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Switching Level Modeling And Operation Of Interline Power Flow Controller.

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ABSTRACT

The fast development of power electronics technology has given birth of new devices, which are very useful improving the power system performances called Flexible AC Transmission system(FACTS).The emergence of FACTS device is really a step forward for the Flexible control of power system operation. An advance and versatile member of FACTS controller is Interline power flow controller (IPFC). It is the new concept of FACTS controller which is used for series compensation with the unique capability of controlling power flow among multi-lines within the same corridor of the transmission line. Interline Power Flow Controller employs two or more voltage source converters (VSC) with a common dc-link. Each voltage source converter can provide series compensation for the selected line of the transmission system also real power can be transferred via the common dc-link between the VSC and each Voltage source converter is capable of exchanging reactive power with its own transmission system.

In this project, it is proposed to develop the Static Synchronous Series Compensator and Interline power flow controller using Switching level simulation modeling. Switching level modeling is nothing but modeling of converters by using high speed semiconductor power electronic switches (IGBT). The basic characteristics of SSSC is to be analysis on Single Machine Infinite Bus system and the basic characteristics of IPFC are to be analyses on two similarly dimensioned parallel Transmission lines. The model has to be simulated with Matlab simulink program to demonstrate behavior of SSSC and IPFC. Numerical results are to be demonstrated on the practical Bus system with the Interline power flow controller model. It has to be validating that there is a possibility of regulating active power flow, reactive power flow and minimizing the power losses simultaneously with proposed IPFC parameter.

I. FLEXIBLE AC TRANSMISSION SYSTEM (FACTS)

1.1 INTRODUCTION

It is attractive for electrical utilities to have a way of permitting a more efficient use of the transmission lines by controlling the power flows. Such a means could be also interesting for the independent system operator (ISO) in a deregulated system, in order to assure a maximum level of competition among producers. Until a few years ago, the only means of carrying out this function were electromechanically devices such as switched inductors or capacitors banks and phase shifting transformers. However, specific problems related to these devices make them not very efficient on some situations. They are not only relatively slow, but they also cannot be switched frequently, because they tend to wear quickly.

In recent years, the fast progress in the field of power electronic and microelectronics has resulted into new opportunity for more flexible operation of power systems suppressing these drawbacks. The FACTS program was launched by EPRI to develop a number of controllers for this purpose. These new devices have made the present transmission and distribution of electricity more reliable, more controllable and more efficient. Power system, around the world, has been forced to operate in almost their full capacities due to the environmental and/or economical constraints to build new generation centers and transmission lines. Due to these problems it is necessary to change in the traditional concepts and practices of power system and which also provides the needed correction on transmission line parameters so that the existing transmission system be fully utilized within the thermal limit of the line. Hence for the better utilization of transmission line the concept of FACTS were introduced. It opens new opportunities for controlling power and enhancing the usable capacity of existing transmission line.

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FACTS is a technology states that how the parameter of line should change to improve the performance of line by using the series and shunt compensation principle. A FACTS technology development has been an area of interest for many research organizations. These organizations recognized the potential benefits of inverter-based FACTS devices to allow utilities to operate their transmission system at higher capacities, more efficiently and with improved reliability.

1.2 FLEXIBLE AC TRANSMISSION SYSTEM (FACTS)

Flexible AC Transmission System (FACTS) is a new integrated concept based on power electronic switching converters and dynamic controllers to enhance the system utilization and power transfer capacity as well as the stability, security, reliability and power quality of AC system interconnections.

As a result of recent environmental legislation, rights of way issues, increase in construction cost and deregulation policies, there is an increasing recognition of the necessity to utilize existing transmission system assets to the maximum extent possible which can be achieved with the help of FACTS devices. The flexible ac transmission system is the result of related developments in electronic devices designed to overcome the limitations of traditional mechanically controlled power transmission systems. By using reliable high-speed electronic controllers, the technology offers opportunity for increased efficiency. Some advantages which FACTS devices can offer are:Greater control of power, so that it flows on prescribed transmission routes.

- Secure loading of transmission lines to level nearer their thermal limits.
- Greater ability of transfer between controlled areas.
- Prevention of cascading outages.
- Damping of power system oscillations.

The active power transmitted over an AC transmission line is defined by the equation (2.1)

$$P = \quad 2.1$$

Where V_1 and V_2 are the voltages at the ends of the transmission line. X is the equivalent impedance of the transmission line, and $\delta1 - \delta2$ is the phase angle difference between both ends of transmission line. From the equation (2.1), it is evident that the transmitted power is a function of three parameters, the magnitude of sending end voltage and receiving end voltage, impedance and voltage angle difference. Traditional techniques of reactive line compensation and step like voltage adjustment are generally used to alter these parameters to achieve power transmission control. Different type of facts devices can be used to control one or more of these parameters to control the existing power system network. The fast response of FACTS devices improves the controllability of the system and thus makes the system more versatile.

1.1. ROLE OF FACTS DEVICES IN POWER SYSTEM.

FACTS devices play an important role in enhancing performances of power system. Some are given below:FACTS devices by controlling power, can improve the power system performance considerable such as improvement of power quality and security of the supply. FACTS technology can prevent the cascaded outages by limiting the impact of multiple faults, thereby improving the reliability of power supply. Upgrading of transmission lines can increase power quality by increasing voltage and /or current capacity with the help of these devices.

- The “free flow” mode of power system operation may be changed onto a controlled power flow mode of operation due to powerful controllability of FACTS technology where the power flow in one or more transmission lines is controlled in predetermined manner.
- FACTS technology can increase secure loading of transmission lines their steady state, short time and dynamic limits. Thus it enhances transient, voltage and small signal stability of power system.
- Due to high capital cost of high voltage transmission, cost considerations are main concerns. Although the price of FACTS devices in high, compared to other methods of solving transmission loading problem, yet FACTS technology is probably the most viable resort because of their ability to effectively control power flows, the power system can be operated in more optimized situation. As a result, large amount of money may be saved. Also, as people pay more and more attention to the environmental impact of new projects. Thus, it becomes very common for environmental opposition to frustrate attempts to established new transmission routes. Using FACTS technology, however, it is possible to transfer more power over existing routes, thus meeting consumer demand without the construction of new transmission lines. Although FACTS devices themselves need some places to be constructed, compared to the high voltage transmission line, the total environmental improvement is obvious.

BASIC TYPES OF FACTS CONTROLLERS

In this context, FACTS technology has been rapidly developed in the last ten years. The first FACTS device is Static Var Compensator (SVC) and has been in service for nearly two decades. It is a shunt device to maintain a healthy voltage profile in system. TCSC, TCSR are series controllers used to control line flows. Three Thyristor Controlled Series Compensation (TCSC) projects have been working successfully in USA since 1991. In general, FACTS controller can be divided into four categories, the general symbols for which is shown in Fig. 1.1, to Fig. 1.2.

- ✓ Series Controller
- ✓ Shunt Controller
- ✓ Combined Series-Series Controller
- ✓ Combined Series- Shunt controller

1.4.1 SERIES CONTROLLERS

The series controller could be variable impedance, such as capacitor, reactor, etc or power electronics based variable source of main frequency, sub synchronous and harmonic frequencies (or a combination) to serve the desired need. In principle, all series controller inject voltage in series with the line. Even variable impedance multiplied by the current flow through it represents an injected series voltage in the line. As long as the voltage is in phase quadrature with the line current, the series controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well. Common types of series FACTS controllers generally used are as follows:

1.Static Synchronous Series Compensator (SSSC)
2.Interline Power flow controllers(IPFC)
3.Thyristor Controlled Series Capacitor(TCSC)
4.Thyristor Switched Series Capacitor(TSSC)
5.Thyristor Switched Series Reactor(TSSR)

1.4.2 SHUNT CONTROLLER

As in the case of series controller, the shunt controllers may be variable impedance, variable source or a combination of these. In principle, all shunt controllers inject current into the system at the point of connection. Even variable shunt impedance connected to line causes a variable current flow and hence represents injection of current into the line as long as the injected current is in phase quadrature with the line voltage, the shunt controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well. The common type of shunt controllers in use are:

- ➢ Static synchronous compensator
- ➢ Static Synchronous Generator
- ➢ Static VAR Compensator
- ➢ Thyristor Controlled Reactor
- ➢ Thyristor Switched Reactor
- ➢ Thyristor Switched Capacitor
- ➢ Thyristor Controlled Breaking Resistor

1.4.3 COMBINED SERIES-SERIES CONTROLLERS

This could be a combination of separate series controllers, which are controlled in a coordinated manner, in a multi-line system. Or it could be a unified controller in which series controllers provide independent series reactive compensation for each line but also transfer realpower among the lines via the power link, the real power transfer capability of the unified series-series controller, referred to as interlink power flow controller, makes it possible to balance both the real and reactive power flow in the lines and thereby maximize the utilization of the transmission system. Note that the term 'unified' here means that the dc terminals of all controller converters are connected together through real power transfer link.

1.4.4 COMBINED SERIES- SHUNT CONTROLLERS

This could be a combination of separate shunt and series controller, which are controlled in a coordinated manner or a unified power flow controller with series and shunt elements. In principle, combined shunt and series controllers inject current into the system with the shunt part of the controller. However, when the shunt and series controllers are unified, there can be a real power exchange between the series and shunt controllers via the power link. Common types of these controllers are;

1. Unified Power Flow controller
2. Thyristor Controlled Phase Shifting Transformer
3. Inter-Phase Power controller.

Types of FACTS Controller :

The different FACTS Devices are helpful in controlling different parameters effectively. Generally the FACTS devices with both series and shunt controllers are most versatile devices. The operation for which a particular device can be used is given in the table 1.1. The implementation of any of the new FACTS controller is not an easy task. Although they offer substantial advantages for steady state and Dynamic operation by controlling the power flow in the transmission line, it brings major challenges in power electronics, device control and protection design which involves huge cost and efforts.

