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Fuzzy System Approach for TCSC Based Controller Design

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Abstract - *FACTS devices are the most multifarious devices used to control real and reactive power in transmission line for economic, flexible operation in the power system. Facts Technologies promise a variety of opportunities for significant advances in the delivery of power and flexibility of power system control. Fuzzy system approach is applied to design a Thyristor Controlled Series Compensator (TCSC)-based Controller to enhance power system Stability and efficiency. The design objective is to improve both rotor angle stability and system voltage profile .Superior results are obtained when comparing the designed fuzzy controller with conventional lead-lag and with no control.*

Key Words:

FACTS: Flexible AC Transmission

TCSC: Thyristor-Controlled Series Compensator

DEWA: Dubai Electricity and Water Authority

ANFIS: adaptive neuro-fuzzy inference system

1. Introduction to Facts

Today's changing electric power systems create a growing need for flexible, reliable, fast responding and accurate answers to questions of analysis, simulation, and design in the fields of electric power generation, transmission, distribution, and consumption. The Flexible Alternating Current Transmission Systems (FACTS) technology program utilizes power electronics components to replace conventional mechanical elements yielding increased flexibility in controlling the electric power system.

1.1 Benefits of FACTS

Benefits of FACTS include decreased response times and improved overall dynamic system behavior. Facts devices allow the design of new control strategies, e.g. independent control of active and reactive power flows which were not realizable a decade ago. Increased loading and more effective use of transmission corridors, increased power system stability, increased system security, increased system reliability, Added flexibility in sitting new generation, Elimination or Deferral of the Need for new transmission Lines.

2. Power System Control with TCSC

Transient and dynamic stability are very important to secure a smooth operation of power systems. FACTS devices with suitable control strategy have the potential to significantly increase the system transient stability margin. This allows increasing utilization of the existing network closer to its thermal loading capacity, and avoiding the need to construct new transmission lines.

Series capacitive compensation was introduced decades ago to cancel a portion of the reactive line impedance and thereby increase the transmittable power. Recent development of power electronics introduces the use of flexible AC transmission Systems (FACTS) controllers in power system. Thyristor Controlled Series compensator (TCSC) is one of the important members of the FACTS family that is increasingly applied with long transmission lines by the utilities in modern power systems. It can have various roles in the operation and control of power systems such as scheduling power flow; decreasing unsymmetrical components; reducing net loss; providing voltage support; limiting short-circuit currents; mitigating subsynchronous resonance(SSR); damping the power oscillation and enhancing transient stability.

3. Power System under Study

The block diagram of the proposed system, including the controller that utilizes ANFIS design methodology, is shown in Fig.1.

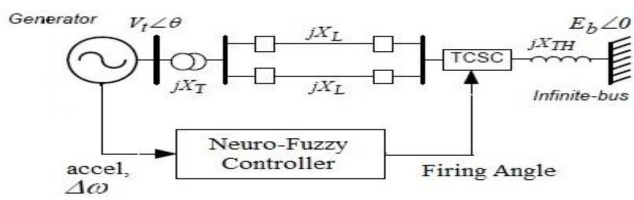

Figure .1 Block diagram of the Controller that utilizes ANFIS design methodology.

The Synchronous generator is delivering power to the infinite-bus through a double circuit transmission line and a TCSC. V_t and E_b are the generator terminal and infinite bus voltage respectively;X_t X_l and X_{th} represent the reactance of the transformer, transmission line per circuit and the

Thevenin's impedance of the receiving end system respectively.

4. Anfis Approach

The three layers Multi-Layer Perceptron (MLP) structure model of ANN is applied for TCSC controller. This structure of ANN has an input layer, an output layer, and one hidden layer. Research has proved that ANNs have a wide number of applications in the power engineering due to many advantages

1) Capability of synthesizing complex and transparent mappings

2) Rapidity due to parallel mechanism

3) Robustness and Fault tolerance

4) Adaptability due to its inherent property to adopt new conditions

5) Easy Software simulation and hardware implementation

6) Less memory required.

