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Power System Stability using Interline Power flow Controller in Multiline Transmission System

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Abstract— In this paper, a circuit model for IPFC is developed and simulation of interline power flow controller is done using the four bus system circuit model. Simulation is done using MATLAB/ Simulink. IPFC in an integrated power system networks. Authors strongly believe that this survey article will be very much useful to the researchers for finding out the relevant references in the field of enhancement of power system stability by using different FACTS controllers in an integrated power system network. Interline Power Flow Controller (IPFC), is an advanced voltage-sourced converter (VSC) based FACTS (Flexible AC Transmission Systems) controller suitable for the power flow management of multiline systems. In recent years, power demand has increased substantially while the expansion of power generation and transmission has been severely limited due to limited resources and environmental restrictions. In its general form the interline power flow controller employs number of DC to AC inverters each providing series compensation for a different line The reactive voltage injected by individual Voltage Source Converter (VSC) can be controlled to regulate active power flow in the respective line. While one VSC regulates the DC voltage, the other one controls the reactive power flows in the lines by injecting series active voltage. Since each inverter is also able to provide reactive compensation, the IPFC 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 the corresponding reactive line power, and to increase the effectiveness of the compensating system against dynamic Disturbances.

Key words: FACTS, IPFC, MATLAB/SIMULINK, Power Injection Model, Optimal Power Flow

I. INTRODUCTION

A. *Facts*

The FACTS technology is not a single high power Controller, but rather a collection of Controller, which can be applied individually or in coordination with others to control one or more of the interrelated system parameters mentioned below. The evolution of power industry in recent years has imposed many challenges due to the radical changes in the energy market as power demand in more than the availability. Due to heavy demand of power, distribution networks are always in stress which results in reduced voltage across the load and it affect on the performance. It is necessary to improve the performance of power system to received quality power at the consumer end. Reactive power compensation is the main measure to keep power network running with high voltage stability, high power quality and minimum system loss. Flexible AC transmission system (FACTS) devices are found to be a very effective controller to enhance the system performance. FACTS Technology invented in 1986 by N. G. Hingorani from the Electric Power Research Institute (EPRI) USA and it is based on thyristor operation techniques. FACTS controllers are broadly classified as series and shunt both used to modify the natural electrical characteristics of ac power system. Series compensation modifies the transmission or distribution system parameters, while shunt compensation changes the equivalent impedance of the load. In both the cases the reactive power flow that flows through the system can be effectively controlled by FACTS, which improves the overall performance of ac power system. The later approach has two inherent advantages over the more conventional switched capacitor and reactor based compensators. Firstly the power electronics based voltage sources can internally generate and absorb reactive power without the use of ac capacitors or reactors. Secondly, they can facilitate both reactive and real power flow. The family of compensators and power flow controllers based on synchronous voltage sources, which are relevant to this paper, and the Static Synchronous (shunt) Compensator (STATCOM), the Static Synchronous Series Compensator (SSSC) and the Unified 1 Power Flow Controller (UPFC). Whereas the STATCOM and SSSC are usually employed as reactive compensators, the UPFC could be considered as a comprehensive real and reactive power compensator capable of independently controlling both the real and reactive power flow in the line. This capability of the UPFC is facilitated by its power circuit which is basically an ac to ac power converter, usually implemented by two back to back dc to ac inverters with a common dc voltage link. The output of one inverter is coupled in series, while the output of the other is in shunt with transmission line. With this arrangement, the UPFC can inject a fully controllable voltage (magnitude and angle) in series with the line and support the resulting generalized real and reactive compensation by supplying the real power required by the series inverter through the shunt connected inverter from the ac bus. The UPFC concept provides a powerful tool for the cost effective utilization of individual transmission lines by facilitating the independent control of both the real and reactive power flow, and thus the maximization of real power transfer at minimum losses in the line.