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Table 1.1: Different type of FACTS controller and it Control parameters.

FACTS CONTROLLERS	CONTROL PARAMETERS
Static Synchronous Compensator (Without Storage)	Voltage Control, VAR Compensation, Damping Oscillations, Voltage Stability
Static Synchronous Compensator (With Storage)	Voltage Control, VAR Compensation, Damping Oscillations, Voltage Stability, Transient and Dynamic Stability
Static VAR Compensator (SVC, TCR, TCS, TRS)	Voltage Control, VAR Compensation, Damping Oscillations, Voltage Stability, Transient and Dynamic Stability
Thyristor- Controlled Breaking Resistor (TCBR)	Damping Oscillations, Voltage Stability, Transient and Dynamic Stability
Static Synchronous Series Compensator (SSSC without Storage)	Current Control, Damping Oscillations, Transient and Dynamic Stability, Voltage Stability, Fault Current Limiting
Static Synchronous Series Compensator (SSSC with Storage)	Current Control, Damping Oscillations, Transient and Dynamic Stability, Voltage Stability
Thyristor Controlled Series Capacitor (TCSC, TSSC)	Current Control, Damping Oscillations, Transient and Dynamic Stability, Voltage Stability, Fault Current Limiting
Thyristor Controlled Series Reactor (TCSR, TSSR)	Current Control, Damping Oscillations, Transient and Dynamic Stability, Voltage Stability, Fault Current Limiting
Thyristor Controlled Phase Shifting Transformer(TCPR)	Active and Reactive Power control, Voltage Control, VAR Compensation, Damping Oscillations
Unified Power Flow Controller (UPFC)	Active and Reactive Power control, Voltage Control, VAR Compensation, Damping Oscillations
Interline Power Flow Controller (IPFC)	Reactive Power Control, Voltage Control, Damping Oscillations, Transient and Dynamic Stability, Voltage Stability

II. STATE OF ART

Flexible AC Transmission Systems (FACTS), based on either voltage or current source converter (VSC/CSC), can be used to control steady-state as well as dynamic/transient performance of the power system. Converter- based FACTS controllers, when compared to conventional switched capacitor/reactor and thyristor-based FACTS controllers such as Static Var compensator (SVC) and Thyristor-controlled series capacitor (TCSC) have the advantage of generating/absorbing reactive power without the use of ac capacitors and reactors. In addition, converter-based FACTS controllers are capable of independently controlling both active and reactive power flow in the power system. Various basic concepts about was explained in book, 'understanding FACTS concepts and Technology of Flexible AC Transmission systems' by author N. Hingorani and L. Gyugyi [1].

Series connected converter-based FACTS controllers include Static Synchronous Series Compensator (SSSC), unified Power Flow Controller (UPFC), and Interline Power Flow controller (IPFC). A SSSC is a series compensator with ability to operate in capacitive/inductive modes to improve system stability was discussed in paper [2, 3].

The UPFC includes a Static Synchronous Compensator (STATCOM) and a SSSC that share a common dc-link. The IPFC consists of two or more SSSC with a common dc-link, so each SSSC contains a VSC that is in series with the transmission line through a coupling transformer, and injects a voltage with controllable magnitude and phase angle into the line. IPFC provide independent control of reactive power of each individual line, while active power could be transferred via the dc- link between the compensated lines. An IPFC can also be used to equalize active/reactive power between transmission lines, and transfer power from overloaded lines to under-loaded lines [4].

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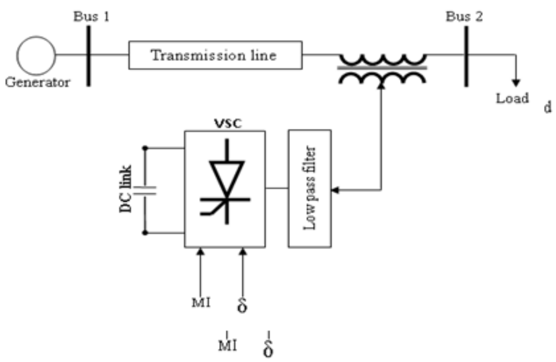
A simple model of IPFC with optimal power flow control method to solve overload problem and the power flow balance for the minimum cost has been proposed [5]. A multi control functional model of static synchronous series compensator (SSSC) used for steady state control of power system parameters with current and voltage operating constraints has been presented [6]. The injection model for congestion management and total active power loss minimization in electric power system has been developed [7]. Mathematical models of generalized unified power flow controller (GUPFC) and IPFC and their implementation in Newton power flow are reported to demonstrate the performance of GUPFC and IPFC [8]. An indirect unified power flow controller model to enhance reusability of Newton power flow codes has been proposed [9]. A current based model of static synchronous series compensator (SSSC) and interline power flow controller (IPFC) has been presented.

III. SWITCHING LEVEL MODELING OF SSSC & IPFC

3.1 STATIC SYNCHRONOUS SERIES COMPENSATOR



Static synchronous series compensator shown in Fig. 3.1 consists of a series transformer and a VSC. The primary of the series transformer connected in series with the transmission line and the secondary of the series transformer connected to the AC side of the VSC through small low pass filter. The purpose of the low pass filter is to eliminate the harmonic around its switching frequency. The function of the Static synchronous series compensator is to inject the voltage with the controllable magnitude in series with the transmission line. SSSC can inject the voltage in three ways. Lagging, in phase and leading with respect to line current. When the injected voltage lags the line current means, the converter will create the capacitive effect on an existing line, now the converter injects the reactive power to the system. When the injected voltage leads the line current means, the converter will create the inductive effect on an existing line, now the converter observes the reactive power from the system. As long as the injected voltage is in phase quadrature with the line current, the series controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power. The amount of real and reactive power exchange between converter and transmission line is controlled by varying the Modulation Index (MI) and phase angle (δ).

3.2 OPERATION OF SSSC AND THE CONTROL OF POWER FLOW

3.2.1 DESCRIPTION

The Schematic of a SSSC is shown in Fig. 3.2(a). The equivalent circuit of the SSSC is shown in Fig. 3.2(b).

The magnitude of V_c can be controlled to regulate power flow. The winding resistance and leakage reactance of the connecting transformer appear is series with the voltage source V_c. If there is no energy source on the DC side, neglecting losses in the converter and DC capacitor, the power balance in steady state leads to

$R_e\,[\,V_c * I] = 0$

above equation shows that compensating voltage ($V_{C)}$ is in quadrature with line current (I). If V_c lags I by 90^o, the Operating mode is capacitive and the current (magnitude) in the line is increased with Resultant increase in power flow. On the other hand, if V_c leads I by 90 degree, the operating mode is inductive, and the line current is decreased. Note that we are assuming the injected voltage is sinusoidal (neglecting harmonics).

Since the losses are always present, the phase shift between I and V_c is less than 90 degree (in steady state). In general, we can write,

$$V_c = V_c(cos\gamma - j sin\gamma)e^{-j\emptyset} = (V_{cp} - jV_{cr})e^{-j\emptyset}$$

Where Ø is the phase angle of the line current, γ is the angle by which V_c lags the current. V_{cp} and V_{cr} are the in-phase and quadrature components of the injected voltage with reference to the line current. We can also term them as active or real and reactive components. The real component is required to meet the losses in the converter and the DC capacitor.

We use the convention that the reactive voltage lagging the current by 90 degree as positive. According to this convention, the positive reactive voltage implies capacitive mode of operation while negative reactive voltage implies inductive mode of operation since γ is close to ±90 degree, we can write,

$$\gamma = sgn(V_{cr})[-90^{\circ} + \alpha^{\circ}]$$

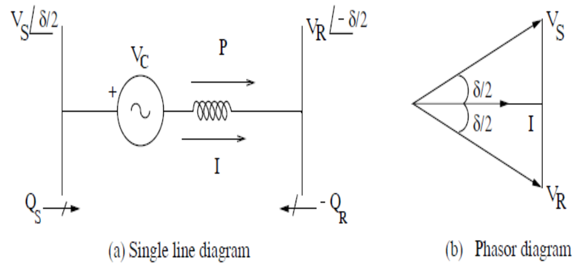


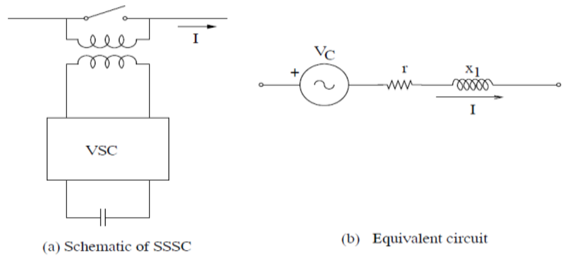
Fig.: Single line diagram of SSSC, Fig. 3.3(a): Phasor diagram

Where sgn indicates the sigma function whose value is +1 if the argument is Positive and -1 if the argument is negative substituting Eq. 3.3 in Eq. 3.2 we can write,

$$V_{cp} = V_c sin\alpha$$

$$V_{cr} = V_c cos\alpha$$

Sine losses are expected to be small (typically below 1% the magnitude of V_{cp} is very small and be neglected to simplify the analysis. V_{cp} will vary during a transient to increase or decrease the voltage across the DC capacitor (Particularly in the case of type 2 Converter where the ratio between the AC voltage and the DC voltage is constant, with no modulation).



