World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:7, No:12, 2013

Investigations into Effect of Neural Network Predictive Control of UPFC for Improving Transient Stability Performance of Multimachine Power System

Sheela Tiwari, R. Naresh, R. Jha

Open Science Index, Electrical and Computer Engineering Vol:7, No:12, 2013 publications.waset.org/9996599.pdf

***Abstract*—**The paper presents an investigation in to the effect of neural network predictive control of UPFC on the transient stability performance of a multimachine power system. The proposed controller consists of a neural network model of the test system. This model is used to predict the future control inputs using the damped Gauss-Newton method which employs 'backtracking' as the line search method for step selection. The benchmark 2 area, 4 machine system that mimics the behavior of large power systems is taken as the test system for the study and is subjected to three phase short circuit faults at different locations over a wide range of operating conditions. The simulation results clearly establish the robustness of the proposed controller to the fault location, an increase in the critical clearing time for the circuit breakers, and an improved damping of the power oscillations as compared to the conventional PI controller.

***Keywords*—**Identification, Neural networks, Predictive control, Transient stability, UPFC.

I. INTRODUCTION

LARGELY interconnected electrical power systems are becoming the order of the day but the large sizes are making their control even more difficult. Such systems are continuously at the risk of losing stability following a disturbance. Transient instability has always been one of the dominant stability problems on most of the systems [1]. It refers to the ability of synchronous machines of an interconnected power system to remain in synchronism after being subjected to a severe disturbance, such as a short circuit on a transmission line. For years, Power System Stabilizers (PSSs) have been used to add damping to the power system oscillations. However, the damping provided by the PSS has been found to be inadequate, especially for the inter area mode of oscillations under some operating conditions resulting in to instability of the system. To overcome this problem, the power system planners, engineers and operators have been continuously under-utilizing the existing network by providing greater operating margins and redundancies.

The ever increasing complexities in the power systems and the growing need to provide a reliable and quality power can be addressed by the Flexible AC Transmission System (FACTS) devices which not only increase the amount of energy transferred but also result in enhancement of the transient stability and reliability of the power system [2]. Of all the FACTS devices, unified power flow controller (UPFC) is the most versatile and capable of providing stability to the system subjected to transient disturbances. The work undertaken here therefore employs a UPFC for improving the transient stability performance of a multimachine power system.

The use of different control system design methods in designing supplementary controllers for the UPFC for improving transient performance of power systems have been reported in literature. The conventional PID (Proportional+ Integral+ Derivative) types of controllers are the simplest but their performances deteriorate as the operating conditions deviate from the one for which they are tuned initially. This motivates to look for alternatives that overcome the drawback of the PID controllers. Controllers based on robust control techniques [3]-[9] and direct methods [10], [11] have been reported. These methods require a mathematical model of the system and the uncertainties involved therein. However, it is becoming increasingly difficult to generate the mathematical model of the complex power systems that have become the order of the day.

Artificial Neural Networks (ANNs) have been known to have the capability to learn the complex approximate relationships between the inputs and the outputs of the system and are not restricted by the size and complexity of the system. Since these approximate relationships are learnt on the basis of actual inputs and outputs, they are generally more accurate as compared to the mathematical models based on assumptions. This advantage of the ANNS have led the authors to propose Neural Network Predictive Control (NNPC) of UPFC employing a neural network model of the power system to improve the damping performance of the power systems [12], [13]. Though the superior damping performances of the NNPC scheme has been reported by the authors but further investigations are required to study its effect on the Critical Clearing Time (CCT) of the circuit breakers in the system. Moreover, its robustness to fault location also needs to be established. The present work,

Sheela Tiwari is with the Department of Instrumentation and Control Engineering, Dr B R A National Institute of Technology, Jalandhar - 144011, Pb., India (phone: +91-9779090688; e-mail: tiwaris@ nitj.ac.in).

R. Naresh is with the Department of electrical Engineering, National Institute of Technology, Hamirpur, H.P., India (e-mail: rnareshnith@ gmail.com).