B. *Interline Power Flow Controller*

Interline Power Flow Controller (IPFC), is an advanced voltage-sourced converter (VSC) based FACTS (Flexible AC Transmission Systems) controller suitable for the power flow management of multiline systems. In recent years, power demand has increased substantially while the expansion of power generation and transmission has been severely limited due to limited resources and environmental restrictions [1]. In its general form the interline power flow controller employs number of DC to AC inverters each providing series compensation for a different line The reactive voltage injected by individual Voltage Source Converter (VSC) can be controlled to regulate active power flow in the respective line. While one VSC regulates the DC voltage, the other one controls the reactive power flows in the lines by injecting series active voltage. Since each inverter is also able to provide reactive compensation, the IPFC 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 the corresponding reactive line power, and to increase the effectiveness of the compensating system against dynamic Disturbances [4]. In this seminar, a circuit model for IPFC is developed and simulation of interline power flow controller is done using the four bus system circuit model. Simulation is done using MATLAB/ Simulink. The power systems of today are mechanically controlled and as a result there is no high-speed control. Also, such mechanical controls cannot be initiated frequently because mechanical device tend to wear out very quickly compared to 2 static electronic devices. The FACTS technology is essential to alleviate some but not all of these difficulties by enabling utilities to get the most service from their transmission facilities and enhance grid reliability. The possibility that current through a line can be controlled at a reasonable cost enables a large potential of increasing the capacity of existing lines with larger conductors, and use of one of the FACTS controllers to enable corresponding power to flow through such lines under normal and contingency conditions. FACTS controllers can enable a line to carry power closer to its thermal rating. Interline Power Flow Controller (IPFC) is an extension of static synchronous series compensator (SSSC). A mathematical model of the IPFC in steady state operation has been developed in [1]. In [2], the basic principle of the IPFC is discussed in detail and simulation results are shown to demonstrate the capability of the IPFC to realize power balance between transmission systems with two identical parallel lines. An attempt is made in the present work to develop circuit model for four bus system with IPFC. 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 Fig.1. IPFC is designed as a power flow controller with two or more independently controllable static synchronous series compensators (SSSC) which 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.

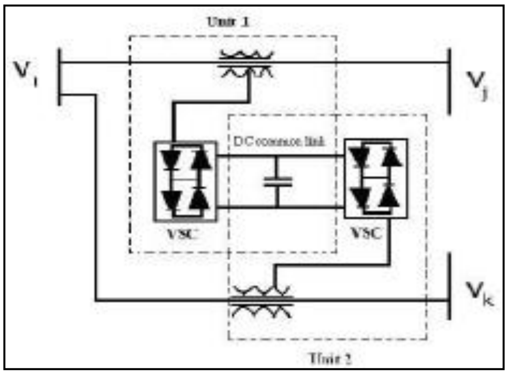

Fig. 1: Basic Configuration of Interline Power Flow Controller

II. LITERATURE REVIEW

Due to their ability to provide reactive power support and control active power flow, voltage sourced converter (VSC) -based flexible ac transmission system controllers can be used to improve the power transfer capability of congested transmission lines. A converter based controller structure has the inherent feature to be used to provide shunt or series compensations. This inherent feature is utilized in the convertible static compensator installed at the New York Power Authority’s Marcy substation, which can operate in 11 configurations of shunt and series compensations. Moreover each configuration can be operated in different control modes. This seminar presents a novel approach to model converter based transmission controllers for load flow calculations. The seminar focuses on modeling converter based controllers when two or more VSCs are coupled to a dc link (eg., unified power flow controller(UPFC), interline power flow controller, and a generalized unified power flow controller). This approach also allows efficient implementation of various VSC operating limits, where one or more VSCs are loaded to their rated capacity [1][9][11].

This paper presets an advanced FACTS controller for power flow management in transmission system using IPFC. Regulator uncertainty, cost, and lengthy delays to transmission line construction are just a few of the barriers that have resulted in the serious deficiency in power transmission capacity that currently prevails in many regions. Solving these issues requires innovative tool on the part of all involved. Low environmental impact technologies such as flexible AC transmission system (FACTS) and dc links are a proven solution to rapidly enhancing reliability and upgrading transmission capacity on a long term and cost effective basis [2][7].

Interline power flow management among multi-line of a substation. In this work mainly concentrated on choosing a suitable voltage source converter, to employ it in the IPFC. A 48 pulse multilevel inverter has been developed by cascading several units of three level diode clamped multilevel inverter (NPCI) with the help of phase shifting transformer [3][6]. This study presented the mathematical model and control strategy of IPFC. The multi series converters of IPFC are represented by multi-series voltage sources with associate transformer leakage reactance. The parameter of IPFC is modeled into power flow equation and thus it is used to determine control strategy. This study used Bang- Bang control strategy. This swing curves of the three phase faulted power system without and with an IPFC are tested and compared in various cases [4][8].

The IPFC (Interline Power Flow Controller) is among the FACTS devices aimed at simultaneously controlling the power flow in multiline systems. This seminar presents the IPFC main features and limitations while controlling the power flow. In order to observe these advantages and disadvantages, a mathematical model based on the d-q orthogonal coordinates was developed. Issues like the relationship between the transmission angle and the IPFC controlled region as well as the converters operative region in steady state will also be presented. It is also used the real power being transferred between the compensated lines. For this purpose, 3 phase transmission line model associated with the converter station has been developed and incorporated in an IPFC model using SIMULINK. The results indicate that IPFC improves system reliability [6][12].