3.2.2 POWER FLOW CONTROL CHARACTERISTICS

A SSSC controls the power flow in a transmission line by varying the magnitude and polarity of the reactive voltage injected in series with line. In this section, we will study the control characteristics of a SSSC in the P – Q plane where P and Q are the power and reactive power at the receiving end. In deriving the control characteristics we will relax the assumptions about losses in the line and the equality of sending end and receiving end voltage magnitudes.

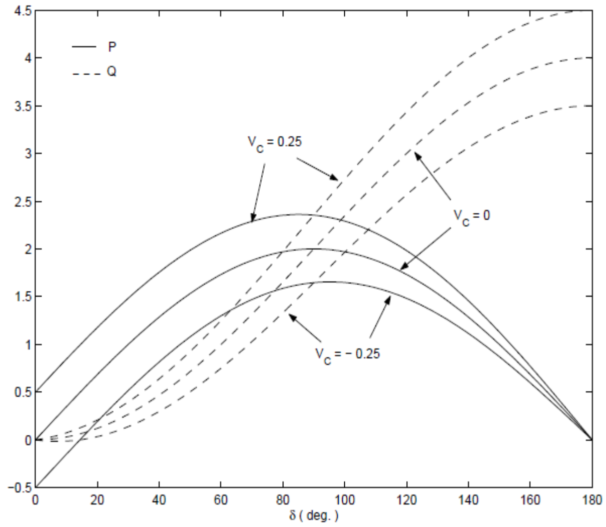


Fig.: Variation of P and Q with δ

If Z = R +jX represents the series impedance of the line shown in Fig. 3.4, the complex power at the receiving end (SR) is given by 3.4

$$S_R = P_R + jQ_R = \frac{\bar{V_r}(\bar{V_s} - \bar{V_C} - \bar{V_R})*}{Z*}$$

If $V_C = 0$, then S_R is defined as

$$S_R = S_o = P_o + jQ_o = \frac{\bar{V_r}(\bar{V_s} - \bar{V_R})*}{Z*}$$

Substituting Eq. 3.5 in 3.4 we get

$$S_R = S_o - \frac{\bar{V_r}(V_c)*}{Z*}$$

Assume V_c is purely reactive Voltage, then

$$\bar{V_c} = -jA\hat{I}, \qquad A = \frac{V_C}{|I|}$$

Substituting Eq. 3.7 in 3.6 and noting that

$$I^* = \frac{S_R}{V_R}$$

We obtain,

$$S_R = S_o - \frac{\bar{V_r}(jAI^*)}{Z^*} = S_o - j\,\frac{AS_R}{Z^*}$$

From the above, we can solve for S_R as,

$$S_R = \frac{S_o Z^*}{Z^* + jA} = \frac{S_o Z^*}{R} + j(A - X)$$

Operating region and control characteristics of a SSSC in the P_R - Q_R plane

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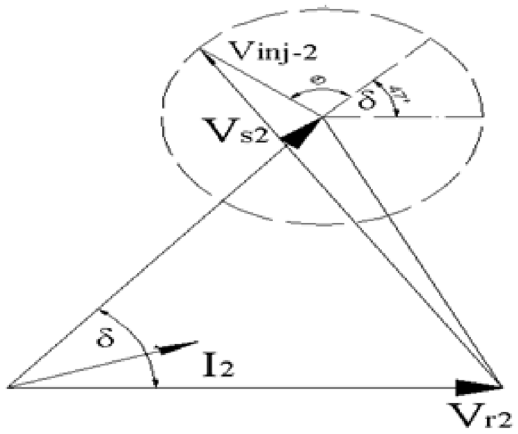
As A varies from -∞ to +∞, the locus of R = j (A-X) in the R-X plane is a straight line parallel to the X axis and passing through the point (R, 0). The locus of the reciprocal of R + J(A-X) is a circle with the center ((1/2R), 0) and radius 1/2R. From Eq. 3.9, it can be seen that SR describes a circle in the P-Q plane with $(S_oZ^*)/(2R)$ as center and radius of $|(S_oZ^*)/(2R)$.

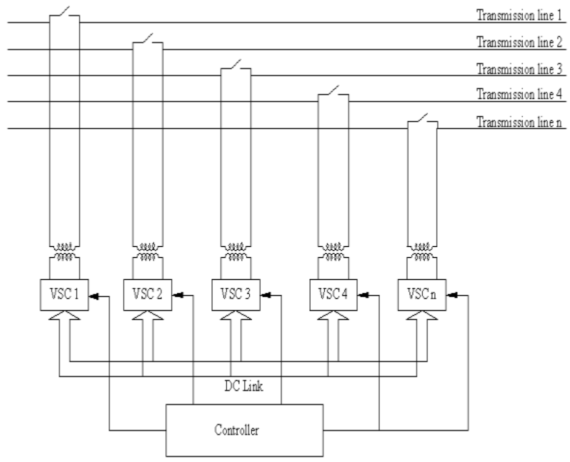
Note that this circle passes through the origin as well as the point S_0 (corresponding to V_C= 0). The locus of P_R and Q_R lie on the circumference of the circle which is a function of S_0 and the ratio X/ R. The value of S_0 (P_R and Q_R in the absence of SSSC) is a function of δ and the line impedance Z (for specified V_S and V_R). However, different combinations of Z and δ can give a specified value of S_0.



If $|S_0|$ = 1.0 and X/R = 10, then the radius of the circle is 5.025 Pu. Fig. 3.5 shows the control characteristics for P_0 = 1.0, Q_0 = 0.0, with $|S_0|$ = 1.0. The range of operation of a SSSC is only a part of the circle around the operating point S0. This is due to the limitations imposed by the rating of SSSC. Fig. 3.5 also shows the range of operation of a SSSC which is bounded by a circle with S_0 as centre and radius = $|V_{C\ max}$ V/ Z

3.3 INTERLINE POWER FLOW CONTROLLER

An interline power flow controller consist of two or more SSSCs that share a common DC-link. The SSSCs are usually utilized as a reactive compensator, while IPFCs could be employed as a comprehensive active and reactive compensator. IPFCs provide independent control of reactive power of each individual line, while active power could be transferred via the DC terminal between the compensated lines. This gives the IPFC an additional degree of freedom to control and added variable in the power system. This capability makes it possible to transfer power from overloaded to under-loaded lines, reduce the line resistive voltage drop, and increase the stability of the power system against dynamic disturbances.



The IPFC provides several operation functions depending on the system operating requirements, such as independent active and reactive power flow control, transmission angle regulation and transmission line impedance control.

3.4 BASIC PRINCIPLE OF IPFC OPERATION

Fig. 3.6 shows a basic scheme of an IPFC consisting of two back- to-back VSCs that inject voltages in series with the transmission line. Each VSC is represented by a synchronous voltage source. V_{s1} and V_{r1} are the sending-end and receiving-end voltage phasor of line1 respectively.

V_{s2} and V_{r2} are the sending-end and receiving-end voltage phasor of the line 2 respectively. The transmission lines impedances are represented by X_{L1} and X_{L2}. The VSC's injected voltages are represented by $V_{inj-1}\angle Ø_1$ for line 1 and $V_{inj-2}\angle Ø_2$ for line 2. The two lines are assumed identical and $V_{s1}=V_{r1}=V_{s2}=V_{r2}=1$ pu. The phasor diagrams of system 1 and sysem 2 are show in Fig. 3.8.

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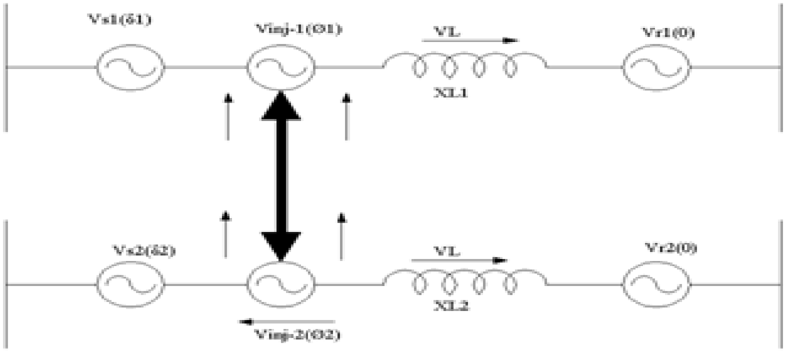
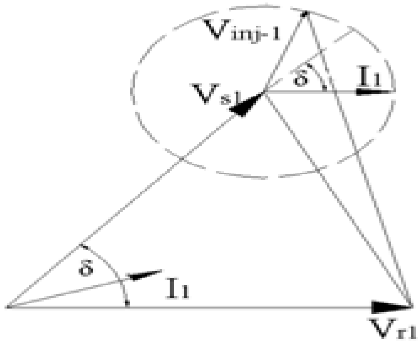


Fig. : Phasor diagram of IPFC (a)



phasor operating area is a circle and depends on its amplitude and angle, so the voltage drop across the transmission line can be regulated.