R. Jha is with IET Technical Campus, Ropar, Pb., India (e-mail: rjharjha@ yahoo.com).

Open Science Index, Electrical and Computer Engineering Vol:7, No:12, 2013 publications.waset.org/9996599.pdf

therefore, has the following objectives:

a) Determination of the maximum duration for which the system can withstand contingencies at different operating conditions without circuit breaker operation.
b) Determination of critical clearing time for the circuit breakers in the system subjected to faults on the tie lines at different operating conditions.

II. POWER SYSTEM WITH UPFC

For identifying and controlling the dynamics of a UPFC equipped power system, the 2 area, 4 machine system [14] is considered. This system was specifically proposed to study the low frequency electromechanical oscillations of the large interconnected power systems. Since the scope of the work undertaken is restricted to investigation in to the performance of the proposed control scheme in improving the transient performance of a UPFC equipped multimachine power system, this system has been taken up as the test system with the UPFC installed at the midpoint of the tie lines due to the symmetric structure of the system. For any other multimachine system, the effect of placement of the UPFC in the system on the performance of the UPFC needs to be investigated before examining the performance of the proposed controllers. The system under consideration for the undertaken work is a two area system with active power flowing from Area 1 to Area 2. In spite of the small size of the system, its behavior mimics the behavior of a large power system in actual operation. Each area comprises of two 900 MVA machines and the two areas are connected by a 220 kV double circuit line of length 220 km. The load voltage profile is improved by installing additional 187 MVAr capacitors in each area. All the machines in the system under study are equipped with PSS. The system has a UPFC installed at the midpoint of the tie lines between bus 11 and bus 12 with bus 11 common to the shunt and the series converters and the other side of the series converter connected to bus 12 as shown in Fig. 1. The test system is modeled and simulated using MATLAB/SIMULINK.

Since the rotor oscillations are the result of real power mismatch, emphasis is on effective control of real power P so as to improve the transient stability performance of the system. As the real power is controlled by the quadrature component V_q of the series injected voltage, there is a need for an effective control of the quadrature component V_q of the series injected voltage for improving the transient behavior of the system [15]. Similarly, the in phase component of the series injected voltage can be controlled to independently regulate the reactive power flowing through the line, if required. Since the primary objective in this work is to improve the transient stability performance of the test system, a neural network predictive controller is proposed to provide a reference for only the quadrature component, V_q of the series voltage to be injected by the UPFC as shown in Fig. 2. The real power reference for this controller is obtained from the steady state power flow requirements. The values of V_q are restricted within the range +0.1pu and -0.1pu (10% of the nominal line-to-ground voltage) so that for the given VA rating of the series converter, series compensation can still be provided even at higher levels of line current. This in turn, will help in improving transient stability performance of the system at higher power flow levels. A very small, non-zero reference for the direct component, V_d of the series injected voltage is assumed to be already available to the UPFC. The variation of the voltage across the dc link and the voltage at the connected bus 11 are controlled by using the PI controllers.

