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Power Quality Enhancement using Neuro-Fuzzy Based Interline Power Flow Controller [IPFC]

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ABSTRACT: With the growth and development of power electronics in the field of power system enumerates the new and efficient forms of controlling the power. This paper deals with a systematic approach to design an Interline Power Flow Controller (IPFC) for power system is proposed. It is an independent controller system which is suitable for an individual line compensation of a multilane power system. A Simulink model of an IPFC based multi-machine system along with Neuro-fuzzy is developed. The IPFC performance is tested with PI controllers in comparison with Neuro-fuzzy logic based controller under healthy and abnormal operating conditions. The IPFC Neuro-fuzzy controller is design to coordinate two Separate control inputs: change in voltage and change in capacitor voltage to improve the transient stability of the multi machine system. The Interline Power Flow Controller [IPFC] with fuzzy logic controller is designed with simple fuzzy rules to coordinate the additional damping signal. The proposed controller for IPFC is able to achieve improved designed performance of the power system. Digital simulations are carried out in MATLAB environment.

KEYWORDS:- Flexible AC Transmission System, Interline Power Flow Controller, Fuzzy Logic, Power quality

I. INTRODUCTION

Power semiconductor devices have a major impact in the field of electrical power system all over the world and the evolution of Thyristors has resulted in a new breed of Thyristors based operating devices for the control and switching operations. Flexible AC transmission system (FACTS) seems to be a wide speed application in the field of power industry for active and reactive power control, in common the power system provides an inadequate line flow control which may result in an overloaded line, and even some of the neighboring lines could be operating under an idle like state. Many researchers present work on various nonlinear VSC based FACTS devices for stability improvement of the power system under various system conditions. Among these, the Unified Power Flow Controller (UPFC) is the most versatile FACTS device for improvement of transient stability and damping of oscillations [1]-[3]. Among all other the converter based series FACTS controllers, the Interline Power Flow Controller (IPFC) can provide good solution for congestion management in a multilane power system. Interline Power Flow Controller (IPFC) is an extension of static synchronous series compensator (SSSC). In its general form the interline power flow controller employs number of DC to AC inverters each providing series compensation for a different line. 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. IPFC device performs independently controllable reactive series compensation of each individual line and also to transfer real power between the compensated lines. This capability of IPFC makes it possible to: equalize both real and reactive power flow between the lines; reduce the burden of overloaded lines by real power transfer; compensate against resistive line voltage drops and the corresponding reactive power demand and increase the effectiveness of the overall compensating system [4]. In this proposed system an interline power flow controller is developed and the performance analyzed using fuzzy technology and the steady state response of the controller is analyzed by simulation results.

Fuzzy Logic is a form of many-valued logic. Fuzzy logic controller is robust and easily modified. It can use multiple input and output sources. Fuzzy logic has the advantage that the solution to the problem can be cast in terms that human operators can understand, which is useful for the design of the controller. Also, it does not require precise numerical values of the control inputs and the system parameters. Furthermore, it allows the knowledge from experiences to be incorporated into the control scheme by means of logical reasoning. Hence, fuzzy logic control is an ideal and suitable approach for controlling IPFC. The coordination of control signals through a conventional technique is very difficult, where as fuzzy logic control allows the knowledge from experiences to be incorporated into the control scheme by means of logical reasoning. In multi machine system, the behavior of conventional IPFC controllers is required to

coordinate parameters for better performance. Chandrakaret *al.* [10]-[12] have analyzed the effect of coordinated fuzzy logic based UPFC, STATCOM, SSSC for improvement of transient stability of single machine infinite bus system and multi-machine test system under normal and abnormal condition. The fuzzy application is proved to be more effective control strategy over PI based controllers in nonlinear FACTS devices. Fuzzy controller with POD as additional damping controller further improves the dynamic performance of the system. The designed objective is to achieve improvement in first peak stability and damping of power system oscillations. The IPFC controller is tested under steady state condition as well as disturbed condition of the power system. The comparative performance of PI based controller and fuzzy logic based IPFC for improved power system performance is demonstrated. The results are validated in MATLAB environment.

