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MODELLING AND SIMULATION OF INTERLINE POWER FLOW CONTROLLER FOR POWER FLOW MANAGEMENT IN POWER SYSTEM

Apoorv H. Prajapati[1], Piyush R. Patel[2], Himalay V. Patel[3]
[1]PG Scholar, [2]Assistant Professor, [3]Lecturer
Electrical Department, SCET, Saij, Kalol, Gujarat, India

ABSTRACT: In order to meet PQ standard limits, it may be necessary to include some sort of compensation. Modern solutions can be found in the form of active rectification or active filtering. In recent years, solutions based on flexible ac transmission systems (FACTS) have appeared. The application of FACTS concepts in distribution systems has resulted in a new generation of compensating devices. A interline power flow conditioner (IPFC) is the extension concept at the distribution level. It consists of combined series and shunt converters for simultaneous compensation of voltage and current imperfections in a supply feeder. An IPFC consists of two series VSCs whose dc capacitors are coupled. This allows active power to circulate between the VSCs. With this configuration, two lines can be controlled simultaneously to optimize the network utilization. However, since the source impedance is very low, a high amount of current would be needed to boost the bus voltage in case of a voltage sag/swell which is not feasible. It also has low dynamic performance because the dc-link capacitor voltage is not regulated. This paper presents a power flow management in interline (IPFC), capable of simultaneous compensation for voltage and current in multi-bus/multi-feeder systems. In this configuration, one shunt voltage-source converter (shunt VSC) and two or more series VSCs exist. The system can be applied to adjacent feeders to compensate for supply-voltage and load current imperfections on the main feeder and full compensation of supply voltage imperfections on the other feeders. In the proposed configuration, all converters are connected back to back on the dc side and share a common dc-link capacitor. Therefore, power can be transferred from one feeder to adjacent feeders to compensate for sag/swell and interruption. The proposed topology can be used for simultaneous compensation of voltage and current imperfections in both feeders by sharing power compensation capabilities between two adjacent feeders which are not connected. The system is also capable of compensating for interruptions without the need for a battery storage system and consequently without storage capacity limitations.

I. INTRODUCTION

With increasing applications of nonlinear and electronically switched devices in distribution systems and industries, power-quality (PQ) problems, such as harmonics, flicker, and imbalance have become serious concerns. In addition, lightning strikes on transmission lines, switching of capacitor banks, and various network faults can also cause PQ problems, such as transients, voltage sag/swell, and interruption. On the other hand, an increase of sensitive loads involving digital electronics and complex process controllers requires a pure sinusoidal supply voltage for proper load operation [1]. In order to meet PQ standard limits, it may be necessary to include some sort of compensation. Modern solutions can be found in the form of active rectification or active filtering [2]. A shunt active power filter is suitable for the suppression of negative load influence on the supply network, but if there are supply voltage imperfections, a series active power filter may be needed to provide full compensation [3]. In recent years, solutions based on flexible ac transmission systems (FACTS) have appeared. The application of FACTS concepts in distribution systems has resulted in a new generation of compensating devices. [5]. It consists of combined series and shunt converters for simultaneous compensation of voltage and current imperfections in a supply feeder [6]–[8]. Recently, multi converter FACTS devices, such as an interline power-flow controller (IPFC) [9] and the generalized unified power-flow controller (GUPFC) [10] are introduced. The aim of these devices is to control the power flow of multi lines or a sub network rather than control the power flow of a single line by, for instance, a UPFC. When the power flows of two lines starting in one substation need to be controlled, an interline power flow controller (IPFC) can be used. An IPFC consists of two series VSCs whose dc capacitors are coupled. This allows active power to circulate between the VSCs. With this configuration, two lines can be controlled simultaneously to optimize the network utilization. The GUPFC combines three or more shunt and series converters. It extends the concept of voltage and power-flow control beyond what is achievable with the known two-converter UPFC.

In general, the GUPFC can be used to increase the transfer capability and relieve congestions in a flexible way. This concept can be extended to design multi converter configurations for PQ improvement in adjacent feeders. For example, the interline unified power-quality conditioner (IUPQC), which is the extension of the IPFC concept at the distribution level, has been proposed in [11]. The IUPQC consists of one series and one shunt converter. It is connected between two feeders to regulate the bus voltage of one of the feeders, while regulating the voltage across a sensitive load in the other feeder. In this configuration, the voltage regulation in one of the feeders is performed by the shunt-VSC. However, since the source impedance is very low, a high amount of current would be needed to boost the bus voltage in case of a voltage sag/swell which is not feasible. It also has low dynamic performance because the dc-link capacitor voltage is not regulated. In this paper a power flow management in interline (IPFC), capable of simultaneous compensation for voltage and current in multi-bus/multi-feeder systems is presented. The system is extended by adding a series-VSC in an adjacent feeder. The proposed topology can be used for simultaneous compensation of voltage and current imperfections in both feeders by sharing power compensation capabilities between two adjacent feeders which are not connected. The system is also capable of compensating for interruptions without the need for a battery storage system and consequently without storage capacity limitations.

POWER QUALITY

The contemporary container crane industry, like many other industry segments, is often enamored by the bells and whistles, colorful diagnostic displays, high speed performance, and levels of automation that can be achieved. Although these features and their indirectly related computer based enhancements are key issues to an efficient terminal operation, we must not forget the foundation upon which we are building. Power quality is the mortar which bonds the foundation blocks. Power quality also affects terminal operating economics, crane reliability, our environment, and initial investment in power distribution systems to support new crane installations. To quote the utility company newsletter which accompanied the last monthly issue of my home utility billing: ‘Using electricity wisely is a good environmental and business practice which saves you money, reduces emissions from generating plants, and conserves our natural resources.’ As we are all aware, container crane performance requirements continue to increase at an astounding rate. Next generation container cranes, already in the bidding process, will require average power demands of 1500 to 2000 kW – almost double the total average demand three years ago. The rapid increase in power demand levels, an increase in container crane population, SCR converter crane drive retrofits and the large AC and DC drives needed to power and control these cranes will increase awareness of the power quality issue in the very near future.

