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Design of Neuro-Fuzzy inference distributed power flow controller for transient stability improvement

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Abstract. Neuro-Fuzzy systems are the systems that neural networks (NN) are incorporated in fuzzy systems, which can use knowledge automatically by learning algorithms of NNs. They can be viewed as a mixture of local experts. Neuro-Fuzzy inference system (NFIS) is one of the examples of Neuro Fuzzy systems in which a fuzzy system is implemented in the framework of adaptive networks. In this paper, NFIS performance is also investigated in the Neuro-Fuzzy control of a DPFC system. NFIS is used in specialized learning algorithm as a controller. Simple NFIS structure is designed and implemented in closed loop control scheme. The performance of NFIS controller is also compared with that of NN for the case under study.

Keywords: NN, fuzzy systems, estimator, NFIS, DPFC

1 Introduction

FACTS Technology is concerned with the management of active and reactive power to improve the performance of electrical networks. The concept of FACTS technology embraces a wide variety of tasks related to both networks and consumers problems, especially related to power quality issues, where a lot of power quality issues can be improved or enhanced with an adequate control of the power flow.

By FACTS, operator governs the phase angle, the voltage profile at certain buses and line impedance. Power flow is controlled and it flows by the control actions using FACTS devices, which include:

a. Static VAR Compensators (SVC);
b. Thyristor Controlled Series Capacitors (TCSC);
c. Static Compensators (STATCOM);
d. Static Series Synchronous Compensators (SSSC);
e. Unified Power Flow Controllers (UPFC).

1.1 Neural networks

A neural network is a data processing system consisting of a large number of simple, highly interconnected processing elements (artificial neurons) in architecture.

They represented the activity of individual neurons using simple threshold logic elements, and showed how networks made out of many of these units interconnected could perform the logical operations. Rosenblat (1959) developed the concept of perceptron, a generalization of the McCulloch and Pitts concept of the functioning of the brain, by adding learning (Lisboa 1992). These studies were the initiations of NNs. NNs are applied in many areas of science and engineering (Svrcek 2001).

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The totality of the neurons, connected with each other and with the environment, forms the NN. Fig. 1 shows the basic structure of the neural network.

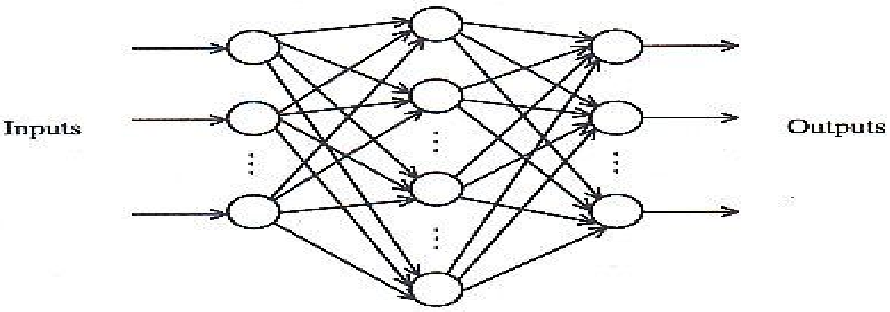

Fig. 1. Basic structure of neural network

1.2 Fuzzy logic systems

Fuzzy logic systems had found successful applications in wide variety of fields such as: automatic control, pattern recognition, signal processing, expert systems, communication, system identification and time series prediction (Czogala and Leski 2000). Since Fuzzy Logic Control (FLC) does not require a model and the control is based on expertise human reasoning, they have been applied in many control schemes.

The structure of fuzzy inference engine is shown in Fig. 2.

1.3 Neuro Fuzzy systems

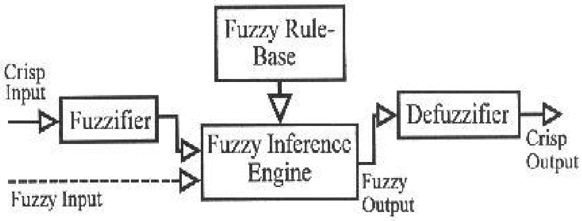

Fig. 2. Fuzzy inference engine

However, every expert does not want to share his knowledge and there is no standard method that exists to utilize expert knowledge. As a result, NNs were incorporated into fuzzy systems to be able to acquire knowledge automatically by learning algorithms.