The back-propagation is an iterative method employing the gradient decent algorithm for minimizing the minimum square error between the actual output and the target for each pattern in the training is applied, the generalized delta rule in the back-propagation algorithm.

The ANFIS system consists of the components of a conventional fuzzy system except that computations at each stage is performed by a layer of hidden neurons and the neural networks learning capacity is provided to enhance the system knowledge.

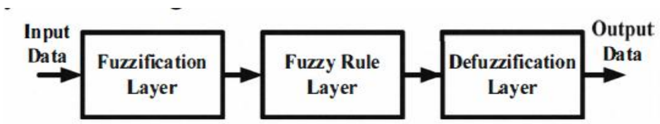

Figure. 2 ANFIS Architecture

5 TCSC-Based Anfis Controller:

The proposed ANFIS controller utilizes Sugeno-type Fuzzy Inference System (FIS) controller, with the parameters inside the FIS decided by the neural-network back propagation method. The ANFIS is designed by taking speed deviation & acceleration as the inputs. The output stabilizing signal is computed using the Fuzzy membership functions depending on these variables. The effectiveness of the proposed approach to modeling and simulation of TCSC controller is implemented in MATLAB. ANFIS editor is used for realizing the system and implementation.

The FLC uses 49 Rules and 7 membership functions in each variable to compute the output and exhibit good performance. The FLC rule base is shown in Table1 below

Table 1 :

TABLE I RULE BASE FOR SEVEN MEMBERSHIP FUNCTION

w↓ wprime →	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
NS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	ZE	PS	PM	PL	PL	PL	PL

6. Design and Limitation

GENERATOR TCSC-Controller with Dubai Electricity Loading Values

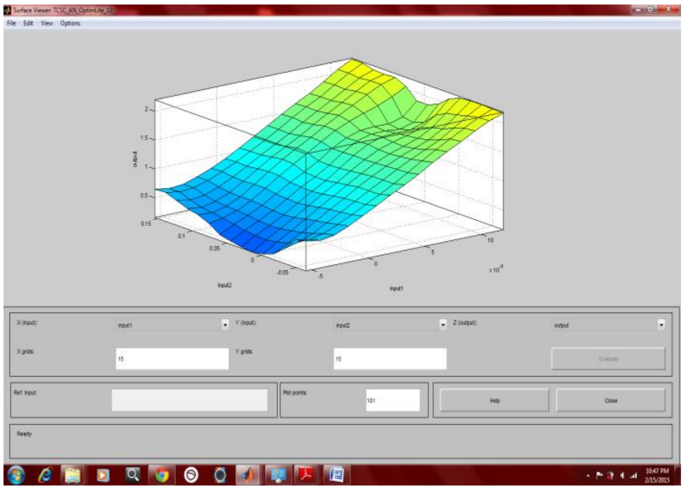

Figure 1.9 TCSC controller used for the Dewa Loading Values

Input 1 is speed and input 2 is acceleration and output is output variable ***TCSC reactance (xtcsc).*** Different values from the one used in the IEEE paper (Anfis approach for TCSC-based Controller Design for power system Stability figure 4 pg 151) speed here is -0.005 to 0.001 while in the paper its from -0.01 to 0.01.The acceleration in the paper is from -0.1 to 0.1 while here the acceleration range is from -0.05 to 0.15,because the proposed fuzzy controller utilizes Sugeno-type Fuzzy Inference System(FIS) controller, with the parameters inside the FIS decided by the neural-network back propagation method the fuzzy controller is designed by taking speed deviation & acceleration as the inputs. The output stabilizing signal is computed using the fuzzy, membership functions depending on these variables. The effectiveness of the proposed approach to modeling and implementation of TCSC controller is implemented in matlab code. Fuzzy logic Controller FLC has a rule set consisting of 49 rules the FLC rule set input values. To design the FLC some data is needed a set-of two dimensional input vectors and associated set of one-dimensional output vectors are required. Training data has been generated by sampling input variables speed deviation& acceleration uniformly and computing the value of stabilized signal for each sampled point as shown in figure 1.9.