POWER QUALITY PROBLEMS

For the purpose of this article, we shall define power quality problems as: ‘Any power problem that results in failure or mis-operation of customer equipment manifests itself as an economic burden to the user, or produces negative impacts on the environment.’ When applied to the container crane industry, the power issues which degrade power quality include:

- Power Factor
- Harmonic Distortion
- Voltage Transients
- Voltage Sags or Dips
- Voltage Swells

The AC and DC variable speed drives utilized on board container cranes are significant contributors to total harmonic current and voltage distortion. Whereas SCR phase control creates the desirable average power factor, DC SCR drives operate at less than this. In addition, line notching occurs when SCR’s commutate, creating transient peak recovery voltages that can be 3 to 4 times the nominal line voltage depending upon the system impedance and the size of the drives. The frequency and severity of these power system disturbances varies with the speed of the drive. Harmonic current injection by AC and DC drives will be highest when the drives are operating at slow speeds. Power factor will be lowest when DC drives are operating at slow speeds or during initial acceleration and deceleration periods, increasing to its maximum value when the SCR’s are phased on to produce rated or base speed. Above base speed, the power factor essentially remains constant. Unfortunately, container cranes can spend considerable time at low speeds as the operator attempts to spot and land containers. Poor power factor places a greater KVA demand burden on the utility or engine-alternator power source. Low power factor loads can also affect the voltage stability which can ultimately result in detrimental effects on the life of sensitive electronic equipment or even intermittent malfunction. Voltage transients created by DC drive SCR line notching, AC drive voltage chopping, and high frequency harmonic voltages and currents are all significant sources of noise and disturbance to sensitive electronic equipment. It has been our experience that end users often do not associate power quality problems with Container cranes, either because they are totally unaware of such issues or there was no economic Consequence if power quality was not addressed. Before the advent of solid-state power supplies, Power factor was reasonable, and harmonic current injection was minimal. Not until the crane Population multiplied, power demands per crane increased, and static power conversion became the way of life, did power quality issues begin to emerge. Even as harmonic distortion and power Factor issues surfaced, no one was really prepared. Even today, crane builders and electrical drive System vendors avoid the issue during competitive bidding for new cranes. Rather than focus on Awareness and understanding of the potential issues, the power quality issue is intentionally or unintentionally ignored. Power quality problem solutions are available. Although the solutions are not free, in most cases, they do represent a good return on investment. However, if power quality is not specified, it most likely will not be delivered.

Power quality can be improved through:

- Power factor correction,
- Harmonic filtering,
- Special line notch filtering,
- Transient voltage surge suppression,
- Proper earthing systems.

In most cases, the person specifying and/or buying a container crane may not be fully aware of the potential power quality issues. If this article accomplishes nothing else, we would hope to provide that awareness. In many cases, those involved with specification and procurement of container cranes may not be cognizant of such issues, do not pay the utility billings, or consider it someone else's concern. As a result, container crane specifications may not include definitive power quality criteria such as power factor correction and/or harmonic filtering. Also, many of those specifications which do require power quality equipment do not properly define the criteria. Early in the process of preparing the crane specification:

- Consult with the utility company to determine regulatory or contract requirements that must be satisfied, if any.
- Consult with the electrical drive suppliers and determine the power quality profiles that can be expected based on the drive sizes and technologies proposed for the specific project.
- Evaluate the economics of power quality correction not only on the present situation, but consider the impact of future utility deregulation and the future development plans for the terminal.

II. POWER QUAITY AND ROLE OF FACTS DEVICE

A. DEFINITION OF POWER QUALITY:-

Power quality is a term that means different things to different people. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as "the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment." As appropriate as this description might seem, the limitation of power quality to "sensitive electronic equipment" might be subject to disagreement. Electrical equipment susceptible to power quality or more appropriately to lack of power quality would fall within a seemingly boundless domain. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment, or a household appliance. All of these devices and others react adversely to power quality issues, depending on the severity of problems. A simpler and perhaps more concise definition might state: "Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy." This definition embraces two things that we demand from an electrical device: performance and life expectancy. Any power-related problem that compromises either attribute is a power quality concern. In light of this definition of power quality, this chapter provides an introduction to the more common power quality terms. Along with definitions of the terms, explanations are included in parentheses where necessary. This chapter also attempts to explain how power quality factors interact in an electrical system. The common concerns of power quality are long duration voltage variations (overvoltage, under voltage, and sustained interruptions), short duration voltage variations (interruption, sags (dips), and swells), voltage imbalance, waveform distortion (DC offset, harmonics, inter harmonics, notching and noise), voltage fluctuation (voltage flicker) and power frequency variations. Most reasons of these concerns stems from loads connected to electric supply systems. During converting, harmonic currents on the power grid are generated. Producing harmonic currents at the point of common coupling (PCC) cause several adverse effects such as a line voltage distortion at PCC, equipment overheating, transformer derating, overheating, failure of sensitive electronic equipment, interference with telecommunication systems due to harmonic noises, flickering of fluorescent lights, erratic operation of circuit breakers and relays, fuse blowing and electronic equipment shutting down, conductor overheating due to Triplen harmonics in 3-phase 4- wire system, increased RMS current. Personal computers, fax machines, printers, UPS, adjustable speed drives, electronic lighting ballasts, ferromagnetic devices, DC motor drives and arcing equipment are examples of nonlinear loads.

B. Power Quality Issues and Its Consequences:-

Power quality problem is any power problem manifested in voltage, current, or frequency deviation that results in failure or malfunctioning of customer equipment. Power quality is a two-pronged issue, with electronic equipment playing both villain and victim. Most new electronic equipment, while more efficient than its mechanical predecessors, consumes electricity differently than traditional mechanical appliances. Power supply quality issues and resulting problems are consequences of the increasing use of solid state switching devices, nonlinear and power electronically switched loads, electronic type loads .the advent and wide spread of high power semiconductor switches at utilization, distribution and transmission leaves have non sinusoidal currents.

Cost of poor power quality:-

Poor Power Quality can be described as any event related to the electrical network that ultimately results in a financial loss. Possible consequences of poor Power Quality includes as follows:-

- Equipment failure or malfunctioning.
- Equipment overheating (transformers, motors) leading to their lifetime reduction.
- Damage to sensitive equipment (PC's, production line control systems).
- Electronic communication interferences.
- Increase of system losses.
- Need to oversize installations to cope with additional electrical stress with consequential increase of installation and running costs and associated higher carbon footprint.
- Penalties imposed by utilities because the site pollutes the supply network too much.

