Simulation and Analysis of IPFC in power studies

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***Abstract*— Development of electrical power transmission systems follows closely the increasing demand on electrical energy. With the increasing size and complexity of the transmission networks, the performance of the power systems decreases due to problems associated with load flow, power oscillations and voltage quality. Flexible ac transmission systems (FACTS) and High-voltage direct current (HVDC) technologies offer some effective schemes to meet these demands. In recent years, FACTS technology has been considered as one of feasible solutions, to increase power grid delivery capability and remove identified network bottlenecks. An attempt is made in this paper to discuss the developments, types of FACTS and simulation of IPFC, using SIMULINK is carried out for comparing issues relating to power transmission.**

Keywords*— *FACT:Voltage regulatio:,IPFC:

I. Introduction

Present day electrical power systems have a high rate of complexity and there is expansion in power transmission networks due to the increase in generation, loads, and also due to extensive interconnections due among various power utilities. The present AC power transmission poses following key challenges:-

- Power flow in parallel paths is determined according to their reactance.
- Increase in load levels results in higher reactive power consumption in the line reactance.
- Power flow in AC lines is limited by system stability and thermal stability considerations.
- Lack of control in AC lines implies that normal power flow in a line is kept much below the peak value.
- AC transmission network requires dynamic reactive power control to maintain satisfactory profile under varying load conditions.

Improved utilization of the existing power system is provided through the application of advanced control technologies that is Flexible AC Transmission systems (FACTS); provide solutions to address these new operating challenges. FACTS technologies allow for improved transmission system operation with minimal infrastructure investment, environmental impact, and implementation time of the existing transmission system compared to the construction of new transmission lines.

Regulator uncertainty, cost and lengthy delays to transmission line construction are a few barriers that have resulted in the serious deficiency in power transmission capacity that exists in many regions. Low environmental impact technologies such as FACTS and dc links are a solution to rapidly enhancing reliability and upgrading transmission capacity on a long-term and cost-effective basis. Interline power flow controller (IPFC) is a new concept of FACTS controller for series compensation with the unique capability of power flow management among multi-line of a substation. [1]

An IPFC is a converter based FACTS controller for series compensation with capability of controlling power flow among multi-lines within the same corridor of the transmission line. The basic characteristics of IPFC are to be analyses on two similarly dimensioned parallel transmission lines. A model has been simulated with MATLAB program to demonstrate system behavior of IPFC. [2]

Operation of IPFC is analysed in transmission line power flow control which is used for controlling transmission line voltage, flow of power, decreasing power losses, and decreases the amplitude of an oscillation while transferring power. Finding of the optimal placement of IPFC to maintain the voltage profile, active and reactive power flow in transmission line in power system to obtain the maximum possible benefit of power transfer is analysed. [3]

The capability of injecting series voltages with controllable magnitude and phase angle makes it a powerful tool for better utilization of existing transmission lines in a multiline transmission system. IPFC is used to regulate active and reactive power flow in a multiline system. All degrees of freedom of IPFC and decoupled synchronous frame concept are used in the MATLAB control structure. [4]

IPFC converters are considered as hypothesis bus in the power flow equations and then are matched with the Newton-Raphson power flow, a program in MATLAB, in order to extend conventional NR algorithm based on this model. [5]

A program in MATLAB has been written in order to extend conventional Newton-Raphson algorithm based on this model and numerical results are carried out on IEEE 14-bus system to demonstrate the performance. It is shown that there is a possibility of regulating bus voltages, active power flow, reactive power flow and minimizing the power losses simultaneously with proper IPFC parameters. [6]

The basic control for the IPFC is such that the series converter of the UPFC controls the transmission line real/reactive power flow and the shunt converter of the (IPFC and UPFC) controls the bus voltage/shunt reactive power and the DC link capacitor voltage. Since each inverter is able to provide reactive compensation, the (IPFC & UPFC) is able to carry out an overall real and reactive power compensation of the total transmission system. This capability makes it possible to equalize both real and reactive power flow between the lines, transfer power from overloaded to under loaded lines, compensate against reactive voltage drops and corresponding reactive line power and to increase the effectiveness of the compensating system against dynamic disturbances. [7]