7. Procedure to get DEWA Loading Results

Edit the matlab code files (Containing TCSC parameters) as follows:

Replace the existing values of real power (pe) and reactive power (qe) for each loading case with the new values. The order of these values MUST be: Nominal, then Light, then Heavy. DEWA loading values are as Table 2.

Table 2

DEWA loading values

	Nominal Loading	Light Loading	Heavy Loading
Pe(Real power)	0.96	0.47	1.45
Qe (reactive power)	0.36	0.24	0.45

8. DEWA Nominal Loading Condition

A three phase fault is applied at the generator terminal bus bar at t=1.0 sec and cleared after five cycles. The original system is restored upon the fault clearance Figure 2 to figure 2.5 show the time response of the speed deviation, power angle, line current, electrical power, voltage and TCSC reactance for three different system conditions; namely, for the system without TCSC controller, for the system with lead-lag controller and for the system with the proposed ANFIS fuzzy controller

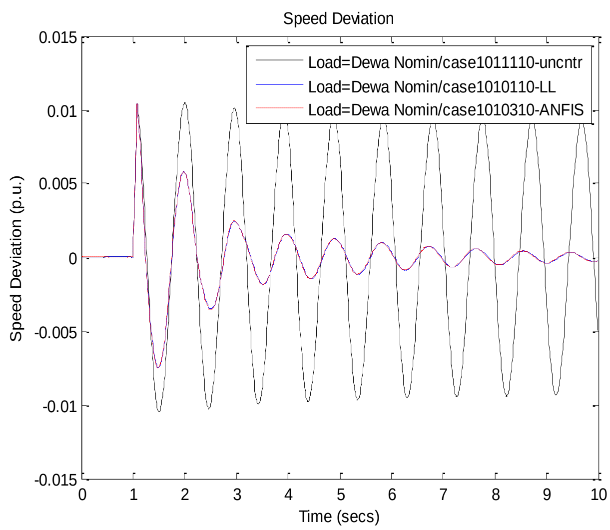

Figure 2: DEWA (Nominal) Speed deviation

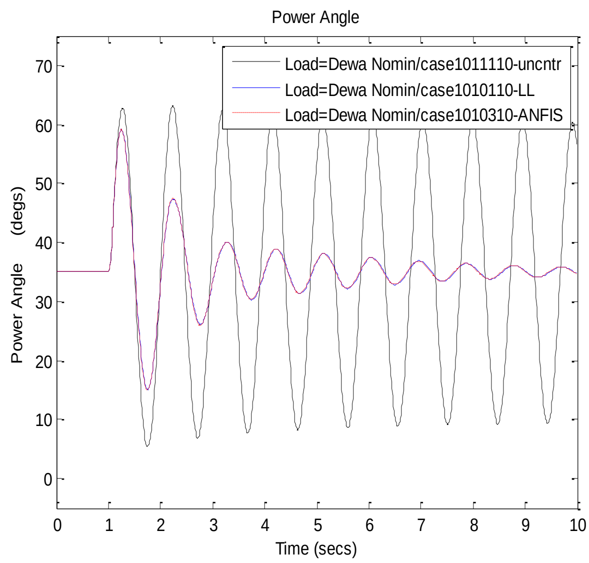

Figure 2.1: DEWA (Nominal) Power Angle.