3.4.1 ACTIVE POWER EXCHANGE OF IPFC

Controlling the phase angle of the injected voltage regulates the active power exchange between the IPFC and the transmission line. If the transmission line resistance is neglected the exchange active power can be estimated as follow

$$P_{ex} = \frac{VV_{inj}}{X_L} (\sin(\delta + \theta) - \sin\theta)$$

3.4.2 POWER FLOW AT THE RECEIVING END

In IPFC, since the DC-Link voltage is maintained by one of the SSSCs the rest of the SSSCs can be considered as voltage sources with controllable magnitude and phasor angle. Therefore, both active and reactive power flow in the transmission lines controllable. The power flow at the receiving-end can be estimated by the following equations if the line resistance neglected.

$$P_r = \frac{V^2}{X_L} (\sin\delta) + \frac{VV_{inj}}{X_L} (\sin(\delta \quad 3.11$$

$$Q_r = \frac{V^2}{X_L} (\cos\delta - 1) + \frac{VV_{inj}}{X_L} (\cos(\delta + \quad 3.12$$

In this thesis, an IPFC application for transmission line impedance regulation is investigated.

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3.5 IPFC CONSTRAINTS OPERATING LIMITS

The IPFC has the following limitations:

- Series VSC, complex power rating
  $|S_{ser\text{-}i}| \leq S_{ser\text{-}max}$
  Where $S_{ser\text{-}I}$ is the complex power that is injected in to the transmission line by VSC. The rated power of the IPFC is specified by its rated injected voltage amplitude and rated transmission line current.
- The injected series voltage in to the transmission line
  $V_{ine\text{-}I} \leq V_{ine\text{-}max}$
- The active power supply is constrained by the minimum transmission line current. Basically, in IPFC the active and reactive power compensation are independent. But in inductive mode of operation by increasing the degree of compensation the transmission line current decreases and the VSC has limited voltage rating to provide the required MVA for the transmission line.

3.6 THE ACTIVE POWER IN DC LINK

In the IPFC, the active power extracted by one of the VSC must be equal to the active power that is supplied in to the other transmission lines, if the VSCs losses are neglected. Therefore, the total active power that the IPFC can exchange with the transmission line is zero i.e.

(i= 1, 2, 3…)

Where $S_{series\text{-}i}$ shows the active power that each SSSC exchange with the transmission line and can be calculated by

$$P_{Series-i} = V_{inj-1} * I_{line-1} * \cos(\emptyset_1)$$

Where $\emptyset_1$ is the phase angle between the injected voltage and the transmission line current of each line.

IPFC CONTROLLER STRATEGY

4.1 IMPEDANCE CONTROLLER

Depending on the operating requirements of the power system, the IPFC can have several operational functions. In this project, the IPFC is designed to maintain the impedance of the two transmission lines. The first Converter is capable of injecting both resistive and inductive impedance into the transmission line. The second Converter keeps the DC-link voltage at desired level. In both control systems, the series VSCs are equipped with a direct controller. Hence the DC-link voltage is kept constant, and by varying the converters gain and phase angle the injected voltage isregulated. Each SSSC is independently controlled. Thus, the preliminary

IPFC consist of two converter system.

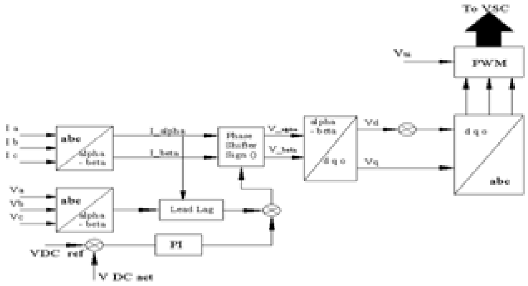
(a) A master converter system that is capable of regulating impedances of Line 1.

(b) A slave converter system that regulates dc-link voltage of the VSC at a desired level.

Figure 4.1 shows the block diagram for the slave system, the function of the slave controller is to maintain the DC-link voltage controller constant at a desire level. Block 1 is used to transform the three phase voltage injected by the VSC ($Ninj_a$, $V_{inj\ b}$, and N_{inja}) in to the two phases as the equation (4.1).

Block 2 is used to transform the three phase line currents (Ia, Ib and Ic) to the α – β – 0 coordinated using the RWG block. For generating reference waveforms for control purposes, the three phase currents are transformed from a – b

Fig. : IPFC slave converter system controller



– c to α – β – 0 coordinates, by using equation (4.2).

Block 5 (Lead/ Lag Block) receives the reference signal of the line voltage V_α and from

block 3 and the reference signal of the line current I_α from block 2 and computes the 90° phase shift and its sing, whether leading (+1) or lagging (-1) of this angular displacement. This information is summed with the output angle from the DC voltage controller.

Block 3 receives the I_α and I_β reference signals from block 2. These signals are modulated by the sum of the signals from the DC voltage controller and Lead/ Lag blocks to generate the modified reference signals V_α' and V_β'.

$$\begin{bmatrix} S_d \\ S_q \end{bmatrix} = \begin{bmatrix} \cos\omega t & \sin\omega t \\ -\sin\omega t & \cos\omega t \end{bmatrix} * \begin{bmatrix} S_\alpha \\ S_\beta \end{bmatrix}$$

Block 4 is the α – β – 0 to d – q- 0 transformation block used to convert the two phase reference components in stationary frame V_α' and V_β' to two phase reference component in synchronously rotating frame V_d' and V_q' as per the equation 4.3. These signals are then fed to PWM trigger unit to generate the pulse.

$$\begin{bmatrix} v_{inj-\alpha} \\ v_{inj-\beta} \\ v_{inj-o} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} v_{inj-a} \\ v_{inj-b} \\ v_{inj-c} \end{bmatrix}$$

$$\begin{bmatrix} i_{\alpha} \\ i_{\beta} \\ i_{o} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_{a} \\ i_{b} \\ i_{c} \end{bmatrix}$$

The active power exchange is regulated by the phase angle ϕ of the injected voltage in response to an error in the DC-link voltage via a PI controller. The dc-link voltage Vdc is maintained constant and is equal to Vdc-ref and by changing the converter dc/ac gain, the injected voltage amplitude is controlled.

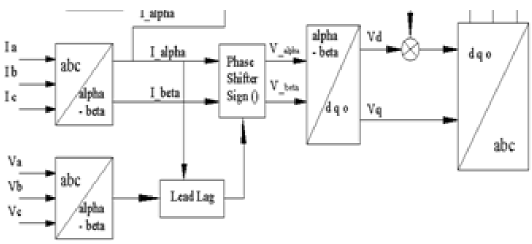
Fig.4.2 shows the overall control structure of the master IPFC system. This block diagram is similar to the block diagram of the slave IPFC system and has many of the same blocks except for two major differences: (a) the dc voltage controller and (b) Impedance controller. Since the dc-link voltage is controlled by the slave system, the dc voltage controller no longer needed. In order to control the impedance of the transmission line 1 impedance controller is added in addition to the slave controller.

To regulate the injected impedance, an impedance Controller is used. The injected impedance Z_{inj-1} is compared to a reference Z_{ref} and error is fed to a PI controller. The resultant is added to the d- component of the desired reference waveform V_d'. In this particular case, a PID may also apply to reduce the oscillations of the time response.

Block 6 receives the modified d- and q- components V_d' and V_q' and transform them to three phase coordinated as per the equation 4.4, these signals are used as the reference signals V_a*, V_b* and c* of PWM controller. And the PEM block provides firing pulses for the VSC switched. Since the master converter system regulates the dc- link voltage to a fixed level, theoretically it is capable of injecting a voltage with a phase angle in the range of 0-360°.

$$\begin{bmatrix} S_d \\ S_q \\ S_0 \end{bmatrix} = \sqrt{\frac{2}{3}} * \begin{bmatrix} \cos\omega t & \sin\omega t & 0 \\ -\sin\omega t & \cos\omega t & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} * \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix}$$

Fig. : Simulink model of SMIB system with SSSC



The dynamic behavior of the IPFC with this type of controller was investigated and results were given in the chapter 6.

4.2 VOLTAGE CONTROLLER

The features of this type of controller are

1. (i). Maintain the Injected voltage constant irrespective of variation in the load.
2. Power flow on the transmission line can be controlled by controlling the injected voltage.
3. Injected voltage can be controlled by varying the DC link voltage constant instead of keeping constant

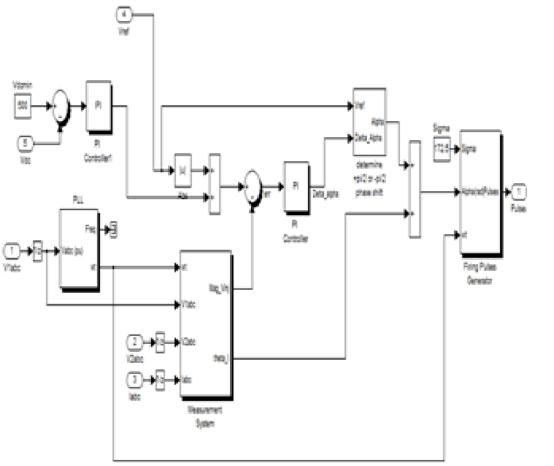
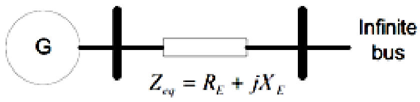


Fig. 4.3: Voltage controller

MODELING OF PRACTICAL UTILITY SYSTEM

5.1 SINGLE MACHINE INFINITE BUS SYSTEM

An infinite bus system is the source of constant frequency and voltage either in magnitude or angle. The Fig. 5.1 shows the representation of the single machine infinite bus system. In this section we will study the power flow analysis on a single machine connected to a large system through transmission line.