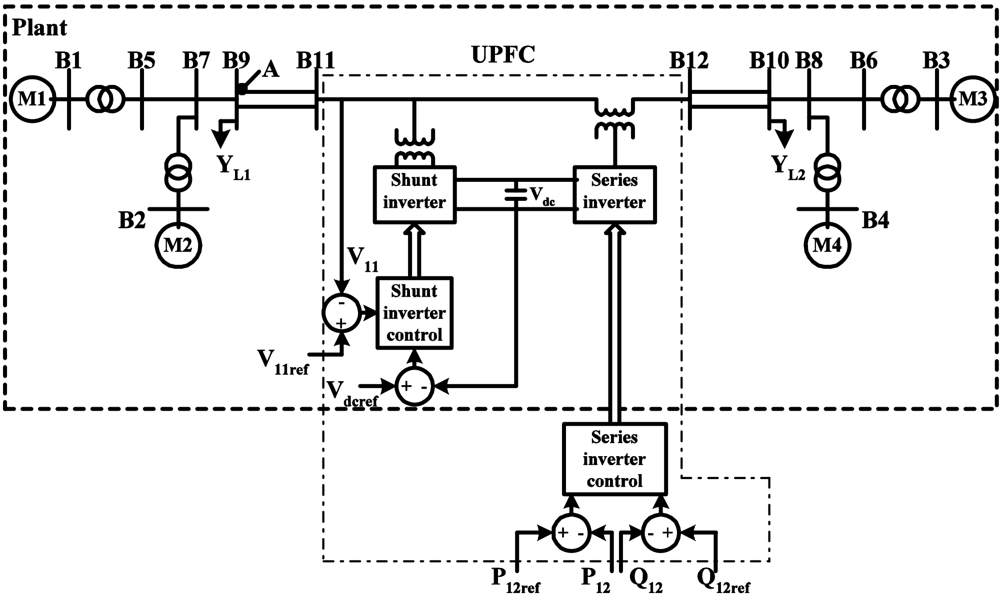

Fig. 1 Two area, four machine system equipped with UPFC

Open Science Index, Electrical and Computer Engineering Vol:7, No:12, 2013 publications.waset.org/9996599.pdf

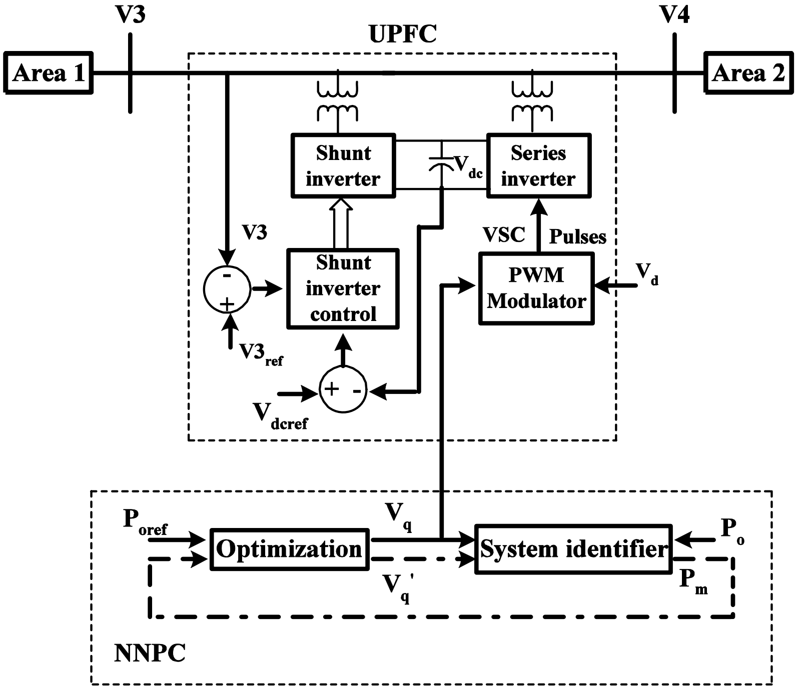

Fig. 2 Block diagram of the 2 area system using NNPC

III. Elements of the Neural Network Predictive Control

Generalized Predictive Control (GPC) is a receding-horizon method that depends on predicting the plant's output over several steps based on assumptions about future control actions [16]-[18]. It was originally developed with linear plant predictor models [19].

For non linear plants, a reasonable model of the plant is required as the quality of the model affects the accuracy of the prediction. As ANNs have been proved to possess an inherent capability to capture the non linear dynamics of a plant, the use of a neural network to model nonlinear plants instead of using the standard modeling techniques will surely enhance the prediction capability of the GPC. Neural network predictive control is actually model predictive control with a neural network employed as the model of the plant / process to predict future outputs of the plant / process. A neural network predictive control system is shown in Fig. 3.