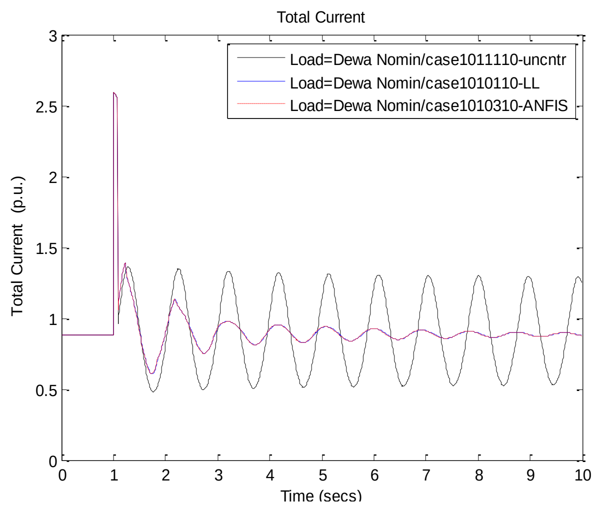

Figure 2.2: DEWA (Nominal) Total Current

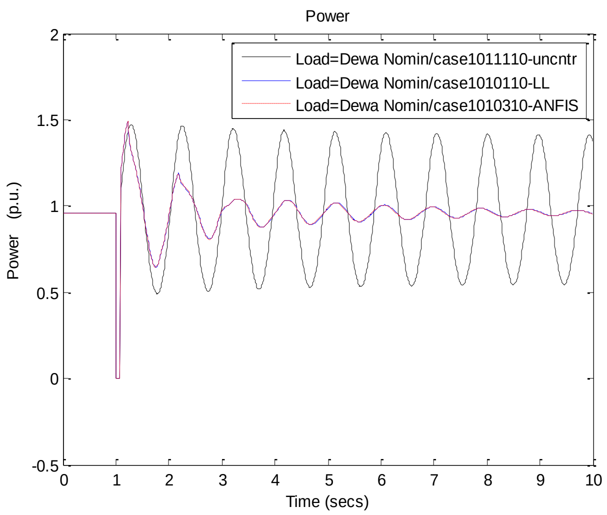

Figure 2.3: DEWA (Nominal) Power

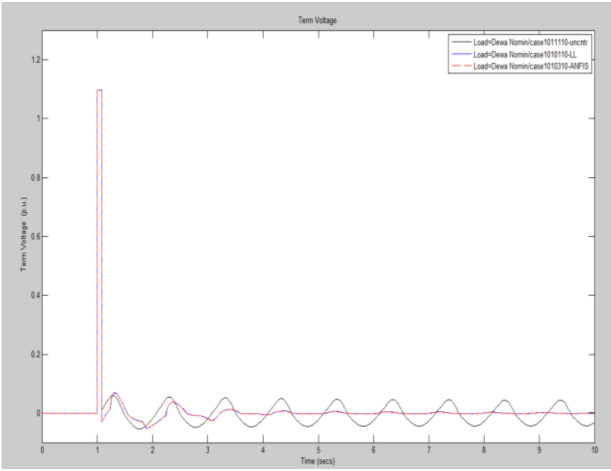

Figure 2.4 :DEWA (Nominal) Term Voltage

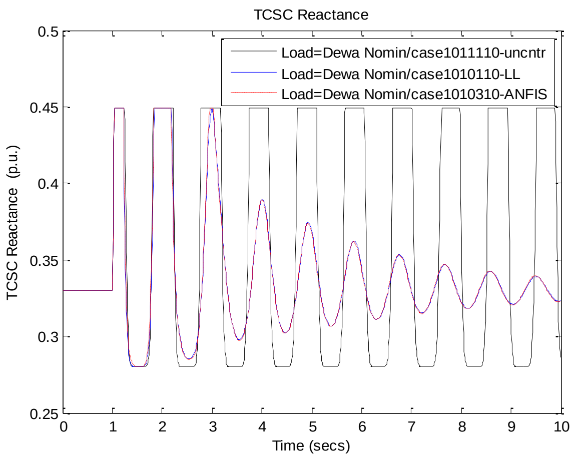

Figure 2.5 :DEWA (Nominal) TCSC Reactance

9. Explanation of Dewa Nominal Loading Results:

The fuzzy controller significantly improves the damping of the subsequent power swings.The system power angle response for the above contingency is shown in figure 2.3 it is clear from figure 2.1 that, without controller even though the system is stable, power system oscillations are poorly damped.It is also clear that, proposed TCSC controller significantly suppresses the oscillations in the power angle and provides good damping characteristics to low frequency oscillations by stabilizing the system much faster.