In this seminar a circuit model for IPFC is developed using series coupling transformers and comparison of active and reactive power of Transmission Lines with and without IPFC is presented using the proposed circuit model. Comparison is also done with individual Static Synchronous Series Compensators (SSSCs), one on each line of a two line system and the results are compared with the previous one [5][7].

Many research efforts have been undertaken on single-circuit line fault location in the past several decades. On the other hand, various fault location techniques for double circuit lines have been proposed as well. An algorithm has been proposed by T.Takagi and Y Yamakoshi utilizing one-terminal voltage and current data, but the accuracy of fault location is influenced by fault resistance and the unsymmetrical arrangement of the transmission line. L.Eriksson employs phase voltages and currents from the near end of the faulted section as input signals and fully compensates the error introduced by the fault resistance. Assuming that the line is homogeneous Kawady and J Stenzel utilize the modal transformation and the local terminal voltage and current to locate the fault [10][13].

III. INJECTION MODEL OF AN IPFC

The functionality of the IPFC can be represented by two VSCs that compensate two lines, as presented in Fig.3.1. Reactances and are the sum of the reactances of the IPFCs series transformer and the reactance of the line. The voltages at the line ends are different. The system is assumed to be lossless. It should be noted that the magnitudes of the series-injected voltages are considered to be independent of the magnitude of the bus voltage Ui as they are generated by VSCs. Therefore, the control parameters of each IPFCs branch are the magnitude and the angle of the series-injected voltages respectively. Of course, by changing these parameters other system parameters could be controlled, such as bus voltages, active and reactive power-flows, etc. In an IPFC consisting of n branches, 2n-1 parameters can be independently controlled, as one parameter has to provide the active-power balance of the device. In order to be able to construct the structure-preserving energy function of an IPFC, an IPFC should be represented by an injection model. The injection model for each branch of an IPFC is similar to the general SSSC injection model presented in [12]. By connecting both branches to a common DC circuit, an IPFC can be represented by an injection model, shown in Fig.3.1.

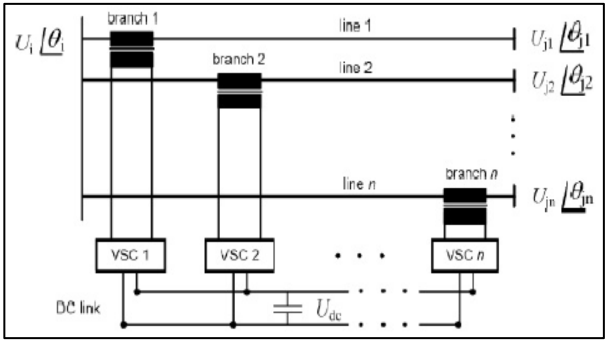

Fig. 2: Model of an IPFC consisting of n series branches

Since the control parameters of an IPFC are the magnitude and the angle of the series injected voltage in each branch, according to Fig. [3.1] although they are not independent, as [11] has to be fulfilled the active and the reactive power injections of the equivalent injection model according to Fig[3.1]shown can be determined. These power injections of the injection model are the basis for the development of the energy function of an IPFC.

IV. MATLAB /SIMULATION FOR IPFC

Digital Simulation of IPFC system is done using MATLAB Simulink and the results are presented. A. model for IPFC system the single phase model of four bus system with IPFC is shown in figure 3. The transformer between the lines is indicated by a dependent voltage source [3]. By providing converters between two transmission lines, the reactive power, active power can be controlled.

