UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION
INSTITUE OF SCIENCE AND TECHNOLOGY

IMPROVEMENT OF REAL AND REACTIVE POWER CONTROL BY PUTTING UNIFIED POWER FLOW CONTROLLERS (UPFC) IN THE OPTIMAL LOCATIONS OF TRANSMISSION LINES

MASTER THESIS

Mohammed Talib GHALIB

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN
ELECTRICAL AND ELECTRONICS ENGINEERING

ANKARA, 2017

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Supervisor: Prof. Dr. Doğan ÇALIKOĞLU

Mohammed Talib Ghalib, having student number 1406030021 and enrolled in the Master Program at the Institute of Science and Technology at the University of Turkish Aeronautical Association, after meeting all of the required conditions contained in the related regulations, has successfully accomplished, in front of the jury, the presentation of the thesis prepared with the title of: Improvement Of Real And Reactive Power Control By Putting Unified Power Flow Controllers (UPFC) In The Optimal Locations Of Transmission Lines.

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Thesis Defense Date: 09 October 2017

STATEMENT OF NON-PLAGIARISM PAGE

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09.10.2017
Mohammed Talib GHALIB

ACKNOWLEDGEMENTS

I would first like to thank my thesis advisor, Prof. Dr. Doğan ÇALIKOĞLU of the Electrical and Electronic Engineering Department at Turkish Aeronautical Association University, without whose helpful advice, valuable comments and guidance, this thesis would not have been completed. His door was always open for me whenever I needed his help. To those who lighted up my way through darkness, to those who made me what I am today and yet did not have the opportunity to see what a great man he left behind, my dear father – God bless his soul. I would like to express my deepest gratitude to my mother, brother and sister – God bless you all. I wish them many years ahead by my side. Finally, I would especially like to thank my family for their patience and encouragement – God bless them. Finally, many thanks to the committee discussion to attend their.

October 2017 Mohammed Talib GHALIB

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LIST OF ABBREVIATIONS

FACTS : Flexible AC transmission system.
SVC : Static Var Compensator.
STATCOM : Static Synchronous Compensator.
TCSC : Thyristor controlled series compensator.
SSSC : Static synchronous series compensator.
UPFC : Unified Power Flow Controller.
V_S : Sending end voltage.
V_R : Receiving end voltage.
V_{pq} : Series injected voltage.
X_L : Reactance of the AC system.
n : Voltage ratio.
n_{ref} : Boosting up or steeping down of the voltage.
V_B : Base voltage of the AC system.
S_B : Base power of the AC system.
V_d : D.C voltage.
I_d : D.C current.
P : Real Power in p.u
Q : Reactive Power in p.u
m_1, m_2 : Pulse width modulation parameters.
PMW : Pulse width modulation.
V_1, V_2 : Inverter AC side voltages in p.u
Θ_1, Θ_2 : Phase angles of V_1 and V_2.
φ_1, φ_2 : Firing angles of converters.
Dmp – sig : Damping signal.
Θ_S : Phase angle for sending voltage.
Θ_R : Phase angle for receiving voltage.
W_i : Weighting angle.
T.L : Transmission lines.
X_{t1} : Reactance of shunt transformer.
X_{t2} : Reactance of series transformer.
$\dot{E}_G$: Generator internal voltage.
$\dot{V}_U$: AC terminal bus voltage.
$\dot{I}_U$: UPFC current injecting to the AC network.
r_s : stator winding resistance.
X_d' : transient reactance for d- axis.
X_q' : transient reactance for q- axis.
E_q' : transient voltage for q- axis.
E_d' : transient voltage for d- axis.
T_{do}' : d- axis open circuit transient time constant.
T_{qo}' : q- axis open circuit transient time constant.

E_f : Field voltage.
Mm : Mechanical Torque.
Te : Electrical Torque.
D : Damping coefficient.
H : Per unit inertia constant.
CSI : Contingency Severity Index.
PSO : Particle Swarm Optimization.
GA : Genetic Algorithm.
P_{best} , G_{best} : Local best and Global best.

ABSTRACT

IMPROVEMENT OF REAL AND REACTIVE POWER CONTROL BY PUTTING UNIFIED POWER FLOW CONTROLLERS (UPFC) IN THE OPTIMAL LOCATIONS OF TRANSMISSION LINES

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October 2017, 58 pages

In this thesis, the objective of the work is to improve the real and reactive power control by placement of a unified power flow controller (UPFC) in the optimal locations of transmission lines. The MATLAB/ SIMULINK environment is utilized in this work for verifying the improvement of real and reactive power through transmission line systems of a 500 kv. The optimal locations of the UPFC device are specified based on Particle Swarm Optimization (PSO) algorithm which is an effective method used for determining the optimal location, size and number of UPFC devices in a power system network to mitigate the congestion when recognized in most of critical lines and to enhance voltage security in critical buses. The proposed technique is implemented on a 24- bus power system.

So, in this thesis the performance of the UPFC is investigated to improve real power and reactive power control in the transmission lines. The associated results obtained in this thesis strengthen the earlier results for the improvement with and without using a Fuzzy Logic controller, and also PSO algorithm for the allocation of UPFC devices to relieve congestion and enhance voltage security of the transmission power lines.

Keywords: FACTS, Unified Power Flow Controller (UPFC), Voltage security, Congestion alleviation, Particle Swarm Optimization (PSO), power flow controller, Fuzzy Logic controller.

ÖZET

İLETIM HATLARININ OPTIMAL YERLERINE BIRLEŞTIRILMIŞ GÜÇ AKIŞI KONTROLÖRLERINI (UPFC) KESKEN GERÇEK VE REAKTIF GÜÇ KONTROLÜNÜN GELIŞTIRILMESI

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Ekim 2017, 58 sayfa

Bu tez çalışmasının amacı, iletim hatlarının en uygun yerlerinde birleştirilmiş bir güç akışı denetleyicisi (UPFC) yerleştirerek gerçek ve reaktif güç kontrolünün iyileştirilmesidir. MATLAB / SIMULINK ortamı, 500 kv'lik bir iletim hattı sistemi vasıtasıyla gerçek ve reaktif gücün iyileştirilmesini doğrulamak için bu tezde kullanılmıştır. UPFC cihazının en uygun yerleri, bu tezde, güç sistem ağında yer alan UPFC cihazlarının sayısının ve sayısının belirlenmesi için etkili bir yöntem olan Parçacık Sürüsü Optimizasyonu (PSO) algoritmasına dayanılarak belirlenmiştir. Bu yöntem, tıkanıklığın azaltılması için kritik hatların çoğunda tanınır ve kritik otobüslerde voltaj güvenliğini artırır. Önerilen teknik 24 veriyolu güç sisteminde uygulanmaktadır.

Bu nedenle, bu tezde, iletim hatlarında gerçek güç ve reaktif güç kontrolünü iyileştirmek için UPFC'nin performansı araştırılmış ve bu tezde elde edilen önemli sonuçlar, Bulanık Mantık denetleyicisi kullanan ve kullanmadan önceki iyileştirme sonuçlarını güçlendirmiş ve aynı zamanda PSO algoritması için tıkanıklığı gidermek ve iletim güç hatlarının gerilim güvenliğini arttırmak için UPFC cihazlarının tahsisi.

Anahtar Kelimeler: GERÇEKLER, UPFC, Gerilim güvenliği, Tıkanıklığın hafifletilmesi, Parçacık Swarm Optimizasyonu (PSO), güç akışı denetleyicisi, Bulanık Mantık denetleyicisi.

CHAPTER ONE

INTRODUCTION

1.1 Presentation of the Work

In this work, an investigation is performed on various approaches to improve power quality control in transmission lines. In particular, optimal location of UPFC for enhancing voltage security and relieving congestion using Particle Swarm Optimization algorithm to examine and test the work. A recent method called Unified Power Flow Controller (UPFC) is used in this work, which is one of modern power electronic converters and controllers, and it is one of the complex and advanced Flexible AC Transmission Systems (FACTS) devices. Also Particle Swarm Optimization (PSO) method is used in this work to determine optimal location for UPFC in the transmission lines, which is the main motivation behind this work.

Thus, the results achieved from this work show that the UPFC device has an excellent capability and quick for controlling real power and reactive power flow through the transmission lines with and without using Fuzzy Logic controller. The significant results obtained indicate the effectiveness of PSO algorithm for the allocation of UPFC device to relieve congestion and enhance voltage security of the transmission power lines. So, we benefit from this control the stability of electrical power systems network.

The modern society depends on the electrical power so much, therefore consequences of a blackout can be very severe. The reliability of the electrical power transmission system is of great concern [1].

There are many problems which affect significantly on the performance of the AC transmission lines such as (choice of voltage levels and design of the electrical network). So, these problems can cause instability of the network. In the past, traditional capacitor solved these problems, but this method is not suitable for smart grids and modern systems.

While the demand for electrical power continue to grow, it is becoming more difficult for utility companies to approval to build new transmission facilities because of the increasing public awareness of environmental issues of. Therefore, there is a trend to load transmission facilities to their upper limits, which increases the stresses of power systems [1].

Therefore, it was the invention of a new concept and method known as the Unified Power Flow Controller (UPFC) to improve real and reactive power control in transmission lines, which is one of modern power electronic converters and controllers, and it is one of the complex and advanced Flexible AC Transmission Systems (FACTS) devices.

All these features of modern power systems demand more coordinated and sophisticated control of the power systems from the point of view of both operation optimization and system security [2].

The control of the AC power system mainly falls into these objectives: (security, quality, and economic benefits). However, traditional control is limited to speed governor control and excitation control in generators. The control was mainly realized in the rest of the power transmission systems by slow responding facilities such as mechanical taps of transformers. Because they are not fast enough to deal with the dynamics of the system, the dynamic security problems become the bottleneck from the safe running of the power system. The limits of power transfer have to be imposed so that the system can be operated safely under different types of emergency which led to severe economic losses.

In recent years, the advancement in higher power semiconductor devices has stimulated development of a modern implementation in the energy system well define as the "flexible alternating current transmission systems" (FACTS) [3].

FACT is known by the IEEE as "A.C transmission systems combines between power electronic and another static controller to rise power transfer ability and to enhance controllability of the power system". In other words, the major aims of an implementation of the FACTS device are to enhance the benefit of existing transmission facilities and to provide direct control of energy flux over the specified transmission routations for a more economical operation.

FACTS controllers consist of fast responding power electronic devices which enable a response that is quick, flexible and accurate control of the power system dynamics over the rest of the transmission systems.

Thus, the FACTS device is considered to be a revolutionary step and milestone of power engineering. The FACTS device consists of equipment that uses high power electronics with its real time operating control [4, 5].

1.2 Unified Power Flow Controller (UPFC)

1.2.1 The Importance of (UPFC) and Its Applications

The UPFC combines the concept of a synchronous static compensator (STATCOM) and a static synchronous series compensator (SSSC). It contains of two voltage source converters connected back to back through a common DC link having capacitor. This link provides a path to exchange real power between two inverters. One inverter is in parallel and the other is in series with the transmission line.

The shunt inverter injects current into the transmission line via a shunt transformer. The inverter 1 (in shunt) is used primarily to provide the active power requested of the inverter 2 (in series) through a common DC link.

The inverter 2 injects a voltage at the fundamental frequency with the magnitude voltage controller and phase angle to the AC system terminal via a series transformer to control the real power and reactive power flows through the T.L. The injection voltage and the line current determine the real and reactive power [6].

A UPFC device is able to control all parameters like (voltage magnitudes, phase angles and impedances) individually and simultaneously and also it maintains the voltage and reduces the severity of any changes. Therefore, it is suitable for several applications which require effective stability of power flow control and improvement of dynamical stability and transience [7, 8].

1.2.2 The Types of (UPFC) Device and Its Various Properties

Generally, the modern UPFC device is one of the types of FACTS devices which are used in electrical power systems. There are two types of this device, the first one is Unified power flow controller (UPFC), and in addition to the first one there is a second type knows as Distributed of Unified Power Flow Control (D-UPFC).

For the first type, which was included in a research study has many applications in power transmission lines, such as:

1. Medium voltage transmission lines.
2. High voltage transmission lines.
3. Ultra voltage transmission lines.

The UPFC device able is to provide simultaneous control of the magnitude of voltage, in an adaptive fashion and the real and reactive power flows. Therefore, it has various properties, like [8]:

1. The ability to control phase angle, line impedance, and voltage in the electrical power system grid.
2. The enhancement of power transfer capability.
3. The capability to decreasing of cost generation.
4. The capability to improvement of stability and security.
5. The application of control of power flow, and control of loop flow.

1.3 Literature Review

There are several factors like economical and operational which make energy systems to benefit maximum percentage of their transmission ability and then work near to stabilizer limit with lesser margins. The presence of transport systems constraints dictates the amount limit of the electrical energy that it is moved between two points on the electrical network. Practically, it is impossible to submit all binary and multi contracts in complete and supply all requests at less pool cost because it could lead to a violation of operational restrictions like voltage profiles and line increase loads (congestion) [9].

Flexible Alternating Current Transmission System (FACTS) controllers are been utilizes increasingly to supply control of power flux and voltage in several uses. With power fluxes in heavy lines load, producing increased in load ability, improved stability of the grid, low system loss, reduced production cost and attention to contractual demands.

It is very important to ensure the placement for put these devices due to their high costs. UPFC among whole FACTS devices supplies a strong tool for the cost active uses of individual T.L. by easily and independently controlling both the real and reactive power flux over transmission lines [10].

UPFC can improve network voltage security and it is capable of regulating the power flux of a T.L. Therefore, it is expected that a UPFC can be used to solve complex problems for the management of congestion, transport grid, particularly under the environmental conditions of transmission open access.

Many works have been performed previously for mitigate the congestion and manage of power transport grids in deregulated and traditional environment [11, 12]. Therefore, some of this approach depends upon an optimum energy re-schedule of the generator.

In [13], an optimum based on the methodology for the location of FACTS devices, like SVC, TCSC can be used to alleviate congestion in the power T.L; however, increasing the voltage level and static margin security of the power system given.

In [14], a zonal/cluster-found for the manage congestion approaches has been suggested. In this way, generators in more sensitive areas, with a powerful and non uniform distributed of sensitive index, are specified for re-schedule their active power production for the management of congestion.

In reference [15], an optimum based method for decreasing the number of sharing generators and optimally re-schedules of their outputs; however, congestion management in a gathering of lower re-scheduling cost has been proposed. These references supply a technique to congestional management problems so as to avoid offline transmission ability limit in relation to stability. Therefore, this limit on line power flow is changed by an optimum power flux related to constraints in order to ascertain the security of voltage.

In [12], an approach for mitigation of the grid increase loads under de-regulation environmental has been presented. From this path, the control which is used for increase loads mitigation, is active power generated and re-schedule depending on concept of proportional electrical distance.

The contribution of every generator for a special increase loaded line is first specified, then based on concept of proportional electric distance the demanded proportions of generations for the demanded increase load mitigating is got, therefore the system become less losses in transmission and more stabilization margins with and stressful environment, voltage instability and power system congestion may be established as main threats that can face the operators of the system with them. The system operator must ascertain the operating of transportation system within acceptable operative boundary.

1.4 The Main Aspects of the Work and its Importance (the Contributions Involved)

The importance of this work due to the simulation results, where we managed to obtain quick responses of the UPFC activated in controlling active and reactive power flows over a T.L. and the steady state having been investigated. Moreover, we managed to recognize the most critical lines and the most critical buses and identify optimal locations for installation of the UPFC device in the network by using PSO method. This will be discussed in more detail in later sections.

In chapter 2, the power frequency model of the UPFC for power system dynamic analysis will represent. The major and supplementary controller strategies for UPFC are also discussed.