The dynamic behavior of IPFC and UPFC small-signal model in a benchmark creating a new structure, used to effectively improve system damping without requiring the design of a tuned feedback controller. The IPFCs two series branches in contrast to the UPFC's single series branch permit more opportunities for network segmentation. Hence, the IPFC has greater potential for improving the system's dynamic performance. [8]

A mathematical model of IPFC, power injection model, is incorporated in a MATLAB power flow program based on Newton-Raphson algorithm to study the power flow control in transmission lines in which IPFC is placed. By this, an enhanced controllability over independent transmission systems or those lines whose sending end are connected to a common bus can be obtained. The power flow through the line can be regulated by controlling both magnitudes and angles of the series voltages injected by an IPFC. [9]

The control parameters of voltage source converters used in IPFC are designed to realize optimal power flow in a power system with modified Newton-Raphson method. The optimal control parameters are derived to minimize the transmission line losses employing three intelligent optimization techniques, namely Particle Swarm Optimization, Genetic Algorithm and Simulated Annealing. The simulation results validate the efficacy of the three optimization techniques and PSO technique is proved to be more efficient compared to the other two techniques. [10]

The IPFC belongs to a family of a series of compensating FACTS devices and has the ability to manage power flow among multiline transmission systems. It has voltage source converters, which can be adjusted to regulate the power flow in a corresponding line. A study of the capability of IPFC to reduce transmission loss is established and the IPFC controller is considered as an optimization problem and the parameters are tuned by applying differential evolution, artificial bee-colony and particle swarm optimization. [11]

The power flow through the line can be regulated by controlling both magnitudes and angles of the series voltages injected by an IPFC. Differential evolution to determine the control parameters on an IPFC is tested on a sample multi-machine system. [12]

Three types of particle swarm optimization techniques,
basic particle swarm optimization, inertia weight approach particle swarm optimization and constriction factor approach particle swarm optimization are applied to optimal power flow control of an electrical power system incorporating IPFC. The power flow control constraints of the controller are included in optimal power flow problem in addition to the normal conventional constraints. [13]

FACTS is a concept proposed by Hingorani[14] that involves the application of high power electronic controllers in a c transmission networks that enable fast and reliable control of power flows and voltages. This technology is integration of high power electronic controllers, which can be applied individually or in coordination with others to control one or more of the interrelated system parameters. [15] The thyristor or high-power transistor is the basic element for a variety of high-power electronic controllers. FACTS deal with-

- Regulation of power flow in prescribed transmission routes.
- Secure loading of lines near the thermal limits.
- Prevention of cascading outages by contributing to emergency control and
- Damping oscillations which can threaten the security or limit the usable line capacity.

Types of FACT controllers

FACTS Controllers can be classified into-(1)Series Controllers (2) Shunt Controllers (3) Combined Series-Series controllers (4) Combined Series-Shunt Controllers

(1) Series Controllers

Series controllers may be variable impedance as capacitor; reactor etc., or power electronics based variable source of main frequency, sub-synchronous frequency and harmonic frequency or any combination of these. The basic principle of series controller is to inject voltage in series with the line. If the injected voltage is in phase with line current, real power is not consumed or supplied.

(2)Shunt Controller:

Series controller element can be used as a shunt controller by connecting it in parallel with the line. In principle, all shunt controllers inject current into the system at the point of connection. Even variable shunt impedance connected to the line voltage causes a variable current flow and hence represents injection of current into the line. Types of Shunt connected controllers:

(a) Static Synchronous Compensator (STATCOM):A static synchronous generator operated as a shunt-connected static var compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage.

(b) Static Var Compensator (SVC): A shunt-connected static var generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system.

(c) Thyristor Controlled Reactor (TCR): A shunt-connected, thyristor-controlled inductor whose effective reactance is varied in a continuous manner by partial-conduction control of the thyristor valve.