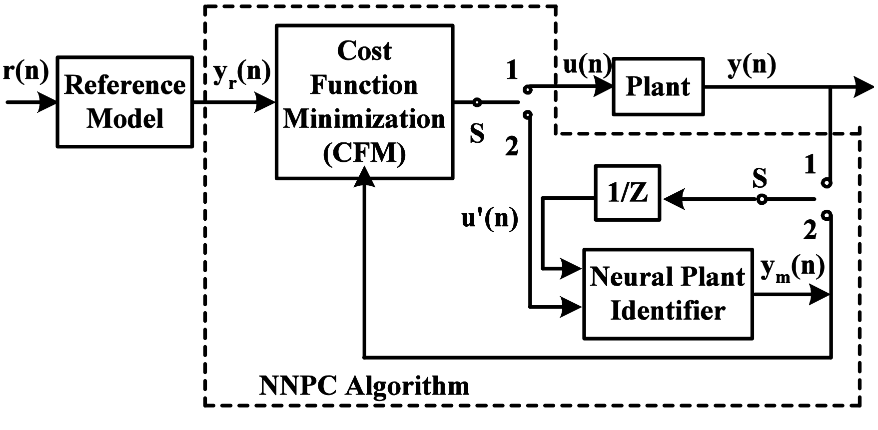

Fig. 3 Block diagram representation of the NNPC system

An input signal r (n) is converted into y_r (n) which is fed to the Cost Function Minimization (CFM) block. Tentative control inputs for specified number of future time instants are first fed to the neural identifier by setting the switch S at position 2 to enable the CFM to use the response from the neural identifier to calculate the next control input. The best control input calculated by the CFM is then fed to the plant by setting the switch at position 1. The neural network predictive controller employed in the current work consists of the following elements:

Open Science Index, Electrical and Computer Engineering Vol:7, No:12, 2013 publications.waset.org/9996599.pdf

A. Prediction Model

The proposed neural network predictive controller employs a neural network for identifying the non linear test system under consideration. The neural identifier in Fig. 4 that identifies the test system (including the UPFC) under consideration uses the current value and the value at three previous instants of the quadrature component of the series injected voltage and the active output power P at four previous instants as inputs to predict the current value of the active output power. Hence, it is a two-layer feedforward neural network with 8 inputs, a single hidden layer with 13 sigmoidal neurons and one linear output neuron. The data required for training the network is generated from simulation of the operation of the test system under consideration by applying randomly generated values for to the plant at regular intervals of 0.03125 second. The Backpropagation algorithm employing the Levenberg-Marquardt algorithm for faster convergence is used to train the neural network shown in Fig. 4 to identify the plant.

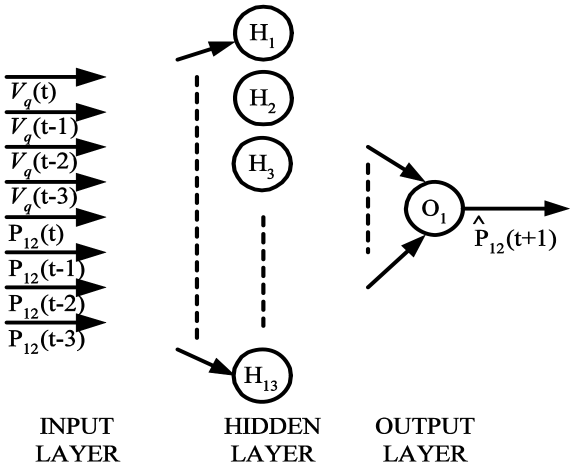

Fig. 4 Architecture of the neural identifier

B. Objective Function

The general aim of the objective function is that the future output on the considered horizon should follow a determined reference signal and at the same time, the control effort should also be penalized [20]. As the rotor angle oscillations are the result of real power mismatch, this work attempts to control only the real power, P and not the reactive power, Q in order to damp the rotor oscillations. Since the rotor oscillations are to be damped by controlling the active power P effectively to the steady state level, the difference between the actual value of the real power and its steady state value over some specified future time horizon needs to be minimized. The deviation in the control action is also minimized making it smooth and ensuring its steady state behavior. The actual value of the active power at future time instants corresponding to the tentative control inputs are predicted by the neural identifier. A cost function employing the Integral Square Error (ISE) criterion and consisting of squared deviations between the reference and predicted active power values and the weighted square of the change in control input over successive future time instants is formulated as following:

$$C = \left(\sum_{j=N_1}^{N_2} \left(P_{oref}(t+j) - P_m(t+j) \right)^2 \right) + \rho \sum_{j=1}^{N_u} V_q' \left((t+j-1) - (t+j-2) \right)^2 \qquad (1)$$

where N_1, N_2 and N_u specify the horizon over which the tracking error and the control increments are evaluated and ρ is the control weighting factor. The value for P_m is given by the prediction model. The active power reference P_{oref} is obtained from the steady-state power flow requirements by simulating the test system in MATLAB/SIMULINK platform and is a constant reference power trajectory which depends on the specified operating conditions.