The connection of fuzzy systems with an NN is called neuro-fuzzy, NF, systems. Like in NNs where knowledge is saved in connection weights, it is interpreted as fuzzy if then rules in NF systems. The most frequently used NN in NF systems is radial basis function neural network, FNN in which each node has radial basis function such as Gaussian and Ellipsoidal. Their popularity is due to the simplicity of structure, well-established theoretical basis and faster learning than in other types of NNs.

Network based fuzzy inference system, NFIS, is one of them. It is type of FNN. Basic NFIS architecture that has two inputs x and y and one output z is shown in Fig. 3.

2 Proposed DPFC system structure

The UPFC of present technology is typically located at either the sending end or receiving end of a transmission line. It will be referred to as a concentrated UPFC. There are three major problem areas associated with the UPFC that have hindered its widespread acceptance by the electric utilities-reliability, cost, and

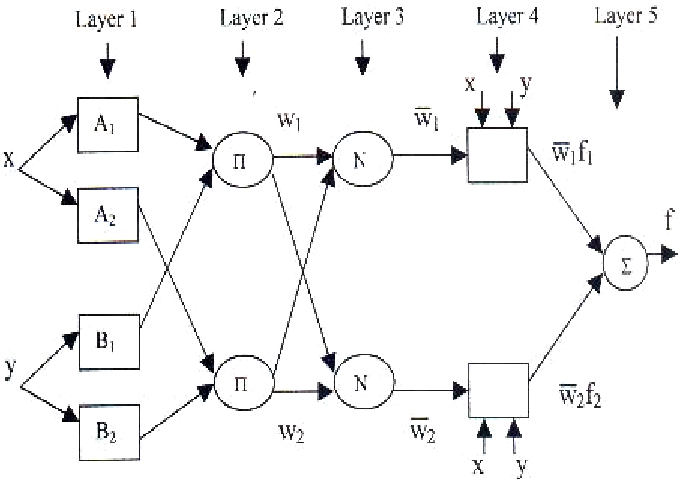

Fig. 3. Basic structure of NFIS

footprint requirement. This novel technology is called the Distributed Power Flow Controller (DPFC). The following discussion clarifies the problems attributed to the UPFC while introducing the DPFC advantages. The proposed DPFC lends itself to a standard design suitable for assembly line manufacture. The implementation of the emerging SiC or CVD switch technology should allow use of simple SPWM switching schemes rather than the transformer mixing of 24-48 step waveforms as done with the present FACTS technology. Further, the high voltage capability of the emerging switches has the potential to operate the shunt portion of the DPFC with direct connection to the transmission level voltages, it is anticipated that the DPFC initial cost can be in the \$100/kVA range. The DPFC should also show advantage in maintenance cost. Warehousing of spare units will now be practical. Replacement of failed units can be handled by utility linemen. Failed units can be serviced at repair centers. To the problems the UPFC confronts, this work provides a feasible solution C the Distributed PFC (DPFC). Same as the personal computer to main frame, the concept of the DPFC intends to utilize the economics of scale to decrease the cost, complexity, and to improve the reliability of the Power system. The Proposed structure of a DPFC Simulink model unit is shown in Figure 8. A certain number of DPFC units are installed along the transmission line between two buses. The number of DPFC units is decided by thetotal required KVA rating divided by the KVA rating of single DPFC unit. For implementation, a central control unit accepts control commands from the system operator. Those commands include real and reactive power to be transmitted from one bus to the other, and the voltage to be controlled at some point along the transmission line. The central control unit computes the total required series voltage, and the shunt real and reactive power based on control commands, sampled voltage and power flow data from the transmission line. It also calculates series voltage and shunt real/reactive power commands, Vsen and Qshn, for every DPFC unit. The central control unit provides an efficient interface between the system operator and the power transmission system. It also monitors working conditions from the field. The communication between the central control unit and the power transmission line and the DPFC units can be done by power line carrier signal or by wireless signal through communication satellite.

2.1 A.controller for the DPFC

The multi-purpose controller for power flow control, POD, and transient stability which is proposed here for the DPFC is based on the same principles as the CSC controllers. The controller has a structure according to Fig. 4.

In this figure, the different controllers contribute with the terms XPOD, XTr, and XPI to the reactance of the TSSC/TSSR-XTSSC/TSSR. All controllers use the active power on the DPFC line, PX or estimations based on PX as input signals. The transient controller also uses the RMS value of the current on the DPFC line, IX as an input signal as well as remote system information for triggering. This control structure has most properties in common with the multi-objective controller proposed for CSC devices in the previous section.