(d) Thyristor Switched Capacitor (TSC): A shunt- connected thyristor- switched capacitor whose effective reactance is varied in a stepwise manner by full or zero conduction operation of the thyristor valve.

(3) Combined Series - Series Controllers

This could be any combination of series controllers, controlled in coordinated manner or it can be a unified controller. Unified controller provides independent series reactive compensation for each line. The term "unified" implies that DC terminals of all converters are connected. Transfer of real power between the lines takes place through this link, called power link. Unified controller provides independent series reactive compensation for each line.

(4)Combined Series - Shunt Connected Controller

Unified Power Flow Controller (UPFC): A combination of STATCOM and SSSC are coupled via a common dc link, to allow bidirectional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM, and are controlled to provide concurrent real and reactive series line compensation without an external electric energy source. The UPFC, by means of angularly unconstrained series voltage injection, is able to control, concurrently or selectively, the transmission line voltage, impedance, and angle or, alternatively, the real and reactive power flow in the line. The UPFC may also provide independently controllable shunt reactive compensation.

(5)Combined Series-Series Controller

Interline Power Flow controller (IPFC): Conventionally, series capacitive compensation is employed to increase the transmittable real power over a given line and also to balance the loading of a normally encountered multi-line transmission system. However, independent of their implementation, series reactive compensators are unable to control the reactive power flow in, and thus the proper load balancing of, the lines. This problem becomes particularly evident in those cases where the ratio of reactive to resistive line impedance (Xm) is relatively low. Series reactive compensation reduces only the effective reactive impedance X and, thus, significantly decreases the effective X/R ratio and thereby increases the reactive power flow and losses in the line. (Fig 1)

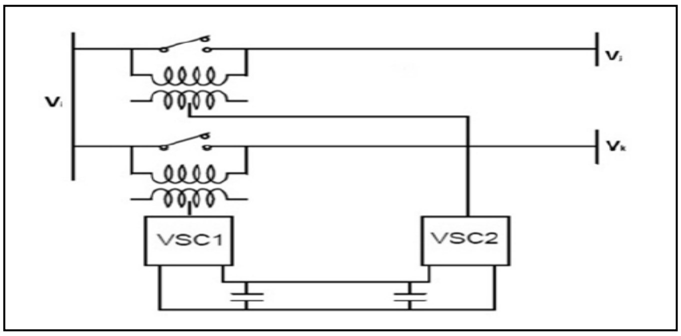

Figure 1. IPFC diagram

II BASIC PRINCIPLE OF IPFC

The IPFC scheme proposed provides, together with independently controllable reactive series compensation of each individual line, a capability to directly transfer real power between the compensated lines. This capability makes it possible to: equalize both real and reactive power flow between the lines; transfer power demand from overloaded to under loaded lines; compensate against resistive line voltage drops and the corresponding reactive power demand; increase the effectiveness of the overall compensating system for dynamic disturbances. That is, the IPFC can provide a highly effective scheme for power transmission management at a multi-line substation.

In its general form the Interline Power Flow Controller employs a number of dc to ac inverters providing each series compensation for a different line. In other words, the IPFC comprises a number of Static Synchronous Series Compensators. However, within the general concept of the IPFC, the compensating inverters are linked together at their dc terminals, as in Fig. 2.