Analysis of system having such simple configuration is extremely useful in understating basic effects and concepts. After we develop an appreciation for the physical aspects of the phenomena and gain experience with the analytical techniques, using simple

Fig. 5.1: Schematic representation of SMIB system

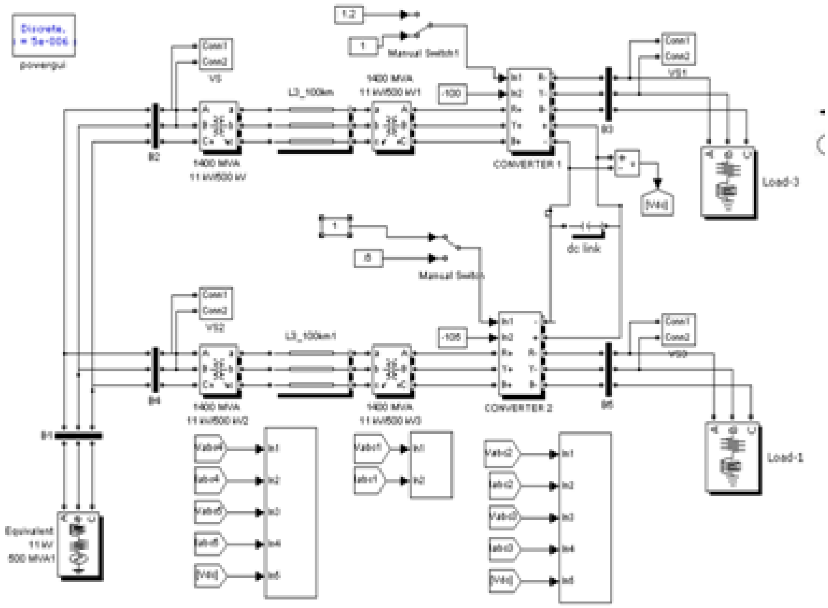
low order system, we will be in a better position to deal with large complex systems

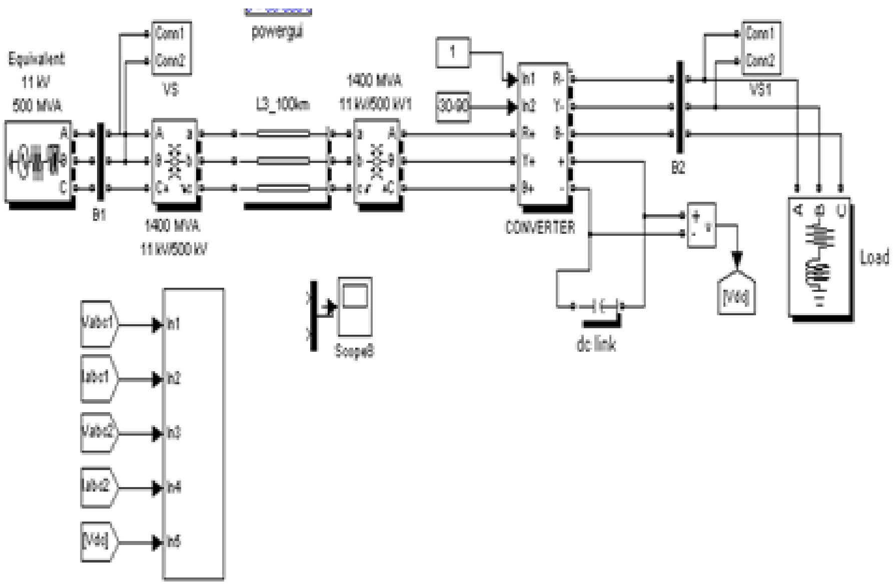
The simulink model of the single machine infinite bus system is shown in the Fig. 5.2, for the analysis purpose the synchronous generator is modeled as the three phase voltage source followed by impedance. The value of the internal impedance decides the max KVA rating of the generator. The transmission line is modeled using the distributed parameter block available in the simulink tool box. The power system connected to the system is modeled using the PQ load. Power flow analysis results were discussed in the 6th chapter.

5.2 PARALLEL TRANSMISSIONS

If the load demands on the existing transmission line is increased above the specified limit. There is a possibility of line outage. This problem can be overcome by running the parallel transmission line in addition to the existing line this will be often called as parallel transmission. The general representation of parallel transmission line is shown in the Fig. 5.3. The load flow results were presented in the 6th chapter.

5.3 MODELING OF IEEE 30 BUS SYSTEM





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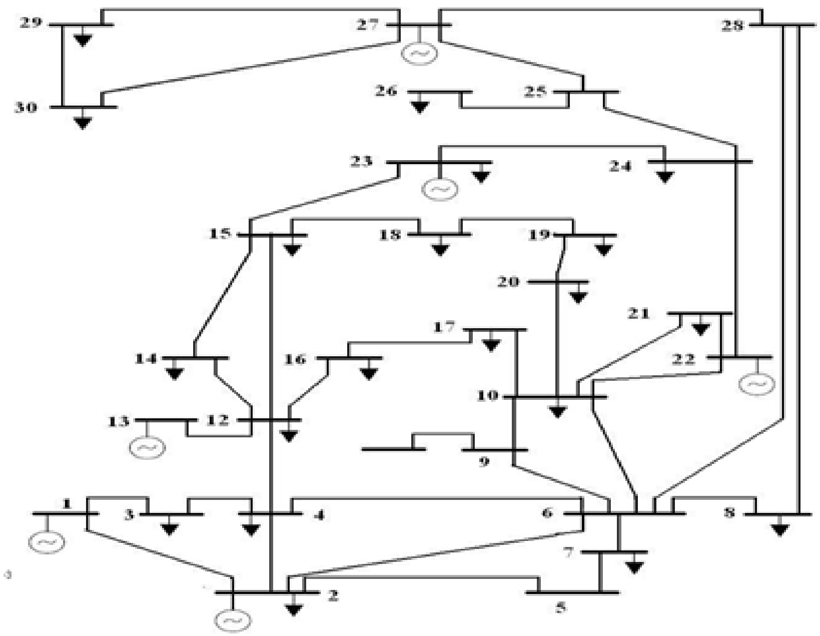
It consists of six generating units, 41-transmission lines, two VAR injecting sources, and four tap changing transformers. The base real power demand of the system is 281.43MW and the base reactive power demand of the system is 134.3 KVAR. The single line diagram of the IEEE 30 bus system is shown in Fig. 5.4. The line data are given the table 5.1. The bus data are given in the table 5.2. To study the dynamic behavior of the IPFC on the IEEE 30 bus system power flow analysis were carryout. The voltage profile, real power flow and reactive power flow at various buses are measured which was discussed detain in the 6th chapter.

Fig. : Single line Diagram of IEEE 30 Bus system



Bus No.	Type of bus	Voltage at Bus (pu)	Angle (Deg)	load PL (MW)	QL (MVAR)
1	1	1.06	0	0.0	0.0
2	2	1.04	0	21.70	12.7
3	0	1.0	0	2.4	1.2
4	0	1.06	0	7.6	1.6
5	2	1.01	0	94.2	19.0
6	0	1.0	0	0.0	0.0
7	0	1.0	0	22.8	10.9
8	2	1.01	0	30.0	30.0
9	0	1.0	0	0.0	0.0
10	0	1.0	0	5.8	2.0
11	2	1.08	0	0.0	0.0
12	0	1.0	0	11.2	7.5
13	2	1.071	0	0.0	0.0
14	0	1.0	0	6.2	1.6
15	0	1.0	0	8.2	2.5
16	0	1.0	0	3.5	1.8
17	0	1.0	0	9.0	5.8
18	0	1.0	0	3.2	0.9
19	0	1.0	0	9.5	3.4
20	0	1.0	0	2.2	0.7
21	0	1.0	0	17.5	11.2
22	0	1.0	0	0.0	0.0
23	0	1.0	0	3.2	1.6
24	0	1.0	0	8.7	6.7
25	0	1.0	0	0.0	0.0
26	0	1.0	0	3.5	2.3
27	0	1.0	0	0.0	0.0
28	0	1.0	0	0.0	0.0
29	0	1.0	0	2.4	0.9
30	0	1.0	0	10.6	1.9

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Bus No.	Generator				Injected (MVAR)
	P_{Gen} (MW)	Q_{Gen} (MVAR)	Q_{min} (MVAR)	Q_{max} (MVAR)	
1	173.8	0	0.0	0.0	0.0
2	49.99	0	-20	100	0.0
3	0.0	0	0.0	0.0	0.0
4	0.0	0	0.0	0.0	0.0
5	21.38	0	-15	80	0.0
6	0.0	0	0.0	0.0	0.0
7	0.0	0	0.0	0.0	0.0
8	22.630	0	-15	60	0.0
9	0.0	0	0.0	0.0	0.0
10	12.929	0	-6	24	19
11	0.0	0	-10	50	0.0
12	12.00	0	0.0	0.0	0.0
13	25.0	0	-15	60	0.0
14	0	0	-20	80	0.0
15	0	0	0.0	0.0	0.0
16	0	0	0.0	0.0	0.0
17	0	0	0.0	0.0	0.0
18	0	0	0.0	0.0	0.0
19	0	0	0.0	0.0	0.0
20	0	0	0.0	0.0	0.0
21	0	0	0.0	0.0	0.0
22	0	0	0.0	0.0	0.0
23	0	0	0.0	0.0	0.0
24	0	0	0.0	0.0	4.3
25	0	0	0.0	0.0	0.0
26	0	0	0.0	0.0	0.0
27	0	0	0.0	0.0	0.0
28	0	0	0.0	0.0	0.0
29	0	0	0.0	0.0	0.0
30	0	0	0.0	0.0	0.0