10. DEWA Light Loading Condition:

To show the robustness of the Proposed TCSC controller to operating conditions and type of contingency, the operating point is changed to light loading condition. One of the parallel transmission line is permanently tripped off at t=1.o sec.The system response for the above contingency is shown in Figure 2.6 to Figure 3.1.it can be seen from figure 2.8 to 3.1 that the system is poorly damped without TCSC Controller.

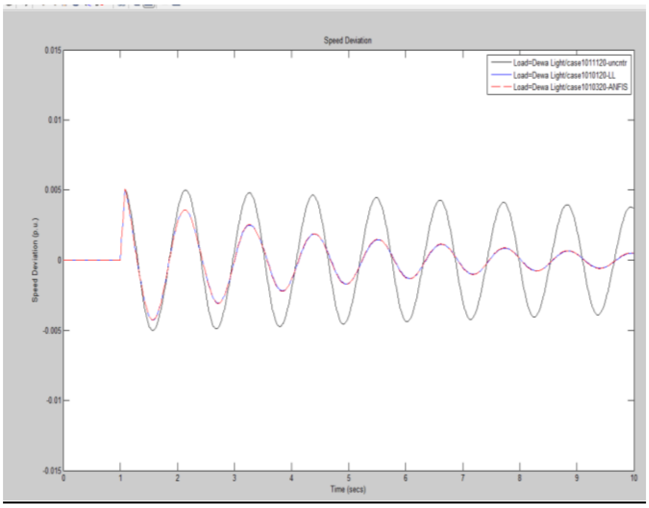

Figure 2.6: DEWA (Light) Speed deviation

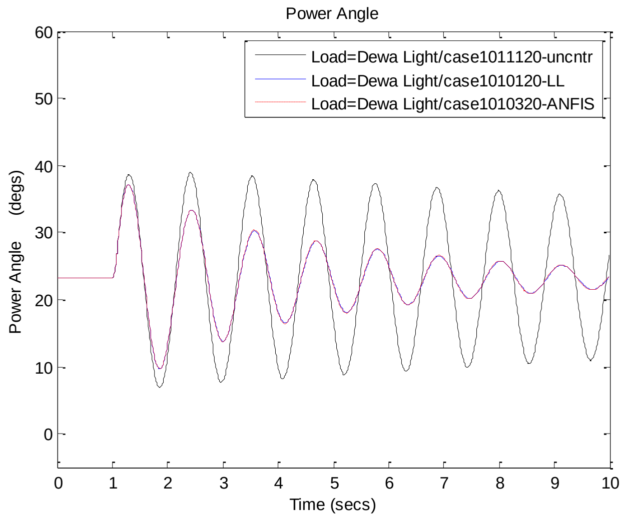

Figure 2.7: DEWA (Light) Power Angle

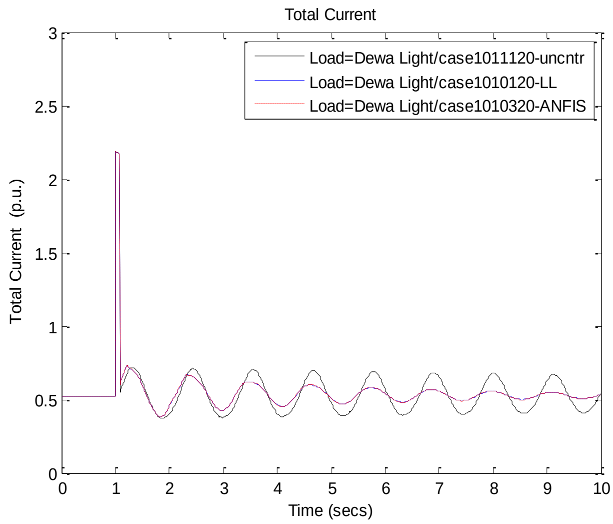

Figure 2.8: DEWA (Light) Total Current

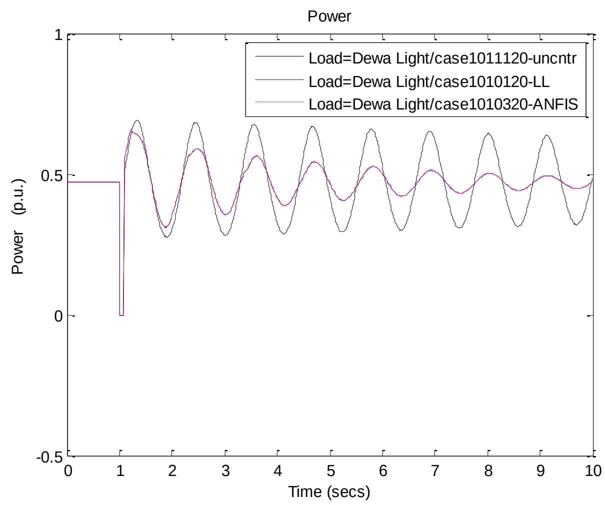

Figure 2.9: DEWA (Light) Power

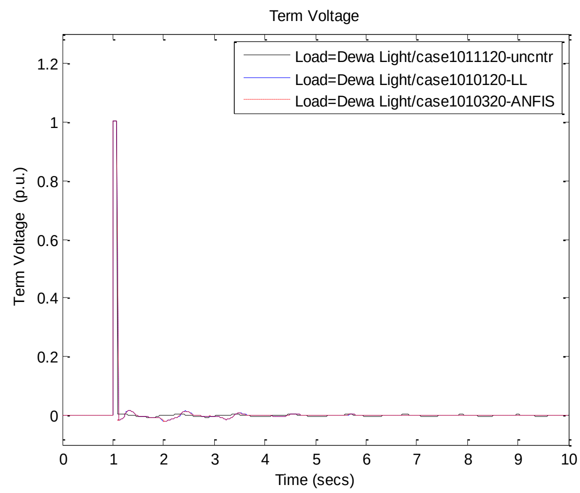