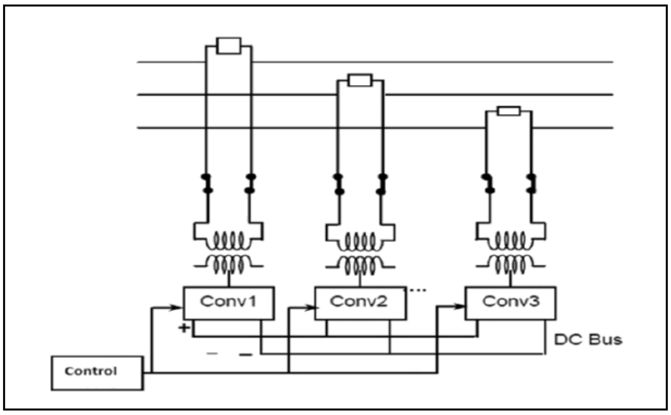

Figure2. Principle of IPFC

With this scheme, in addition to providing series reactive power compensation, any inverter can be controlled to supply real power to the common dc link from its own transmission line. Thus, an overall surplus power can be made available from the underutilized lines which then can be used by other lines for real power compensation. In this way, some of the inverters, compensating overloaded lines or lines with a heavy burden of reactive power flow, can be equipped with full two-dimensional, reactive and real power control capability, similar to that offered by the UPFC. Evidently, this arrangement mandates the rigorous maintenance of the overall power balance at the common dc terminal by appropriate control action, using the general principle that the under loaded lines are to provide help, in the form of appropriate real power transfer, for the overloaded lines.

SIMULINK MODEL

The IPFC model is simulated using SIMULINK and the results are as shown. (Figure 3 to Figure 7 and Table I to Table III)

