Anfis Coordination of Changes In Power Oscillation Damper Parameters with Variation In Power System Operating Point

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***Abstract*—In this paper an Adaptive Neuro-Fuzzy Controller was designed to adaptively adjust the parameters of a power Oscillation Damper as the power system operating point changes due to change in operating point in a large interconnected Network fitted with FACTS device and Power Oscillation Damper. As a foundational work the generalized mathematic model of multi-machine power system with embedded FACTS was developes. The results obtained clearly reveals the effectiveness of this approach.**

Keywords-Neuro-Fuzzy Controller; Mathematic Model; Oscillation Damper; Interconnected Network

I. INTRODUCTION

Most of the FACTS based damping controllers belong to the PI (Proportional + Integral) type and work effectively in single machine system [1]. However, the performance of the above mentioned damping controllers deteriorates in multi-machine power systems. The damping performance of the FACTS based damping controllers in multi-machine power systems can be improved by using fuzzy coordinated design [2]. Furthermore Power Oscillation Damper are designed for specific operating point, but operating point changes as demand changes for optimal performance the parameter of power oscillation damper must continually change with changes in operating point for this reason ANFIS is deployed to predict the future values of POD parameters based on large population of such parameters obtained from all possible operating scenarios. The structure of the proposed Adaptive Neuro Fuzzy coordinated controller is shown in Figure 1, where the inputs are speed deviation of synchronous machines and their acceleration. Thus, the conventional damping controllers are adaptively tuned by using ANFIS controllers.

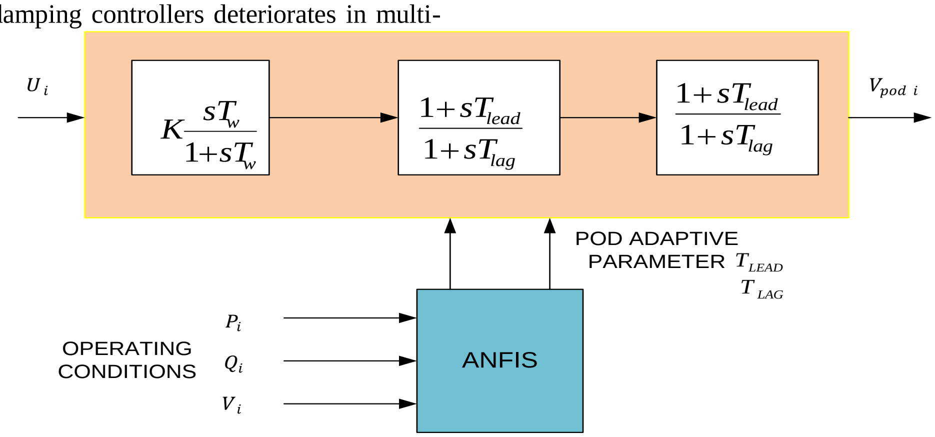

Figure 1. Proposed Adaptive POD Controller

II. LITERATURE REVIEW

An attempt has been made to apply hybrid neuro-fuzzy approach for the coordination between the conventional power oscillation damping (POD) controllers for multi-machine power systems. With the help of MATLAB, a class of adaptive networks, that are functionally equivalent to fuzzy inference systems, is proposed. The proposed architecture is referred to as ANFIS (Adaptive Neuro-Fuzzy Inference System) [2]-[6]. An adaptive fuzzy inference system (ANFIS) based UPFC supplementary damping controller to superimpose the damping function on the control signal of UPFC for damping of power system electromechanical oscillations was proposed in [7]-[8].

The acronym ANFIS derives its name from adaptive neuro-fuzzy inference system. Using a given input/output data set, the toolbox function ANFIS constructs a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted) using either a back propagation algorithm alone, or in combination with a least squares type of method. This allows fuzzy systems to learn from the data they are modeling [8]. It has a network-type structure similar to that of a neural network. Thus, it maps inputs through input membership functions and associated parameters and then through output membership functions and associated parameters to outputs, can be used to interpret the input/output map. The parameters associated with the membership functions will change through the learning process. The computation of these parameters (or their adjustment) is facilitated by a gradient vector, which provides a measure of how well the fuzzy inference system is modeling the input/output data for a given set of parameters [9]-[10]. Once the gradient vector is obtained, any of several optimization routines could be applied in order to adjust the parameters so as to reduce some error measure (usually defined by the sum of the squared difference between actual and desired outputs) [11]-[12].