In chapter 3, is devoted to determining a versatile interface for integrating the UPFC into a power system dynamic analysis program. Computer simulation results with MATLAB/SIMULINK for the UPFC are given.

In chapter 4, overview of the recently applied optimization algorithms. Problem formulation (in terms of optimization) is discussed. Details for chosen Swarm of Particle Optimization (PSO) algorithm to identify optimum location of the UPFC.

In chapter 5, results of the optimal location. In chapter 6, conclusion for research work.

CHAPTER TWO

MATHEMATICAL MODEL AND CONTROL STRATEGIES

2.1 Power Frequency Model of the UPFC

Figure 2.1 present the schematic drawing for the UPFC, so X_{t1}, n_1 and X_{t2}, n_2 are the reactance and voltage ratio of the series and shunt transformers successively. In the UPFC model all the variables used are indicate in the figure with partial lines appearing phasors [16, 17].

The per unit system with its variables which is used by the AC system can be calculated according to the system part S_B and V_B, but the direct current variables can express it in Standard International units.

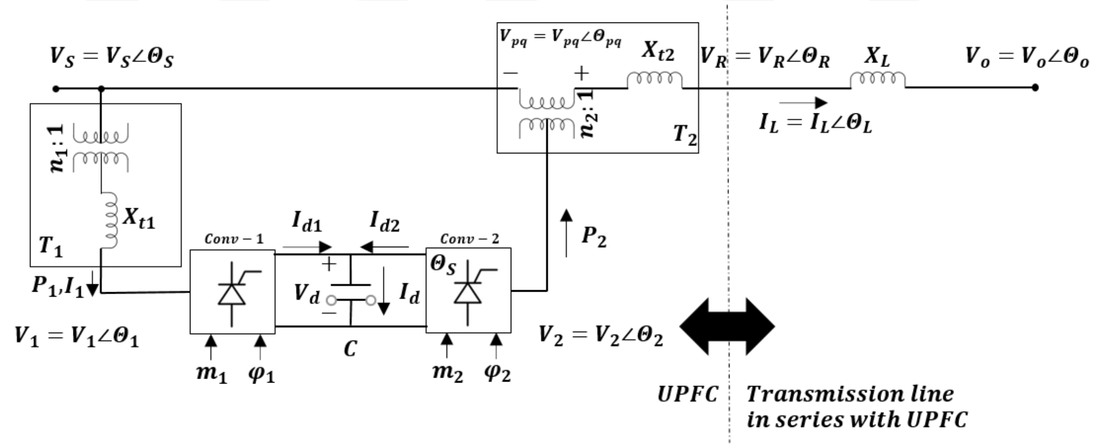


Figure 2.1: Show the transmission line (T.L) with UPFC installed [17].

For the neglected harmonics, the DC currents I_{d1} and I_{d2} has the following relation with the capacitor current and voltage [16, 17]:

$$\begin{gathered} I_d = C\frac{dV_d}{dt} \\ I_d = I_{d1} + I_{d2} \end{gathered} \tag{2.1}$$

Assuming that the inverters are lossless, then the real power in per unit exchange with the AC system will be:

$$\begin{cases} P_1 = V_d\, I_{d1}/S_B \\ P_2 = -\, V_d\, I_{d2}/S_B \end{cases} \tag{2.2}$$

From equations (2.1) and (2.2), we have:-

$$CV_d \frac{dV_d}{dt} = (P_1 - P_2)S_B \tag{2.3}$$

Otherwise, we can calculate (P1 & P2) from:-

$$\begin{cases} P_1 = R_e\left(\dot{V}_1 \dot{I}_1^*\right) = R_e\left[\dot{V}_1 \left(\dfrac{n_1\dot{V}_S - \dot{V}_1}{jX_{t1}}\right) *\right] \\ P_2 = R_e\left(\dot{V}_{pq} \dot{I}_L^*\right) = R_e\left[\dot{V}_{pq} \left(\dfrac{\dot{V}_S + \dot{V}_{pq} - \dot{V}_R}{jX_{t2}}\right) *\right] \end{cases} \tag{2.4}$$

While the PWM control technique is adopted, the relationship between the direct current side and the alternating current side voltage of the inverters are:-

$$\begin{cases} V_1 = m_1\, V_d/V_B \\ V_2 = m_2\; V_d/V_B \end{cases} \tag{2.5}$$

Where the points m_1 & m_2 is the PWM control parameters corresponding to the demand converter AC part voltages V_1 & V_2 sequentially. V_1 & V_2 are in (p.u.), and V_B is the alternating current base voltage system.

The phase angles of V_1 and V_2 are indicated as Θ_1 & Θ_2 sequentially. They are regulated by the firing angle φ_1 & φ_2 of the two inverters and have the relationship with respect to the phase angle of $\dot{V}_S$ is as following:

$$\begin{cases} \theta_1 = \theta_S - \varphi_1 \\ \theta_2 = \theta_S - \varphi_2 \end{cases} \tag{2.6}$$

Taking series transformer ratio into consideration, we have:-

$$\begin{cases} V_1 = m_1 \; V_d/V_B \\ \theta_1 = \theta_s - \varphi_1 \\ V_{pq} = m_2 \, V_d/V_B/n_2 \\ \theta_{pq} = \theta_s - \varphi_2 \end{cases} \tag{2.7}$$

Equations (2.3) and (2.7) assign the power frequency model of UPFC is used for power system stability study. However some of the papers do not considered the capacitor dynamic for simplicity reasons, so the result may be inaccurate [16, 17].

The power exchanges in practice from inverter 1 to inverter 2 continuously through the DC link capacitor. The capacitor voltage be different because of charging and discharging of the current. A battery energy storage system for useful applications is basically too large uninterruptible power supply.

Then it connected DC battery to the AC network through a voltage source inverter. The storage system behaves like a synchronous machine which is capable of exchanging both the reactive power and active power with the network.

So battery energy storage for utility applications has been used for leveling the load and as spinning reserve on insulated grids.

In this model, the dynamic of the DC link capacitor is included, so that the result is more reliable and accurate. The power can freely flow in any directions between two inverters [18].

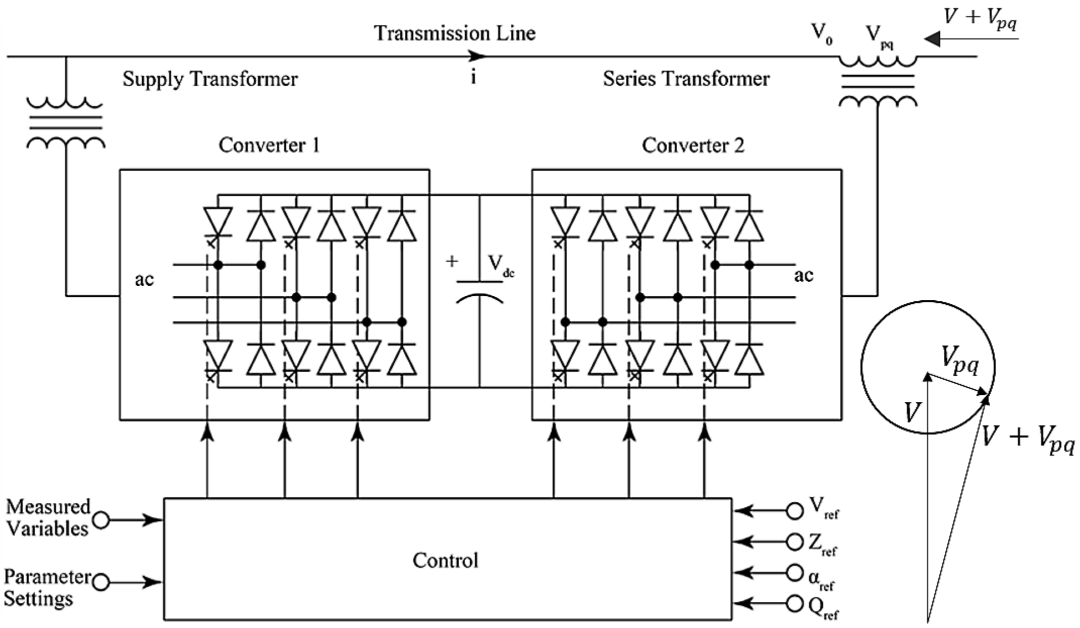


Figure 2.2: Basic circuit arrangement of UPFC [8].

2.2 Main Control of the UPFC

2.2.1 Shunt Element Control

The UPFC major control consists the series and shunt element controls [19, 17]. A block diagrams for the shunt element control are be presented in figure 2.3: (a) constant DC link capacitor voltage controller and (b) constant UPFC terminal bus voltage controller.

dmp - sig is the damping signal from the supplementary controller, that it will be discussed in later section.

The synchronous voltage source acts as like to the synchronous ideal machine which generate an equilibrium group of sinusoidal voltages with phase angle and quickly controllable amplitude. The reactive power absorbs or generated by the system is controlled by changing the amplitude of inverter voltage. If the amplitude of the output voltage is greater than the voltage system, so the inverter gives reactive power to AC network (capacitive mode).

And vice versa, the inverter absorbs reactive power from the AC network when the output voltage amplitude is smaller than the voltage system. Practical applications of the shunt are prevention of voltage collapse and voltage support, damping of power oscillation and improvement of transient stability.

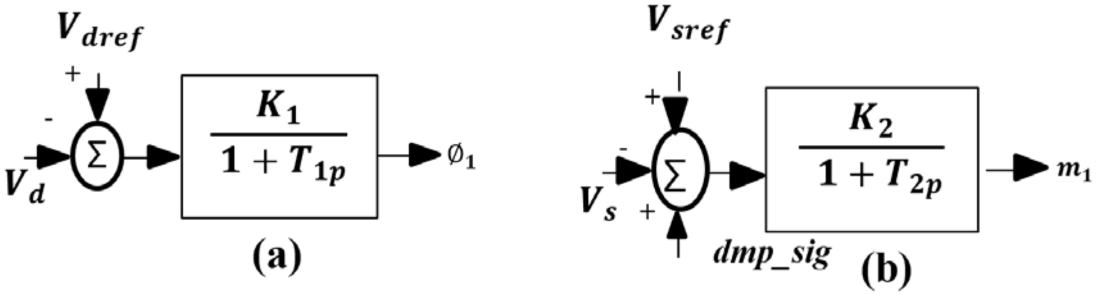


Figure 2.3: Show the shunt element control for UPFC [17].

A. Constant DC Link Capacitor Voltage Control:

In the direct current the voltage capacitor is controlled with the firing angle φ_1 of inverter one. The active power interchange between the inverter and AC network is determined by the phase angle difference between Vs and V_1 (inverter 1 output voltage). When φ_1 is positive (V_1 lagging Vs), the real power flows from the network to the capacitor through inverter (1) so as to charge up the capacitor [19, 17].

And vice versa, inverter (1) pushes back the real power from capacitor to the network so as to discharge the capacitor if φ_1 is negative. By this mechanism, the voltage of the DC link capacitor is kept as a dynamic fixed.

B. Constant UPFC Terminal Bus Voltage Control:

The UPFC terminal bus voltage can be kept constant by controlling the PWM Parameter m_1 of the inverter 1. According to:-

$$Q_1 = \frac{V_S^2 - V_S V_1 \cos(\theta_S - \theta_1)}{X_1} \tag{2.8}$$

The reactive power change between converter 1 and the alternating current network is regulated by the V_1 which is directly proportional to m_1 equation (2.5). The UPFC terminal bus voltage control can then be maintained constant through shunt reactive power compensation.

2.2.2 Series Element Control

The phase angle of the series controllable voltage V_{pq} , as it can be any value in the range of $(0,2\pi)$ with a magnitude being variable between the zero and the limited maximum value *V*pq, max, which makes the UPFC realize every basic control functions by adding suitable voltage phasor V_{pq} in series to the T.L so as for controlling. In figure (2.4), we can see that the series inverter output voltage compensator $\dot{V}_{pq} = V_{pq}\angle \Theta pq$ ($\Theta_{pq} = \Theta_2 = \Theta_S - \varphi_2$) it can be decomposed as a Vp and Vq.

In this implementation, a voltage source converter may be produces suitable voltage on the fundamental frequency of AC system, in series with the line to cancel partly the drop voltage developed via inductive line impedance by the basis component from the line current [19, 17].

The output voltage lags behind the line current (90^0) and the voltage injection in series with line current.

The former is vertical to $\dot{V}_s$ and according to:-

$$P = \frac{V_S V_R}{X}\sin(\theta_S - \theta_R) \tag{2.9}$$

The addition of the perpendicular component to V_R would vary the difference between the phase angle Θ_S and Θ_R .Thus, V_P has the strong impact on the real power flow.

Otherwise, according to:

$$Q = \frac{V_S^2 - V_S V_R \cos(\theta_S - \theta_R)}{X} \tag{2.10}$$

Since, the difference between Θ_R and Θ_S is small:

$$cos(\theta_S - \theta_R) \approx 1 \tag{2.11}$$

Hence,

$$Q \approx \frac{V_S(V_S - V_R)}{X} \tag{2.12}$$

As V_q is in phase with the $\dot{Vs}$ and, according to the equation (2.12), it has significant effects on the reactive power flow.

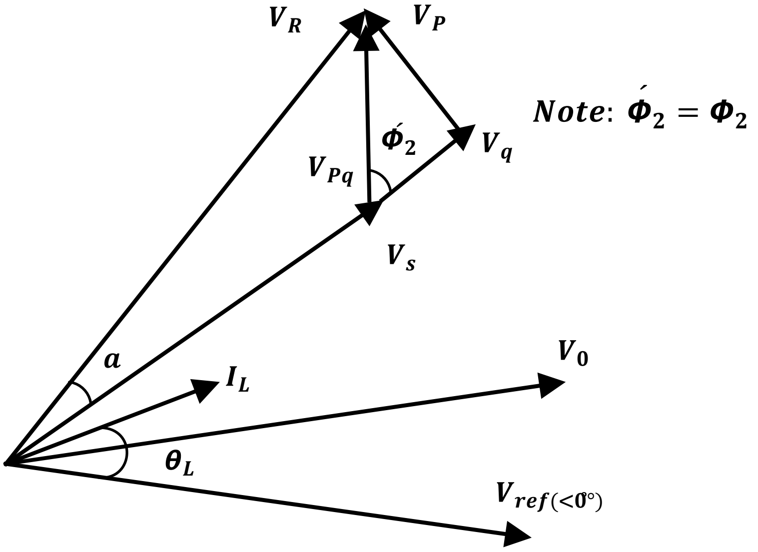


Figure 2.4: Show the phasor diagram of UPFC series voltage injected [17].

The series element controls are the fundamental of the UPFC [16, 17]. They are:

1. Constant real and reactive power flow control.
2. Constant series compensator control.
3. Transformer like controller.
4. Phase shifter like controller.

For each control, a desired of V_q and V_p may be obtained from the control system. Four pairs of V_q and V_p can be joined with a final pair V_q and V_p via weight factors. After crossing from the smoothing block, a final pair of V_q and V_p can be turned into the corresponding φ_2 & m_2 for firing angle controller and PWM of converter 2 (figure 2.5).

It is excepted to use optimal theory for generating the time –varying weighting factor W_i, the UPFC could be achieved it's the good steady state and dynamical performance. Only crispy W_i (o or 1) and the simplify 1st order model which used for the four fundamental controllers of the UPFC.