The following are the main contributors to Low Voltage poor Power Quality can be defined:-

1. Reactive power, as it loads up the supply system unnecessary, Harmonic pollution, as it causes extra stress on the networks and makes installations run less efficiently,

2. Load imbalance, especially in office building applications, as the unbalanced loads may result in excessive voltage imbalance causing stress on other loads connected to the same network, and leading to an increase of neutral current and neutral to earth voltage build-up,

3. Fast voltage variations leading to flicker.

C. Introduction to FACTS:-

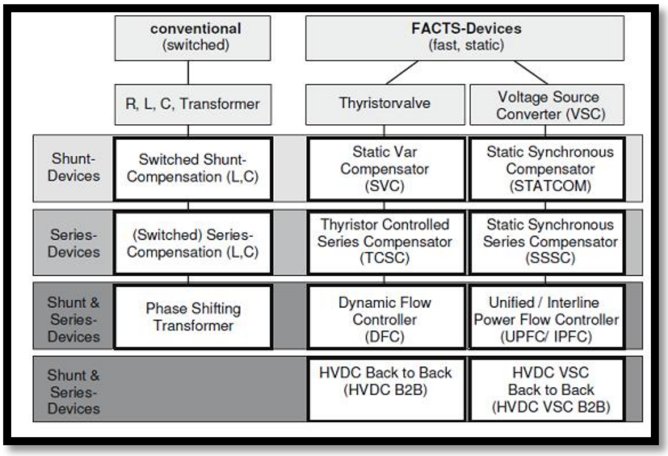
Flexible AC Transmission Systems, called FACTS, got in the recent years a well known term for higher controllability in power systems by means of power electronic devices. Several FACTS-devices have been introduced for various applications worldwide. A number of new types of devices are in the stage of being introduced in practice.

In most of the applications the controllability is used to avoid cost intensive or landscape requiring extensions of power systems, for instance like upgrades or additions of substations and power lines. FACTS-devices provide a better adaptation to varying operational conditions and improve the usage of existing installations. The basic applications of FACTS-devices are:

- Power flow control,
- Increase of transmission capability,
- Voltage control,
- Reactive power compensation,
- Stability improvement,
- Power quality improvement,
- Power conditioning,
- Flicker mitigation,
- Interconnection of renewable and distributed generation and storages.

For the FACTS side the taxonomy in terms of 'dynamic' and 'static' needs some explanation. The term 'dynamic' is used to express the fast controllability of FACTS-devices provided by the power electronics. This is one of the main differentiation factors from the conventional devices. The term 'static' means that the devices have no moving parts like mechanical switches to perform the dynamic controllability. Therefore most of the FACTS-devices can equally be static and dynamic.

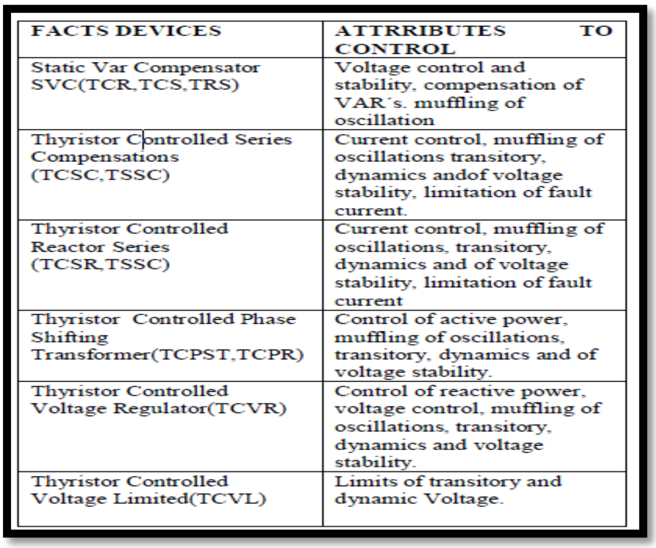
Types of facts devices:-



	conventional (switched)	FACTS-Devices (fast, static)	
	R, L, C, Transformer	Thyristorvalve	Voltage Source Converter (VSC)
Shunt-Devices	Switched Shunt-Compensation (L,C)	Static Var Compensator (SVC)	Static Synchronous Compensator (STATCOM)
Series-Devices	(Switched) Series-Compensation (L,C)	Thyristor Controlled Series Compensator (TCSC)	Static Synchronous Series Compensator (SSSC)
Shunt & Series-Devices	Phase Shifting Transformer	Dynamic Flow Controller (DFC)	Unified / Interline Power Flow Controller (UPFC/ IPFC)
Shunt & Series-Devices		HVDC Back to Back (HVDC B2B)	HVDC VSC Back to Back (HVDC VSC B2B)

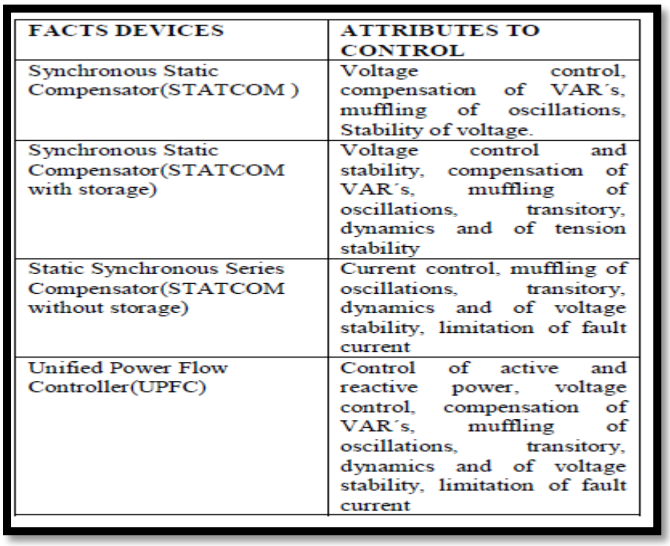
Fig 2.1 Types of FACTS Devices

The left column in Figure-2.1 contains the conventional devices build out of fixed or mechanically switch able components like resistance, inductance or capacitance together with transformers. The FACTS-devices contain these elements as well but use additional power electronic valves or converters to switch the elements in smaller steps or with switching patterns within a cycle of the alternating current. The left column of FACTS-devices uses Thyristor valves or converters. These valves or converters are well known since several years. They have low losses because of their low switching frequency of once a cycle in the converters or the usage of the Thyristors to simply bridge impedances in the valves. The right column of FACTS-devices contains more advanced technology of voltage source converters based today mainly on Insulated Gate Bipolar Transistors (IGBT) or Insulated Gate Commutated Thyristors (IGCT). Voltage Source Converters provide a free controllable voltage in magnitude and phase due to a pulse width modulation of the IGBTs or IGCTs. High modulation frequencies allow to get low harmonics in the output signal and even to compensate disturbances coming from the network. The disadvantage is that with an increasing switching frequency, the losses are increasing as well. Therefore special designs of the converters are required to compensate this.