II. EQUIVALENT SYSTEM MODEL OF IPFC

In its general form the IPFC employs a number of dc to ac each providing series compensation for a different line. In other words, the IPFC comprises a number of Static Synchronous Series Compensators (SSSC) [4]. The IPFC obtained by combining two or more series-connected converters working together extends the concept of power flow control beyond what is achievable with the known one converter series FACTS devices – SSSC. The output voltage of the VSC contains high-order harmonics components, low-pass and tuned filters are used to provide a clean sinusoidal waveform in both master/slave systems. In a typical transmission system with the exchange of reactive power between the series converter and the network, control of active power through the transmission line is achieved. The outputs of two converters are coupled to the transmission lines by using two different series transformers. The injected voltage vector is controllable irrespective of the transmission line current. Hence it can simulate effective impedance of the transmission lines and power flow control is obtained, even power from under-utilized lines to heavily loaded lines.

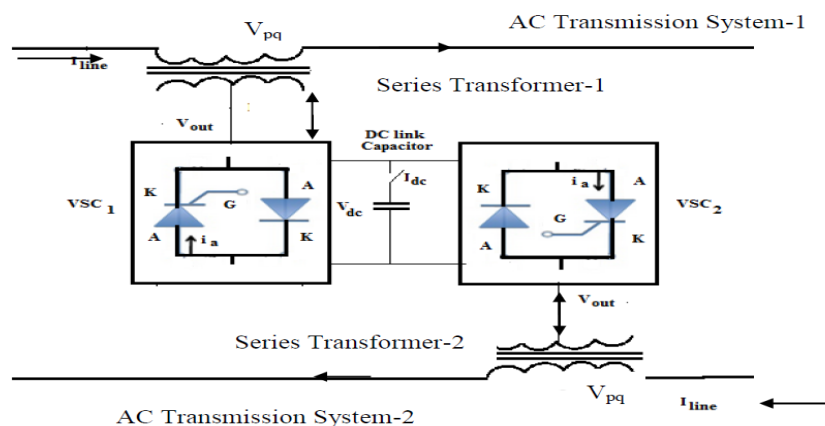


Figure 1 Schematic diagram of IPFC

The reactive power control can be totally independent in each converter whereas the real power flowing into or out of each converter has to be coordinated in such a way that the DC link voltage is kept constant. Also the overall surplus power from the under-utilized lines can be used by other over-loaded lines for real power compensation. The equivalent circuit of the IPFC is shown in Fig. 2.

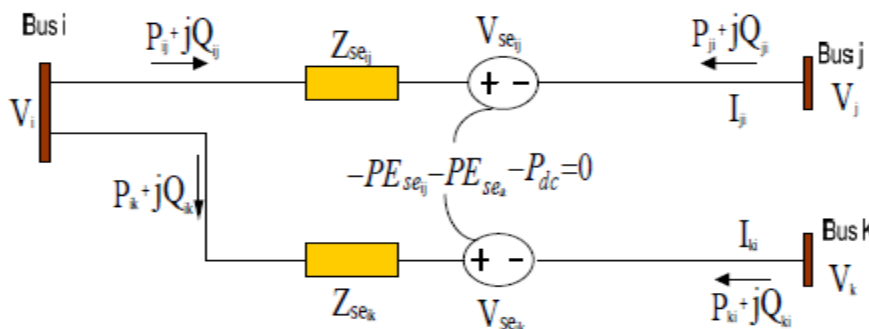


Fig. 2. Equivalent circuit of IPFC

The power flow equations are as follows:

$$P_i = V_i^2 g_{ii} - \sum_{j=1, j \neq i}^n V_i V_j (g_{ij} \cos(\theta_j - \theta_i) + b_{ij} \sin(\theta_j - \theta_i)) - \sum_{j=1, j \neq i}^n V_i V s_{e_{ij}} (g_{ij} \cos(\theta_i - \theta s_{e_{ij}}) + b_{ij} \sin(\theta_i - \theta s_{e_{ij}})) \tag{1}$$

$$Q_i = V_i^2 b_{ii} - \sum_{j=1, j \neq i}^n V_i V_j (g_{ij} \sin(\theta_j - \theta_i) + b_{ij} \sin(\theta_j - \theta_i)) - \sum_{j=1, j \neq i}^n V_i V s_{e_{ij}} (g_{ij} \sin(\theta_i - \theta s_{e_{ij}}) + b_{ij} \sin(\theta_i - \theta s_{e_{ij}})) \tag{2}$$

where V : bus voltage magnitude
 θ : bus angle
 Vse : magnitude of injected voltage
 θse : angle of injected voltage

III. FUZZY CONTROL SCHEME FOR MASTER CONVERTER OF IPFC

The initial phase for designing IPFC based fuzzy is to pick the state variables, illustrative of system element execution, must be taken as the input signals to the controller. Decision of proper variables in the fuzzy control rule is additionally a vital calculates the execution of the fuzzy control system. These variables change the numerical estimations of the information of the fuzzy input, to fuzzy quantities the second step is to pick the linguistic variables, remembering that the quantity of linguistic variables indicates nature of the control. As the number of the linguistic variables expands, the computational time and memory likewise increment. Along these lines a balance between the nature of control and computational time is expected to pick the quantity of linguistic variables. For the test systems, taking seven linguistic variables for Input and Output. The Membership Functions of Input and Output Variables are following: (i) LP (Large Positive), (ii) MP (Medium Positive), (iii) SP (Small Positive), (iv) ZE (Zero), (v) SN (Small Negative), (vi) MN (Medium Negative) and (vii) LN (Large Negative).

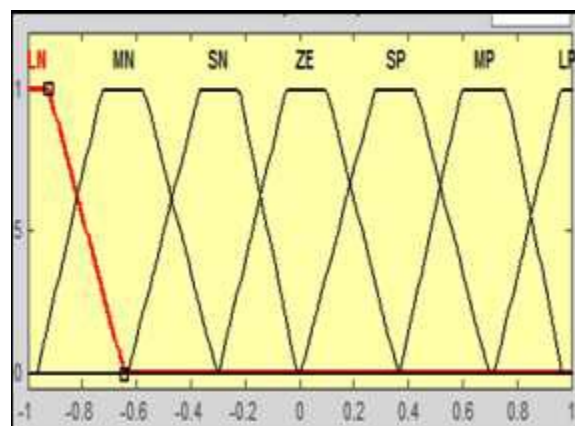


Figure2. Trapezoidal Membership Functions of Input and Output Variables

IV. ANN CONTROL SCHEME FOR SLAVE CONVERTER OF IPFC

Neural Network (NN) has been widely used to solve complex problems of pattern recognition and they can recognize patterns very fast after they have already been trained. The training process requires a training algorithm, which uses the training data set to adjust the networks weights and bias so as to minimize an error function, such as the mean squared error function (MSE), and try to classify all patterns in the training data set [21]. training a neural network. In this paper Back Propagation (BP) training algorithm is used.

V. SIMULINK TEST MODEL OF IPFC

It is proposed to have a controller using fuzzy technology for the power transfer and control between the lines. The proposed model shows a simulation of independent control of multi-machine operating at different voltages [6]. The compensation model includes the effect of shunt and series converter when there is an overloading in the first line, series and shunt converters are individually represented in the simulated diagram. This combination of series and shunt converter constitute interline power flow controller. Output waveforms are drawn after including the compensation effect with Fuzzified IPFC model for the designed circuits. It can prove from the previous analysis using a system with an IPFC controller that, the transmission of power between the multilines is enhanced with the power quality problems. In this paper multi-machine system has been analyzed to enhance power distribution without loss by transferring the power between the lines. An IPFC controller was designed incorporated with a specific fuzzy controller, which improve the performance of a specific transmission line [9]