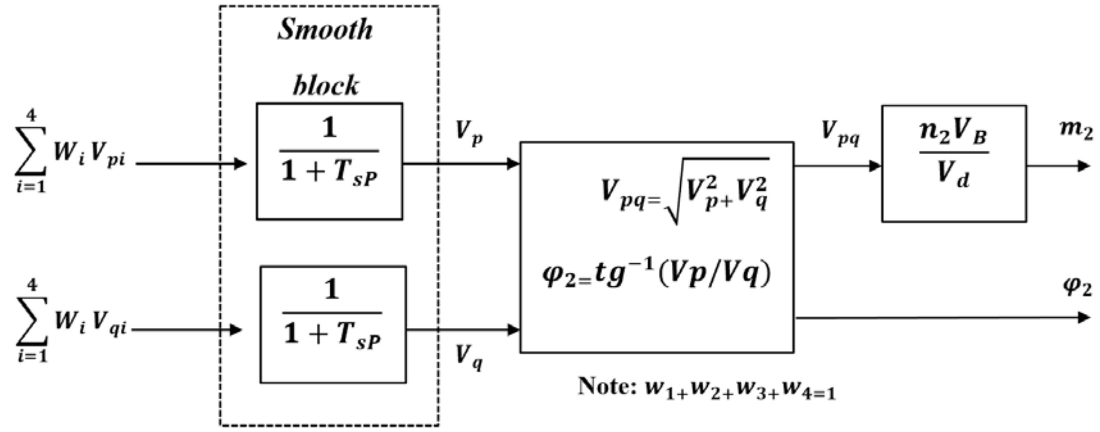


Figure 2.5: Block diagram of control parameter generation of inverter 2 [17].

A. Constant Active and Reactive Power Flow Control:

Figure 2.6 present the block diagram of the constant active and reactive power flows control. We have clearly discussed in previous section, there are direct relationships between reactive and real power flux over T.L and the (V_q, V_p).

Then, we can arrange a designated amount of reactive and real power flow (Q_{Lref} & P_{Lref}) by controlling proper of V_q and V_p.

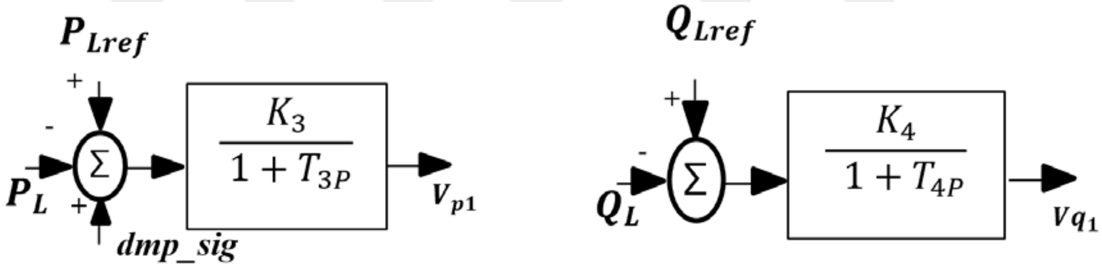


Figure 2.6: Block diagram of constant active & reactive power flow controller [17].

B. Constant Series Compensation Control:

The inverter 2 inject a series voltage (Vpq) of the UPFC, perpendicular to the A.C line current via series transformer. Then the voltage source works at the basic frequency as a series condenser [16, 17].

Figure 2.7 present the control block diagram of the constant series compensation control. In performance, as we want the voltage lags behind the line current 90^0, so it can be derived from the phasor diagram (figure 2.4) that:

$$\varphi_2{}'_{ref} = \pi / 2 + \theta_L - \theta_S \tag{2.13}$$

$V_{pqref} = K_{ref} X_L I_L$ it is calculating accordance to the measurements of true time of (Θ_L-Θ_S) and I_L.K_{ref} ($1 \geq K_{ref} \geq 0$) determines the degree of compensation.

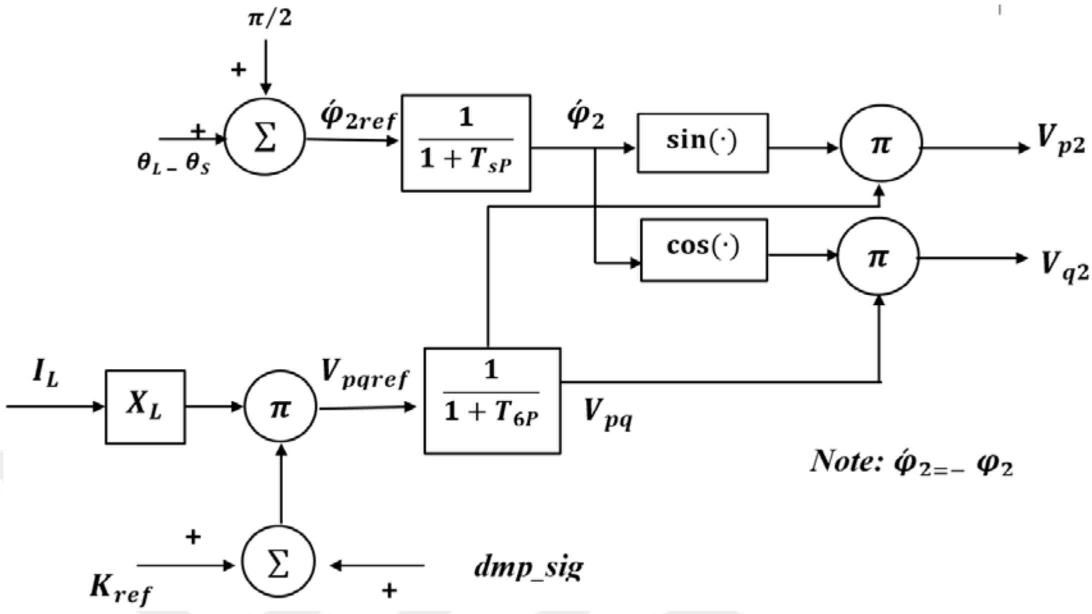


Figure 2.7: Block diagram of constant series compensation control [17].

C. Transformer like Controller:

The terminal voltage of the UPFC is regulated by the transformer like control.

Its effect is similar to a transformer tap changer by the continuous tap ratio. Mechanical tap changers for the transformer have been used in the power industry for several years to regulate the magnitude of the output voltage [16, 17].

If the mechanical tap changer is changed by the thyristor switches, the output voltage as it can be very fast adjusted to compensate for transient voltage changes on the input side. The high speed tap changer is capable to insulate the loads from exposure to system voltage transients and enhance transient stability via modulating the terminal voltage.

The control block diagram in the figure 2.8 is shown. The ratio of the sending and receiving end voltages ($n = V_S/V_R$) is calculating according to the measurement of true time. The demand value for stepping down or boosting up of the voltage is represented by n_{ref}.

Any mismatch between n_{ref} *and* n will be eliminated with the superimposing a series voltage V_{pq} (positive or negative) in phase with the V_s.

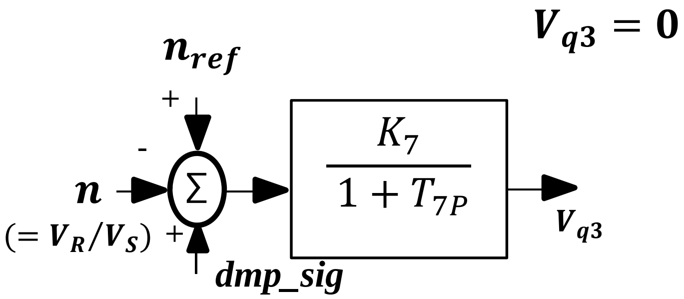


Figure 2.8: Block diagram of transform like controller [17].

D. Phase Shifter Like Control:

UPFC effect is similar to a phase shifting transformer when its operates in this control strategy. Modifying the voltage phase angle between sending end and receiving end voltages can control the power flow over transmission line. The phase shifter angle accomplished this through specially connected mechanical regulating transformers to inset a variable quadrature voltage in series with the power T.L.

The phase shifter angle as it is quickly changed by replacing the mechanical tap changer of the transformer with the thyristor switching network. By this way, it can be employed to change transient power flow during outages and disturbances [18].

Figure 2.9 present the block diagram of this control. The difference between the phase angle of the sending end and the receiving end voltages ($\alpha = \Theta_R - \Theta_S$) is calculated according to real time measurement of the variables.

During the Performance, the desired Vq is assumed in order to be zero so only the perpendicular component Vp is generated for phase shifting.

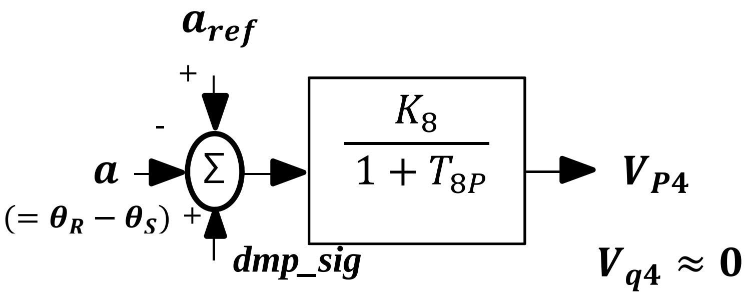


Figure 2.9: Block diagram of phase shifter like control [17].

2.3 Supplementary Control of the UPFC

The supplemental control for UPFC device is improved the power oscillation damping on a balance lines during the subsequent swings. For improved damping control, electronic switching extends the function of the braking resistors by designed to improve the stability limits of the synchronous generator by dissipating energy during the faults of the system. They are connected to the AC system through the circuit breaker.

Figure 2.10 shown the block diagram of transport function of the supplementary control is very similar to the power system stabilizer (PSS). The input signal used in this figure is the balance line active power flow P_L [17].

The supplemental control is applied to the statcom element control through voltage modulation (figure 2.3(b)) or is applied to the series dement through power modulation (figure 2.6) or to the series compensation degree modulation (figure 2.7) or voltage modulation (figure 2.8) or phase-shift-angle modulation (figure 2.9), depending according to the control strategy adopted.

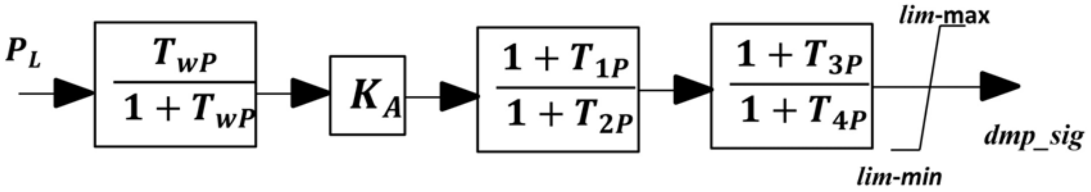


Figure 2.10: Block diagram of supplementary control of UPFC [17].

2.4 Summary

The frequency power model of the UPFC can be drawn by the DC link capacitor dynamical including. The structure for the UPFC is divided into two main parts, (i.e. the series element control and the shunt element control).

For series element control, four principal control strategies are presented, such as power flow line controller, series compensator controller, transformer like controller, and in addition phase shift like controller.

For shunt element the control strategy keeps the UPFC terminal alternating current bus voltage (the UPFC terminal bus voltage control can then be maintained constant through parallel reactive power compensation), and direct current link voltage capacitor constant (the active power change between inverter and AC network is determined by the phase angle difference between Vs and V_1) .

The supplemental control is applying to the UPFC for damping the low frequency oscillation along the balance T.L.

The power exchange between two inverters via DC link capacitor. The capacitor voltage be different because of charging and discharging of the current.

CHAPTER THREE

ENCORPORATION OF THE UPFC TO POWER SYSTEM DYNAMIC ANALYSIS PROGRAM

To study the mathematical model of a synchronous machine differs from very from elementary classical model to more detail models. Usually, a mathematical model consists of a set of algebraic and/or differential equation that describes the behavior of power systems via quantitative representation. More than one model is available in order to be used in the analyses.

More detailed representations provide more accurate results; however, they are more complex and require longer computation time. Normally, the selection of a specific model is depending primarily on the nature and the purpose of the study [20, 21].

3.1 Modeling for Other Elements Power System

3.1.1 Synchronous Generator Model

The sixth order sub transient model for the synchronous generator model can be used for computer simulation. As it can be derived from the Park's equation and its flux linkage equation with the assump as following [20, 21]:

1) The transients of the *d, q* windings are neglected (i.e. $\frac{d\psi_d}{dt} = \frac{d\psi_q}{dt} = 0$)
2) In stator voltage equation, assume that $\omega \approx 1$

A q-damper winding is added on the q-axis so as to consider the damping effect of the solid rotor along the q-axis. (E_x' , E'_q , E_d'' , E_q'' , ω and δ) are the state variables used in the model. The corresponding sixth order model is:

Stator and rotor winding voltage equations as follows:

$$\begin{gathered}
U_d = E_d'' + x_q'' i_q - r_a i_d \\
U_q = E_q'' - x_d'' i_d - r_a i_q \\
T_{do}' pE_q' \approx E_f - x_{dr}E_q'' + x_{dr}E_q' - E_q' \\
T_{qo}' pE_d' \approx -x_{qr}E_d'' + x_{qr}E_d' - E_d' \\
T_{do}'' pE_q'' \approx -E_q'' + E_q' - (x_d' - x_d'')i_d \\
T_{qo}'' pE_d'' \approx -E_d'' + E_d' + (x_q' - x_q'')i_q
\end{gathered} \tag{3.1}$$

Rotor motion equation:

$$\begin{gathered}
2H\,(d\omega/dt) = M_m - \left[E_q'' i_q + E_d'' i_d - (X_d'' - X_q'')i_d i_q\right] - D(\omega - 1) \\
d\delta/dt = \omega - 1
\end{gathered} \tag{3.2}$$

3.1.2 Excitation System Model

The fundamental work of the excitation model is to adjusting and providing the D.C current to the field winding synchronous machine automatically in order to keeping the terminal voltage for generator. Furthermore, the excitation system model provides protective and control functions essential to perform satisfactory of the energy systems with regulating the field voltage and hence the current field.

The functions of the control are including an enhancement of the systems stability and regulating of the voltages and the reactive power flow [20, 21].

An excitation system model as it should be able to responding quickly to an upset so as to improve the transient stability, and modulating the generator field to boost the stability of small signal. The protective functions assure that the ability limits of the excitation system and the synchronous machine, and another equipment are not exceeded.

Different types of excitation system are available while the DC1 (DC comutator kind exciter with internally acting voltage) exciter model as presented in the fig. 3.1 is available in this figure. The phase compensation block of voltage regulator is neglected for the simplicity reason. So, it is a third order model consisting of the following component as follows:

i.) Voltage regulator $\{\frac{KA}{1+STA}\}$

ii.) Exciter $\{\frac{1}{sT_E}\}$ & $\{S_E + K_E\}$

iii.) Feedback $\{\frac{sK_F}{1+sT_F}\}$

On the left hand side, the first transfer function $\{\frac{1}{1+sT_R}\}$ is a simple time constant. T_R representing the regulator input filter and rectifier of the measured terminal voltage V_{TR}. The first summation point compares the regulator signal with the input and output filter, and the feedback signal is to determine the voltage mismatch input to the regulator amplifier.

The second transfer function representing the voltage regulator is usually modeled as one gain and one lead lag block with the inertia. However, since T_C and T_B (voltage regulator time constant) are very small, the phase compensation block is as so often neglected.

The gain K_A normally is $(20 \sim 400)$ while is tens of millisecond to hundreds of milliseconds. The minimum or maximum limits of the regulator are enjoined so that the large input error signal would not result in a regulator output exceeding practical limits.

The exciter block is an inertia block with saturation. The negative feedback block has the time constant of T_F (excitement system stabilizer constant time) and the gain of K_F (excitement systems control systems stabilizer gain). During the steady state, its output is zero so that the steady state characteristic of the excitation system model is not affected [20, 21].