FACTS DEVICES	ATTRRIBUTES TO CONTROL
Static Var Compensator SVC(TCR,TCS,TRS)	Voltage control and stability, compensation of VAR´s. muffling of oscillation
Thyristor Controlled Series Compensations (TCSC,TSSC)	Current control, muffling of oscillations transitory, dynamics andof voltage stability, limitation of fault current.
Thyristor Controlled Reactor Series (TCSR,TSSC)	Current control, muffling of oscillations, transitory, dynamics and of voltage stability, limitation of fault current
Thyristor Controlled Phase Shifting Transformer(TCPST,TCPR)	Control of active power, muffling of oscillations, transitory, dynamics and of voltage stability.
Thyristor Controlled Voltage Regulator(TCVR)	Control of reactive power, voltage control, muffling of oscillations, transitory, dynamics and voltage stability.
Thyristor Controlled Voltage Limited(TCVL)	Limits of transitory and dynamic Voltage.

Table 2.1-first generation facts devices

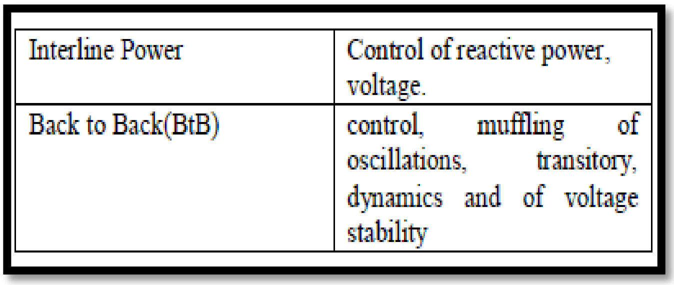


FACTS DEVICES	ATTRIBUTES TO CONTROL
Synchronous Static Compensator(STATCOM)	Voltage control, compensation of VAR´s, muffling of oscillations, Stability of voltage.
Synchronous Static Compensator(STATCOM with storage)	Voltage control and stability, compensation of VAR´s, muffling of oscillations, transitory, dynamics and of tension stability
Static Synchronous Series Compensator(STATCOM without storage)	Current control, muffling of oscillations, transitory, dynamics and of voltage stability, limitation of fault current
Unified Power Flow Controller(UPFC)	Control of active and reactive power, voltage control, compensation of VAR´s, muffling of oscillations, transitory, dynamics and of voltage stability, limitation of fault current

Table 2.2-SECond generation facts devices

D. Power flow controlling devices

Power flow is controlled by adjusting the parameters of a system, such as voltage magnitude, line impedance and transmission angle. The device that attempts to vary system parameters to control the power flow can be described as a Power Flow Controlling Device (PFCD). Depending on how devices are connected in systems, PFCDs can be divided into shunt devices, series devices, and combined devices (both in shunt and series with the system), as shown in Figure 3.3.



Interline Power	Control of reactive power, voltage.
Back to Back(BtB)	control, muffling of oscillations, transitory, dynamics and of voltage stability

Table 2.3-Power flow controlling devices of second generation FACTS devices

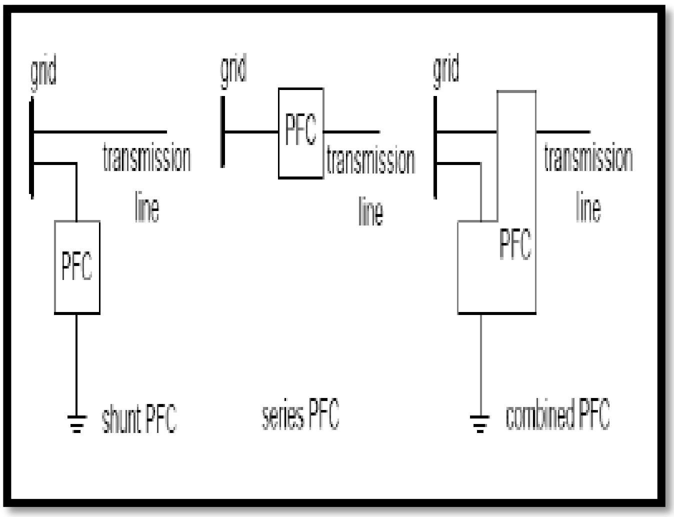


Fig-2.2 Simplified diagram of shunt, series and combined devices

A shunt device is a device that connects between the grid and the ground. Shunt devices generate or absorb reactive power at the point of connection thereby controlling the voltage magnitude. Because the bus voltage magnitude can only be varied within certain limits, controlling the power flow in this way is limited and shunt devices mainly serve other purposes. For example, the voltage support provided by a shunt device at the midpoint of a long transmission line can boost the power transmission capacity.

III. ROLE OF IPFC IN FACTS

A. Basic principle of IPFC:-

The involvement of a new family of FACTS devices which is based on Voltage Source Converters (VSC) added the features like flexible power flow control, transient stability and power system oscillation damping enhancement. Static Synchronous (shunt) Compensator (STATCOM), the Static Synchronous Series Compensator (SSSC) the Unified Power Flow Controller (UPFC) and the Interline Power Flow Controller (IPFC) are the members of family of compensators and power flow controllers based on VSC. The UPFC provide independent control both for the real and reactive power flow of individual transmission lines thereby providing the cost effective utilization. While the Interline Power Flow Controller (IPFC) concept provides compensation in a number of transmission lines. The interline power flow controller (IPFC) is one of the latest FACTS controller used to control power flows of multiple transmission lines. Interline Power Flow Controller (IPFC) is an extension of static synchronous series compensator (SSSC). Any converters within the IPFC can transfer real power to any other and hence real power transfer among the lines may be carried out, together with independently controllable reactive series compensation of each individual line. IPFC employs a number of VSCs linked at the same DC terminal, each of which can provide series compensation for its own line. In this way, the power optimization of the overall system can be realized in the form of appropriate power transfer through the common DC link from overloaded lines to under-loaded lines. The power flow control design for IPFC is proposed and transfer functions are analyzed in this thesis. In its general form the interline power flow controller employs number of DC to AC inverters each providing series compensation for a different line as shown in Fig3.1. IPFC is designed as a power flow controller with two or more independently controllable static synchronous series compensators (SSSC) who are solid state voltage source converters injecting an almost sinusoidal voltage at variable magnitude and are linked via a common DC capacitor. SSSC is employed to increase the transferable active power on a given line and to balance the loading of a transmission network. In addition, active power can be exchanged through these series converters via the common DC link in IPFC. It is noted that the sum of the active powers outputted from VSCs to transmission lines should be zero when the losses of the converter circuits can be ignored. A combination of the series connected VSC can inject a voltage with controllable magnitude and phase angle at the fundamental frequency while DC link voltage can be maintained at a desired level. The common DC link is represented by a bidirectional link for active power exchange between voltage sources.

