International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE)

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

|| Volume 9, Issue 8, August 2020 ||

A Review on Control of Interline Power Flow Controller for Power System Stability Enhancement

Purushottam Kumar[1], Sanjeev Jarariya[2]

PG Scholar, Department of Electrical & Electronics, Corporate Institute of Science &Technology, Bhopal, India[1]

Associate Professor, Department of Electrical & Electronics, Corporate Institute of Science &Technology, Bhopal, India[2]

ABSTRACT: The interline power flow controller (IPFC) is a Flexible ac transmission based device comprises voltage source converter for the series compensation in multiline transmission systems. The IPFC is capable to manage power between two or more interconnected lines. The voltage source converter injects reactive power which is used to flow the active power in the transmission lines. Flow of electrical energy in the transmission line can be controlled adequately by utilizing IPFC. This paper presented a short Review of Adaptive Control Schemes for IPFC for managing power flow and comprehensive analysis of active power.

KEYWORDS: interline power flow controller (IPFC);Artificial Neural Network controller(ANN);AC transmission; load flow control;

I.INTRODUCTION

In current scenario, the transmission and distribution networks are densely populated due to the surplus demandof global energy consumption. Constructing a new transmission network becomes a challenging one, because ofthe environmental impacts related with law and legislative cries. Also, the cost effective technical challenges arepresented in deregulation of the power network.Energy demands are growing remarkably high, making itextremely difficult for the power quality to meet energydemand which lead to the load shedding problem and powerquality problem [1]. The power quality problem is sensedto be an occurrence of nonstandard voltage, current, orfrequency [2, 3] which is described as the variation in voltage,current, and frequency in a power system [4–6].Also the distance between generating units and load centres are far away. For that reasons losses are huge. So as to minimize the power losses and also to ensure highqualitypower supply up to the end user, concern must be taken.It is clear that the power quality problems such as voltage sag, swell,harmonic distortion, unbalance, transient, and flicker canhave a prominent impact on customer devices to result inmalfunctions and loss of production [12].In this context, very fast reactive compensators, electronically controlled, and power flow controllers have been developed within the overall framework of the Flexible AC Transmission Systems(FACTS) initiative [1].FACTS technology enables the flow of the corresponding load power through the transmissionlines under both emergency and normal conditions.The FACTS controller carries the load closer to its thermalrating. For further performance improvement in the system,the static synchronous series compensator (SSSC) has beenextended to the interline power flow controller (IPFC).Also Among the last generation FACTS controllers using the self-commutated voltage sourced converter (VSC) [2], the unified power flow controller (UPFC) and the interline power flow controller (IPFC) arethe most versatile and powerful devices, improving the transfer capability of existing transmission lines.Among various power interruptions, voltage dips create higher-level disruption in the power supply systems. In publicdistributed systems or in installations, faults occur mainlydue to random events and unpredictable voltage dips. Byinjecting a voltage at the supply mains of distribution in thetransient line, the voltage issues could easily be solved. Theoccurrence of voltage deviation could be compensated byinserting the voltage (phase and magnitude) for upstreamdistribution.The UPFC combines the functions of the shunt and series compensation being capable to control the active and reactive power flows in the transmission line [3]. This is an important achievement that can beused in power flow control, load sharing among parallel corridors, voltage regulation, and enhancement oftransient stability and mitigation of system oscillations.The IPFC with two or more series connected converters working together is conceived for thecompensation of multi-line transmission system. In this way, the power optimization of the overall systemcan be realized in the form of appropriate power transfer from overload to under loaded lines.

It is well known that heavily loaded lines and buses with relatively low voltages are factors that significantly limit (available transfer capability) ATC.Facilitated by its multiple series compensators combined by acommon DC voltage link, the IPFC can not only regulate busvoltages but also directly transfer active power among/betweenthe compensated lines. This feature offers a very good solutionfor ATC enhancement.The interline power flow controller (IPFC) addresses the common substation issuesof transmission lines [18]. The IPFC offers fixed real powertransmission capability between the compensated lines, whilethe reactivepower inthe lines is adjustable.Inter line power flow controller (IPFC) was proposed by Gyugi in 1998 [1]The IPFC is capable to balance the power flow between multiple transmission lines. It hasconsisting no. of voltage source converter connected with thesame DC terminals. Each voltage source converter providesseries compensation to the individual line. In this way, thepower optimization of the overall system can be realizedthrough power transmit from overloaded lines to under loadedlines with dc link.