According to the block diagram, the corresponding quantitative representation of the excitation system model is as follows:

$$\begin{cases} T_A\, PV_R = -V_R + K_A(V_{REF} - V_{TR} - V_{FB}) \\ T_E\ PE_{fd} = -(K_E + S_E)E_{fd} + V_R \\ T_F\, PV_{FB} = -V_{FB} + \frac{K_F}{T_E}(V_R - (K_E + S_E)E_{fd}) \end{cases} \tag{3.3}$$

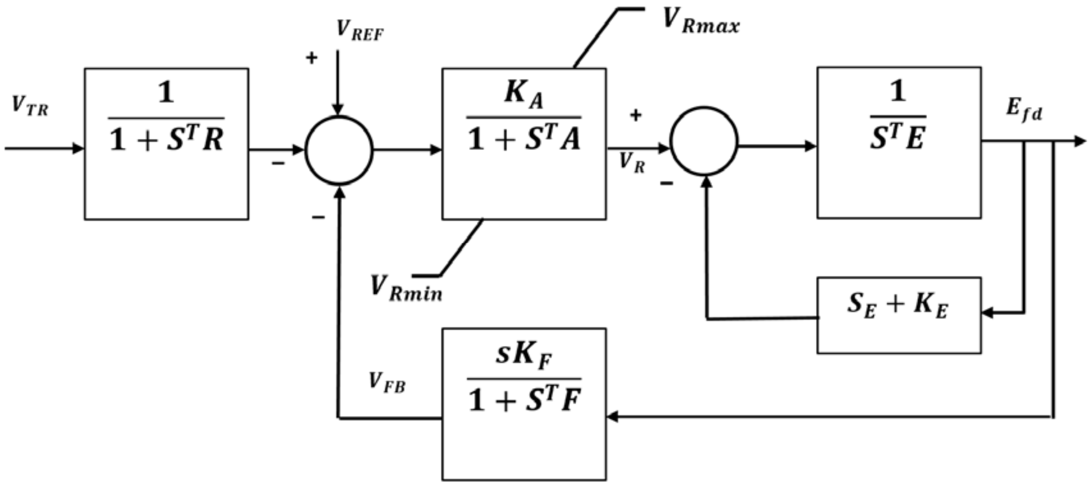
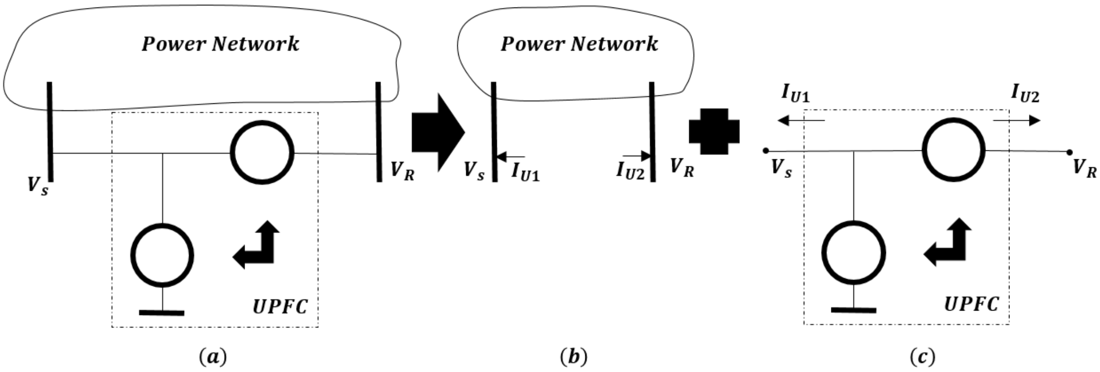


Figure 3.1: Block diagram of DC1 excitation system [20].

3.2 A Versatile Interface Between UPFC and AC Network

The model of the FACTS device has to be incorporated into the exciting power system analyses program to study its effects on wide scale energy system. Figure (3.2) present the interface calculation of the UPFC device to the AC grid which effects significantly to the transient stability analyses accuracy and velocity.

The sequential solution technique that has been applied correctly to the AC/DC interface in the AC-DC load flow power system and in transit system analyses is expanded her for the UPFC interface to the alternating current grid [17, 20].



(a) (b) (c)

Fig 3.2: Show the Interface of the UPFC device to the AC network [20].

It is assumed in the calculation of interface which the bus entry matrix had being reduces to generator interior buses with the UPFC alternating current bus terminal stayed.

In return reduces the equation of bus entry matrix is as follow:

$$\begin{bmatrix} Y_{GG} & Y_{GU} \\ Y_{UG} & Y_{UU} \end{bmatrix} \begin{bmatrix} \dot{E}_G \\ \dot{V}_U \end{bmatrix} = \begin{bmatrix} \dot{I}_G \\ \dot{I}_U \end{bmatrix} \tag{3.4}$$

Where

$\dot{E}_G$ is the generator internal voltage behind the sub transient reactance X''

$\dot{V}_U=[\dot{V}_S, \dot{V}_R]$ is the UPFC alternating current terminal bus voltage, (Fig 3.2)

$\dot{I}_G$ is the generating injected currents to the AC grid.

$\dot{I}_U = [\dot{I}_{U1}, \dot{I}_{U2}]$ is the UPFC injection current to the AC grid (Fig 3.2)

The UPFC current injections to the alternating current grid is expressed by:

$$\begin{cases} \dot{I}_{U1} = -\dfrac{n_1\dot{V}_S - \dot{V}_1}{jX_{t1}} n_1 - \dfrac{\dot{V}_S + \dot{V}_{pq} - \dot{V}_R}{jX_{t1}} \\ \dot{I}_{U1} = \dfrac{\dot{V}_S + \dot{V}_{pq} - \dot{V}_R}{jX_{t2}} \end{cases} \tag{3.5}$$

Suppose that, most the fixed variables at $t=t_{n+1}$ had been predicated in accordance with the numeric integral, and from here we will go so as for making the grid solve for the algebraic changes. The magnitude of the UPFC output voltage $\dot{V}_{pq}$ and $\dot{V}_1$ in equation (3.5) may be obtained from the regulate output and from the equation (2.7). However, their phase angles are unnamed because they are depending on the phase angle $\dot{V}_S$ and after that they must be got from the grid solution through iteration approaches [17, 20].

Substituting equation (3.5) to (3.4) and re-arrange the second part of the equation, we obtain:

$$\begin{cases} \dot{I}_{1G} + \dot{I}_{2G} + \left(Y_{SS} + Y_{RS} + \dfrac{n_1^2}{jX_{t1}}\right)\dot{V}_S + (Y_{SR} + Y_{RR})\dot{V}_R = \dfrac{n_1}{jX_{t1}}\dot{V}_1 \\ \dot{I}_{2G} \quad + \left(Y_{RS} - \dfrac{1}{jX_{t2}}\right)\dot{V}_S \quad + \left(Y_{RR} + \dfrac{1}{jX_{t2}}\right)\dot{V}_R = \dfrac{1}{jX_{t2}}\dot{V}_{pq} \end{cases} \tag{3.6}$$

Or

$$\begin{bmatrix} \left(Y_{SS} + Y_{RS} + \dfrac{n_1^2}{jX_{t1}}\right) & (Y_{SR} + Y_{RR}) \\ \left(Y_{RS} - \dfrac{1}{jX_{t2}}\right) & \left(Y_{RR} + \dfrac{1}{jX_{t2}}\right) \end{bmatrix} \begin{bmatrix} \dot{V}_S \\ \dot{V}_R \end{bmatrix} = \begin{bmatrix} \dfrac{n_1}{jX_{t1}}\dot{V}_1 - \left(\dot{I}_{1G} + \dot{I}_{2G}\right) \\ \dfrac{1}{jX_{t2}}\dot{V}_{pq} - \dot{I}_{2G} \end{bmatrix} \tag{3.7}$$

Where:

$Y_{UU} = \begin{bmatrix} Y_{SS} & Y_{SR} \\ Y_{RS} & Y_{RR} \end{bmatrix}$ and $Y_{UG}\ \dot{E}_G = \begin{bmatrix} \dot{I}_{1G} \\ \dot{I}_{2G} \end{bmatrix}$ could be calculated according to generator state. A constant matrix is defined:

$$\tilde{Y}_{UU} = \begin{bmatrix} \left(Y_{SS} + Y_{RS} + \frac{n_1^2}{jX_{t1}}\right) & (Y_{SR} + Y_{RR}) \\ \left(Y_{RS} - \frac{1}{jX_{t2}}\right) & \left(Y_{RR} + \frac{1}{jX_{t2}}\right) \end{bmatrix} \tag{3.8}$$

And a fictitious time changing the vector current:

$$\tilde{I}_U = \begin{pmatrix} \frac{n_1}{jX_{t1}}\dot{V}_1 - \left(\dot{I}_{1G} + \dot{I}_{2G}\right) \\ \frac{1}{jX_{t2}}\dot{V}_{pq} - \dot{I}_{2G} \end{pmatrix} \tag{3.9}$$

Finally, we have:

$$\tilde{Y}_{UU}\ \dot{V}_U = \tilde{I}_U \tag{3.10}$$

Equations (3.8), (3.10) as they can then be used for calculate the iterations of the UPFC, AC grid interfaces are following:

1) Step 1: estimation of initial voltages of $\dot{V}_S^{(0)}$and $\dot{V}_R^{(0)}$, they say according to the final stage and then calculated $\tilde{I}_U$ depended to equations (2.7) and (3.9).
2) Step 2: solve equation (3.10) for $\dot{V}_U$ = ($\dot{V}_S^{(1)}$, $\dot{V}_R^{(1)}$) .If the different between ($\dot{V}_S^{(1)}$,$\dot{V}_R^{(1)}$) and ($\dot{V}_S^{(0)}$,$\dot{V}_R^{(0)}$) is lesser than the given allowance ,then the ($\dot{V}_S^{(1)}$,$\dot{V}_R^{(1)}$) are considered as solve. On the other hand, move to step 3:
3) Step 3: updating ($\dot{V}_S^{(0)}$,$\dot{V}_R^{(0)}$) by ($\dot{V}_S^{(1)}$,$\dot{V}_R^{(1)}$) and then iterate step one and two until convergence.

Actually, step one agrees to the calculation of UPFC with terminal voltages estimated (see figure 3.2(c)). Step two agrees to solution of AC network with the impact of the UPFC representing as current injections to the alternating current grid (see figure 3.2(b)).

Excepted that, the definition of fictitious vector current is the UPFC- network interfaces change to saving the time of computation. After solving the interface voltage $\dot{V}_U =(\dot{V}_S, \dot{V}_R)$, the first side of the equation matrix (3.4) can be used for the calculation of the generating current injecting $\dot{I}_G$.

By means of using this iteration approach, the stability analyses is achieved simply by adding some new subroutines in the existing programs. It is controlled in the accuracy of network solutions by preparing the tolerance interface. This interface could be used and extended for another FACTS devices [17, 20].

3.3 Summary

In this chapter, the power system element models used in the dynamic analysis are presented. Also they discussed versatile interface between the AC network and the UPFC device. Stator and rotor winding equations are presented. In addition excitation system model is discussed.

CHAPTER FOUR

OPTIMIZATION ALGORITHM

4.1 Introduction to Optimization

Generally, an optimum problem is represented as:

A function f mapped from all of the group A to the true numbers, then member x_o in A like $f(x_o) \geq f(x)$ for all x in A ("maximization") or like $f(x_o) \leq f(x)$ for each x in A ("minimization") [22].

This formula is called mathematical programming problem or an optimization problem (it is a term not directly connected with programming the computer, but remain is used for example in linear programs). Several theoretical problems and real world could be placed along the lines of this generic frame. Problems are framed by uses this way in the computer vision and in the physics fields may indicate to the method as minimization of energy, speaking for function value(f) is as represented the system power been modeled [22].

Generally, A is the subgroup some space of the Euclidean R^n, often limited by a group of equality or inequality, and restrictions to which the elements of A be to accept. The field A of f which called the choice set or the search space, whilst the components of A are called feasible solves or candidate solves.

The function f is called, differently, a loss job or cost job (minimization), an aim function, a useful function, or fitness function (maximization), or, an energy functional or an energy function, in certain fields. A possible solution that (maximizes or minimizes, if that is the aim) an objective function can be called optimization solution. Therefore, an optimization is the process which used to determine the conditions that give the minima or the maxima value of a work. Optimization is a work of attaining the best possible result in construction, design, maintenance under given circumstances. In mathematics, problems of the traditional optimization are usually mentioned in terms of minimizes. In general, except for the feasible region and the objective function are convex in reducing problems, they can be many local minima.

The definition of a local minima x* is a point for that there exist some $\delta > 0$ so that for whole x like:

$$\delta \geq \|x - x^*\|$$

The term is:

$f(x) \geq F(x^*)$

This means, in some area around x* each of the function value is equal or larger than the value in that point. Local maximum is known the same. Whilst a local minimum at least as good as any points nearest, a global minimum at least good as every point possible.

In the convex problem, if there is a local minimum which it is inner (not group of possible points on the edge), it is also the global minimum, however a non-convex problem may have more than one local minimum not all of which necessity to be the global minima.

A big numbers of algorithms suggested to solve non convex problems which includes the mainly of commercial ready solutions are not be able to make a distance between globally optimum solves and locally optimum solves, and it will deal with previous as real solutions for original problem.

Global optimization is the part of numerical analysis and applied mathematics which interested with the deterministic algorithms development that are able to ensure convergence in fixed time to the real optimum solve for non convex problem [22].

4.2 Formulation of the Problem

To identify the optimal place for UPFC, a way is suggested based on determination of a branch and bus that are most effective and sensitive with regard to voltage. So, this part describes the procedure of optimal location for UPFC device through defining and calculating the Contingency Severity Index (CSI), the voltage stability L-index, and an approach of optimization.

A. Location of the UPFC for Relieving Congestion:

The index of congestion of the T.L. can be calculated according to this equation below [23, 24]:

$$CI_j^k = \begin{cases} \frac{LL_j^k - CL_j}{CL_j} \; if \; LL > CL \\ 0 \quad if \quad LL < CL \end{cases} \tag{4.5}$$

Where:

CL_j: Congestion limit of the transmission line j.

LL_j^k: Loading of the transmission line j in condition outage of element k.

CI_j^k: Congestion index of the transmission line j in condition outage of element k.

So as to defining the most critical lines which have the most amount of congestion index (CI) on entire operation of a single contingency, can use the severity congestion index in the following equation:

$$CSI_j = \sum_{k=1}^{Nc} CI_j^k \tag{4.6}$$

Where,

CSI_j: Congestion severity index of the line j for total single contingences.

N_C: Total number of a single contingency of the network branches.

The electrical power T.L that are having the maximum number of CSI are recognizing as critical lines from the point of view of the congestion and also are selected as case for allocation of UPFC device.

B. Location of the UPFC for Enhancing Voltage Security

The static voltage stability L-index can be utilized to define the weakest buses in the power electricity system. Then those buses are recognized as critical buses which are having the most considerable amount of L- index. Therefore, the equations follow are used for defining the buses as critical [23]:

$$L_{n1} = \sum_{k=1}^{Nc} L_{n1}^{k^2} \tag{4.7}$$

$$L_{n1}^k = \left| 1 + \frac{V_{on1}}{V_{n1}} \right| \tag{4.8}$$

$$V_{oj} = - \sum_{i \in G} F_{ij} \quad V_i \tag{4.9}$$

$$F_{LG} = - [Y_{LL}]^{-1}[Y_{LG}] \tag{4.10}$$

Where,

F_{LG}: Complicated matrix which is giving the relationship between source bus voltages and load bus voltages, in addition information about whereabouts of load nodes with regard to generator nodes.