III. PROPOSED METHOD

A. *Fuzzy System Modeling and Controller Philosophy*

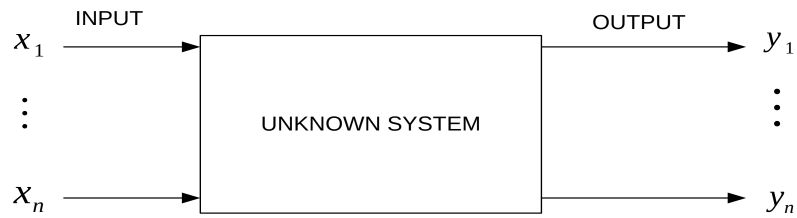

Figure 2. An unknown System as a Black Box

In the unknown system in Figure 2 only a set of input, $x_1 \ldots\ldots x_n$ and output $y_1 \ldots\ldots y_n$ can be measured. The mathematical description relating the input to the output can be a mathematical formula, such as a mapping or a function that relates the input to the output in the form

$$\begin{aligned} y_1 &= f_1(x_1 x_n) \\ &\vdots \qquad\qquad \vdots \\ y_m &= f_m(x_1 x_n) \end{aligned} \tag{1}$$

or a set of differential equations in the form

$$\begin{aligned} y_1 &= g_1(x_1., x_n,\ \dot{x}_1, \dot{x}_n) \\ &\vdots \\ y_m &= g_m(x_1., x_n,\ \dot{x}_1, \dot{x}_n) \end{aligned} \tag{2}$$

or a logical linguistic statement which can be quantified mathematically in the form:

IF (input x_1) AND … AND (input x_n) (3)

THEN (output y_1) AND …. AND (output y_m)

Fuzzy systems modeling is to quantify the logical form of equation (3.51) by using Fuzzy logic and the mathematical functional model of equation (3.49) or by using Fuzzy logic together with the differential equation model of equation (3.50).

The fuzzy logic controller comprises of four stages: fuzzification, a knowledge base, decision making and defuzzification. The fuzzification interface converts input data into suitable linguistic values that can be viewed as label fuzzy sets. To obtain a deterministic control action, a defuzzification strategy is required. Defuzzification is a mapping from a space of fuzzy control actions defined over an output universe of discourse into a space of nonfuzzy (crisp) control actions. The defuzzification of the variables into crisp outputs is tested by using the weighted average method.

After generating the fuzzy inference, the generated information describing the model's structure and parameters of both the input and output variables are used in the ANFIS training phase. This information will be fine-tuned by applying the hybrid learning or the backpropagation schemes. The algorithm employed for ANFIS training is shown in Figure 3.