II.INTERLINE POWER FLOW CONTROLLER (IPFC)

The interline power flow controller (IPFC) is based on the Flexible AC Transmission System (FACTS) controller for the voltage source converter (VSC) and for power flow management among the multiline substation transmission system [20]. The power balancing is attained by IPFC through the lines, thereby permitting additional power and improving the power quality. By IPFC circuit modelling, the transfer of real power and voltages is improved further [21].The IPFC is a device with the capability of controlling both active and reactive powers between the transmission lines, meaning that voltage phase angle and magnitude are under control. It consists of twoor more series connected converters (SSSCs – Static Synchronous Series Compensators) supplied by acommon DC voltage link, which enables the IPFC to compensate multiple transmission lines.The basic operation principle of an IPFC can be found in open literature [7]. A simpler schematic representation of the IPFC is shown in Fig. 1(a)**,** which employs two back-to-back dc-to-ac converters.The converters are connected in series with two transmission lines via series coupling transformers andthe dc terminals of two inverters are connected through a common DC link.The Interline Power Flow Controller is used for compensation in transmission line to control power flow. The staticsynchronous Series controller is employed to boost thetransmittable active power overa specified line and also to provide stability in the multiline transmission system.

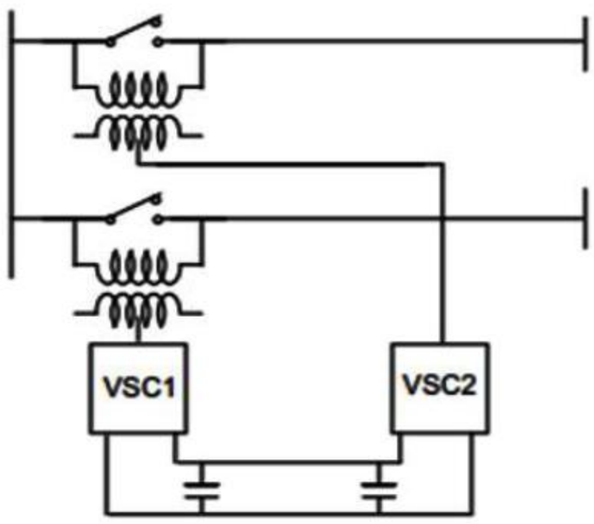

Fig.1 Interline Power Flow Controller

In the shown figure 1 the IPFC consisting of two voltagessourced converters, connected back-to-back and are operatedfrom a common dc link provided by a storage capacitor. Thearrangement shows functions as an ideal ac-to-ac powerconverter in which the real power can freely flow in eitherdirection between the ac terminals of the two converters, andeach converter can independently generate or absorb reactivepower at its own ac output terminal.An elementary IPFC scheme consists of two back-to-back DC-to-AC converters; each compensating a transmission line by series voltage injection is shown in Figure 2. The reactive power control can be totally independentin each converter whereas the real power flowing into or out of each converter has to be coordinated in such away that the DC link voltage is kept constant also the overall surplus power from the under-utilized lines can beused by other over loaded lines for real power compensation. The DC to AC converter is basically voltagesource converter and can inject a controllable voltage into the transmission line irrespective of the transmissionline current. Hence the effective impedance of the transmission line is changed as either inductive or capacitivein nature that is reactive series compensation is obtained [13].In general the transmission lines are inductive in nature as its resistance is very small compared to its inductive reactance. Hence $Z = X_L$and θ = 90^0The real power transfer from the sending end is given by

$$P_{s1} = \frac{V_s V_r}{X_L}\sin(\delta) = \frac{V^2}{X_L}\sin(\delta)$$

Where, $V_s$is the magnitude of sending end voltage,

$V_r$is the magnitude of receiving end voltage,

δ is the phase difference between sending and receiving end voltages.