F_{ij} : Complicated elements of $[\mathrm{F_{LG}}]$ matrix.

$[Y_{LL}]$, $[Y_{LG}]$: Corresponding partitioned parts of the network Y- bus matrix.

n_1 : Number of load bus.

V_j , V_i : Voltage of j_{th} and i_{th} bus.

V_{on1}: Voltage of equivalent generator from the point of view of n_l-bus.

L_{n1}^{k} : L- index of n_l – bus in case of the outage of k element.

L_{n1} : L- index of n_l– bus for the total number of single contingencies.

X_{ij} : is the reactance of T.L .

The limited on the indicator $\mathrm{L_{n1}}$ for stability, must not be violated (maxima limit=1) for either of the n_l- nodes. Therefore, the global index L describes the complete stability sub system is given by L = maximum of $\mathrm{L_{n1}}$ for all n_l (load buses). A value of L-indicator far from 1 and nearby to zero refers an improved security of system.

The most critical buses and weakest buses have the large amount of L are chosen as candidate locations for installing the unified power flow controller (UPFC) device.

C. Definition of Objective Function

After recognize the most critical buses and the critical lines as candidate locations for placing the UPFC, so as to find the suitable and optimum place, size and numbers, an optimal location problem is solved by using PSO method [23].

The fitness function and objective function is calculated using these equations as follows:

$$Obj = minimize \{f(SLI, C_{upfc}, L)\} \tag{4.11}$$

$$\mathrm{FF} = (\alpha_1 \times SLI) + (\alpha_2 \times L) + (\alpha_3 \times C_{upfc}) \tag{4.12}$$

$$SLI = \sum_{k=1}^{N_{line}} a_k \left(\frac{P_k}{P_k^{max}}\right)^4 \quad (4.13)$$

$$L = \sum_{n1=1}^{N_L} L_{n1}^2 \quad (4.14)$$

$$C_{upfc} = 0.0003S^2 - 0.2691S + 188.22 \quad (4.15)$$

Where,

FF : Represents the fitness function.

SLI : Represents the loading severity of each branches.

L : Represents the index L for complete network.

a_k : Weight factor of k element which supposed to be equal to 1 for all Line.

N_{line} : Total number of the grid lines.

N_L : Total number of the grid loads.

P_k : Real power flowing over line k.

P_k^{max} : Maximum real power flowing over line k.

C_{upfc} : Cost function of the UPFC in $ / kVar .

S : Operating range of the UPFC in MVar.

$\alpha_1, \alpha_2, \alpha_3$: Positive constant factors.

Obj : Represents the objective function.

In the process of optimization [25], number of UPFC, size, and the best location of UPFC are identified when the total cost of allocated UPFC's and voltage stability indices and severity of loading of the complete grid are in their minima amount.

Figure (4.1) presents equivalent circuit of UPFC, it contains of two switching inverters and the voltage and phase angle between two buses. Figure (4.2) presents vector diagram depend on the basically principle for UPFC, where I_q is reactive current following in shunt transformer, V_T is voltage transformer.

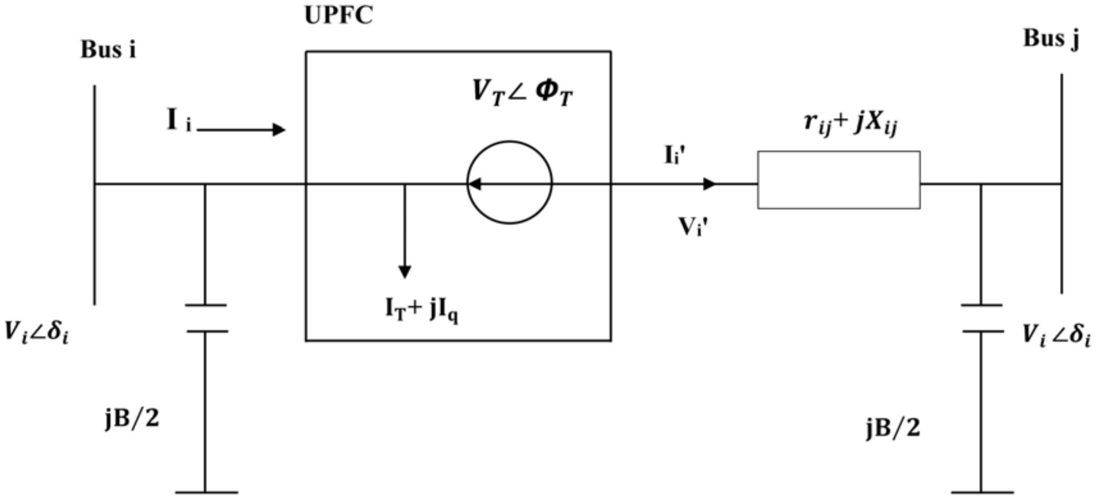


Figure 4.1: UPFC equivalent circuit [25].

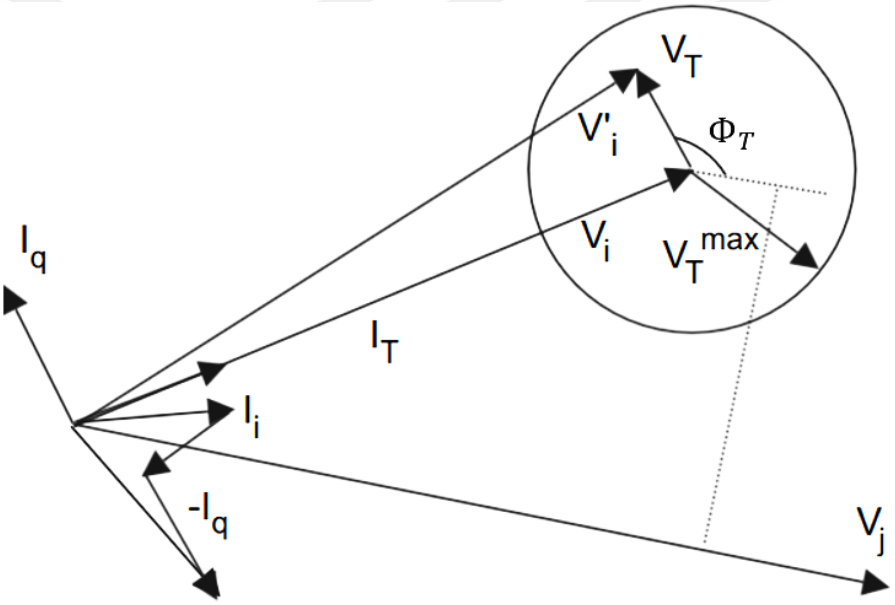


Figure 4.2: Vector diagram of UPFC [25].

4.3 Particle Swarm Optimization

Particle swarm optimization (PSO) is a novel and strong optimization method that it is used recently in order to solve many complex problems relation to electrical power systems. In the recent year, PSO obtains better results in a cheaper and faster way in comparison with another technique such as genetic algorithm (GA) [28, 2].

PSO as the population- founded algorithm, using the people of individuals to prop promising areas for search space. Then, the population can be called a swarm, individuals, and particles.

As repeats a swarm, the fitness for a global best solve enhances (decreases for the minimization problem). So it's expected in order to occur to all the particles being impacted by the global best ultimately approach the global best. If the fitness does not improve in spite of, but several runs the PSO is repeated, then the convergence is investigated. In the creative work on the invention of Kennedy and Eberhart in

Every particle penetrates the search space to search for the global (maximum or minimum). Initially the particle is created randomly with two parameters every (velocity and position) in the D dimensional space like position Si= (S_{i1},S_{i2},……., S_{iN}), and velocity Vi= (V_{i1},V_{i2},…….,V_{iN}).

The particle positions (temporary solutions) will be assessed at the end of each relative iteration to an objective value or the value of the fitness. It is supposed that the particles to save memory of the good situations which have done in occurs flying and exchange these details between the rests. Every particle modify its position during of the flight due to its own experiment (this value is denoted P_{best}), and according to experiment of the neighboring particle (this value is denoted G_{best}), made use for good position faced by itself and its neighboring [28, 2]. Indeed, the particle swarm direction can be identify by a group of neighboring particles and experience the history of particle.

PSO uses (Pbest & Gbest) in order to modification the current check point to avoid the particle moving in the same direction, however to converge gradually towards (Gbest and Pbest). An appropriate chosen of W supplies an equilibrium between local and global discoverations.

And added weight factor W_k to the former speed for particles. This is allowing to control on the technique responsible for the size of speeds, that enhance the danger of swarm divergence and explosion, or quick convergence and falling into local minimum. The second challenge is to finding the weight factor possible W_K which prevents prematurely due to it affects the ability and the convergence between swarm to find the optimal. An appropriate value of W_k provides the desired equilibrium between the local and global exploration ability for swarm, and thus optimizes the algorithm efficacy.

At a first, the big inertial weight is best because it is giving primacy to global exploration for out space. As it can be clearly gradual reduced in order to get repeated solutions [29, 26]. Genetic algorithms (GA) are one of the best ways so as to solution a problem that does not know the little. It is a very general algorithm so they will operate well at any search space. Everything need to know is what you need the solve in order to be capable to do a good job, the genetic algorithm will be capable to selection to produce many of the solutions to a specific problem [26]. Genetic algorithms resort to thrive in an environment where there is a large group of the candidate solutions and that the search space is uneven and has of the several valleys and hills. In fact, GA will work very good in any environmental, but it will not be large out classed by a more specific conditions algorithm in the search spaces simply. So we must keep in mind that the genetic algorithms are not always the best solution. Sometimes it can take some time to run and therefore, they are not always suitable for use in real time. However, it is one of the most strong ways that (relatively) create high quality solutions to a problem quickly [27]. As this technique is more expensive compared to other devices such as Particle Swarm Optimization technique.

4.4 Advantages of Particle Swarm Optimization

The advantages of PSO method are discussed below [29, 26]:

1) It is free of derivative algorithm.
2) PSO algorithm is very easy for the implementation, therefore it can be applied easily both in engineering problems and scientific research.
3) It has limited number of parameters to the solves is small in comparison with the other optimizations method.
4) The calculation in PSO method is very easy.
5) An optimum value for problem can be calculated easily in a short time.
6) It is less dependent on a group of initial points from the another optimum methods.
7) It can also be very simple concept.

4.5 The Algorithm of Particle Swarm Optimization

A particle is randomly generated at first with two parameters velocity and position in the N dimensional space like velocity $Vi= (V_{i1}, V_{i2}, V_{i3},\ldots.., V_{iN})$ and position $Si= (S_{i1}, S_{i2}, S_{i3},\ldots.., S_{i4})$. The particle positions (temporary solves) are estimated at the ending of each iteration relative to fitness or value of an objective [30, 23, 28].

The position and velocity of every particle is calculated according to these equations as follows in the figure (4.3):

$$V_i^{k+1} = W * V_i^k + C_1 * rand_1 * \left(P_{besti} - S_i^k\right)$$
$$+C_2 * rand_2 * \left(G_{besti} - S_i^k\right) \tag{4.16}$$

$$S_i^{k+1} = S_i^k + V_i^{k+1} \tag{4.17}$$

Where:

S_i^k : is the current position of agent i at kth iteration.

S_i^{k+1} : is the current position of agent i at (k+1)th iteration.

V_i^k : is the velocity of agent i at kth iteration.

V_i^{k+1} : is the velocity of agent i at (k+1)th iteration.

C_1 and C_2 : are the acceleration constant: generally C1=C2=2.

$rand_1$ and $rand_2$: are the random values between (1 and 0).

k: is the iteration number.

W: is the inertia weight factor.

Particle swarm optimization utilizes G_{best} and P_{best} to amend the current

Point of the search to avoid the particles moving in the same direction, but to converges gradually towards G_{best} and P_{best}.

An appropriate chosen of inertia weight W supplies an equilibrium between local and global discoversations. Generally, the weight W is put dynamically with the following equations:

$$W = W_{max} - \left(\frac{W_{max} - W_{min}}{iter_{max}}\right) * iter \tag{4.18}$$

So:

$iter_{max}$: number of maximum iterations.

iter: number of iterations.

W_{max}: is the upper limit of the inertia weight.

W_{min}: is the lower limit of the inertia weight.

Where, (W_{max}=0.9, W_{min}=0.2).

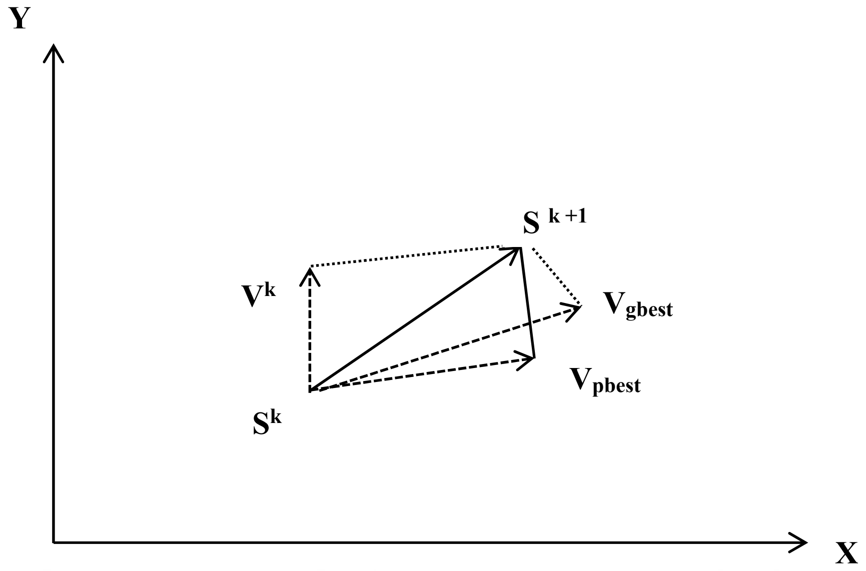


Figure 4.3: Concept of a searching point by particle swarm optimization.

Figure 4.4 describe the entire operation of an optimization by Particle Swarm Optimization. In this operation we identify the most critical buses and lines as candidates for putting UPFC and number of population calculated and we calculated the fitness function, also we defined the stopping criterion is the error between fitness function amount in two sequential iterations and number of iteration. If both of the error and the number of iteration arrives the maxima limit and a predefined fixed error successively, the operation of optimization will be terminated [30, 23, 28].

