvrHi(ii)
if abs(Vvr(ii)) < VvrLo(ii)
Vvr(ii) = VvrLo(ii);
elseif abs(Vvr(ii)) > VvrHi(ii)
Vvr(ii) = VvrHi(ii);
end
end
end
it = it + 1;
end

%End function to check the voltage sources limits in the UPFC

%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 transmission 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 the power flows in the UPFC controller
for ii = 1 : NUPFC
Bkk = - 1/Xcr(ii)-1/Xvr(ii);
Bmm = -1/Xcr(ii);
Bmk = 1/Xcr(ii);
Bvr = 1/Xvr(ii);
for kk = 1 : 2
A1 = VA(UPFCsend(ii))-VA(UPFCrec(ii));
A2 = VA(UPFCsend(ii))-Tcr(ii);
A3 = VA(UPFCsend(ii))-Tvr(ii);
% Computation of Conventional Terms
Pkm = VM(UPFCsend(ii))*VM(UPFCrec(ii))*Bmk*sin(A1);
Qkm = - VM(UPFCsend(ii))^2*Bkk - VM(UPFCsend(ii))...
*VM(UPFCrec(ii))*Bmk*cos(A1);
% Computation of Shunt Converters Terms
Pvrk = VM(UPFCsend(ii))*Vvr(ii)*Bvr*sin(A3);
Qvrk = - VM(UPFCsend(ii))*Vvr(ii)*Bvr*cos(A3);
if kk == 1
% Computation of Series Converters Terms
Pcrk = VM(UPFCsend(ii))*Vcr(ii)*Bmk*sin(A2);
Qcrk = - VM(UPFCsend(ii))*Vcr(ii)*Bmk*cos(A2);
%Power in bus k
Pk = Pkm + Pcrk + Pvrk;
Qk = Qkm + Qcrk + Qvrk;
UPFC_PQsend(ii) = Pk + Qk*i;
%Power in Series Converter
Pcr = Vcr(ii)*VM(UPFCsend(ii))*Bmk*sin(-A2);
Qcr = - Vcr(ii)^2*Bmm - Vcr(ii)*VM(UPFCsend(ii))*Bmk*cos(-A2);

```



```

%Power in Shunt Converter
Pvr = Vvr(ii)*VM(UPFCsend(ii))*Bvr*sin(-A3);
Qvr = Vvr(ii)^2*Bvr - Vvr(ii)*VM(UPFCsend(ii))*Bvr*cos(-A3);
PQvr(ii) = Pvr + Qvr*i;
else
% Computation of Series Converters Terms
Pcrk = VM(UPFCsend(ii))*Vcr(ii)*Bkk*sin(A2);
Qcrk = - VM(UPFCsend(ii))*Vcr(ii)*Bkk*cos(A2);
%Power in bus m
Pcal = Pkm + Pcrk;
Qcal = Qkm + Qcrk;
UPFC_PQrec(ii) = Pcal + Qcal*i;
%Power in Series Converter
Pcr = Pcr + Vcr(ii)*VM(UPFCsend(ii))*Bkk*sin(-A2);
Qcr = Qcr - VM(UPFCsend(ii))*Vcr(ii)*Bkk*cos(-A2);
PQcr(ii) = Pcr + Qcr*i;
end
send = UPFCsend(ii);
UPFCsend(ii) = UPFCrec(ii);
UPFCrec(ii) = send;
Beq = Bmm;
Bmm = Bkk;
Bkk = Beq;
end
end

```