When series connected converter inject voltage in quadrature with the transmission line current it can emulateeither inductive or capacitive reactance in the line. Consider Equation and assume the series converter injecta controllable voltage in the transmission line in such a way to emulate capacitance effect. Hence the net effectivereactance of the line is reduced and power transmission capacity is increased.

$$P_{s3} = \frac{V^2}{X_{L-X_c}}\sin(\delta)$$

It is clear that for the same values of V and δ the transmittable real power P_{s3} is higher than the P_{s2}. The increasein transfer power is given by

$$\frac{P_{s3}}{P_{s2}} = \frac{X_L}{X_{L-X_C}} = \frac{X_L}{X_L\left(1-\frac{X_c}{X_L}\right)} = \frac{1}{1-K}$$

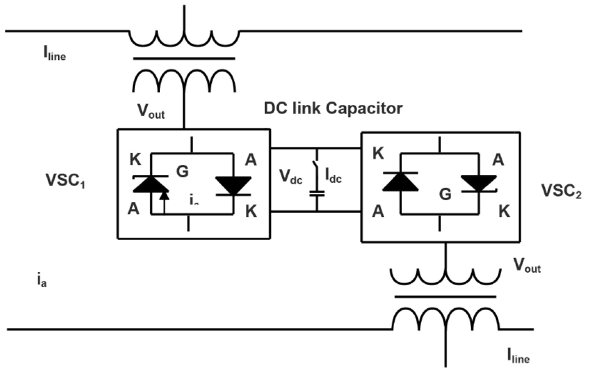

Fig.2Schematic block diagram of IPFC.

III. ADAPTIVE CONTROL SCHEMES FOR IPFC

I) ANN Control Scheme-

Interline Power Flow Controller is series compensating device for series compensation of Active and reactive power with distinctive ability of power flow management between many transmission lines in power network. During disturbances in power system, the stability of system causes deviation from stable operation and causes variation in different parameters of power system like load angle and Rotor speed. To suppress oscillations in load angle and rotor speed, the Artificial Neural Network (ANN) controller with IPFC is proposed to increase the stability of power network. IPFC with ANN is considered for analysis of IEEE 14 Bus system. For different fault conditions analysis is carried out using MATLAB/Simulink.ANN imitates the biological nervous system to perform the tasks on the input data. To solve highly complex tasks such networks are widely used. It consists of input, one or two hidden and output layers. Training of the neural network is controlled by specific leading inputs to achieve the target. Providing multiple instances of inputs to train the network helps it to yield better results. The weights in the network are adjusted until the desired output equals the actual output. The difference between the desired and the actual outputs leads to error.