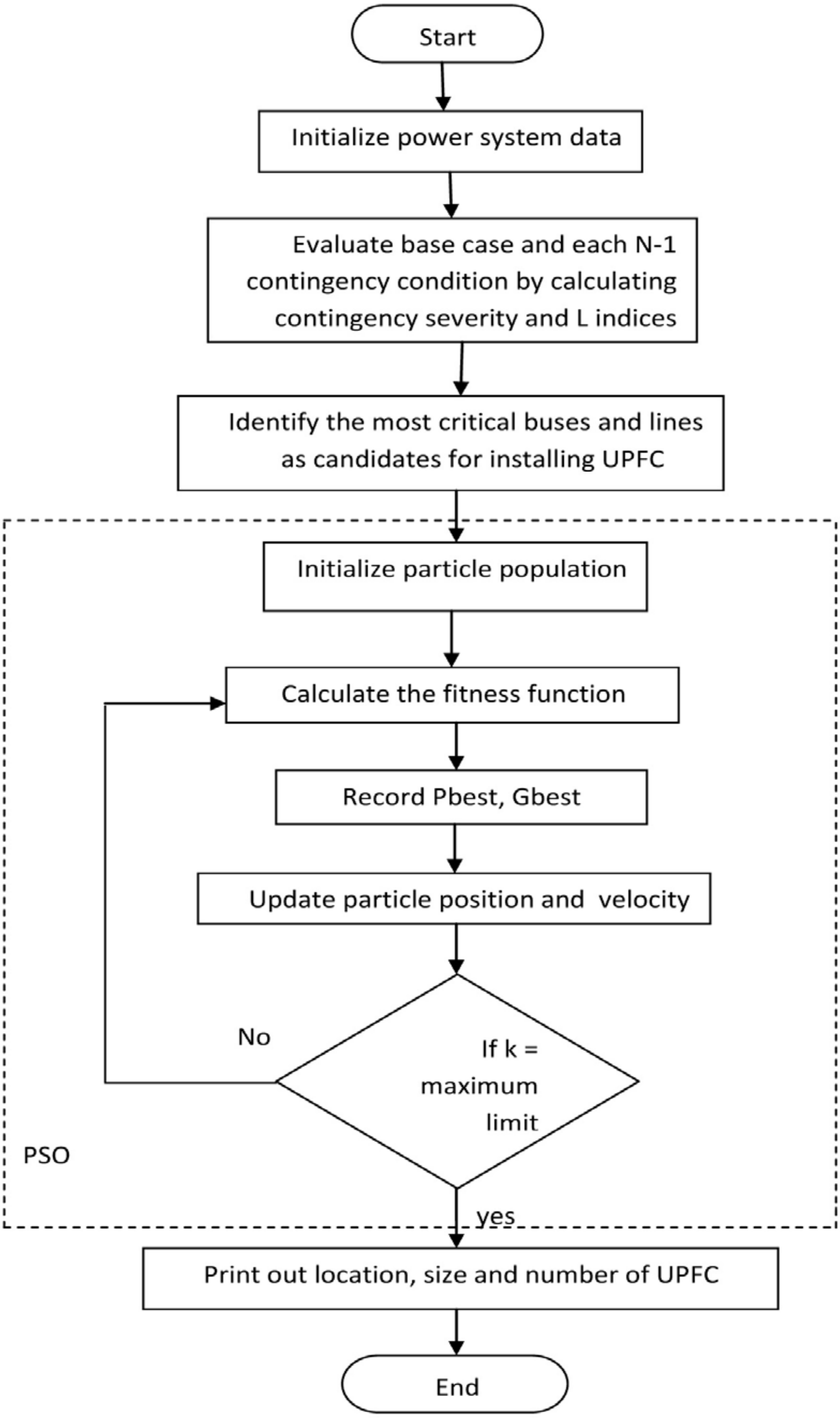


Figure 4.4: Flow chart of optimization process by PSO [23].

4.6 Fuzzy Logic Algorithm Controller

Fuzzy logic is a theory which introduced by Lotfi Zadeh and first used in control by mamadani. It is a generalization of the divalent Boolean logic. For example, so called fuzziness of information is "very" captured in mathematical models as "a bit", "pretty", "strong" or. Fuzzy logic is based on fuzzy sets (fuzzy sets) and so-called membership functions that represent objects on fuzzy sets and matching logic operations on these quantities and their inference. For technical applications also methods for fuzzification and defuzzification must be considered, that is, methods for the conversion of information and relationships in fuzzy logic and back again [31].

The UPFC controller has two fuzzy PI current controllers (as present in fig. 4.5). The fuzzy PI controller receives two inputs such as current error and rate of change of current error and it provide two outputs such as proportional gain and integral gain (as shown in figure 4.6). The range of error and rate of change of error are -1500 to 1500. The range of proportional gain is 0-0.025 and range of integral gain is 0-6.

The inputs are distributed with five bell shaped membership function. The outputs are distributed with five Gaussian membership functions. For 25 rules are generated for each output from the fuzzy. The fuzzy output is used with the proportional and integral output of the PI controller and PI controller provides control signal for next stage.

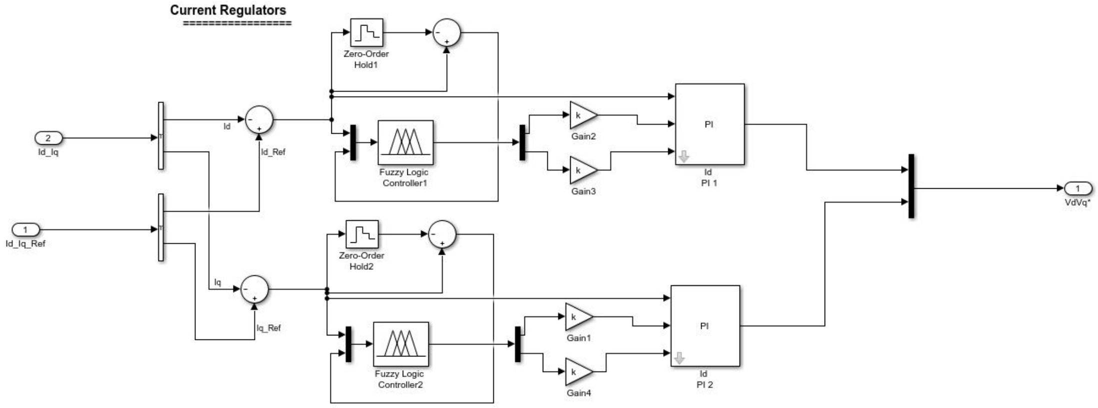


Figure.4.5: Fuzzy PI Current regulator in UPFC control.

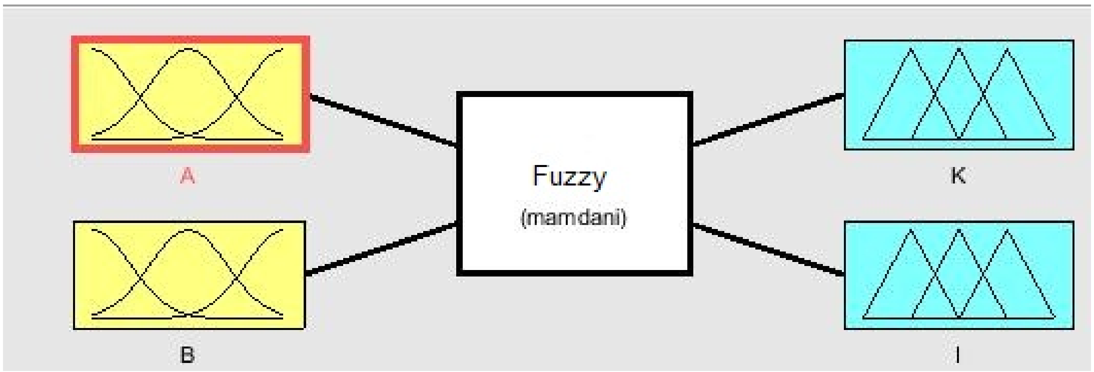


Figure 4.6: Fuzzy PI structure.

Figure (4.7) show that the inputs are distributed with five bell shaped membership function and the range of error and rate of change of error are (-1500 to 1500). The member ship function is the value which defined for seven variables (NB, NM, NS, Z, PS, PM, PB).

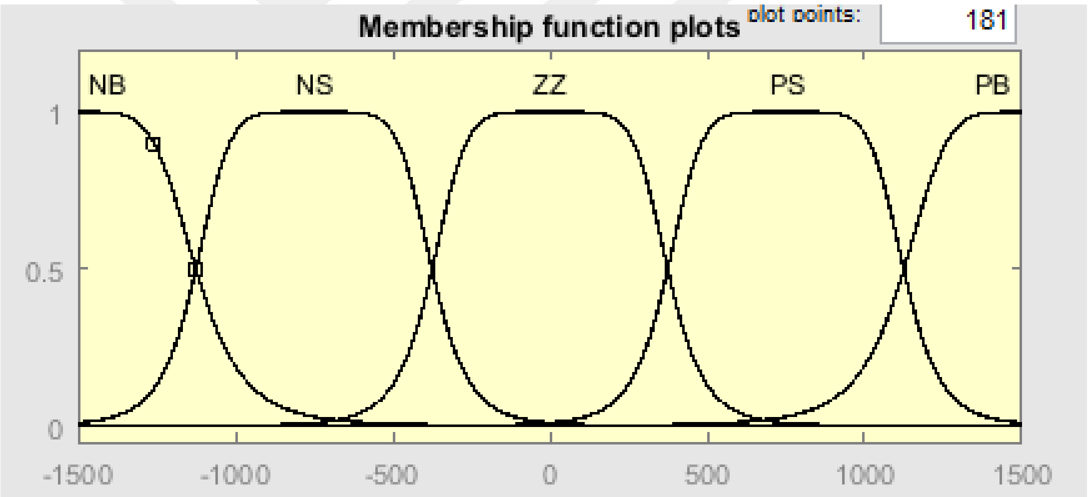


Figure 4.7: Distribution of input membership function.

Figure (4.8) and (4.9) show that the outputs are distributed with five Gaussian membership functions and the range of proportional gain is (0-0.025) and range of integral gain is (0-6).

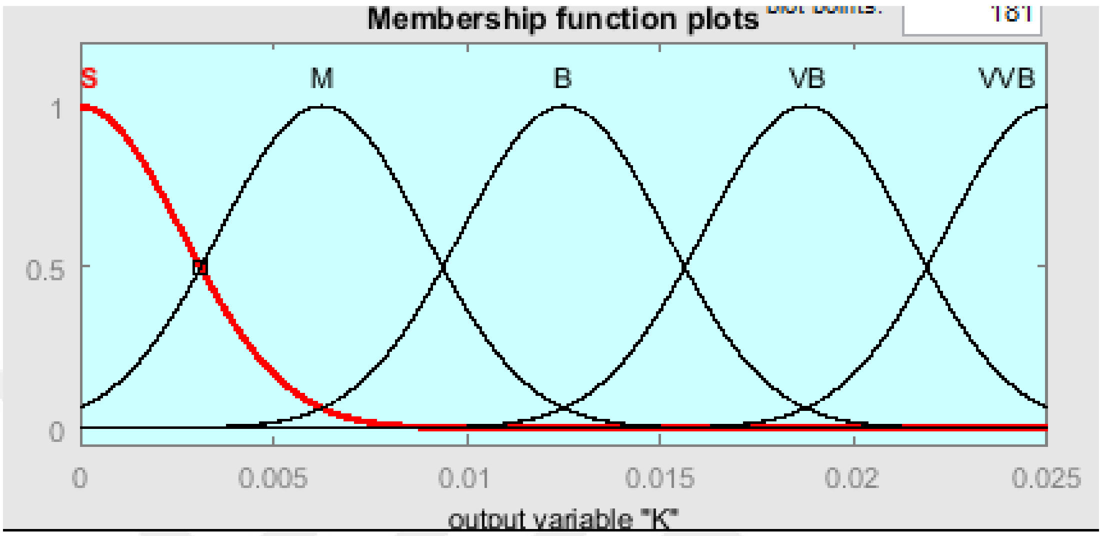


Figure.4.8: Distribution of Proportional gain.

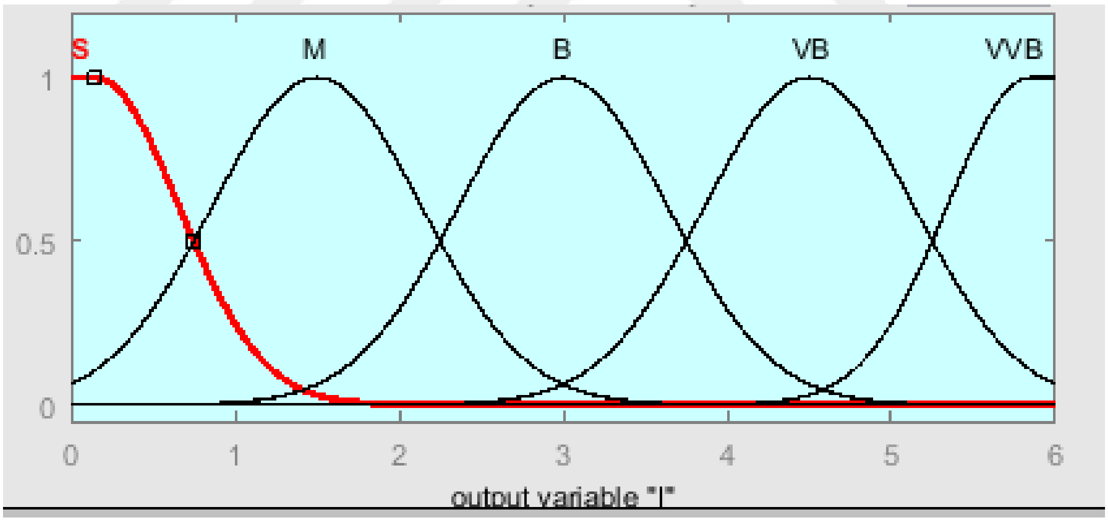


Figure.4.9: Distribution of Integral gain.

Tables (4.1) below shows that there are 25 rules are generated for each output from the fuzzy. The fuzzy output is used with proportional and integral PI controller output and PI controller provides control signal for next stage in order to make the system more stable.

Table 4.1: Fuzzy logic controller rules.

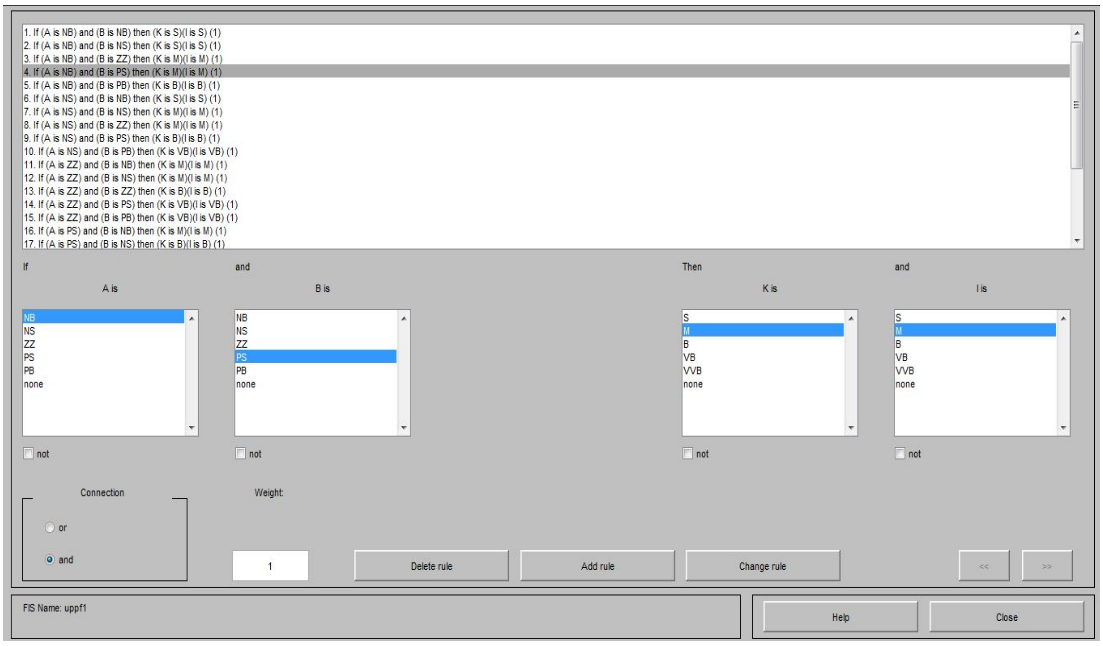
Current Error	Rate of change of Current error						Current Error	Rate of change of Current error					
	K_P	NB	NS	Z	PS	PB		K_I	NB	NS	Z	PS	PB
	NB	NB	VB	VVB	VB	B		NB	VB	VVB	B	B	B
	NS	VB	VB	VVB	VB	B		NS	VB	VB	VVB	B	M
	Z	VVB	VVB	PB	PS	PS		Z	PB	M	S	S	S
	PS	B	M	M	M	M		PS	M	M	M	S	S
	PB	M	M	S	S	S		PB	M	M	S	PS	PS

So we choose range for proportional gain between (0-0.025) and integral gain in between (0-6). And also, error and rate of change of error may vary from (-1500 to 1500) according to these cases are shown in table (4.2) below:

Table 4.2: Remarks about compare cases.