Table 5.2: Line data for 30 bus system

BUS		R (P.U)	X (P.U)	½ B (P.U)	TRANSFORMER (TAP)	MVA (LIMITS)
FROM	TO					
1	2	0.0192	0.0572	0.264	1	130
1	3	0.0452	0.182	0.0204	1	130
2	4	0.057	0.1737	0.0184	1	65
3	4	0.0132	0.0379	0.0042	1	130
2	5	0.0472	0.19983	0.0209	1	130
2	6	0.0581	0.1763	0.0187	1	130
4	6	0.0119	0.0414	0.0045	1	90
5	7	0.046	0.116	0.01102	1	32
6	7	0.0267	0.082	0.0085	1	90
6	8	0.012	0.042	0.0045	1	62
6	9	0	0.208	0	0.9780	16
6	10	0	0.556	0	0.9690	32
9	11	0	0.208	0	1	65
9	10	0	0.11	0	1	65
4	12	0	0.256	0	1	65
12	13	0	0.14	0	1	32
12	14	0.1231	0.2559	0	1	16
12	15	0.00662	0.1304	0	1	32
12	16	0.0945	0.1987	0	1	32
14	15	0.221	0.1997	0	1	16
16	17	0.0824	0.11923	0	1	16
15	18	0.1073	0.2185	0	1	16
18	19	0.0639	0.1292	0	1	16
19	20	0.04	0.068	0	1	16
10	20	0.0936	0.209	0	1	16
10	17	0.0324	0.0845	0	1	16
10	21	0.0348	0.0749	0	1	16
10	22	0.0727	0.1499	0	1	16
21	22	0.0116	0.0236	0	1	16
15	23	0.1	0.202	0	1	16
22	24	0.115	0.179	0	1	30
23	24	0.132	0.27	0	1	16
24	25	0.1885	0.3292	0	1	16
25	26	0.2544	0.38	0	1	16
25	27	0.0193	0.208	0	1	16
28	27	0	0.396	0	0.9680	65
27	29	0.2198	0.4153	0	1	16
27	30	0.3202	0.6027	0	1	16
29	30	0.2399	0.4533	0	1	16
8	28	0.0636	0.2	0	1	32

SIMULATION RESULT

Interline Power Flow Controller is the combination of two or more than two Static Synchronous Series Compensator linked together with the common DC link operating in coordinate manner. The basic building block of Static Synchronous Series Compensator is a voltage source converter. The simulation of Static Synchronous Series Compensator and Interline Power Flow Controller using switching level simulation models with dynamic operating conditions are carryout in this dissertation. Simulation is carryout in the simulink environment. The simulation results are discussed in the following 9 sections.

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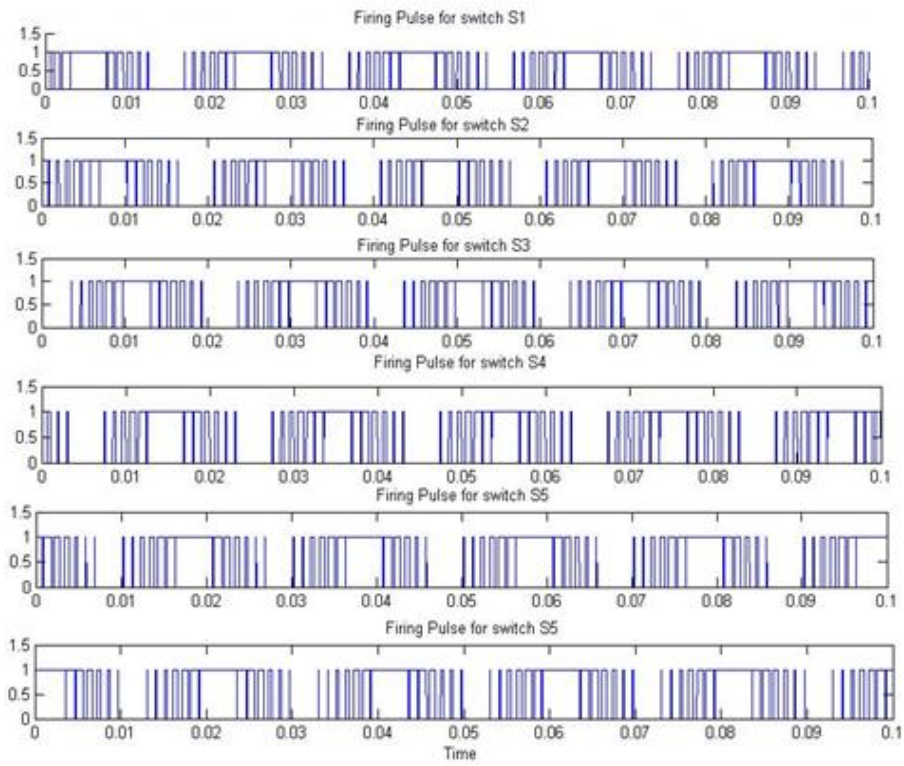

6.1. VOLTAGE SOURCE CONVERTER

SPWM technique sinusoidal reference wave is compared with the triangular carrier wave to generate the pulse. The output voltage of the converter is varied by varying the modulation index. The modulation index is the ratio between amplitude of the sinusoidal reference wave A_r to the amplitude of the carrier wave A_c (MI= A_r/A_c). Fig. 6.1, shows the sinusoidal reference wave is compared with the 900Hz Triangular carrier wave to generate the Firing pulse. Fig. 6.2, shows the

harmonic around it switching frequency is only present. It is inferred that as the switching frequency increases the harmonics are pushed for away from the fundamental frequency.

Sinusoidal pulse width modulation is used to generate the firing pulse for voltage source converter. In the pulse Patten for the power switcher S1 to S6 respectively.

To study the operational characteristic of voltage source converter, initially VSC is operated with resistive load. The phase voltage (V_a) and line voltage (V_{ab}) waveforms are shown in the Fig. 6.3a, and Fig. 6.3b, respectively. In 180 degree mode of conduction phase voltage is a six stepped waveform. Fig. 6.4a, & Fig. 6.4b, shows the frequency spectrum for the phase voltage and line voltage. From the FFT analysis, it is found that the

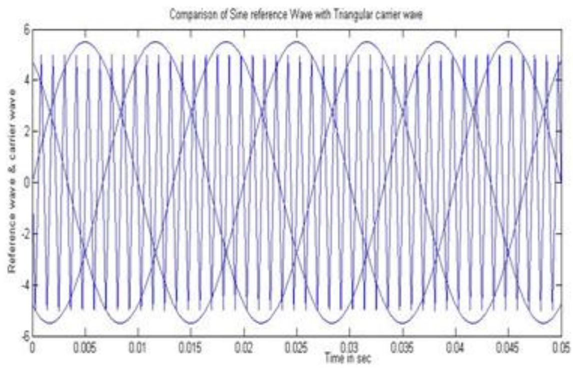

Fig. 6.1: SPWM Switching Waveforms

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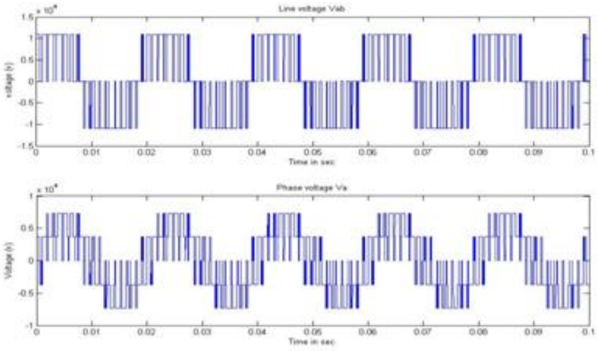

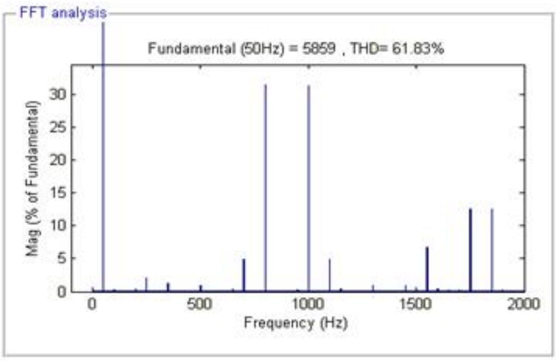

Fig. 6.3a: Inverter output line voltage
Fig. 6.3b: Inverter output Phase voltage

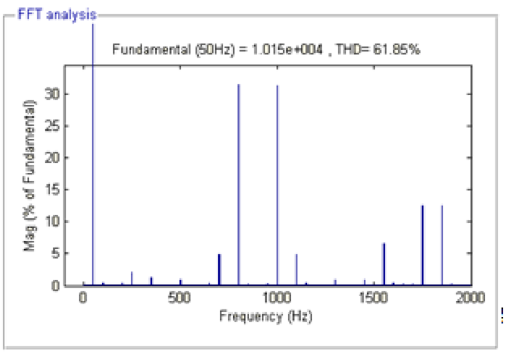

Fig. 6.4a: Harmonic analysis for line voltage

From the Fig. 6.4(a) and Fig. 6.4(b) it is inferred that the THD of the output voltage was found to be 61.8%. Also it is understood that the harmonic around it switching frequency only presents.