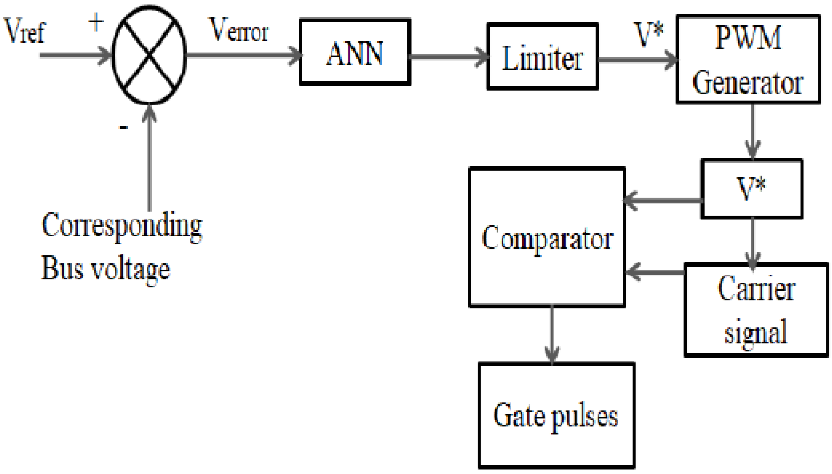

Fig.3, ANN Control Strategy

This error is back propagated to adjust the weights in the network. Such trained networks are used in the testing phase to evaluate the unknown inputs. In the current study, Back propagation algorithm is used to reduce oscillations and they quickly dampen after training [7]. V_{ref} is related with corresponding bus voltage and the error found, V_{error}, is applied to ANN control block. The limiter output Vis fed to the PWM generator. The PWM generator output is compared to the carrier signal using a comparator, to obtain desired gate pulses used for IPFC. For balanced and unbalanced faults with IPFC of a system the settling time is low for the rotor speed. Hence, it is concluded that the IPFC controller be responsible for superior damping of load angle and speed deviations. ANN based IPFC system, provided superior results there by decreasing the disturbances in the power angle and also after fault settling time also reduced by a considerable amount and the system stabilizes rapidly.

II)**Parallel IGBT-Based Interline Dynamic Voltage Restorer**

This Control method mainly spotlights the dynamic processing of energy reloads in common dc-linked energy storage with less adaptive transition. The interline power flow controller (IPFC) scheme has been employed to manage the power transmission between the lines and the restorer method for controlling the reactive power in the individual linesthe proposed system is discussed with its features, analysis, and design methodology. Several changesand lossesmight occur during power distribution.Therefore,the distribution of the load is processed dynamically asa time-varying phenomenon in these transmission lines. To overcome the shortcomings of the existing systems in order toreduce transmission time and losses, the proposed methodologyhas been formulated. A distinguished methodology,the Parallel IGBT-Based Interline Dynamic Voltage Restorer(PIGBT-IDVR), has been proposed to achieve power flowcontrol and voltage control for reducing the transmissiontime and switching time for power from one transmissionprocess to another process.Here, the functions of the voltage restorer determine the range of compensation, and the inductance is assumed to benegligible.The voltage sags and swells (VSS) function and theinjected voltage are expressed as

$$\mathrm{VSS} = \frac{V_{X,n} \mp V_{Y,n}}{V_{X,n}},$$

$$V_{X,n} = V_{Y,n} \mp V_{I,n}.$$

The maximum possible magnitude of the output voltageis approximately equal to the dc voltage in the various cells ofa multilevel inverter. The maximum possible output voltageis expressed by considering $(n-1)/2$ cells. The derivative ofthe injected voltage and the maximum value of VSS can beexpressed as

$$V_{I,n} = \frac{(n-1)}{2} \cdot V_{\mathrm{di}},$$

$$\mathrm{VSS}_{\mathrm{max}} = \frac{(n-1)}{2} \cdot \frac{V_{\mathrm{di}}}{V_{X,n}},$$

When the modules are connected in parallel, the capabilityof the current is defined by the parameters that havebeen used by the individual modules. Due to the variationof parameters between the various modules, the connectionimpedance that is matching may not provide a realistic sharingof the current. Additionally, an unequal device coolingeffect results in a current imbalance within the modules orbetween the modules. The temperature during switching isdirectly dependent on the on-state of the respectivemodules.The dynamic and static current sharing and the currentimbalance between the parallel connection modules result ina momentous variation in temperature. Figure 3 represents the proposed PIGBT Simulink model

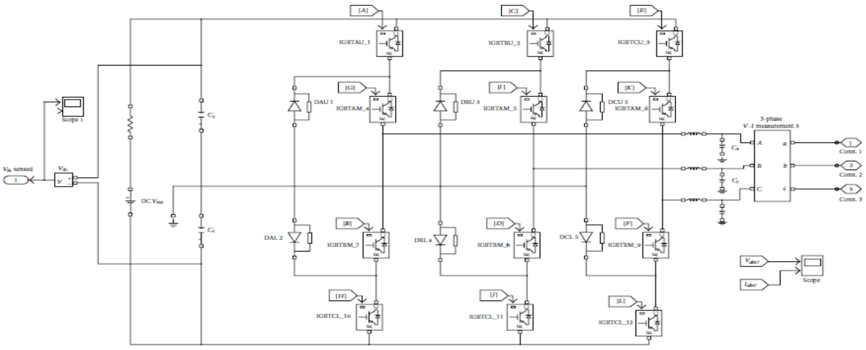

Fig.4.proposedPIGBTSimulinkmodel

The simulation results of the proposedmodule provide better compensation than the existingsystem. The evaluation of the proposed methodology hasbeen performed in a common dc-link to provide a fasterprocess, reduction in switching losses, dynamic processingof energy reload with less transition in energy storage, lesstransmission time, and proper management in the flow ofcurrent and voltage.