Figure 3: DEWA (Light) Term Voltage

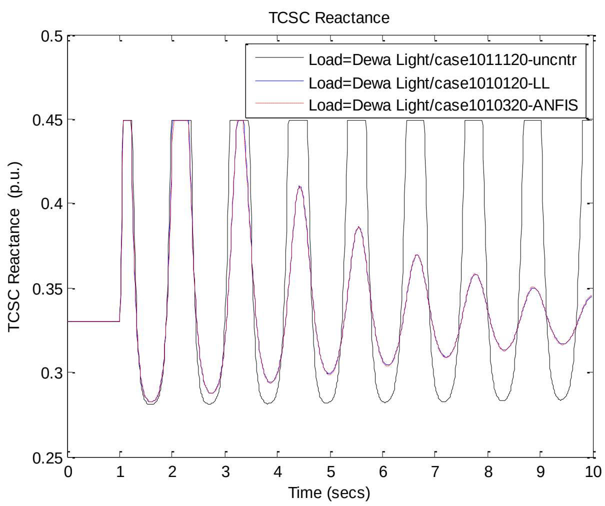

Figure 3.1: DEWA (Light) TCSC Reactance

11. Explanation of Dewa light loading Results

The system response for the DEWA Light Loading is shown in Figure 2.6 to Figure 3.1.it can be seen from figure 2.8 to 3.1 that the system is poorly damped without TCSC controller, while it is little efficient with lead-lag and more stable with the fuzzy controller. Stability of the system is maintained and power system oscillations are well-damped with fuzzy based TCSC controller

12. Dewa Heavy Loading Condition

For completeness the performance of the TCSC controller is verified at heavy loading conditions under small disturbance. The input mechanical power is decreased by 10% at t=1.0 sec and the system response is shown in figure 3.2 to figure 3.7