Case	Error	Rate of change error	Kp	Ki	Remarks
1	1500	1500	0.022	5.5	If error and rate of change of error is positive high and to bring to zero then need to increase the gain in high value.
2	-1500	-1500	0.0022	0.5	If error and rate of change of error is negative high and to bring to zero then need to decrease the gain in low value.
3	0	1500	0.018	4.46	If error is 0 and rate of change of error 1500 or vice versa and gain value should maintained at 75 % of the maximum value fixed.
4	1500	0	0.018	4.46	
5	0	0	0.0125	3	If error and rate of change of error is 0 and gain value should maintained at 50 % of the maximum value fixed.

Figure (4.10) below show the rules of fuzzy of proposed work when we compared between error and derivative of error and then we squeezed to find the kp and ki.



```
1. If (A is NB) and (B is NB) then (K is S)(I is S) (1)
2. If (A is NB) and (B is NS) then (K is S)(I is S) (1)
3. If (A is NB) and (B is ZZ) then (K is M)(I is M) (1)
4. If (A is NB) and (B is PS) then (K is M)(I is M) (1)
5. If (A is NB) and (B is PB) then (K is B)(I is B) (1)
6. If (A is NS) and (B is NB) then (K is S)(I is S) (1)
7. If (A is NS) and (B is NS) then (K is M)(I is M) (1)
8. If (A is NS) and (B is ZZ) then (K is M)(I is M) (1)
9. If (A is NS) and (B is PS) then (K is B)(I is B) (1)
10. If (A is NS) and (B is PB) then (K is VB)(I is VB) (1)
11. If (A is ZZ) and (B is NB) then (K is M)(I is M) (1)
12. If (A is ZZ) and (B is NS) then (K is M)(I is M) (1)
13. If (A is ZZ) and (B is ZZ) then (K is B)(I is B) (1)
14. If (A is ZZ) and (B is PS) then (K is VB)(I is VB) (1)
15. If (A is ZZ) and (B is PB) then (K is VB)(I is VB) (1)
16. If (A is PS) and (B is NB) then (K is M)(I is M) (1)
17. If (A is PS) and (B is NS) then (K is B)(I is B) (1)
```

Weight: 1

FIS Name: uppf1

Figure 4.10: Rules of fuzzy of proposed work.

4.7 Summary

In this chapter, introduction to optimization is given. PSO algorithm is defined and the advantage of PSO algorithm is offered. Also, problem formulation is discussed to determine the optimum placement and putting of UPFC device by using PSO algorithm after recognizing most critical buses and most critical lines. Also Fuzzy Logic with PI controller is discussed.

CHAPTER FIVE

EXPERIMENTAL RESULTS

5.1 Computer Simulation Results

The UPFC, or what the so-called the Unified Power Flow Controller is the most promising FACTS device for power flow control. This section describes the performance of the UPFC device for effective control of real power and reactive power flow on a 500 kV interconnected lines with and without using a Fuzzy Logic controller for the purpose of compensation as well as enhancement of power transmission capability of the transmission line. In order to evaluate the performance of the UPFC, a simulation was carried out in the MATLAB/ SIMULINK environment.

The simulation results showed that the UPFC device has an excellent capability of enhancing real and reactive power flows through the transmission lines. The voltage remained constant during the entire simulation.

To test the effectiveness of the new approach, the UPFC device was used to control the power flow in a 500 kV transmission system. The UPFC device was used to control real and reactive power flow on the transmission line.

The effects of the UPFC installed at the sending end of the transmission line, is shown in figure (5.3) and (5.5) respectively. The simulated results show an improve of power flow through the monitored line using the UPFC device with and without using a Fuzzy Logic controller. The simulation was run for 0.8 seconds.

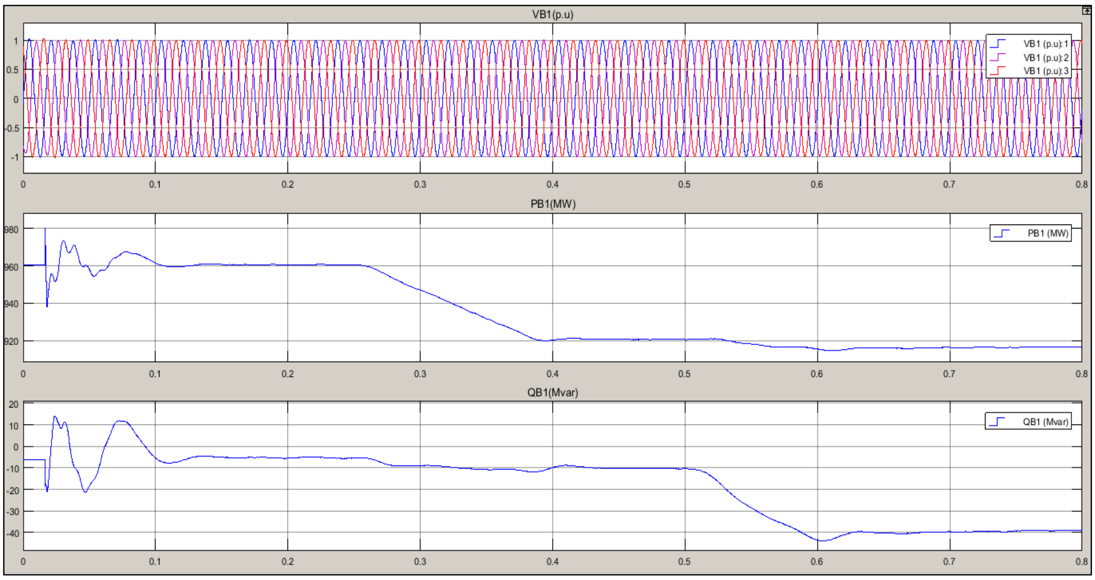


Figure 5.1: Voltage and Real and Reactive power for bus 1.

Figure (5.1) above shows the change of real power and reactive power for bus 1; however, the voltage is kept constant during the entire simulation.

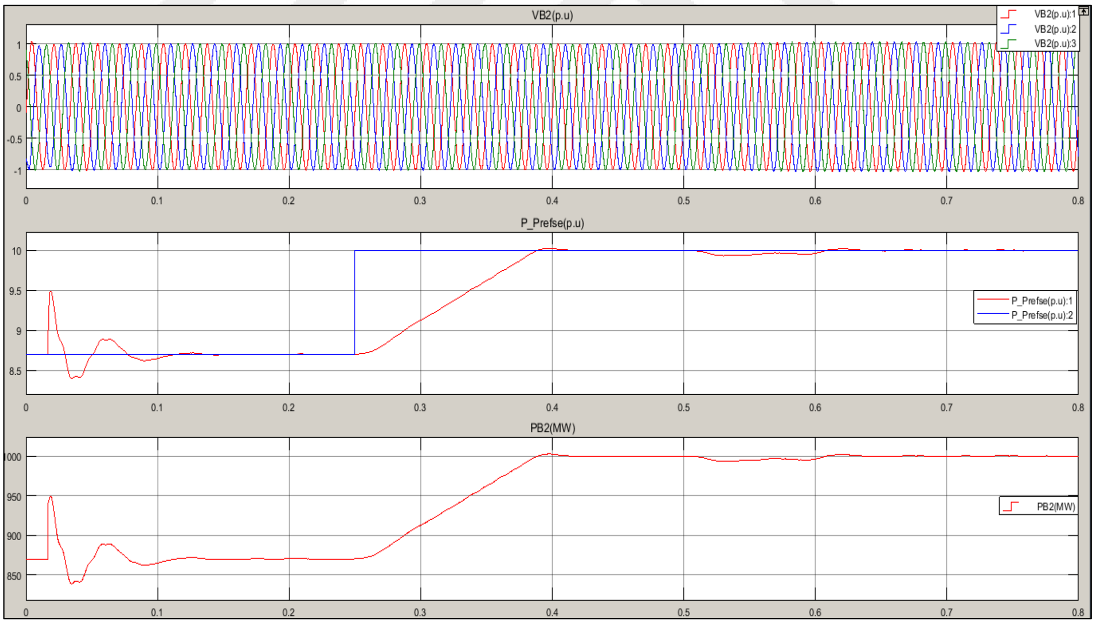


Figure 5.2: Real power for Bus 2 response after UPFC control work without using Fuzzy Logic controller.

Figure (5.2) above shows the effect of UPFC on real power flow which is transmitted through the transmission line without using Fuzzy Logic controller. After a transient period lasting approximately at time t= 0.15sec, the steady state is reached. Then, at time t=0.25sec, UPFC is activated and the real power has started to grow from P= (+8.7)p.u to (10)p.u but the voltage is kept constant during the whole simulation. And also we notice some changes in real power from (t=0.5sec to t=0.6sec) (as shown in figure 5.2), but we don't notice this changed in real power with using Fuzzy logic controller (as shown in figure 5.3).

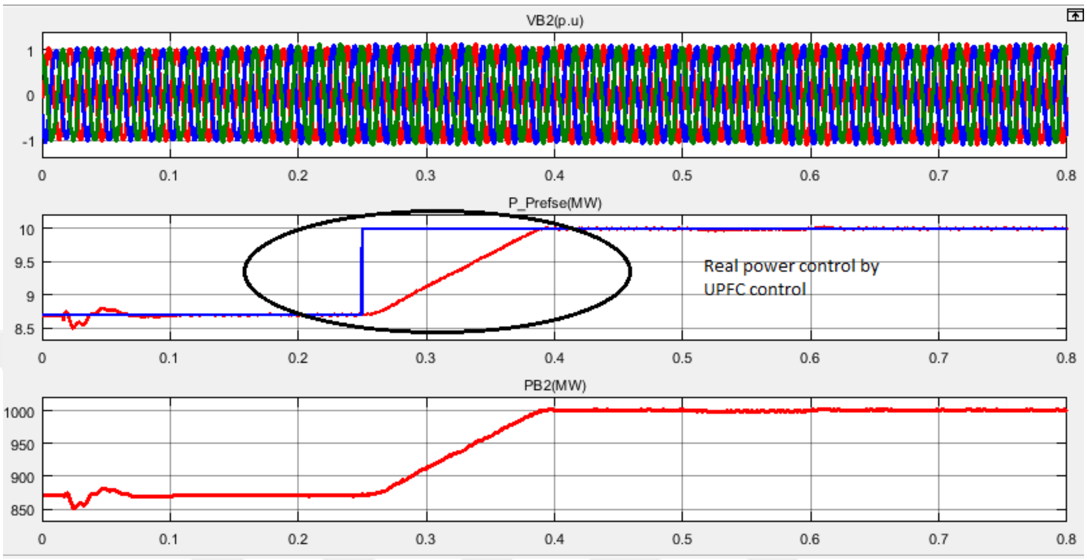


Figure 5.3: Real power for Bus 2 response after UPFC control work with using Fuzzy Logic controller.

In proposed work, the reference value of real power (Pref = +8.7 p.u to 10 p.u). Then at t=0.1sec the steady state is reached with Fuzzy logic controller and at t=0.25 sec the UPFC is activated and real power has started to grow from +8.7 p.u to +10 p.u. (As shown in figure 5.3).

Figure (5.4) below shows the effect of the UPFC on reactive power flow which is transmitted through the line without using Fuzzy Logic controller. After a transient period lasting approximately at time t= 0.45sec, the steady state is reached. The response of the UPFC was noticed after time t= 0.5second and after 0.1 second the reactive power has started to grow from (-0.6)p.u and it has rapidly increased to (+0.6) p.u but the voltage is remained constant during the whole simulation. So, from this work we conclude that the reactive power has a small change around its steady state value due to the changes in the active power.

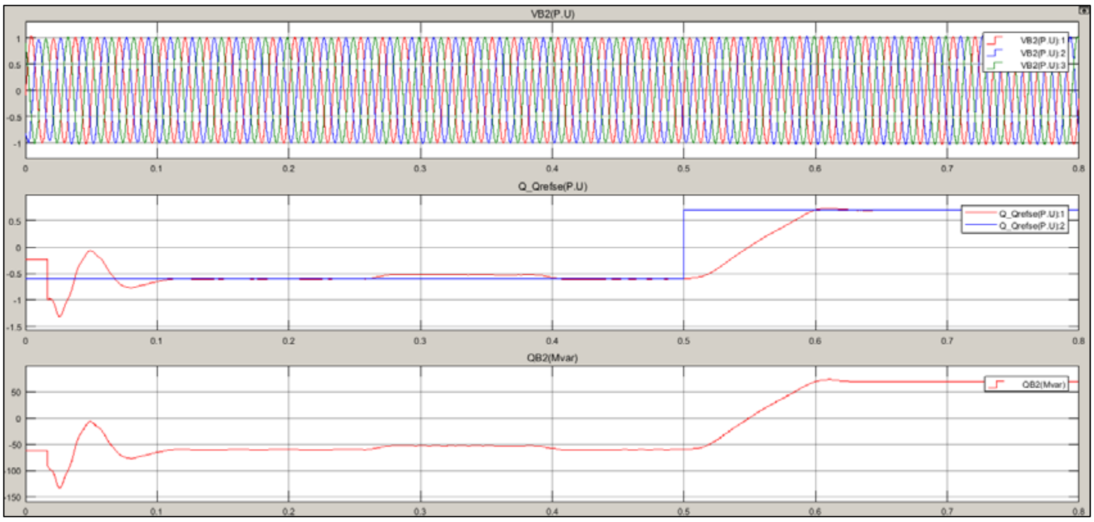


Figure 5.4: Reactive power for Bus 2 response after UPFC control work without using Fuzzy Logic.

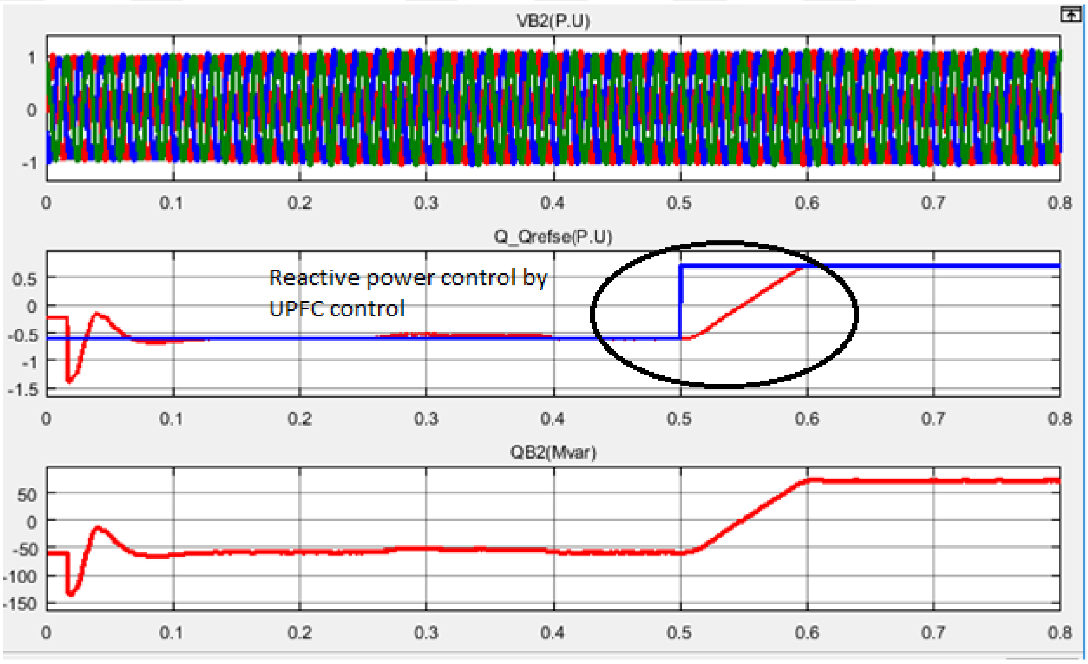


Figure.5.5: Reactive power response after UPFC control work with Fuzzy Logic.