iii)Self-tuning fuzzy damping controller

a novel self-tuned fuzzy damping control scheme for an interline power flow controller(IPFC) to suppress the interarea mode of oscillations in a multimachine power system. The nonlinear adaptive dampingcontroller is based on coordinated operation of two fuzzy inference systems. The first one produces the required *q* –axisvoltage reference of the quasi multipulse series converter in response to generator angle oscillations, while the second oneis used to tune the output of the first one online for further reducing the error signal using a given set of fuzzy rules. Thesimplex method is employed to search for optimal gains of the damping controller by minimizing the objective functionin which speed deviations between generators are formulated.The STFDC consists of two concurrently operating fuzzy modules, i.e. a fuzzy damping controller (FDC) and fuzzified gain tuner (FGT).

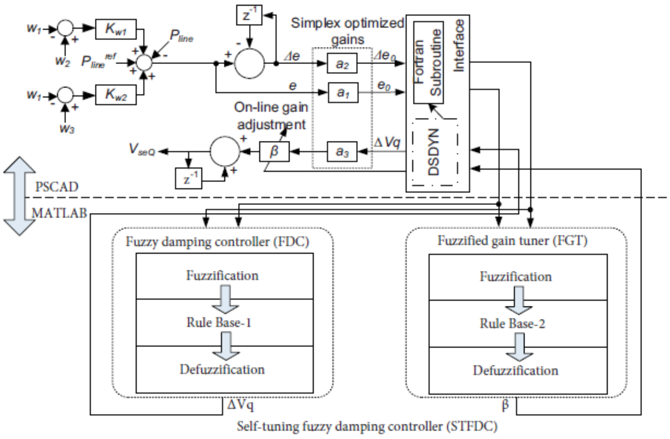

Fig. 5. Schematic diagram of STFDC.

It is demonstratedthat the STFDC exhibits acceptable dynamic performance and improves overall system stability. Moreover, itis shown that the STFDC is robust to change in fault type and fault duration. The STFDC is further verified onthe real power flow control loop of the SSSC, which also yields a particular performance comparison between theIPFC and SSSC. Although there is no voltage control function included in either the IPFC or SSSC operations,both are able to make voltages of the intertie buses less oscillatory in the case of severe faults. Successfuloperations of the IPFC and SSSC are proven by maintaining constant DC link voltage under fault scenarios.The quasi multipulse VSC designed for the FACTS devices do not disturb power quality in terms of harmoniccontent, which complies with the regulations. Hence, no filter is required at the line side.

IV) Optimal power flow (OPF) control-

An ATC computation method based on the optimal power flow (OPF) control is formulated to evaluate the power transfer capability from the specified generation unit to the specified load. The IPFC, represented by its power injection model, is incorporated into the OPF control formulation.During the increase of the active power demand of the sink bus, the ratio of $P_{ls}$to Q_{ls}remains the same as the base case allthe time. The loads connected to buses other than the sink bus,the active power generations of buses other than the source bus,

And all the generator bus voltage magnitudes remain unchangedtoo. The above optimization problem is solved by thesequential quadratic programming (SQP).The application of IPFC to ATC enhancement by OPF control. The power injection model ofIPFC for steady-state analysis is reviewed and incorporated inthe mathematical formulation of ATC calculation by OPFcontrol. When N-1 contingencies and the unavailability of

FACTS devices are taken into account, ATC enhancement isevaluated by probabilistic method. Numerical simulationsshow that the IPFC is a powerful tool for ATC enhancement. Itseffectiveness is affected by the topology of power systems and the parameters of the elements in the power systems. Thecomparison between IPFC and UPFC shows differentcharacteristics of these two powerful combined compensators.In all the numerical examples of this paper, the IPFCdemonstrates its superiority over UPFC in efficiency. This isbecause the UPFC control requires large reactive powergeneration of its shunt compensator. The appropriate choicebetween IPFC and UPFC depends on the demands of thetransmission network owner and system operator, etc. Planningcalculation like the one presented in this paper is necessary formaking the right decision.