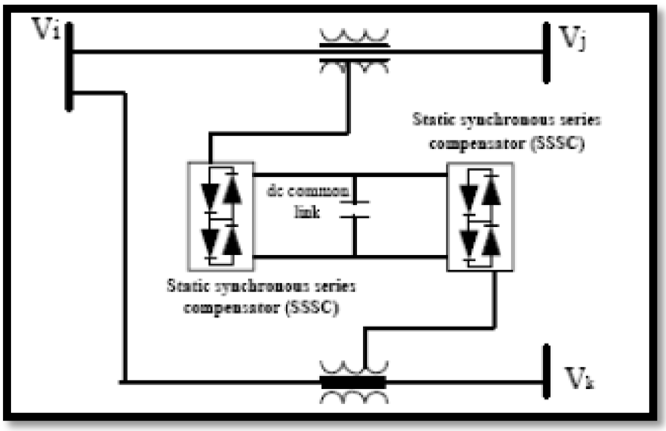


Fig 3.1-Schematic representation of IPFC

B. Generalized Interline Power Flow Controller:-

There can be compensation requirements for particular multi-line transmission systems which would not be compatible with the basic constraint of the IPFC, stipulating that the sum of real power exchanged with all the lines must be zero. This constraint can be circumvented by a generalized IPFC arrangement, in which a shunt connected inverter, is added to the number of inverters providing series compensation as illustrated in fig 3.2.

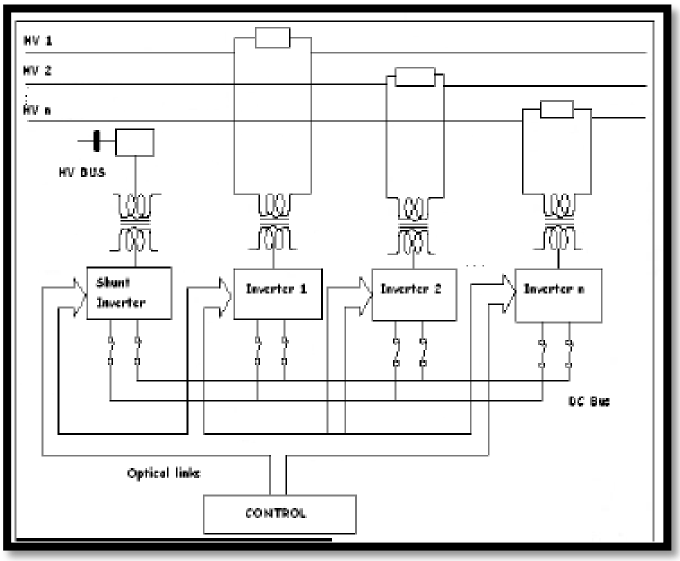


Fig 3.2: A Generalized Interline Power Flow Controller for Power Transmission Management

With this scheme the net power difference at the ac terminal is supplied or absorbed by the shunt inverter, and ultimately exchanged with the ac system at the shunt bus. This arrangement can be economically attractive, because the shunt inverter has to be rated only for the maximum real power difference anticipated for the whole system. It can also facilitate relatively inexpensive shunt reactive compensation, if this is needed at the particular substation bus.

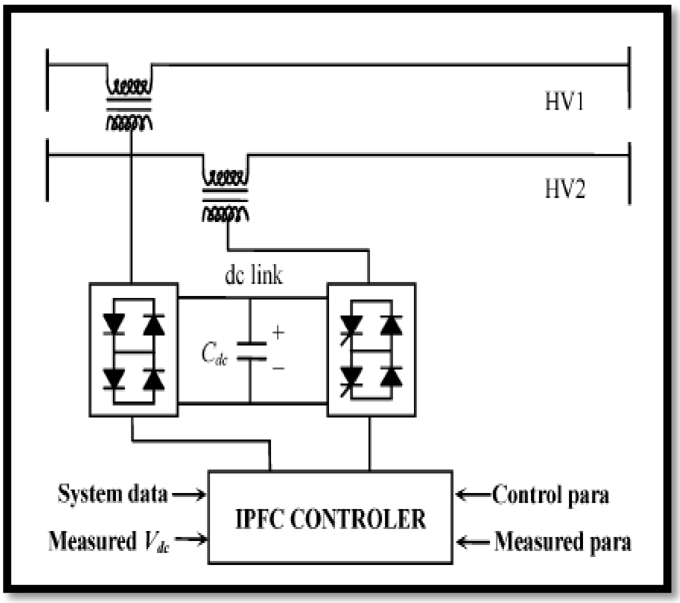


Fig-3.3. Schematic diagram of two-converter IPFC

C. Power-rating analysis of the IPFC:-

The power rating of the IPFC is an important factor in terms of cost. Before calculation of the power rating of each VSC in the IPFC structure, two models of a IPFC are analyzed and the best model which requires the minimum power rating is considered. All voltage and current phasor used in this section are phase quantities at the fundamental frequency. There are two models for IPFC—quadrature compensation (IPFC-Q) and in phase compensation (IPFC-P). In the quadrature compensation scheme, the injected voltage by the series- VSC maintains a quadrature advance relationship with the supply current so that no real power is consumed by the series VSC at steady state. This is a significant advantage when IPFC mitigates sag conditions. The series VSC also shares the volt ampere reactive (VAR) of the load along with the shunt-VSC, reducing the power rating of the shunt-VSC. Fig-3.4 shows the phasor diagram of this scheme under a typical load power factor condition with and without voltage sag.

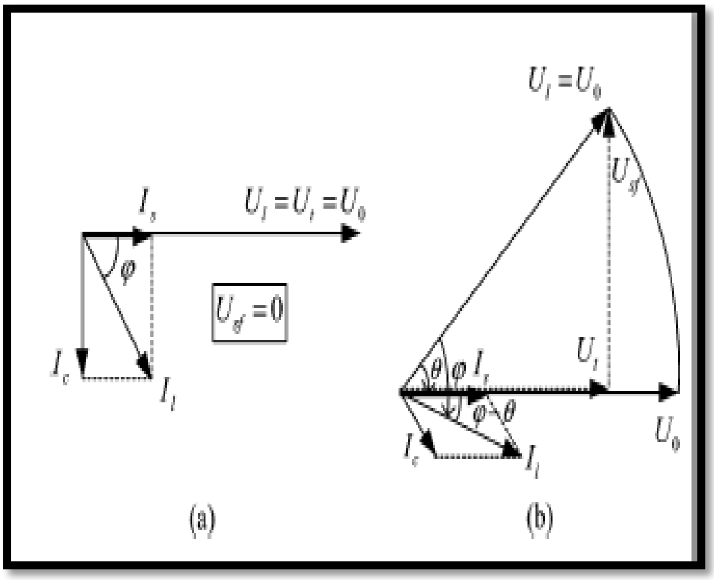


Fig-3.4- Phasor diagram of quadrature compensation- (a) without voltage sag (b) With voltage sag

When the bus voltage is at the desired value, the series-injected voltage is zero [Fig.(a)]. The shunt VSC injects the reactive component of load current I_c , resulting in unity input-power factor. Furthermore, the shunt VSC compensates for not only the reactive component, but also the harmonic components of the load current I_c.