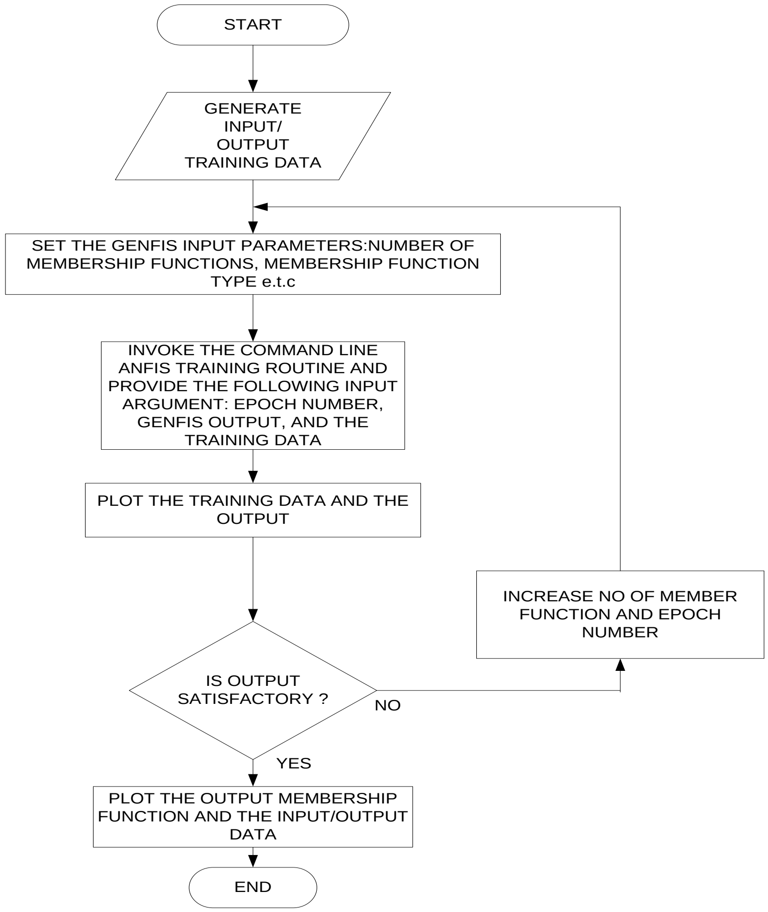

Figure 3. Flowchart of ANFIS Training

IV. RESULTS AND DISCUSSIONS

Power Oscillation Dampers were designed for UPFC embedded in two test case study systems:

a) Kundur Two Area System

b) Nigerian 330kV National Grid

However the optimal performance of these PODs are only guaranteed at the particular operating points under consideration, but at any other operating points, different values of time constant must be determined for the damping to be effective

A. Result of ANFIS Training (Test System 1)

The training data and check data are generated by randomly varying the load (multiplying the load with a factor of 0.1) in the two areas of the test system. At each operating point the actual values of POD parameters T_1 and T_2 were calculated. The ANFIS parameter settings are as shown in Table 1. Fig 4 is the plot of training data and ANFIS output for lead time constant while Figure 5 is the graph of check data and ANFIS output for lead time constant. The plot of the error associated with the training is shown in Figure 6 for both the check data and training data. The corresponding plots for lag time constant are shown in Figures 7 to Figure 9.