V)Neuro-Fuzzy Based Interline Power Flow Controller

In order to improve the real power, compensating the reactive power, proficient power factor and excellent load voltage regulation in the sample test power system, an IPFC is designed. The D-Q technique is utilized here to derive the reference current of the converter and its D.C link capacitor voltage is regulated. Also, the reference voltage of the inverter is arrived by park transformation technique and its load voltage is controlled. Here, a sample 230 KV test power system is taken for study. Further as the conventional PI controllers are designed at one nominal operating point they are not competent to respond satisfactorily in dynamic operating conditions. This can be circumvented by a Fuzzy and Neural network based IPFC and its detailed Simulink model is developed using MATLAB and the overall performance analysis is carried out under different operating state of affairs.The internal structure FIS Fuzzy editor with four inputs and two outputs are shown in Figure 6. A basic architecture of FLC contains fuzzification, inference mechanism,fuzzy rule base, and defuzzification. Fuzzification converts binary data into fuzzy data it has two processes that is derive the membership function for input and output variables. Defuzzification process is to derive the desired crisp output value by combining the membership functions with fuzzy rules. It converts fuzzyo/p values to control signals. It derived by two category, one is off line defuzzification, here all input and output membership functions are based on actual experience, *i.e.*, specified application. Online method is real timecontrollability has higher control accuracy. Fuzzy set allows objects or members to represent a smooth boundarywhereas classical represent sharp boundary and the membership function take the value in the interval 0 and 1.

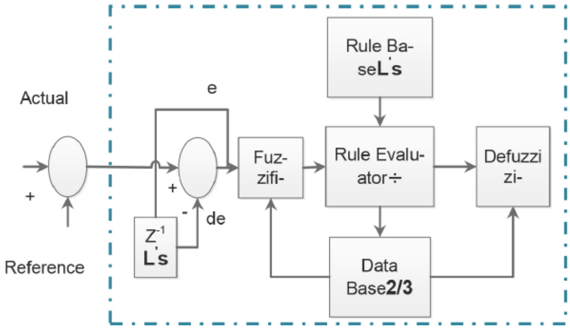

Fig. 6. Internal structure of fuzzy logic controller.

Neural Network (NN) has been widely used to solve complex problems of pattern recognition and they can recognizepatterns 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, suchas the mean squared error function (MSE), and try to classify all patterns in the training data set [12]. The internalstructure of ANN control is depicted in Figure 7. It is very important to choose a proper algorithm fortraining a neural network. In this paper Back Propagation (BP) training algorithm is used. The slave converter in IPFC is used to maintain the DC link voltage constant and provide reactive powerCompensation for line where it is connected. The NN based controller is used to generate control signal for converter2and hence required reactive power compensation is obtained. The stopping condition of training algorithmis either more number of iteration or up to no variation in the weights.

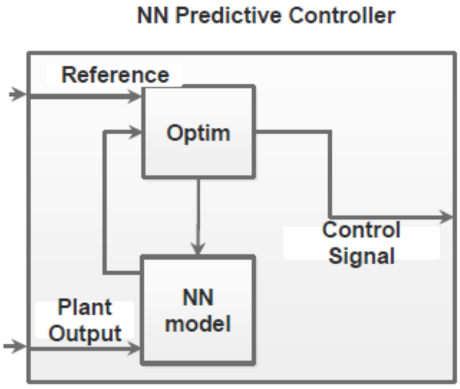

Fig. 7.The structure of ANN control.

The performance of entire system with IPFC isstudied and the simulation results show that using FLC and ANN enhanced the system performance in steadystate region and limited in transient state region. In future, the training algorithm is to be modified for ANN andnumber of rules increased in FLC to meet out the set-back in transient state performance.