In proposed work, the reference value of reactive power (Qref = -0.6 p.u to 0.6 p.u). Then at t=0.25sec the steady state is reached with Fuzzy logic controller and at t=0.5 sec the UPFC is activated and reactive power has started to grow from -0.6 p.u to +0.6 p.u. (As shown in figure 5.5).

We therefore conclude from this work that the combination of the Fuzzy logic controller with the PI controller gives us less time responsible for the steady state and an achieved UPFC activated for control and improvement of real and reactive power rather than by not using the Fuzzy logic controller.

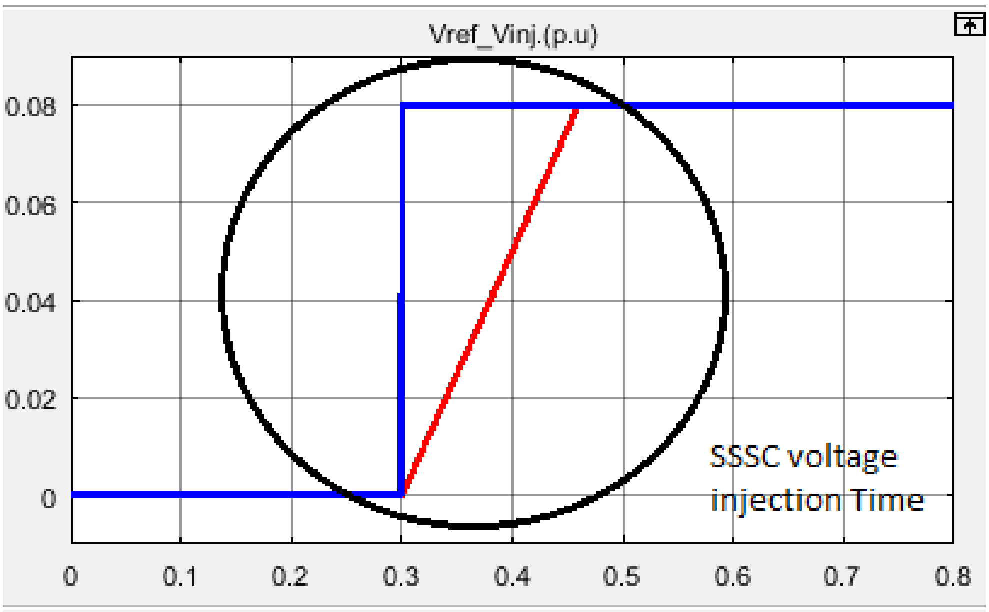


Figure 5.6: Voltage reference and Voltage injection.

Figure (5.6) below show the reference voltage (Vref) and injection voltage in (p.u) for series inverter which the injection voltage is kept constant and match (Vref) during the whole simulation.

This section provides the possibility of installing UPFC device on a 500KV transmission system. Implementation of UPFC for control of the real and the reactive power flow has been discovered. The MATLAB/SIMULINK environment was used to simulate the model which is shown in figure (5.7). The performance and control of UPFC intended for installation over the T.L. is offered. The simulation results refer that the attainable response of the control is very fast, almost instantaneous, and therefore the UPFC device is effective in handling dynamic system response.

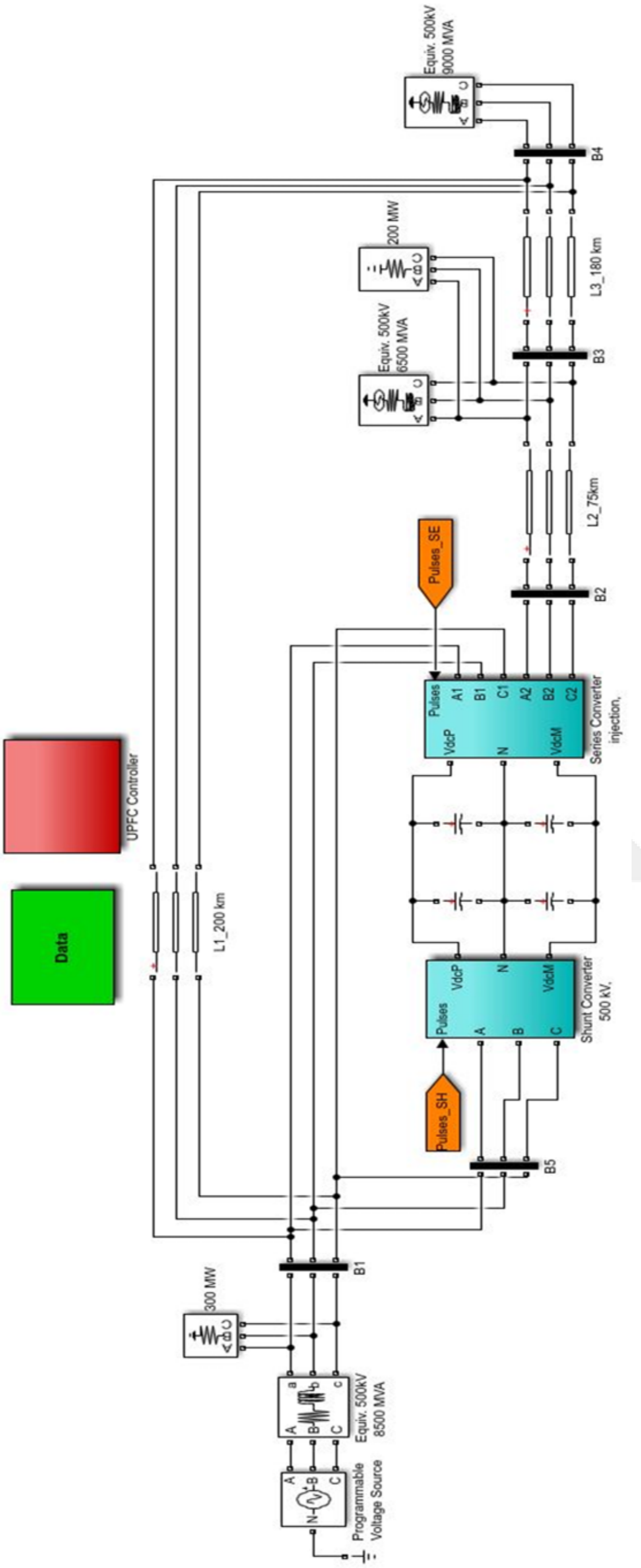


Figure 5.7: The MATLAB/SIMULINK that is used to demonstrate the previous results.

5.2 The Algorithm Results

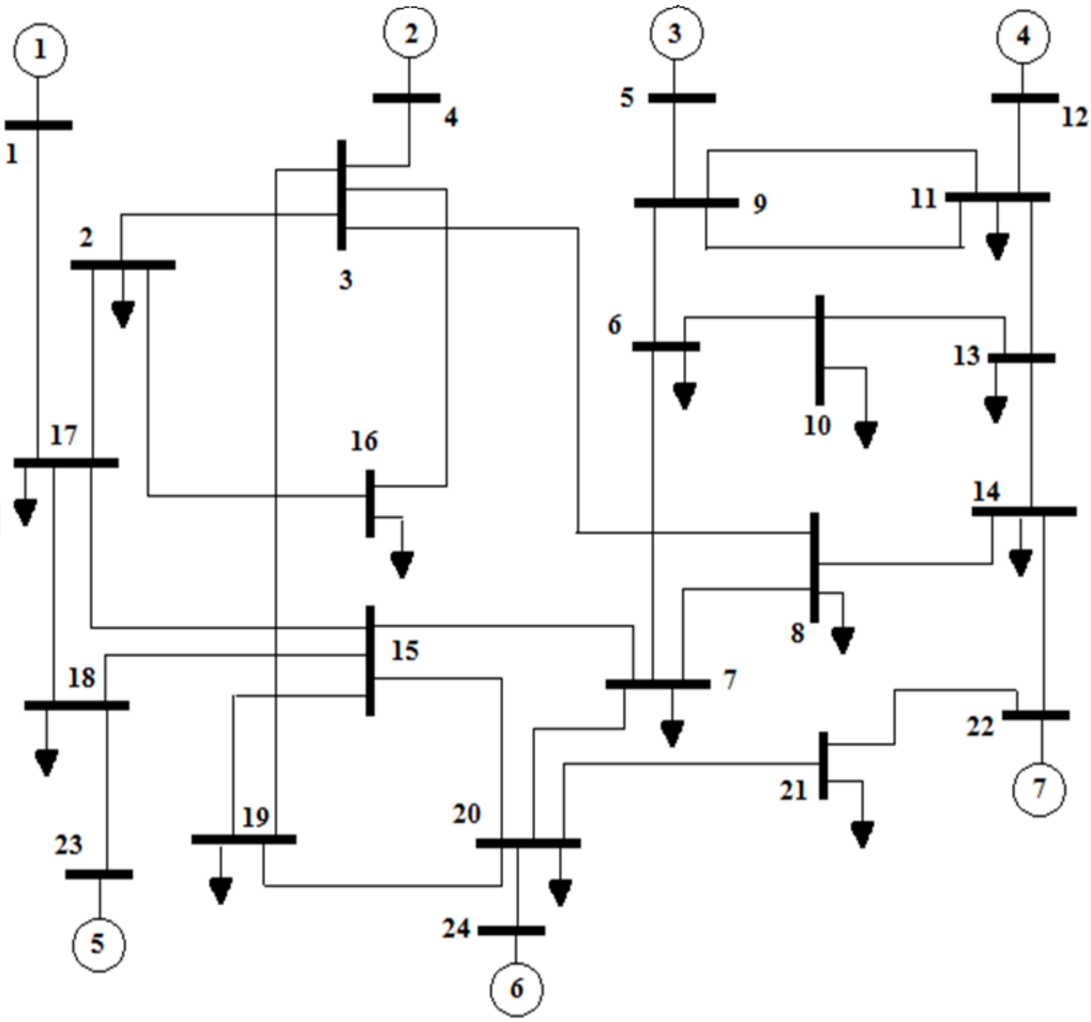


Figure 5.8: The line diagram of a 24- bus test power system.

The parameters of PSO are used in this work as is following:

1) Number of population is 50
2) Maximum generation is 80
3) C1 and C2 are equal to 2

Table 5.1 presents the calculation results of Contingency Severity Index (CSI) for the critical lines. As can be clearly seen, seven lines have the most amount of CSI. So, these lines are recognized as the most critical lines and are identified as the candidate lines.

Table 5.2 presents the calculation results of L-index for the critical buses have the most amount of L. According to the process of optimization on figure 5.6, these buses and lines are chosen for installing UPFC. By implementing this process of optimization on the test of power system, two UPFC's are required in order to install in the network.

Table 5.3 presents the results of the suggested optimization algorithm. As it can be clearly seen, these two UPFC's should be installed on the line (7-15) and on the line (6-7). Also in this table, the rated apparent power corresponding to each UPFC is shown.

Table 5.1: Show the Contingency Severity Index (CSI) for each of critical lines.

No.	From bus	To bus	CSI (Eq 4.6)
1	2	3	5.729547
2	3	8	5.793012
3	6	7	6.266842
4	7	15	5.921812
5	13	14	5.299517
6	15	19	4.161515
7	19	20	3.163496

Regarding about the table (5.1), the results obtained showed us that there are seven critical lines and we calculated the value of Congestion Severity Index for each of these critical lines by applying equation (4.6), then we recognized the more critical two lines (7-15), (6-7). And after that, we chosen the optimal location for installed UPFC devices for each of the two lines by using PSO technique.

Table 5.2: Show the L- INDEX for each of critical buses.

Bus No.	**L index (Eq 4.7)**
4	1.312511
7	1.257351
8	1.277124
6	1.624359
15	1.434163
17	1.352586
18	1.441358
24	1.361549

Regarding about the table (5.2), the results obtained showed us that there are more critical buses and we calculated the value of L- Index for each of these critical buses by applying equation (4.7), then we recognized these buses as a weakest buses by using PSO technique.

Table 5.3: Show the results of optimization problem by particle swarm optimization.

UPFC No.	**Location of UPFC**		**Rated Apparent Power (MVA)**	**Investment Cost of UPFC(US$)**	**Fitness Function**
	Lines No.	**Bus No.**			
1	7-15	7	377	$1.7899*10^6$	$1.5116*10^4$
2	6-7	6	213		

Regarding about the table (5.3), after recognized the more critical lines and more critical buses, we chosen the optimal location for installed UPFCs devices by using PSO method. Then we calculated the apparent power for each line and bus, and then calculated the minimum cost price and fitness function.

5.3 Summary

This thesis focuses on showing the method for optimum location, size and number of UPFC to enhance voltage security and alleviate congestion in addition to the application of PSO to solve this problem.

In this process, the weak buses and the congested transmission lines are determine based on of the highest severity contingency index (CSI) and voltage stability sequentially as the candidate placements for setting UPFC. The problem of optimum placement of UPFC accordance to enhancement of voltage security and congestion mitigation had been modeled as the optimal solution and solved via the PSO method. The suggested algorithm is a practical and active way for the allocation and choice of UPFC in the transmission power lines. (MATLAB/ SIMULINK) is utilized to improvement the real and the reactive power flux over T.L.

CHAPTER SIX

CONCLUSIONS

6.1 Work Completed and Conclusions

In this thesis, MATLAB/ SIMULINK is used to simulate the model of an inverter and rectifier based unified power flow controller (UPFC) connected with transmission lines (i.e. 500kv). This thesis gave control of the UPFC device with and without using a Fuzzy Logic controller for the improvement of real power and reactive power flow through the transmission lines and to obtain the steady state time.

Therefore, the simulation results obtained in this thesis strengthen the earlier results and show that the effectiveness of the UPFC with a Fuzzy Logic controller gives us less time responsible for the steady state and an excellent capability in controlling and improving real and reactive power flows through transmission lines for better than without using a Fuzzy Logic controller. Computer simulation results show that the attainable response of the control is very fast, almost instantaneous, and thus the UPFC is effective in handling dynamic system responses. The concept of UPFC provides a powerful tool for the cost effective utilization of double transmission lines by facilitating the independent control of both real and the reactive power flows through transmission lines. Additionally, UPFC devices are able to enhance the capability of power transmission and improve the stability of an electrical power network.

In addition, Particle Swarm Optimization (PSO) algorithm method was used in this thesis to determine optimal locations, numbers and sizes for installing the UPFC in order to relieve congestion and enhance voltage stability after recognizing most critical lines and critical buses (weakest buses) in the power transmission lines.

A modified version of PSO method has been successfully applied to the problem under consideration. Through the case study, the twenty- four bus system was designed.

Therefore, the obtained results in this thesis strengthen the earlier results and show that this method has good features and is effective for the allocation of UPFC to enhance voltage stability and alleviate the congestion of power transmission lines.

6.2 Future Studies

Computationally speaking, it is worthy to investigate other optimization algorithms for future work for sake of comparison with particle swarm optimization.

Another important issue is that a comprehensive comparison should be performed among the power electronics- based devices that contribute to the improvement of power quality in power system.

The important of such comparison comes from the fact that recently several devices have been invented for power quality improvement.

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