TABLE I. ANFIS PARAMETER SETTINGS

numMFs	5
mfType	'gbellmf'
epoch_n	20

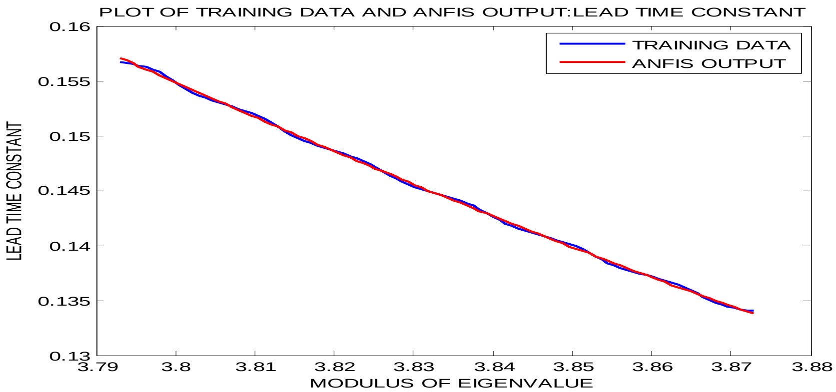

Figure 4. Training Data and ANFIS Output: Lead Time Constant

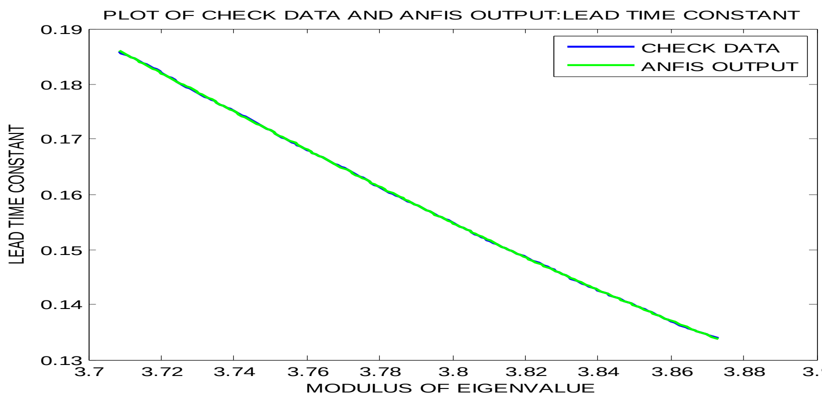

Figure 5. Check Data and ANFIS Output: Lead Time Constant

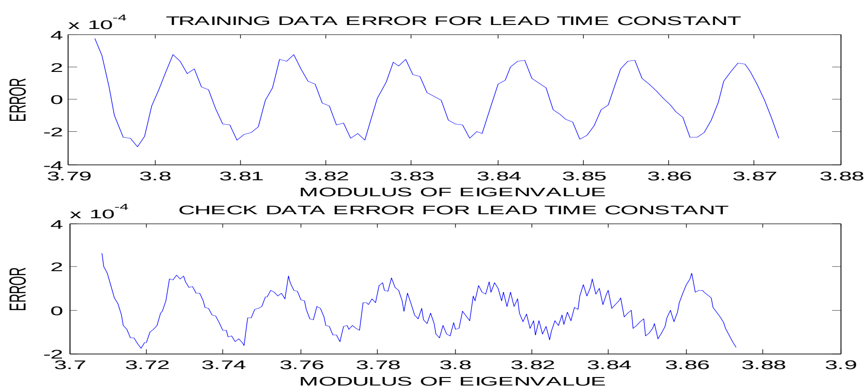

Figure 6. Prediction Error for Training Data and Check Data: Lead Time Constant

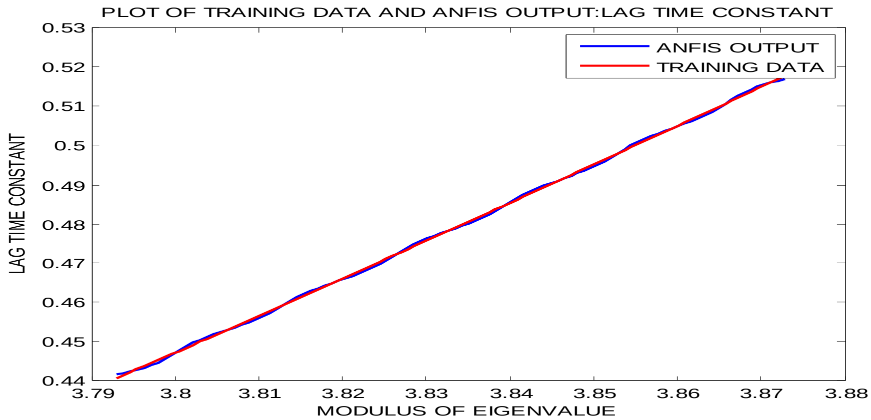

Figure 7. Training Data and ANFIS Output: Lag Time Constant

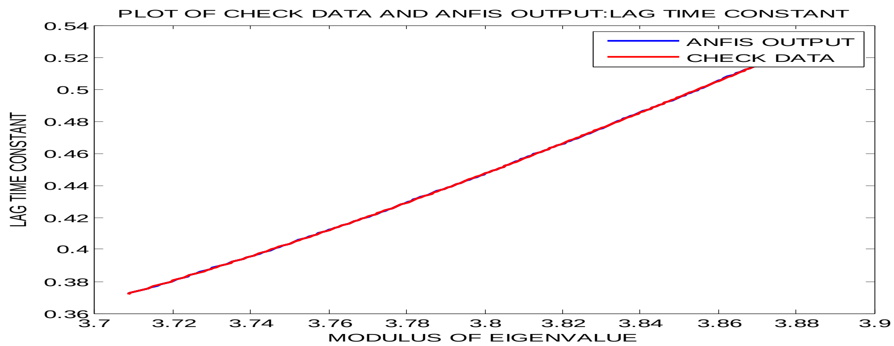

Figure 8. Check Data and ANFIS Output: Lag Time Constant

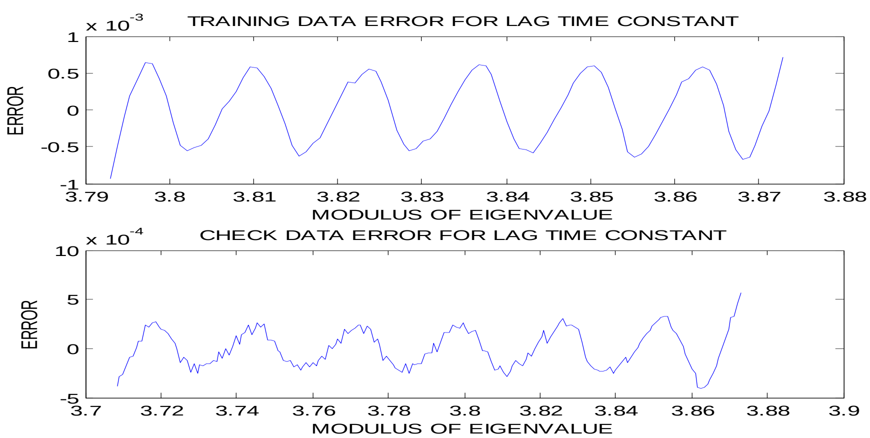

Figure 9. Prediction Error for Training Data and Check Data: Lag Time Constant

B. Result of ANFIS Training (Test System 2)

The data for training were obtained by randomly varying the load in different areas by a factor of 0.01 from low to medium and high values for about 500 scenarios, the data were divided into training data and check data. The lead-lag time constants were recorded as they change with operating conditions as well as the lead and lag time constants that provide the best damping under different operating conditions. The results obtained for lag time constant are as shown in Figures 10 to 12. Figure 13 to 14 are the corresponding results for lead time constant. Figure 15 is the graph of the input membership function while Figures 16 and 17 are the graphs of the ANFIS adjusted membership function that gives the exact simulation of the training data for the lag time constant and lead time constant respectively.