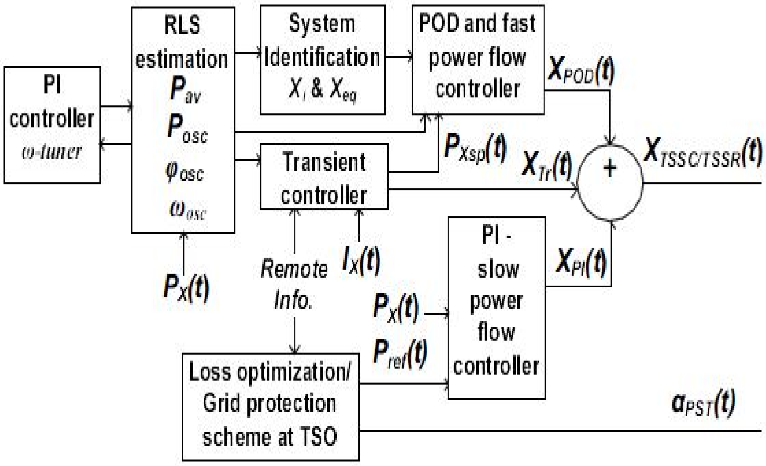

Fig. 4. Schematic illustration of full DPFC controller

The power oscillation damping with its fast power flow control functionality and the transient control structure all have the same functions and input signals as in the CSC case. The system identification part provides the estimated parameters to the controller in the same way as it was done in the CSC controller.

The main differences between the controllers lie in the system model, the estimation routines and the damping algorithms. In the overall structure, it is here assumed that the long term reference value for the DPFC line power Pref is provided by the TSO together with the selected value for the PST tap level. In order to select these values, loss optimization targets and grid security constraints must be considered.

The optimization of the tap level should in most cases be done in a way such that the PST alone is controlling the long-term stationary power on the line keeping the TSSC compensation close to zero. This is done in order to reserve the TSSC capability for corrective control during contingencies. Since this capability is available, the PST can be controlled in a more efficient way in normal operation, optimizing the overall grid losses.

3 Proposed Neuro-Fuzzy inference distributed power flow controller

To operate the DPFC in the automatic control mode, and also to use the DPFC to enhance power system stability and damp low frequency oscillations, two control designs need to be performed. A primary control design, referred to as the DPFC basic control design, involves simultaneous control of (i) real and reactive power flow on the transmission line, (ii) sending bus voltage magnitude, and (iii) DC voltage magnitude. A secondary control design, referred to as the damping controller design, is a supplementary control loop that is designed to improve transient stability of the entire electric power system. The two control designs are described in this chapter.

The UPFC basic control design consists of four separate control loops grouped into a series control scheme, whose objective is to control real and reactive power flow on the line, and a shunt control scheme, whose objective is the control of the sending bus voltage magnitude and the DC voltage magnitude. The proposed structure of a DPFC DC voltage regulator is shown in Fig. 5.

DPFC modeling: To enable the control of the DPFC, controllers for individual DPFC converters are needed. This chapter addresses the basic control system of the DPFC, which is composed of shunt control and series control that are highlighted in Fig. 6.

To design a DPFC control scheme, the DPFC must first be modeled. This section presents such modeling of the DPFC. As the DPFC serves the power system, the model should describe the behavior of the DPFC at the system level, which is at the fundamental and the 3rd harmonic frequency. The modeling of the switching behavior of converters is not required. The modeling of the DPFC consists of the converter modeling and the network modeling. Due to the use of single-phase series converters, they are modeled as a single-phase