For sag compensation in this model, the quadrature series voltage injection is needed as shown in Fig. (b). The shunt VSC injects I_c in such a way that the active power requirement of the load is only drawn from the utility which results in a unity input-power factor. In an in phase compensation scheme, the injected voltage is in phase with the supply voltage when the supply is balanced. By virtue of in phase injection, series VSC will mitigate the voltage sag condition by minimum injected voltage. The phasor diagram of Fig. explains the operation of this scheme in case of voltage sag.

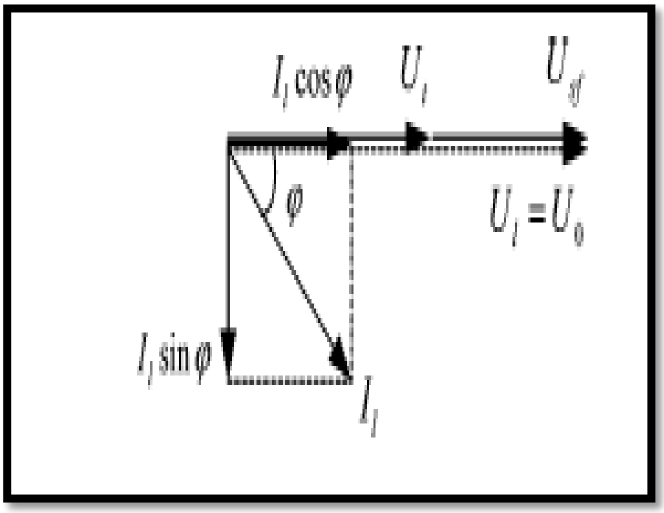


Fig-3.5- Phasor diagram of in phase compensation (supply voltage sag)

A comparison between in phase (IPFC-P) and quadrature (IPFC-Q) models is made for different sag conditions and load power factors in [13]. It is shown that the power rating of the shunt-VSC in the IPFC-Q model is lower than that of the IPFC-P, and the power rating of the series-VSC in the IPFC-P model is lower than that of the IPFC-Q for a power factor of less than or equal to 0.9. Also, it is shown that the total power rating of IPFC-Q is lower than that of IPFC -P where the VAR demand of the load is high. As discussed in Section II, the power needed for interruption compensation in Feeder2 must be supplied through the shunt VSC in Feeder1 and the series VSC in Feeder2. This implies that power ratings of these VSCs are greater than that of the series one in Feeder1. If quadrature compensation in Feeder1 and in phase compensation in Feeder2 is selected, then the power rating of the shunt VSC and the series VSC (in Feeder2) will be reduced. This is an important criterion for practical applications.

IV. MODELLING AND SIMULATION

A. IPFC MODELLING

The IPFC is the most versatile and effective device. The IPFC consists of voltage source converters; connected one in series and the other in shunt and both are connected back to back through a D.C capacitor. In order to investigate the impact of IPFC on power systems effectively, it is essential to formulate their correct and appropriate model. In the area power flow analysis, the IPFC model has series voltage source and a shunt current source model or both the series and the shunt. It is represented by voltage sources which present a decoupled model which is simple to implement but it has some restrictions. Alternately IPFC model is represented by two voltage sources called the voltage source model (VSM) and another model called the power injection model (PIM). The injection model of IPFC device is explained above. The fig-5.1 shows the injection model of IPFC located between buses i and j and its phasor diagram are shown in fig-5.2.

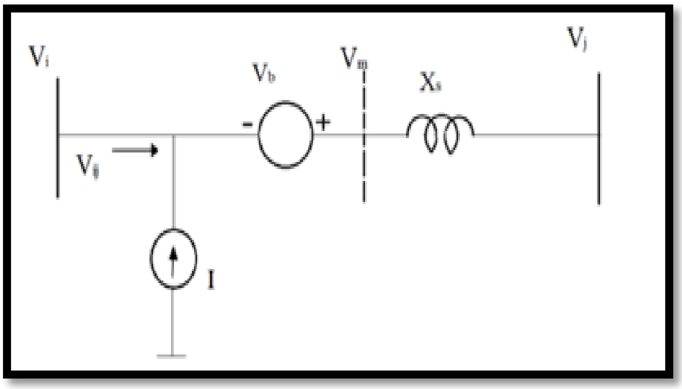


Fig-5.1-Injection model of IPFC

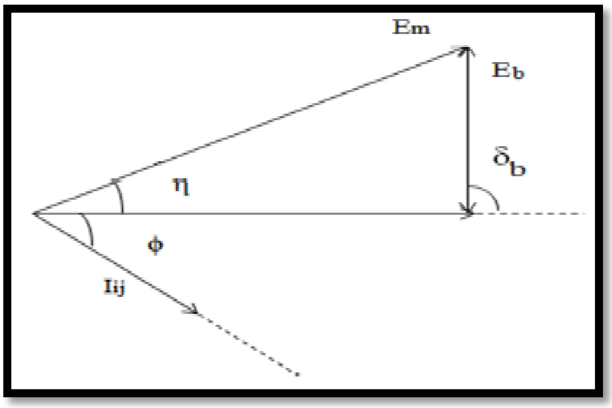


Fig 5.2-Phasor diagram

The simulation model of series compensated transmission system is shown in fig below. The simulation results also shown in fig below:-