C. Optimization Algorithm

A numerical optimization technique uses the predictions of the system identifier to determine the control input that minimizes the cost function over the specified horizon. Minimization of this cost function results into the generation of a control input that enables the plant to track the reference trajectory within some tolerance. A cost function minimization algorithm is used with an objective of minimizing *C* in (1) with respect to $\left[V_q'(n+1)\, V_q'(n+2) \ldots V_q'(n+N_u) \right]^T$ denoted by V_q' where $(n+1)$ is the next immediate time instant in future. Since the cost function *C* is a non linear least squares problem, it is minimized using the damped Gauss-Newton method [21], which is an optimization technique meant for the non linear squares problems.

IV. SIMULATION RESULTS AND DISCUSSION

Different operating points corresponding to different power flow levels in the tie line connecting the two areas of the test system were first identified. As the objective of this work is to investigate and enhance the transient stability performance of the system, emphasis is on the study of the system under stress. Three operating points corresponding to different levels of real power flows through the tie line for the given load combination in areas A1 and A2 were determined. The electrical power system can experience a wide range of contingencies with varying degrees of severity and probability of occurrence. However, it is impractical and uneconomical to design power systems to be stable for every possible disturbance and hence, transient stability always refers to a specified disturbance scenario [1]. In the present work, the test system was subjected to three phase short circuit faults (LLL) at (i) A, sending end of the transmission line, (ii) C, receiving end of the tie line, (iii) bus B7 (near generator G2 in area A1) and (iv) B6 (near generator G3 in area A2) at different operating conditions.

The performance of the system equipped with the NNPC-UPFC working in coordination with PSS is compared with (i)

Open Science Index, Electrical and Computer Engineering Vol:7, No:12, 2013 publications.waset.org/9996599.pdf

the system equipped with only PSS and (ii) the PSS equipped system reinforced with PI controlled UPFC where the PI controllers are tuned manually to reduce the overshoot observed during transient in case of the only PSS system and also to minimize the steady state error. The performance of the test system equipped with different controllers was investigated at operating conditions that are different from the one for which the PI controllers were tuned initially so as to study the effect of deviation in the operating conditions on the performance of the PI controllers.

The maximum duration for which the system can withstand the considered contingencies without losing synchronism was determined by repeated simulations of the system performance when subjected to these contingencies. The maximum duration for which these contingencies can be allowed to persist in the system as per the simulation results are given in Tables I and II. Circuit breakers are an important component of the protection systems but the operation of the circuit breakers in itself can add to severity of an already existing contingency. Therefore, Critical Clearing Time (CCT) is an important measure of the transient stability performance of a power system, especially at higher power flow levels in the tie lines. The CCT (in cycles) for the breakers on the tie lines was determined by simulating the system performance for a three phase short circuit fault of 200ms duration at locations A and C of the tie line at the three identified operating conditions. The performance of the system was simulated repeatedly with the circuit breakers clearing the fault after different clearing times (in cycles). The maximum number of clearing cycles considered is twelve as it corresponds to the duration (200ms) of the fault under study. The CCT (in cycles) for the LLL fault at points A and C established from the simulation results are given in Table III.

The simulation results in Table I clearly establish that the considered contingency at the sending end is more severe as compared to the same fault at the receiving end. Moreover, the severity of the fault increases with the increase in the power flowing through the tie lines. Table II shows that an LLL fault near a generator in area A1 is more severe than a similar fault in area A2. The CCT determined from the simulation studies and given in Table III show that the LLL fault at the sending end is more severe than the LLL fault at the receiving end. This table also establishes a superior performance of the proposed controller as the CCT for the breakers in the system equipped with NNPC-UPFC is a reasonable 3 / 4 even when the LLL fault is at the sending end whereas the PI-UPFC equipped system and the only PSS system were unstable when the circuit breakers operated during the same contingencies.