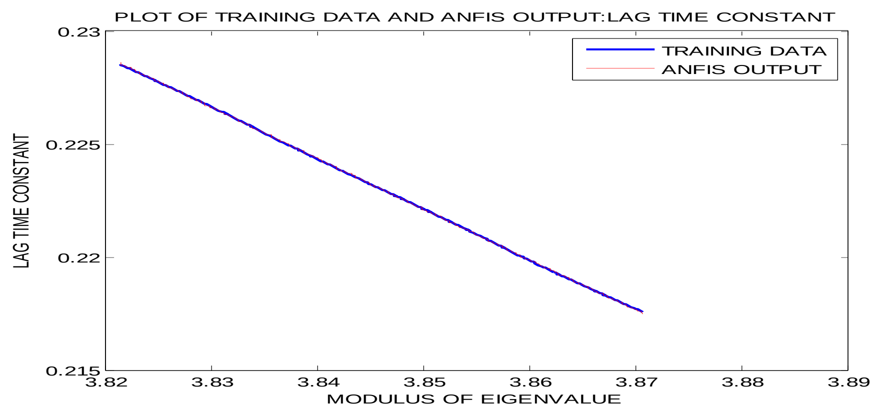

Figure 10. Plot of ANFIS Data and Training Data: Lag Time Constant

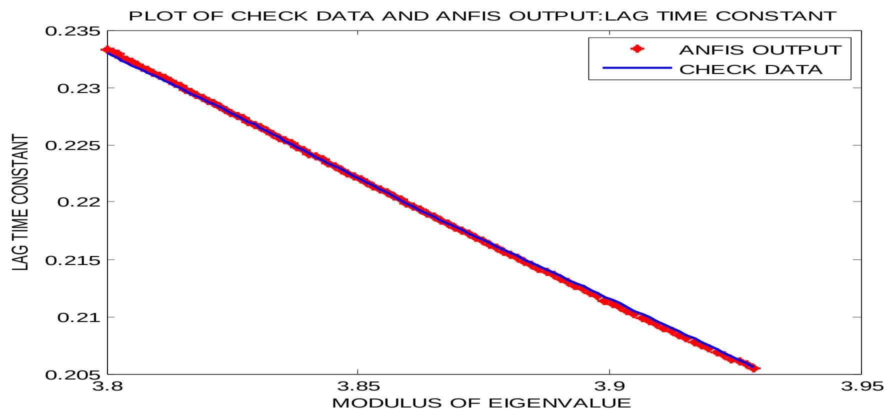

Figure 11. Plot of ANFIS Data and Check Data: Lag Time Constant

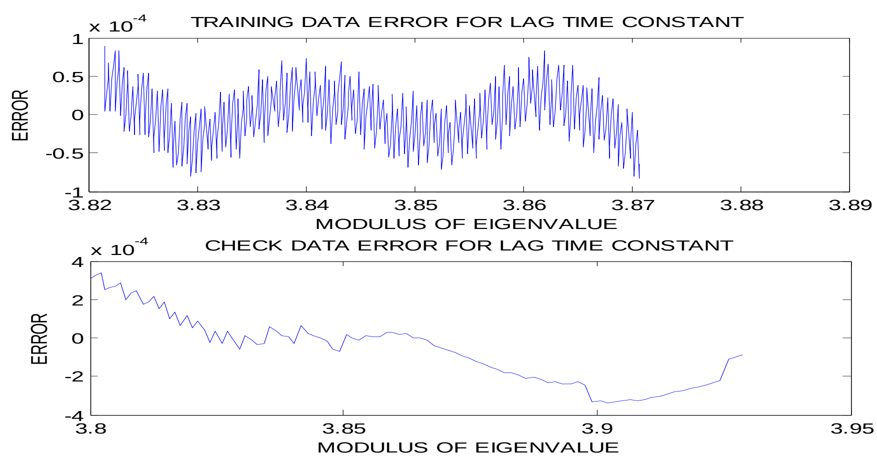

Figure 12. Prediction Error for Training Data and Check Data

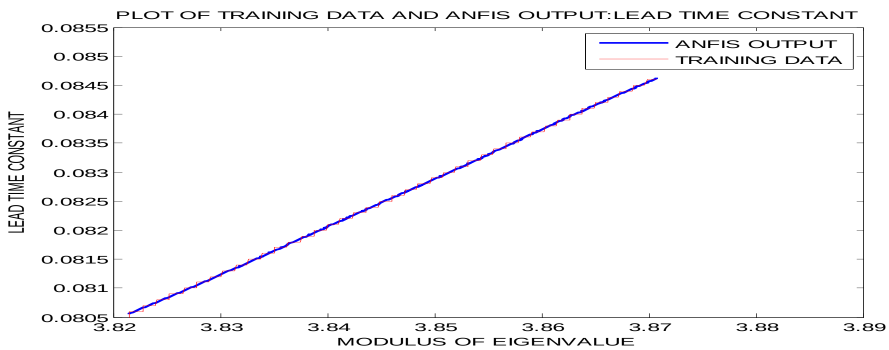

Figure 13. Plot of ANFIS Output and Training Data: Lead Time Constant

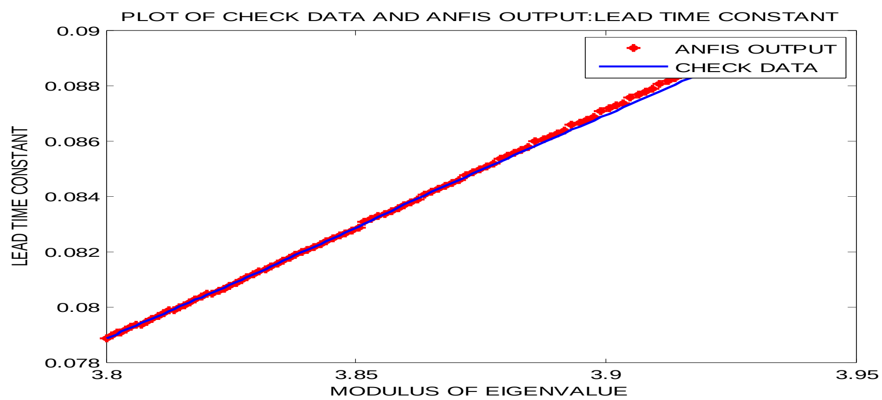

Figure 14. Plot of ANFIS Data and Check Data: Lead Time Constant

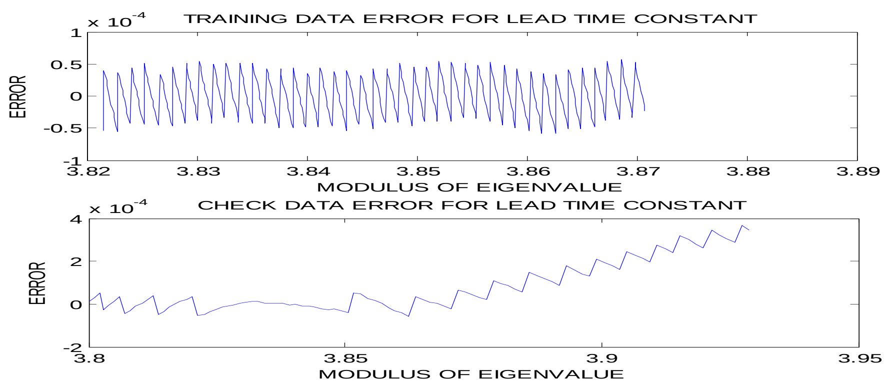

Figure 15. Prediction Error for Training Data and Check Data

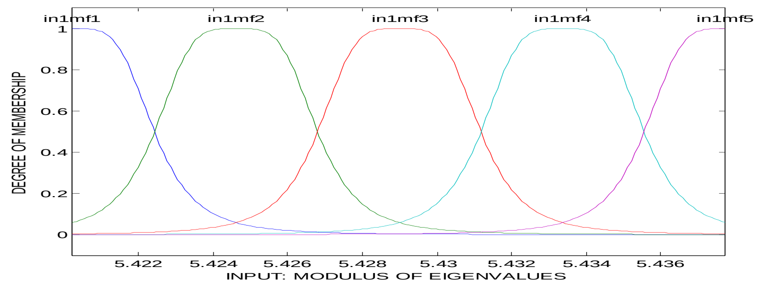