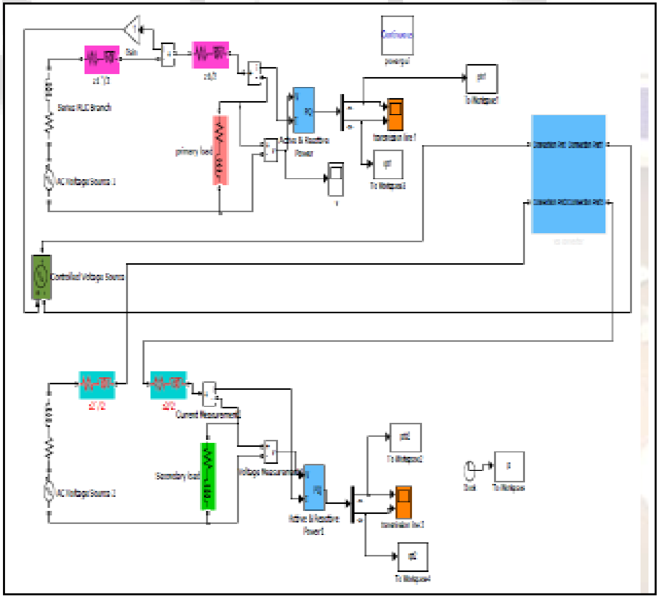

Fig. 3: MATLAB circuit model of IPFC system

V. POWER FLOW EQUATION OF IPFC

As shown in Fig 4. The two-voltage source converters of IPFC can model as two ideal voltage sources one connected in series and other in with the two buses.

The output of series voltage magnitude Vse controlled between the limits Vinjmin ≤ Vinj ≤Vinjmax and the angle Θinj between the limits 0 ≤ Θinj ≤ 2Π respectively. The magnitude and the angle of the converter output voltage used to control the power flow mode and voltage at the nodes. IPFC power Equations (5).

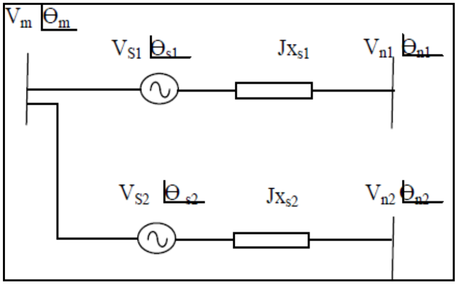

Fig. 4: Line Diagram of Interline Power Flow Controller

Based on the equivalent circuit as shown in Fig 4. The complex power injected by series converter I can be written as Ss1 =Ps1 + JQs1 .The active (Ps1) and reactive (Qs1) powers injected by the series converter I are given by

Ps1=b1VmVs1cos(90-m+s1)+ b1Vn1 Vs1 cos(90m+s1) (1)

Qs1=-b1VmVs1sin(90-m+s1)+b1Vn1Vs1sin(90-n1+s1)+b1V2s1 (2)

Where b1 =1/Xs1 (3)

Where Xs1 is series transformer reactance similarly the active (Ps2) and reactive (Qs2) powers injected by the series converter II are given by

Ps2=-b2 Vm Vs2 cos(90-m+s2)+ b2 Vn2 Vs2 cos(90-m+s2) (4)

Qs2 = -b2 Vm Vs2 sin(90-m+s2) + b2 Vn2 Vs2 sin(90n2+s2) + b2 V2s2 - (5)

The active and reactive power flow in direction m-n1 is given by

Pmn1= -b1 Vm Vs1cos(90+m-s1) - b1Vn1Vs1cos(90+m-s1) (6)

Qmn1 = -b1 Vm Vs1 sin(90+m+s1) + b1 Vn1 Vs1 sin(90-n1+s1) + b1 V2s1 - (7)

The active and reactive power flow in direction m-n2 is given by

Pmn2 = -b2 Vm Vs2 cos(90+m-s2) - b2 Vn2 Vs2 cos(90+m-s2) (8)

Qmn1 = -b2Vm Vs2 sin(90+m+s2) + b2 Vn2 Vs1\2 sin(90+n2-s2) + b2V2s2 (9)

From the above equations we can say that power flow of the power system can be controlled by the series injected voltages. These injected voltages with variable magnitude and variable angle generated by the vsc converters. To find these injected parameters

VI. CONCLUSION

The main attributes and disadvantages characterizing the operation of the IPFC, whilst controlling the power flow in multiline systems, were presented in this paper. It was shown that the mathematical model presented can easily be extended to systems with more than two transmission lines. Although in theory the secondary system can be chosen independently of any restriction, it was shown that this line should be chosen regarding its strength so as not to degrade significantly its own operation. Various operational conditions such as the effect of the transmission angle variation over both primary and secondary systems as well as upon the response of the converters were also addressed. The IPFC, in its simplest form (i.e. with only two series converters), can be very useful in relieving congested systems. Issues like the IPFC instantaneous response and its dynamic behavior, along with their respective simulations, are currently underway 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 simulated using MATLAB. These models are used for simulating a two line-four bus system. Improved model with transformer on both lines and back to back converters is presented which improves the reactive power of the secondary line from 7.088 to 7.110 MVAR. The active power of the secondary is also increased from to 9.492 MW as compared to the value that of without IPFC. In other words the proposed model of IPFC

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