V. CONCLUSION

The transient stability performance of the test system equipped with neural network predictive control of the series converter of the UPFC is investigated at different locations over a wide range of operating conditions. The maximum duration for which the considered contingencies can persist in the system without causing instability of the system and the CCT for the circuit breakers have been determined by simulating the performance of the system. The simulation results clearly demonstrate superior transient stability performance of the system employing neural network predictive control for the UPFC as compared to the system using PI controlled UPFC and the system without UPFC. The results also establish the robustness of the proposed controller to the fault location. This improvement in the transient stability performance of the system equipped with the proposed controller can facilitate large power transfers from one area of the system to another. Though the proposed controller is performing satisfactorily even with an offline trained neural identifier, but the current work shall be extended in future to include online training of the neural identifier for still better control of the system.

TABLE I
TIME DURATION FOR WHICH THE SYSTEM CAN SUSTAIN LLL FAULT AT LOCATIONS A AND C

S. No.	**Operating Condition**	**Duration (ms) for Location A**			**Duration (ms) for Location C**		
		Only PSS	**PSS+PI-UPFC**	**PSS+NNPC-UPFC**	**Only PSS**	**PSS+PI-UPFC**	**PSS+NNPC-UPFC**
1.	(i)	188	196	**229**	200	205	**239**
2.	(ii)	42	50	**103**	66	73	**145**
3.	(iii)	unstable	73	**119**	unstable	113	**163**

TABLE II
TIME DURATION FOR WHICH THE SYSTEM CAN SUSTAIN LLL FAULT AT B7 AND B6

S. No.	**Operating Condition**	**Duration (ms) for Location B7**			**Duration (ms) for Location B6**		
		Only PSS	**PSS+PI-UPFC**	**PSS+NNPC-UPFC**	**Only PSS**	**PSS+PI-UPFC**	**PSS+NNPC-UPFC**
1.	(ii)	40	47	**96**	48	56	**121**
2.	(iii)	unstable	69	**108**	unstable	84	**148**

TABLE III
CCT FOR LLL FAULT AT LOCATIONS A AND C

S. No.	**Operating Condition**	**CCT (cycles) for Location A**			**CCT (cycles) for Location C**		
		Only PSS	**PSS+PI-UPFC**	**PSS+NNPC-UPFC**	**Only PSS**	**PSS+PI-UPFC**	**PSS+NNPC-UPFC**
1.	(i)	10	9	**11**	12	12	**12**
2.	(ii)	unstable	unstable	**3**	unstable	unstable	**10**
3.	(iii)	unstable	unstable	**4**	unstable	unstable	**11**

APPENDIX

PSS data:

Sensor time constant = 15ms   Gain = 30

UPFC ratings:

Series converter = 160 MVA

Shunt converter = 160 MVA

$V_{dcbase} = 40kV$ $C_{dc} = 750\mu F$

Neural identifier:

Initial $\mu=0.001$ $\kappa=10$

Neural network predictive controller data:

$N_1=1$, $N_2=5$, $N_u=2$

Control weighting factor, $\rho = 0.01$

REFERENCES

[1] P. Kundur, J. Paserba, V. Ajjarapu, G. Andersson, A. Bose, C. Canizares, N. Hatziargyriou, D. Hill, A. Stankovic, C. Taylor, T. V. Cutsem, and V. Vittal, "Definition and classification of power system stability," *IEEE Trans. Power Systems*, vol. 19, no. 2, pp. 1387-1401, 2004.

[2] N. G. Hingorani, and L. Gyuvgi, Understanding FACTS concepts & technology of flexible AC transmission systems. Delhi: IEEE Press, 2001, ch. 1.

[3] M. Vilathgamuwa, X. Zhu, and S. S. Choi, "A robust control method to improve the performance of a unified power flow controller," *Electrical Power System Research*, vol. 55, pp. 103-111, 2000.