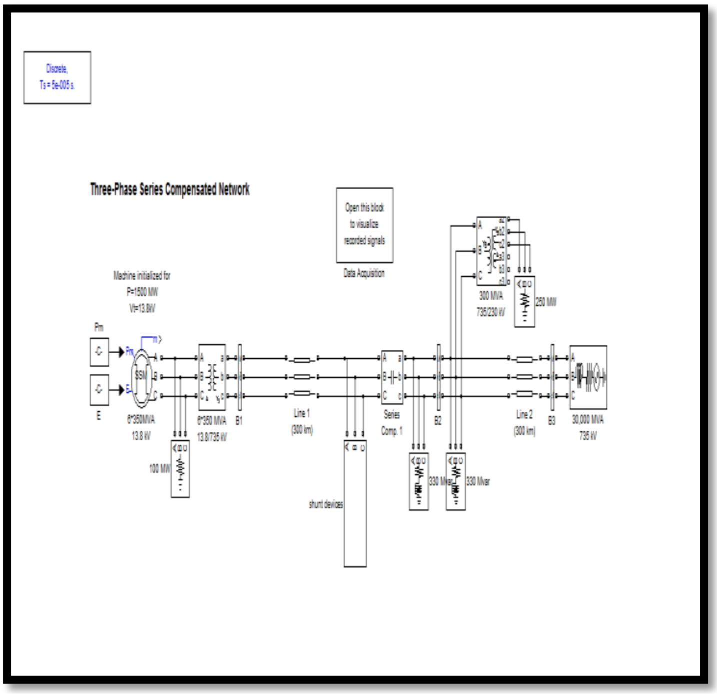


Fig 5.1- Three phase series compensated network without IPFC device

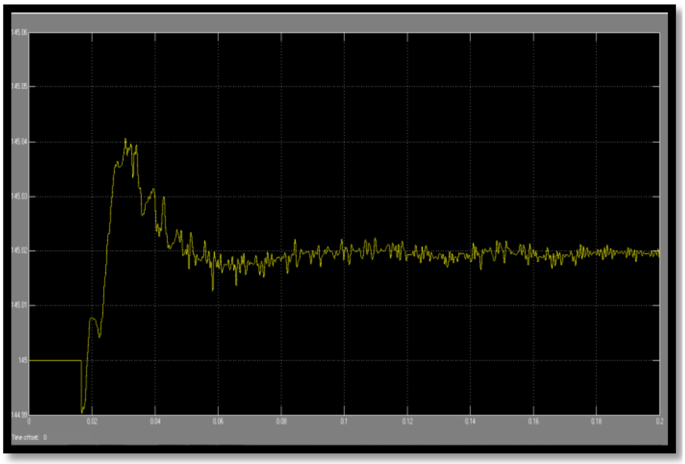


Fig 5.2- Simulation Results of 3-phase voltage Vabc

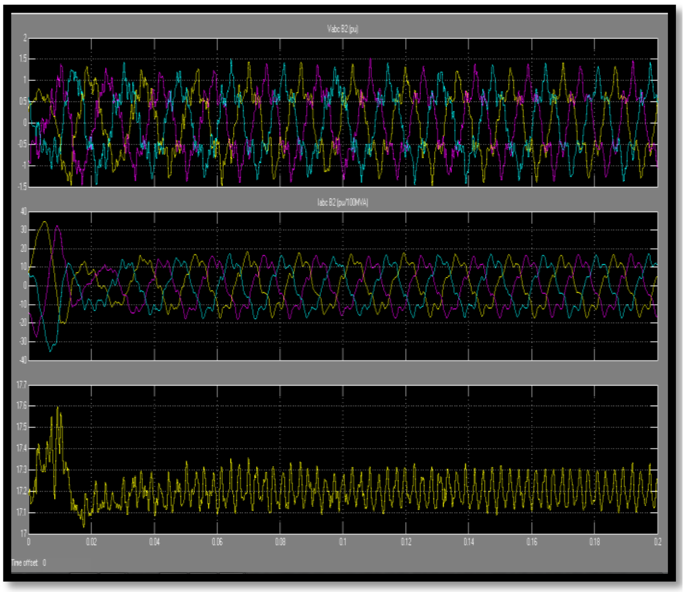


Fig 5.3-Vabc, Iabc, Real and Reactive power (Case-I)

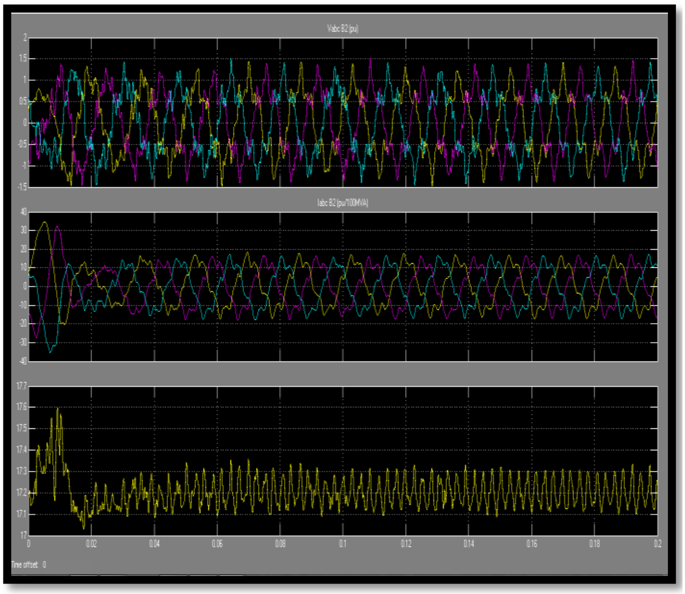


Fig 5.4-Vabc, Iabc, Real and Reactive power (Case-II)

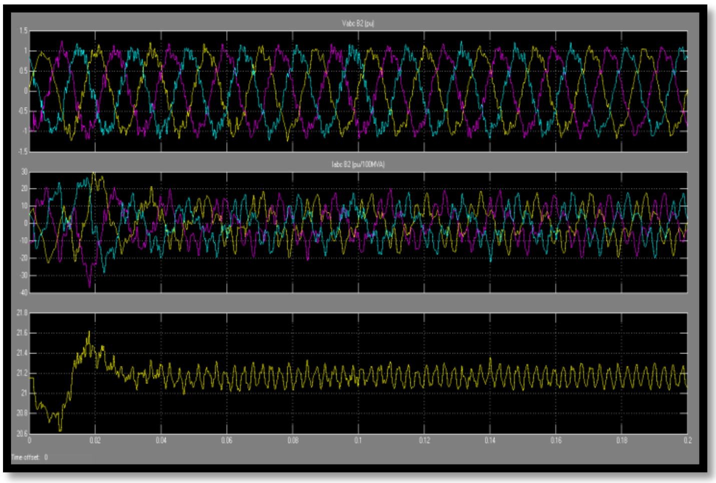


Fig 5.5-Vabc, Iabc, Real and Reactive power (Case-III)