Figure 16. Input Membership Function

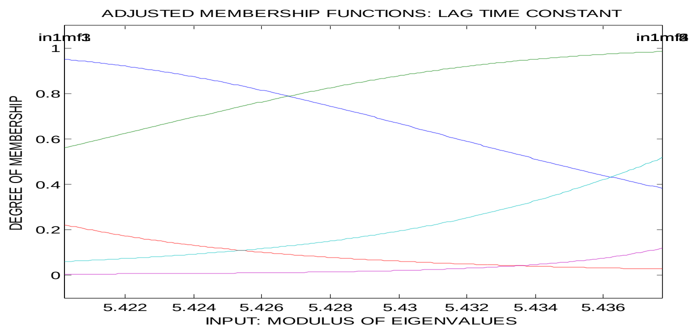

Figure 17. ANFIS Adjusted Membership Function: Lag Time Constant

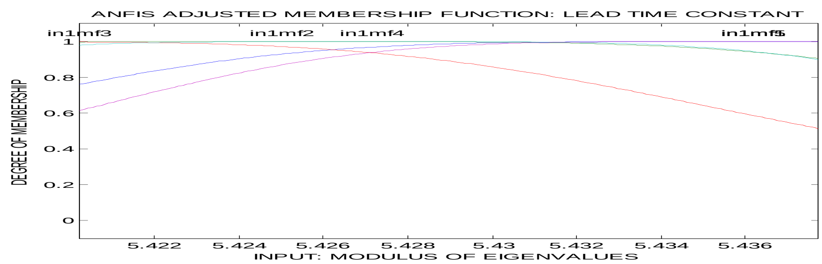

Figure 18. ANFIS Adjusted Membership Function: Lead Time Constant

V. CONCLUSION

In this work an adaptive neuro fuzzy controller has been developed for the purpose of coordinating the changes in power oscillation damper parameters with variation in power system operating point. The accuracy with which the controller was able to predict the values of POD parameters clearly reveals the effectiveness of the proposed approach.

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