[4] B. C. Pal, "Robust damping of interarea oscillations with unified power flow controller," *IEE Proceedings on Generation, Transmission, Distribution*, vol. 149, no. 6, pp. 733-738, 2002.

[5] A. H. M. A. Rahim, and S. A. Al-Baiyat, "A robust damping controller design for a unified power flow controller," in *Proc. 39th IEEE Universities Power Engineering Conference, (UPEC)*, IEEE, Bristol, 2004, pp. 265-269.

[6] A.H M.A. Rahim, J. M. Bakhashwain, and S. A. Al-Baiyat, "Robust damping controls for a unified power flow controller," *International Journal of Emerging Electric Power Systems*, vol. 6, no. 2, pp. 1-21, 2006.

[7] S. A. Taher, S. Akbari, A. Abdolalipour, and R. Hematti, "Robust decentralized controller design for UPFC using μ-synthesis," *Communications in Nonlinear Science and Numerical Simulation*, vol. 15, pp. 2149-2161, 2010.

[8] A.T. Al-Awami, Y. L. Abdel-Magid, and M. A. Abido, "Simultaneous stabilization of power system using UPFC-based controllers," *Electric Power Components and Systems*, vol. 34, no. 9, pp. 941-959, 2006.

[9] K. Wang, B. Yan, M. L. Crow, and D. Gan, "A feedback linearization baed unified power flow controller internal controller for power flow control," *Electric Power Components and Systems*, vol. 40, no. 6, pp. 628-647, 2012.

[10] V. Azbe, U. Gabrijel, D. Povh, and R. Mihalic, "The energy function of a general multimachine system with a unified power flow controller," *IEEE Trans. Power Syst.* vol. 20, no. 3, pp. 1478-1485, 2005.

[11] A. Zangeneh, A. Kazemi, M. Hajatipour, and S. Jadid, "A Lyapunov theory based UPFC controller for power flow control," *International Journal of Electric Power and Energy Systems*, vol. 31, pp. 302-308, 2009.

[12] Sheela Tiwari, Ram Naresh, R. Jha, "Neural network predictive control of UPFC for improving transient stability performance of power system," *Applied Soft Computing*, vol.11, no. 8, pp.4581-4590, 2011.

[13] Sheela Tiwari, Ram Naresh, R. Jha, "Neural network predictive control of UPFC for enhancing transient stability performance of a single machine infinite bus system," *International Journal of Advancements in Electronics and Electrical Engineering*, vol. 1, no. 2, pp.100-104, 2012.

[14] M. Klein, G. J. Rogers, and P. Kundur, "A fundamental study of inter-area oscillations in power systems," *IEEE Transactions on Power Systems*, vol. 6, no. 3, pp.914-921, 1991.

[15] S. Mishra, "Neural network based adaptive UPFC for improving transient stability performance of power system," *IEEE Transactions on Neural Networks*, vol. 17, no. 2, pp. 461-470, 2006.

[16] D. W. Clarke, C. Mohtadi, and P. C. Tuffs, "Generalized Predictive Control – Part I: The Basic Algorithm," *Automatica*, vol. 23, no. 2, pp. 137-148, 1987.

[17] D. W. Clarke, C. Mohtadi, and P. C. Tuffs, "Generalized Predictive Control – Part II: Extensions and Interpretations," *Automatica*, vol. 23, no. 2, pp. 149-160, 1987.

[18] D. W. Clarke, and C. Mohtadi, "Properties of Generalized predictive Control," *Automatica*, vol. 25, no. 6, pp. 859-875, 1989.

[19] D. Soloway, and P.J. Haley, "Neural generalized predictive control- A Newton-Raphson implementation," in: Proc. *IEEE International Symposium on Intelligent Control*, Michigan, USA, September 15-18, 1996, pp. 277-282.

[20] E. F. Camacho, and C. Bordons, *Model Predictive Control*. London: Springer-Veralag GmbH, 2004.

[21] J. E. Dennis, and R. B. Schnabel, *Numerical methods for unconstrained optimization and nonlinear equations*. Philadelphia: SIAM, 1996.