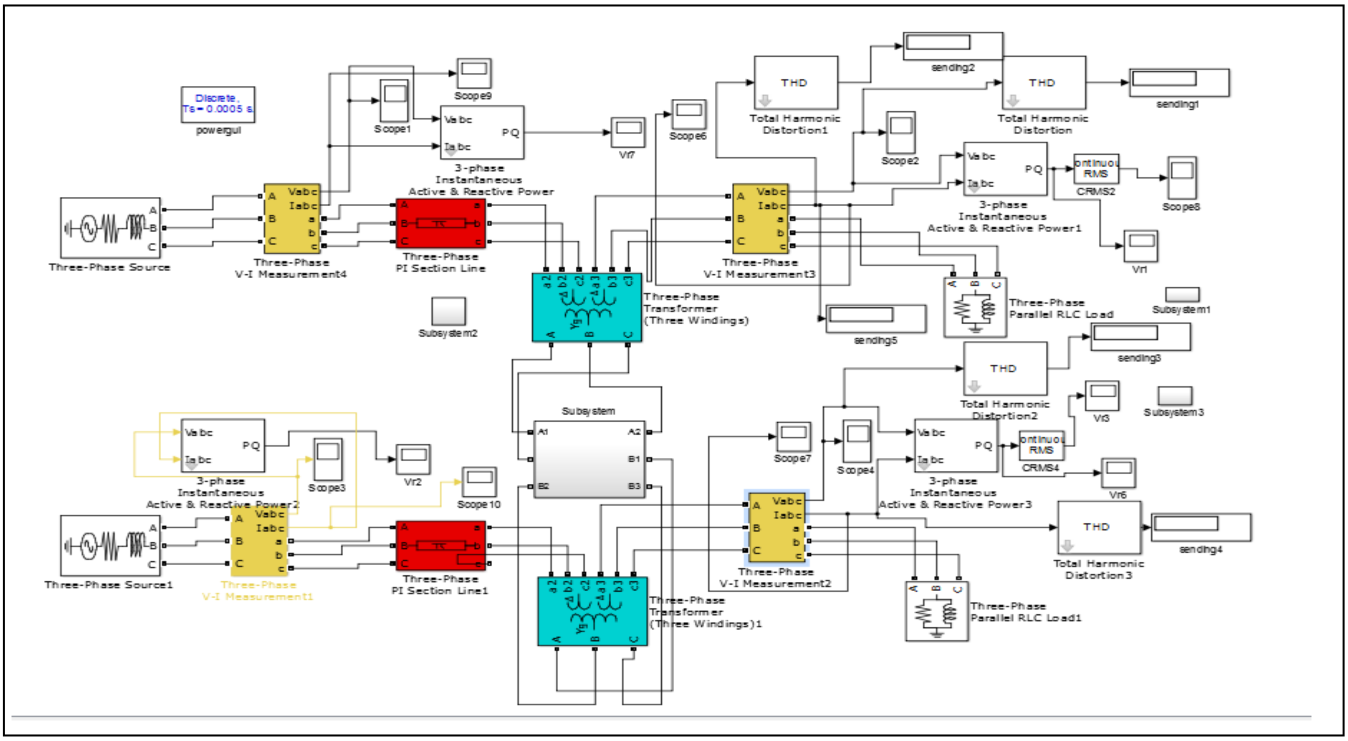

Figure 3. SIMULINK MODEL

TABLE I

Line Length (km)	Input voltage	Output Voltage (kV)	Voltage regulation (%)	Active Power (MW)	Reactive power (MVar)
400	679.5	647.36	4.7	987	1095
500	681	634.5	6.88	830	940
600	686	625	8.0	750	850
700	690	617.4	10.52	684	790
800	693.8	609	12.22	631	736

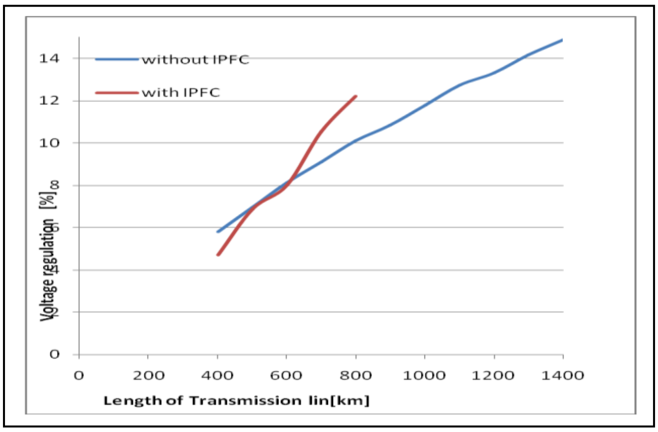

Figure 4. Voltage regulation with and without IPFC

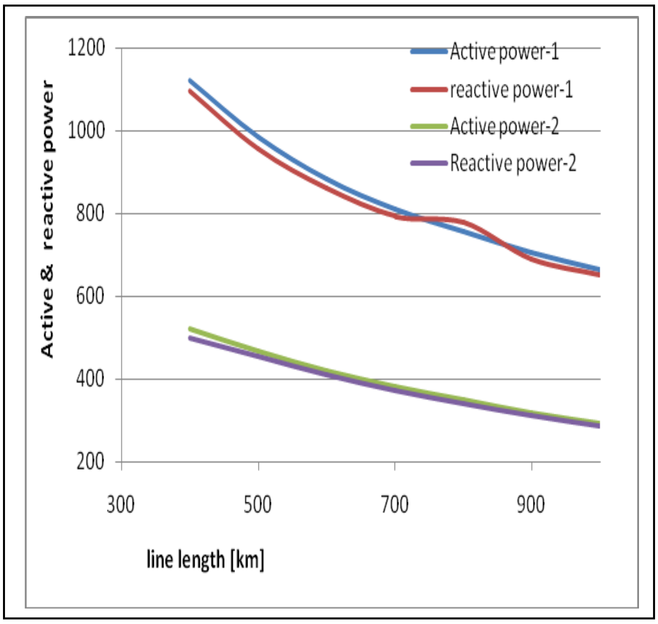

Figure 5. Variation Active power [MW] and reactive power [MVar] for line parameter