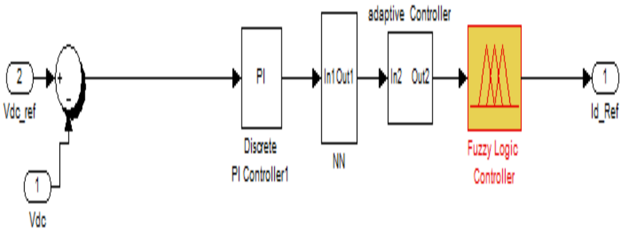

Fig. 5. DPFC DC voltage regulator

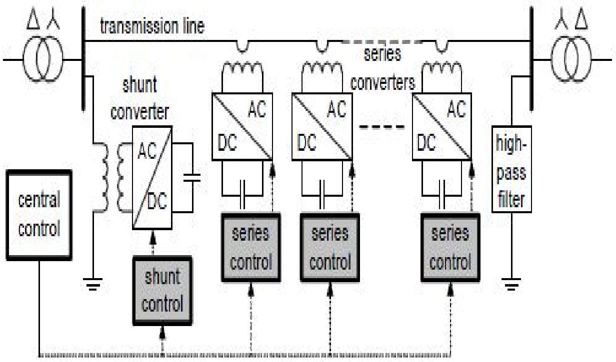

Fig. 6. DPFC basic control

system. To ensure that the single-phase series converter model is compatible with the three-phase network model, the network is modeled as three single-phase networks with 120° phase shift.

The proposed structure of a Neuro-Fuzzy Inference Distributed Power Flow Controller Simulink model unit is shown in Fig. 8.

4 Simulation results and discussions

In this section, the DPFC model is created and simulated on Matlab/Simulink. All the simulations are based on single-phase per-unit system. One shunt converter and two single phase series converters are built and tested. The system under consideration is simulated under different operating conditions to investigate its transient stability performance and to demonstrate the effectiveness of the proposed controller. The contingency under consideration is a three phase fault at the sending end of one of the transmission lines when the generator is operating at different power levels. The fault is considered to occur between $t = 0.2s$ and $t = 0.3s$. The fault is cleared with the operation of transmission line reclosure.

The following case studies were undertaken to make the assessments and shown in Fig. 9 to Fig. 11.

5 Conclusion

This paper deals with the FACTS device known as the Distributed Power Flow Controller that is used to maintain and improve power system operation and stability. The DPFC basic control design and the damping controller design were performed. It has been shown that the DPFC with its basic controllers is capable of controlling independently real and reactive power flow through the transmission line both in steady state and dynamic conditions. This feature cannot be accomplished with the mechanical and other FACTS devices. It has also been shown that DPFC can be used for voltage support and for improvement of transient stability of the entire electric power through a supplementary control loop. The proposed supplementary control based on the fuzzy logic is effective in damping power oscillations. Simulation results have shown that controller exhibits good damping characteristics for different operating conditions and compared to the conventional controller shows superior performance.