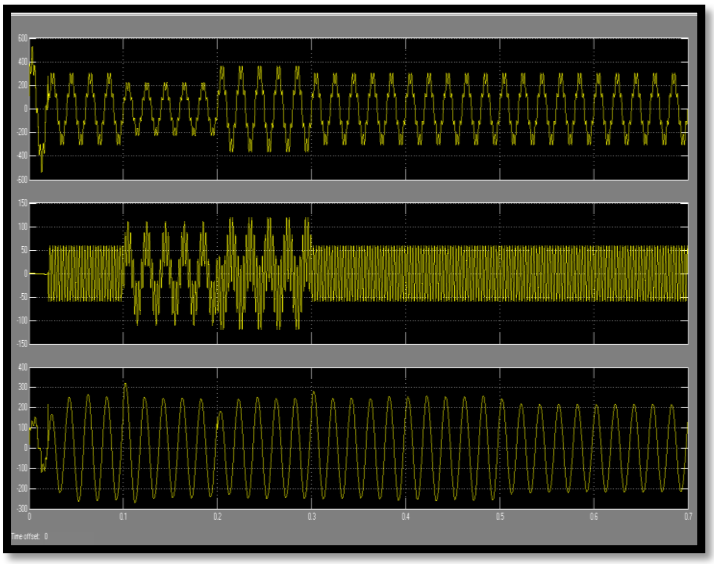


Fig 5.6-(a) Vabc at input side (b) Vabc between series transformer and IPFC (c) Vabc at load side for bus-1

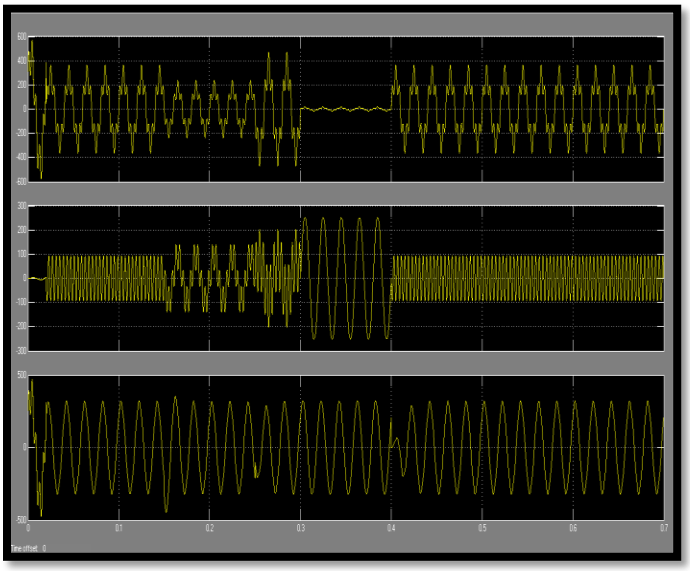


Fig 5.7-(a) Vabc at input side (b) Vabc between series transformer and IPFC (c) Vabc at load side for bus-2

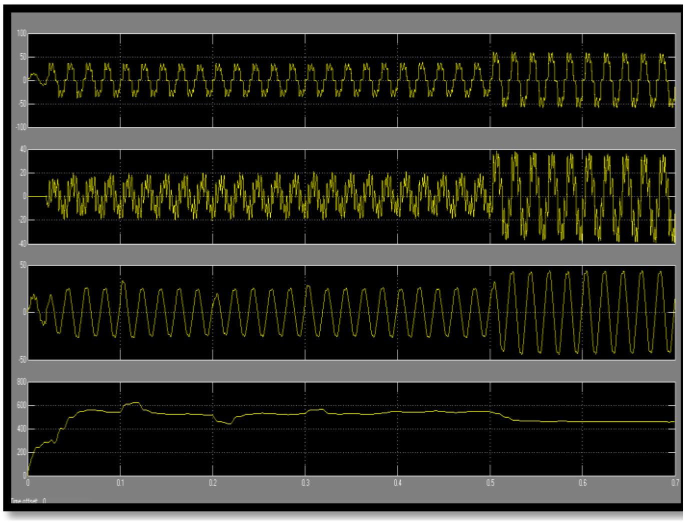


Fig 5.8-(a) Iabc at input side (b) Iabc between series transformer and IPFC (c) Iabc at load side for bus-1 (d) D.C voltage at Common link D.C Capacitor

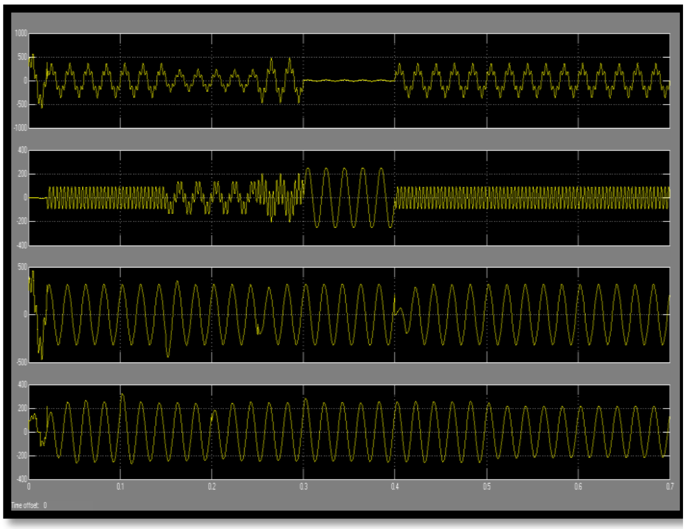


Fig 5.7-(a) Vabc at input side (b) Vabc between series transformer and IPFC (c) Vabc at load side for bus-2 (d) Vabc at load side for bus-1

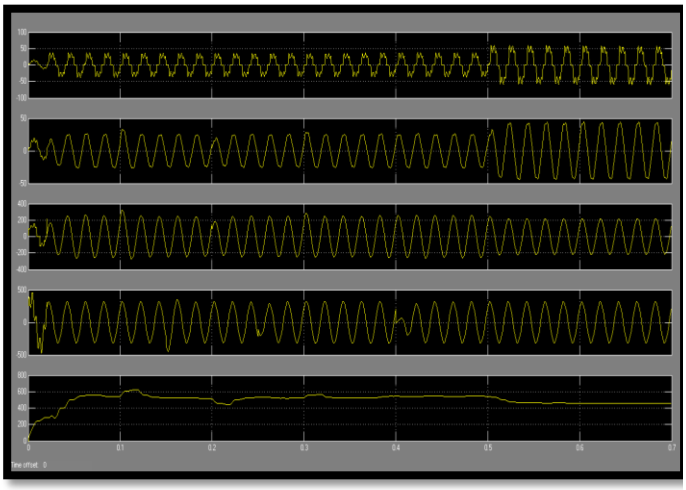


Fig 5.9- load current values for bus-1 and bus-2 and D.C voltage at Common link D.C Capacitor

V. CONCLUSION

In this paper, voltage and power profile has been improved through implementation of IPFC. IPFC is capable of balancing the power through the lines. The power quality is improved since IPFC permits additional power. The circuit models for IPFC system are developed using matlab. These models are used for simulating a four bus system. With these simulation results it can be inferred that with the implementation of IPFC, voltage profile, real power flow and reactive power flow can be controlled, up to a certain value of capacitor values.

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