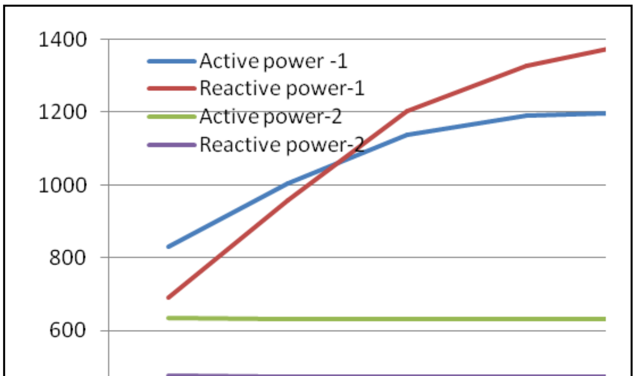

Figure 6. Active power [MW] and reactive power load variation

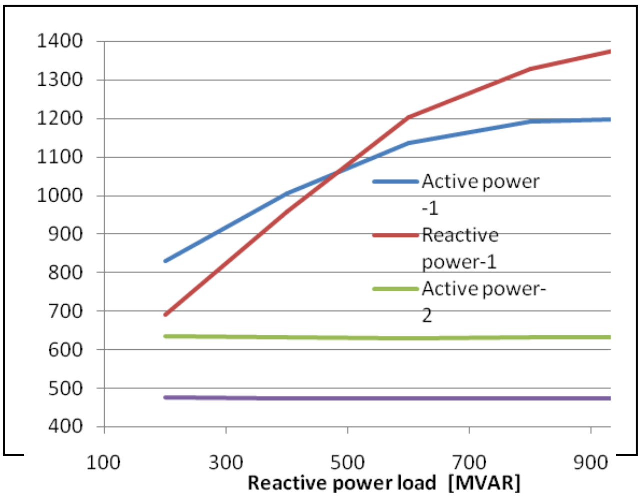

TABLE II Different Fault analysis

Fault analysis		
Type of Fault	Fault Current	
	Without IPFC	With IPFC
L-G	6.975×10^{11}	1.638×10^{3}
L-L	3.99×10^{6}	1.944×10^{3}
L-L-G	5.185×10^{14}	2.02×10^{3}
L-L-L	4.61×10^{6}	1.979×10^{3}
L-L-L-G	3.275×10^{6}	1.985×10^{3}

TABLE III Simulation parameters

Simulation specifications per km			
Line 1 Parameters		Line 2 Parameters	
Resistance	0.14 Ω	Resistance	0.28Ω
Inductance	0.1046 mH	Inductance	0.2092 mH
Capacitace	4.8 nF	Capacitance	9.6nF

The IPFC is modeled as a multi-series voltage injection scheme. 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.

- By using IPFC the voltage regulation decreases as the length of the transmission line increases.
- Reactive power has been decreased and active power is increased.
- Fault study indicates that IPFC provides stability to the system by reducing the high fault current.
- For significant real power compensation transmission lines must have sufficient capacity to carry additional reactive power from the real power of other lines.
- The scheme provides, together with the independent controllable reactive compensation of each line, a capability to transfer real power between compensated lines. This capability makes it possible to equalise both real and reactive power flow between the lines.
- Thus, the IPFC approach is that the strong or under loaded lines are forced to help the weaker or over-loaded lines in order to optimize the utilization of the entire transmission system.

CONCLUSIONS

1) From the power flow result indicates that the IPFC increase the power transfer capability. The practical utility system with IPFC is able to maintain voltage profile within the allowable limit.
2) It has the capable of exchanging the real and reactive power with the system and there is a possibility of regulating bus voltages, active power flow, and reactive power flow. The mathematical model indicates that IPFC can control both active and reactive power flows. Because of the common link, any inverter within the IPFC is able to transfer real power to any other and thereby facilitate real power transfer among the lines of the transmission system.
3) The effect of installing an IPFC in constant power control mode for the series branch is similar to that of disconnecting the transmission line that contains the series branch; this resulting change in network structure introduces significant changes in the corresponding mode frequencies as well as mode damping.
4) With proper selection of the location of the series branch, the resulting network can be made to exhibit improved damping behavior.
5) The improved dynamic performance is essentially caused by a virtual change of the network structure rather than by the tuning of controller parameters as is the case with most traditional approaches; hence, the feedback damping controller design can usually be avoided.
6) Since the IPFC has more series branches it provides more opportunities for network segmentation and, hence, has the potential for greater damping improvement

IPFC scheme is particularly attractive in those cases in which the real power compensation requirement of the weak lines exceeds the real power that can be absorbed from the strong lines without appreciably impacting their own power transmission or when shunt reactive compensation at the substation is required anyway for voltage support. The power flow takes place from the under loaded to the over loaded line and reduces the burden of the over loaded line. Power sharing takes place even when we vary the line length, load active power and load reactive power.

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