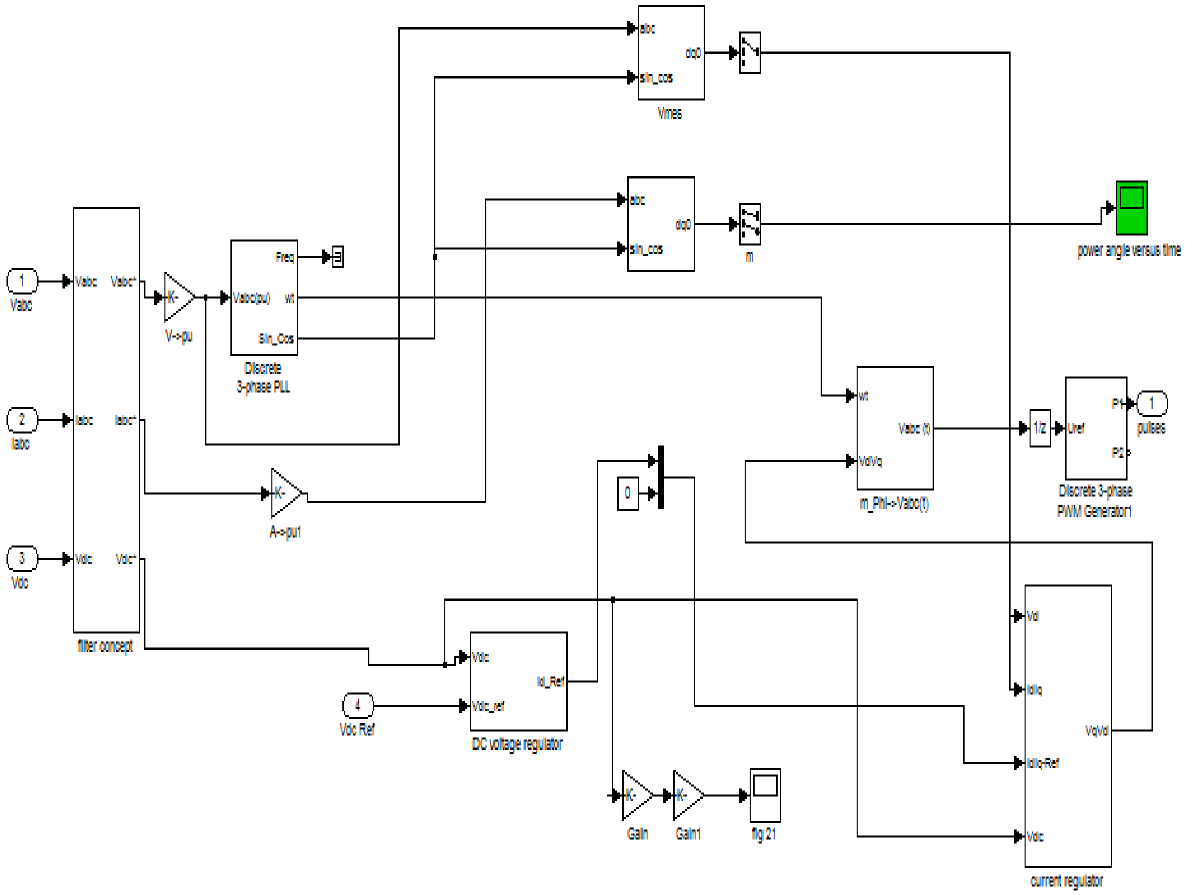

Fig. 7. DPFC shunt converter controller

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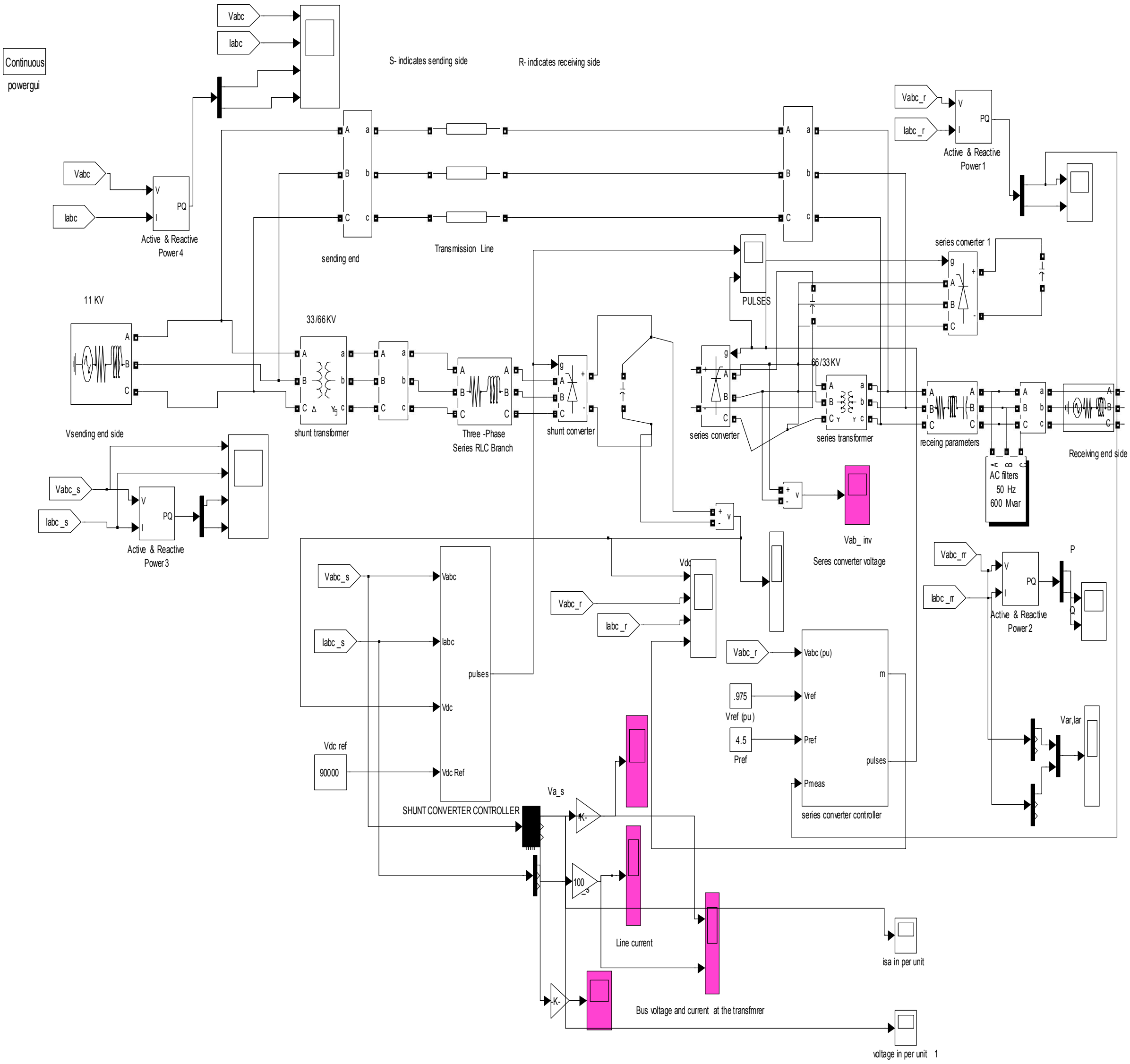