The relationship between modulation index versus output voltage of inverter is shown in Fig. 6.5, if the modulation index lies between 0 <MI < 1 the output voltage increases linearly for any small variation in the MI. When the modulation index is greater than one output voltage get constant at one particular point of time, this will be called as square modulation. This property of the inverter is used as a control parameter in the SSSC and IPFC.

6.2. POWER FLOW ANALYSIS ON SINGLE MACHINE INFINITE BUS SYSTEM

REQUIRED DEMAND ON SMIB SYSTEM	ACTUAL POWER FLOW ON THE SMIB SYSTEM
P_L = 140 MW	P_L = 92.24 MW
Q_L = 130 MVar	Q_L = 90 MVar
V_L = 11 kV	V_L = 9.2 kV

Table 6.1: Power flow analysis on SMIB system

The power flow analysis results on the single machine infinite bus system is shown in the table 6.1. It observed that the required demand on the load side will be 140 MW and 130 MVar at 11 kV, but due to heavy reactive power demand the system will able to deliver only the 92.24 MW and 90 MVar at 9.2 kV. From the result, it is inferred that when the reactive power demand increases voltage profile decreases. System required the reactive power compensation.

6.3. OPEN LOOP RESPONSE OF THE SSSC ON THE SMIB SYSTEM

In the earlier section, it is clearly explain that the function the Static Synchronous Series Compensator (SSSC) is to inject the voltage in series with the transmission line. The SSSC inject the voltage in three different ways, the corresponding voltage waveform, current waveform and power flows on the transmission line are given below. Most of the loads used in the power system are inductive in nature it required more reactive power, in that case the system required capacitive compensation (case i). Under lightly loaded condition or no load condition, due to presence of line charging admittance the receiving end voltage is greater than sending end voltage, in that case the system required inductive compensation (case ii).

Case i : Injected Voltage lagging the line current.
Case ii : Injected voltage in phase with line current.
Case iii: Injected voltage leading the line current

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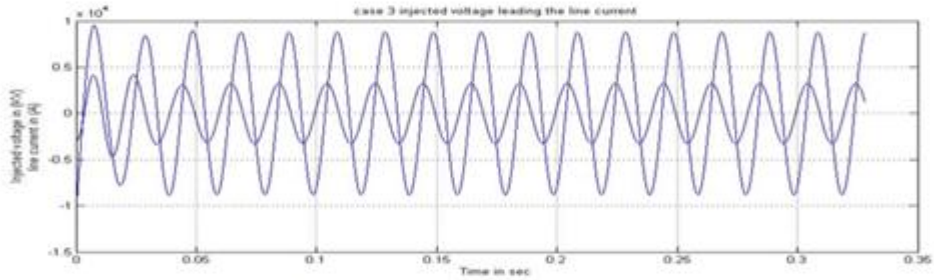

Fig. 6.8: Injected voltage leading the line current

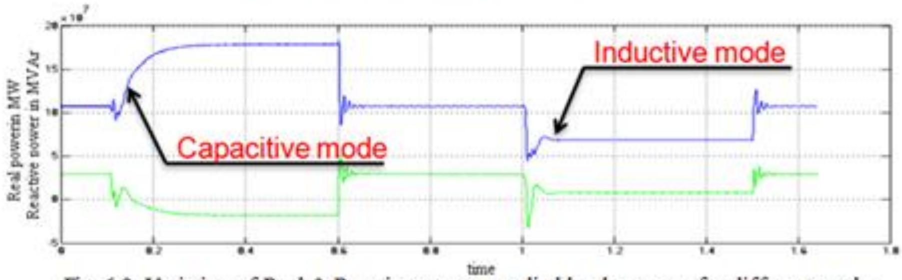

Fig. 6.9: Variation of Real & Reactive power supplied by the source for different mode

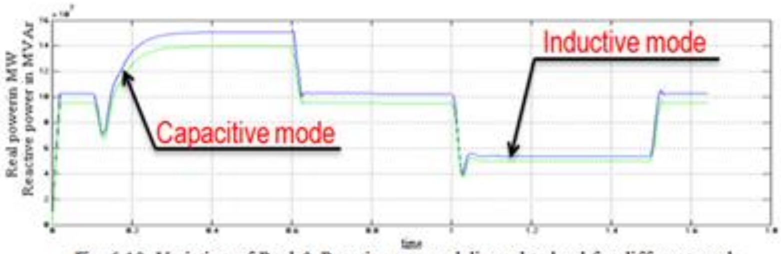

Fig. 6.10: Variation of Real & Reactive power delivered to load for different mode

Fig. 6.6, Fig. 6.7, and Fig. 6.8, show the waveform when the injected voltage lagging, in phase and leading the line current. Their corresponding power flow result is shown in Table-6.2. Fig. 6.9, shows the waveform for variation of real and reactive power derived from the source. Similarly Fig. 6.10, shows the waveform for variation of Real and Reactive power flow delivered to the load for different compensation. The time period between 0-0.1 sec and 0.6-1.0 sec the system will operate as an uncompensated transmission line, under this condition the inverter is bypassed through breaker. The time period in between 0.1-0.6 sec the inverter is switched in to the system in capacitive mode under this condition the converter will injects the reactive power to the system, so the power flow on an existing transmission line will increased. The time period in between 1.0-1.5 sec the inverter is switched in to the system in inductive mode under this condition the converter will observes the reactive power to the system, so the power flow on an existing transmission line will decrease. The power flow result on the SMIB system before and after connecting the SSSC is given in Table 6.2.

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Actual Demand On SMIB system	Power flow on the SMIB system without SSSC	Power flow on the SMIB system with SSSC		
		Case i	Case ii	Case iii
P_L =140 MW	P_L =92.24 MW	P_L =150.6 MW	P_L =25.2 MW	P_L =53.7 MW
Q_L=130 MVar	Q_L=90 MVar	Q_L=139.8 MVar	Q_L=23.4MVar	Q_L=49.94 MVar
V_L=11 kV	V_L=9.2 kV	V_L=11.4 kV	V_L=4.6 kV	V_L=6.81 kV

Table 6.2: Load flow analysis on SMIB system with SSSC

6.4. POWER FLOW ANALYSIS ON PARALLEL TRANSMISSION LINES

If the load demands on the existing transmission line is increased above the specified limit. There is a possibility of line outage. This problem can be overcome by running the parallel transmission line in addition to the existing line. The load flow analysis on the Parallel Transmission line with equal load and unequal load on the both the line are given in the table 6.3, from the table it observed that the required demand on the both line with equal load will be 130 MW and 120 MVar at 11 kV, but due to heavy reactive power demand the system will able to deliver only the 105.5 MW and 22.65 MVar. Similarly the required demand on the both line with unequal loads will be P_{L1} =155 MW, P_{L2}=100 MW, Q_{L1}=140 MVar and Q_{L2}=90 MVar were as the delivered power to the both loads P_{L1}=1207 MW, Q_{L1}=109 MVar, P_{L2}=80.20 MW and Q_{L2}=72.26 MVar, from the power flow results on the parallel transmission lines it is inferred that we need to provide the reactive power compensation. Interline power flow controller will provide the required compensation to the parallel transmission line.

Equal loads on both the lines (P in MW, Q in MVar)				Unequal loads on both the lines (P in MW, Q in MVar)			
Required Demand On the parallel lines system		Actual power flow on the parallel lines		Required Demand On the parallel lines system		Actual power flow on the parallel lines	
Line 1	Line 2	Line 1	Line 2	Line 1	Line 2	Line 1	Line 2
P_L =130	P_L =130	P_L =105.2	P_L =105.2	P_L =155	P_L =100	P_L =120.7	P_L =80.20
Q_L = 120	Q_L = 120	Q_L = 22.65	Q_L = 22.65	Q_L =140	Q_L =90	Q_L =109	Q_L =72.6

Table 6.3: Load flow analysis on Parallel Transmission Line

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6.5. OPEN LOOP RESPONSE OF THE IPFC ON THE PARALLEL TRANSMISSION LINES

To study the operational characteristics of the Interline Power Flow Controller the following two case studies were carryout.

Case i: Interline power flow controller with equal loads on both the lines.

Case ii: Interline power flow controller with Unequal loads on both the lines.

Case i: Interline power flow controller with equal loads on both the lines

Fig. 6.11, shows the variation of the injected voltage by the converter 2 on the line 2 for the variation the modulation of the converter 2 (MI_2) but keeping the modulation index of the converter 1 (MI_1) constant.

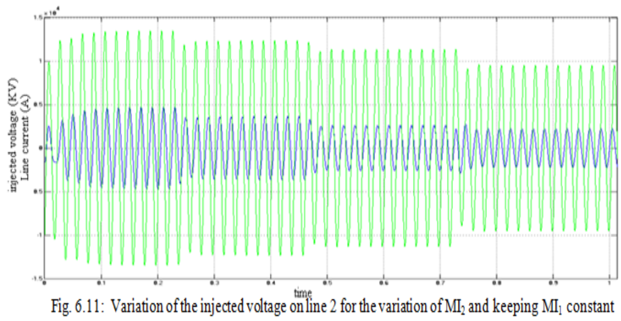

Fig. 6.11: Variation of the injected voltage on line 2 for the variation of MI_2 and keeping MI_1 constant

The time period in between

$0 \le T \le 0.25$	: modulation Index - 1	V_i= 2.180kv
$0.25 \le T \le 0.46$	: modulation Index - 0.7	V_i= 1.546kv
$0.46 \le T \le 0.72$	: modulation Index - 0.5	V_i= 1.034kv
$0.46 \le T \le 0.1$	: modulation Index - 0.1	V_i= 0.890kv

For the variation of the modulation index discussed above the corresponding power delivered to both the loads are shown in the Fig. 6.12, and Fig. 6.13.