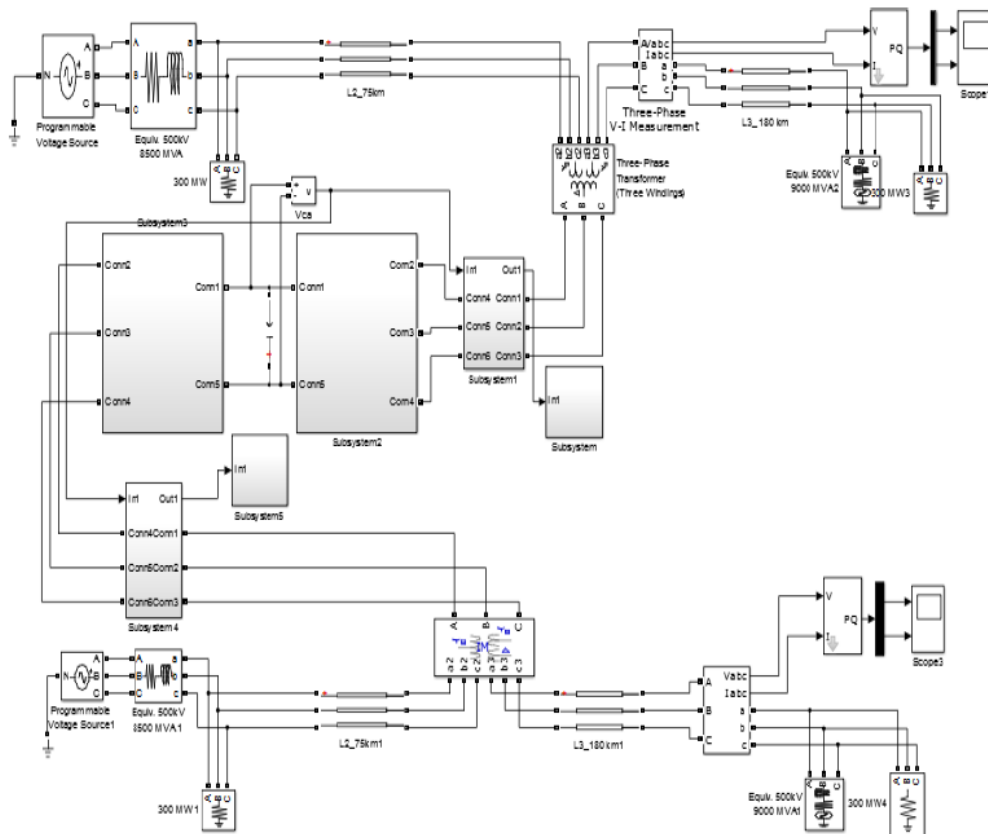


Figure 3. Simulink model of IPFC with four bus test system

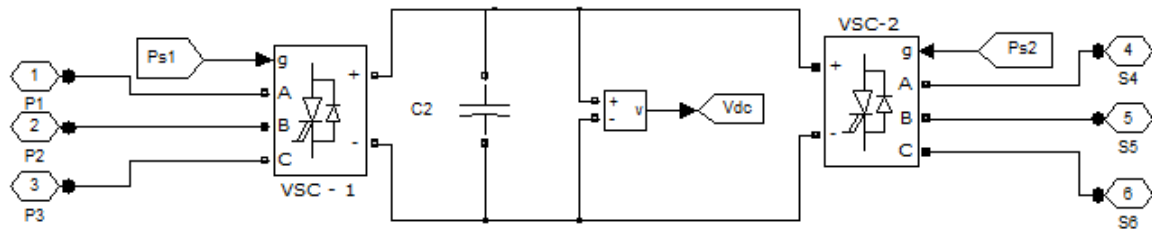


Figure 4. Circuit model of AC-DC-AC converters subsystem

VI. RESULTS AND DISCUSSION

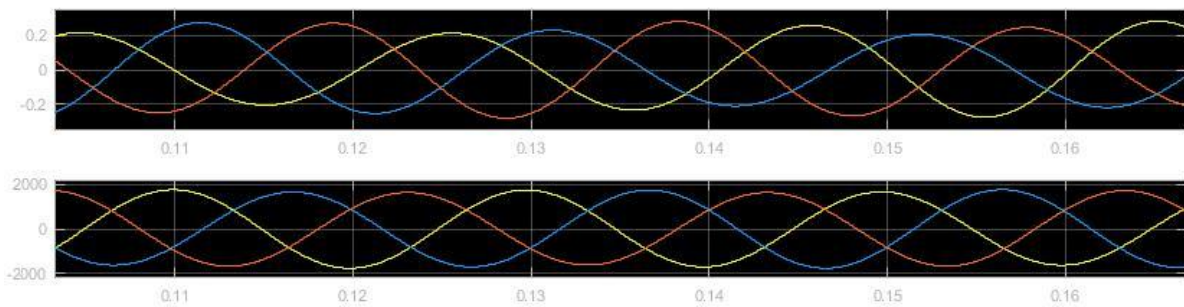


Figure 5. Load voltage and current at load 1

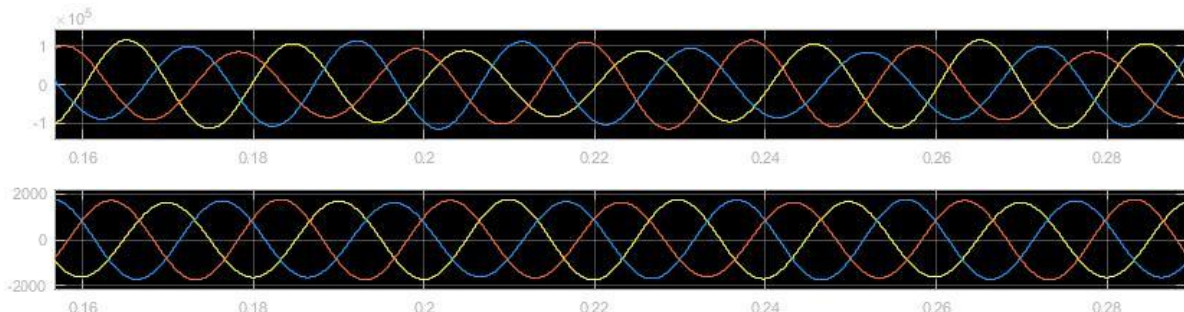


Figure 6. Load voltage and current at load 2

The open loop IPFC circuit model has been developed. Two three phase converters designed and connected back to back each other and their controllers were built in MATLAB/Simulink. The AC side controlled voltage is fed to the transmission lines by using two different series transformer. It is clear that by injecting proper series voltage the impedance of SYSTEM. The overall power flow during variation in the supply side with the presence of IPFC is depicted in as Figure 5 and 6. At 20% change of supply voltage in the positive direction is the worst case compared to the reverse direction that is -20% change of supply voltage.

VII. CONCLUSION

A fuzzy logic based controller for Interline Power Flow Controller (IPFC) has been proposed for multi-machinesystem to improve power system performance. The fuzzy rules have been designed with two inputs change in voltage ΔV and change in capacitor voltage $dc \Delta V$ to minimize transients swing, improvement in damping of oscillations. The controllers comparative performance *i.e.*, PI based IPFC and fuzzy logic based IPFC in terms of transient stability improvement and damping of oscillations is demonstrated. The proposed fuzzy logic controller performance with effective rule base is comparatively better than PI based controller. The fuzzy logic controller demonstrates the robust performance and is easy to coordinate with damping schemes.

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