Fig. 8. Neuro-Fuzzy inference distributed power flow controller simulation model

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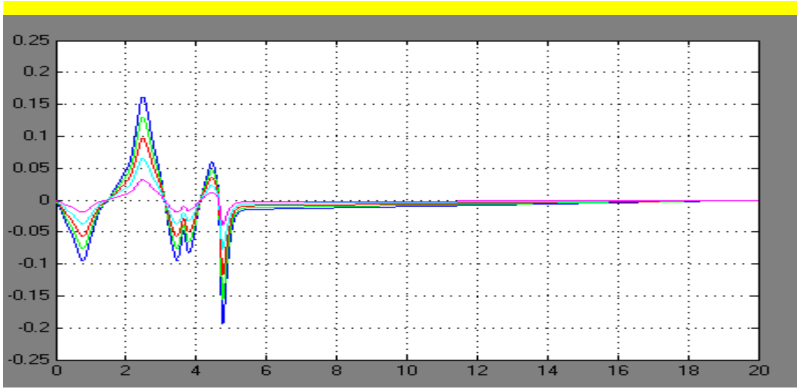

Fig. 9. Speed deviation versus time

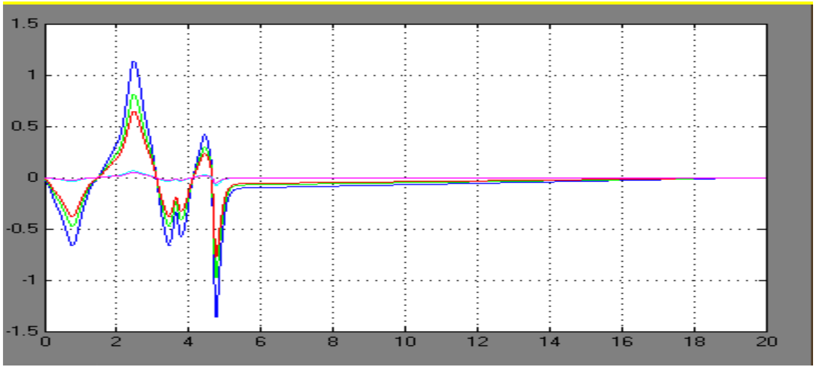

Fig. 10. Power angle versus time

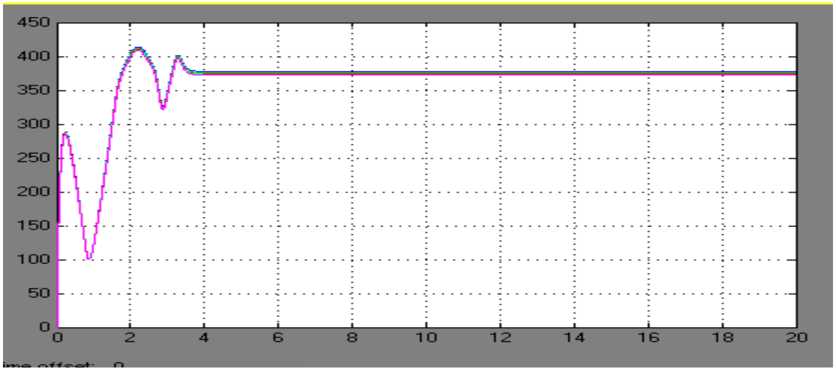

Fig. 11. Real power versus time

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