IV.CONCLUSION

Interline power flow controller have ability to make balance between multiple transmission line.The active power of open loop and closed loop IPFC system is compared with the distorted active powerof uncompensated transmission systems. Various control schemes of interline power flow controller increases activepower and improved voltage profile.Interline power flow controller have ability to make balance between multiple transmission line. In this paper Review of various control techniques used in IPFC. From above all the discussion it has found that neuro fuzzy control given superior result compared to the other control.

REFERENCES

[1]Darly. S. S, VanajaRanjan "Modeling, Simulation and Fault Diagnosis of IPFC using PEMFC for High Power Applications" JEET Vol. 8, 2013.

[2]Akhilesh A. Nimje, Chinmoy Kumar Panigrahi "Interline Power Flow Controller: Review Paper" IEEJ, Vol. 2(2011).

[3]Zhang, J. and Yokoyama, A. (2007) Application of Inter Line Power Flow Controller to ATC Enhancement by Optimal Power Flow Control. *IEEE Lausanne Power Tech*, Lausanne, 1-5 July 2007, 1226-1231.

[4]Sreejith, S., Simon, S.P. and Padhy, N.P. (2013) Estimation of Recovery Cost with the Incorporation of an IPFC in aSCUC Problem. *IEEE Power & Energy Society General Meeting*, Vancouver, 21-25 July 2013, 1-5.

[5]Gyugyi L, Sen KK, Schauder CD. The interline power flow controller: a new approach to power flow management in transmission systems. IEEE Trans. on Power Delivery1999; 14: 1115-1123.

[6] N. G. Hingorami, L. Gyugyi, *Understanding FACTS: Concepts and Technology of Flexible AC Transmission system*, IEEE Press,1999.

[7] A. M. Parimi, I. Elamvazuthi, N. Saad, "Damping of inter areaoscillations using Interline Power Flow Controller based dampingcontrollers," *IEEE 2nd International Power and EnergyConference*, 2008. 1-3 Dec. 2008, pp. 67 – 72.

[8] A. M. Parimi, I. Elamvazuthi, N. Saad, N, "Interline Power FlowController (IPFC) based damping controllers for damping lowfrequency oscillations in a power system," *IEEE InternationalConference on Sustainable Energy Technologies*, 24-27, pp. 334 –339, Nov. 2008.

[9] A. M. Parimi, I. Elamvazuthi, N. Saad, "Interline Power FlowController Application for Low Frequency Oscillations Damping"*WSEAS Transactions on Systems*, Issue 5, Vol. 9, May 2010.

[10] A. M. Parimi, N. C. Sahoo, I. Elamvazuthi, N. Saad, N, "Dynamicmodeling of Interline Power Flow Controller for small signalstability" *IEEE International Conference on Power and Energy*,2010, pp. 583 – 588.

[11] P. Kundur, *Power System Stability and Control*. Mc Graw-Hill,New York, 1994.

[12] H. F. Wang, F. J. Swift, and M. Li, "An unified model for theanalysis of FACTS devices in damping power system oscillationsPart I: Single-machine Infinite-bus power systems," *IEEE Trans.on Power Delivery*, Vol. 12, No. 2, April 1997.

[13] H. F. Wang, F. J. Swift, and M. Li, "An unified model for theanalysis of FACTS devices in damping power system oscillationsPart II: Multimachine power systems," *IEEE Trans. on PowerDelivery*, Vol. 13, No. 4, October 1998.

[14] H. F. Wang, "An unified model for the analysis of FACTS devicesin damping power system oscillations Part III: Unified PowerFlow Contorller," *IEEE Trans. on Power Delivery*, Vol. 15, No. 3,July 2000.

[15] H. F. Wang, "Applications of modeling UPFC into multi-machinepower systems.", IEE proc. – C, Vol. 146, N0. 3, pp.306-312, May1999.

[16] E. V. Larsen, J. S. Gasca, and J. H. Chow, "Concepts for design ofFACTS controllers to damp power swings," *IEEE Trans. OnPower System*, vol. 10, no. 2, pp. 948-956, May 1995.