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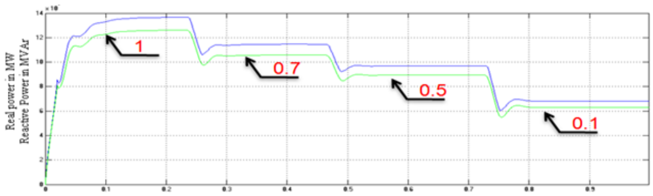

Fig. 6.12: Real and Reactive power flow on line 2 for the variation of the MI_2

- 43 -

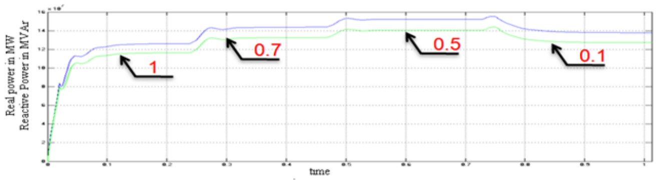

Fig. 6.13: Real and Reactive power flow on line 1 for the variation of the MI_2

From the above result, it is observed that as the modulation was index varied, the injected voltage on the line by the converter is also varies correspondingly and hence the power flow on the corresponding line will varies, at the same time the power flow on the another line will be automatically adjusted. The comparison of the power flow on the parallel Transmission line with and without interline power flow controller is given in the Table 6.4.

Equal loads on both the lines(P in MW, Q in MVar)					
Actual Demand On the parallel lines system		Power flow on the parallel lines without IPFC		Power flow on the parallel lines with IPFC	
Line 1	Line 2	Line 1	Line 2	Line 1	Line 2
P_L =130	P_L =130	P_L =105.2	P_L =105.2	P_L =135	P_L =135
Q_L =120	Q_L =120	Q_L =22.65	Q_L =22.65	Q_L =123	Q_L =123

Table 6.4: Comparison of power flow on the parallel Transmission line with and without IPFC for case 1

Case 2: Interline power flow controller with unequal loads on both the lines

Fig. 6.14, Fig. 6.15, shows the variation of real and reactive power flow on line-1 and line-2 with unequal loading condition. Time period between 0-0.17 secs the modulation index of both lines are kept at 1, under this condition the power delivered to the load 1 is lesser then the actual demand, whereas the power available on the line-2 two is more than the actual demand. At the time t = 0.17 sec the modulation index of both the line is adjusted to (MI_1=1.1&MI_2=0.78) achieve the required power flow on the line. The comparison of power flow on the transmission line with and without interline power flow controller for unequal loading condition is shown the table 6.5.

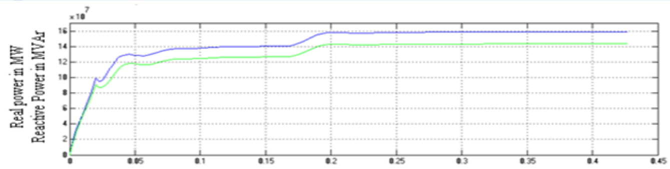

Fig. 6.14: Real and Reactive power flow on line 2 for the variation of the MI_2

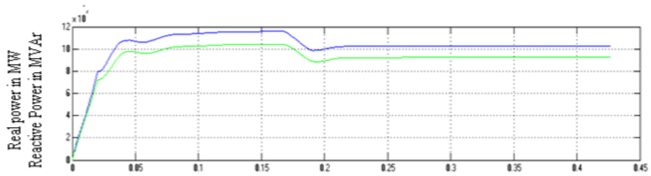

Fig. 6.15: Real and Reactive power flow on line 1 for the variation of the MI_2

Different loads on both the lines(P in MW, Q in MVar)							
Actual Demand On the parallel lines system		Power flow on the parallel lines without IPFC		Power flow on the parallel lines with IPFC			
				MI 1=1, MI 2= 1		MI 1=1.1, MI 2= .78	
Line 1	Line 2	Line 1	Line 2	Line 1	Line 2	Line 1	Line 2
P_L=155	P_L=100	P_L =120.7	P_L =80.28	P_{L1}=140.7	P_{L2}=115.9	P_{L1}=159.1	P_{L2}=102.7
Q_L=140	Q_L= 90	Q_L = 109	Q_L =72.26	Q_{L1}=127.1	Q_{L2}=104.3	Q_{L1}=143.7	Q_{L2}=92.7

Table 6.5: Comparison of power flow on the parallel Transmission line with and without IPFC for case 2

From Fig. 6.14, and Fig 6.15, it is observed that after adjusting the modulation index at time t=0.17sec the part of the real power demand on the line one is supplied from the line 2 via the common DC link. It clearly understood that the IPFC will supply the power from the underloaded line to overloaded line. Fig. 16, Fig. 17, show the modulation index versus real and
reactive power flow for the variation of the modulation-2, while the modulation index of the other line remains unchanged.

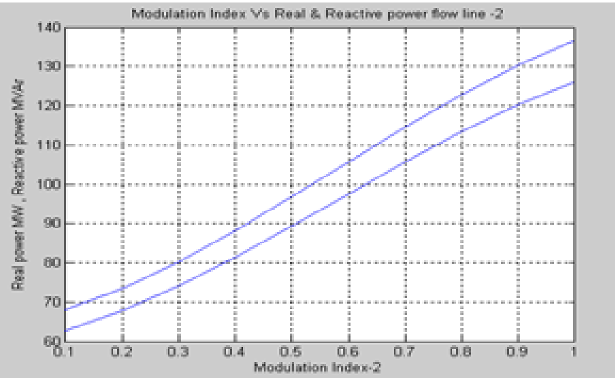

Fig. 6.16: Modulation index Vs P&Q on line 2

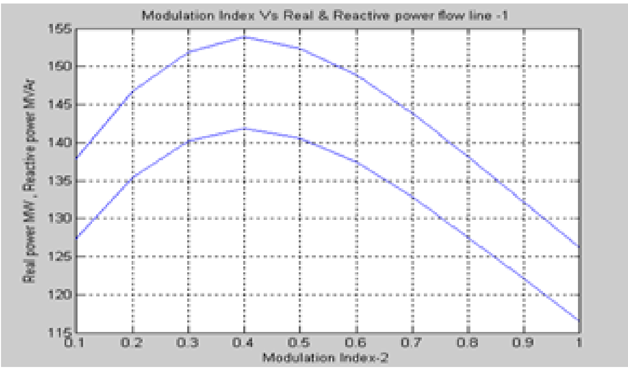

Fig. 6.17: Modulation index Vs P&Q on line 1

6.6. CLOSED LOOP RESPONSE OF THE INTERLINE POWER FLOW CONTROLLER

The IPFC is designed to maintain the impedance characteristic of the two transmission lines. The IPFC consists of two converter systems: (i) A master converter system that is capable of regulating impedances of Line 1 and (ii) A slave converter system that regulates the common dc-link voltage of the VSC. The dynamic behavior of the controller is verified by applying the following inputs. (a) Impact of step change in reference values of the injected impedance on IPFC performance. (b) Impact of step change in reference values of DC link voltage on IPFC performance.

6.6.1 Step change in the injected impedance 0.3pu to 0.7pu

The time period in between 0 < t < 2 sec the reference value of the injected impedance is maintained at Z_{ref} = 0.3pu, and the time t=2 sec the reference value is increased to Z_{ref} = 0.7pu. The actual injected impedance on the line1 for the step change in reference value is shown in the Fig. 6.18, the corresponding DC link voltage and power flows on the both the line is shown in the Fig. 6.19, to Fig. 6.23.

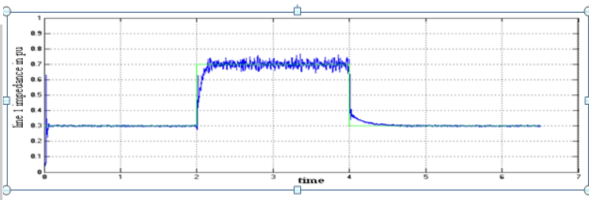

Fig. 6.18: Step change in injected impedance from 0.3pu to 0.7pu

VII. CONCLUSION

This thesis presents the development of Simulink based models of series voltage source converter (VSC) applications in the FACTS type power transmission systems. It includes the implementation of an exact model of three phase voltage source converter that is used to build the SSSC and IPFC applications for transmission systems. These offer potential of improving power transfer capability on existing transmission systems.

The IPFC is a multi-line FACTS device and consists of several SSSCs with a common DC-link. Bothe SSSC and IPFC are capable of controlling various parameters in power systems, such as active and reactive power flow, line impedance, and injected voltage in power transmission lines.

In this project work the detailed model of SSSC and IPFC was implemented. Both the FACTS device has the capable of exchanging the real and reactive power with the system. The performance of the SSSC on the single machine infinite bus system and the performance of the IPFC on the parallel transmission lines were demonstrated. Simulation results show the effectiveness of the controller on controlling the impedance of the transmission line and hence the power flows on the chosen system.

The effect of IPFC characteristic on the practical IEEE 30 bus system was demonstrated and three different case studies were carryout

(i) Base load condition
(ii) 10% increasing in load condition
(iii) Fault condition

From the power flow result we conclude that the Interline power flow controller increase the power transfer capability. The practical utility system with IPFC is able to maintain voltage profile within the allowable limit.

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