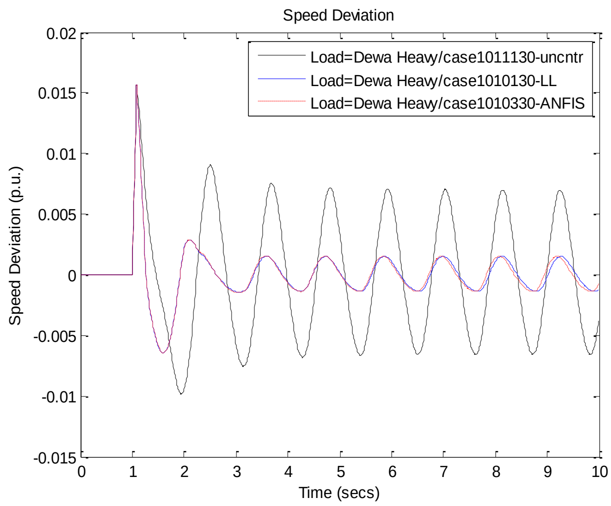

Figure 3.2: DEWA (Heavy) Speed deviation

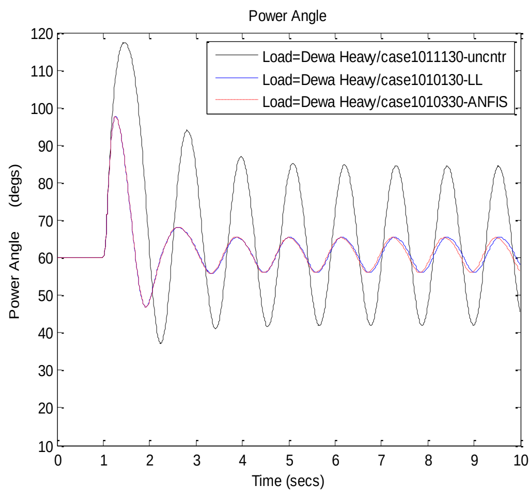

Figure 3.3: DEWA (Heavy) Power Angle

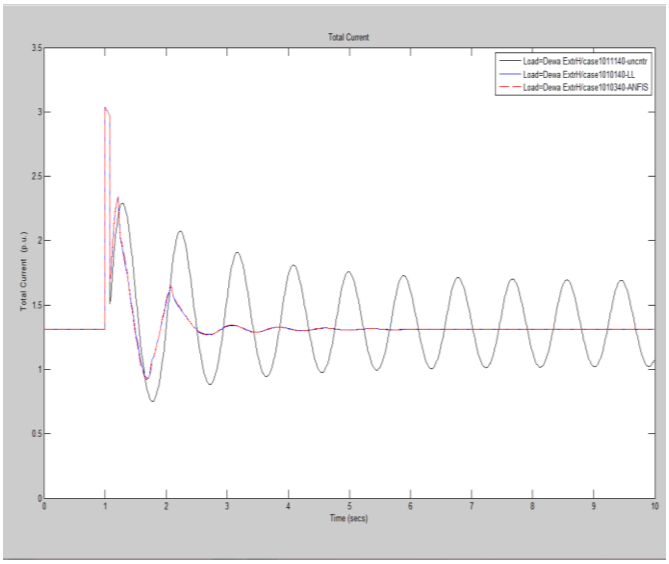

Figure 3.4: DEWA (Heavy) Total Current

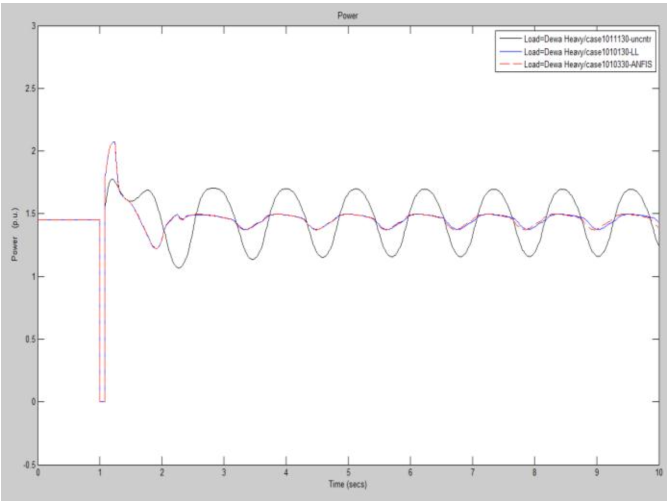

Figure 3.5: DEWA (Heavy) Power

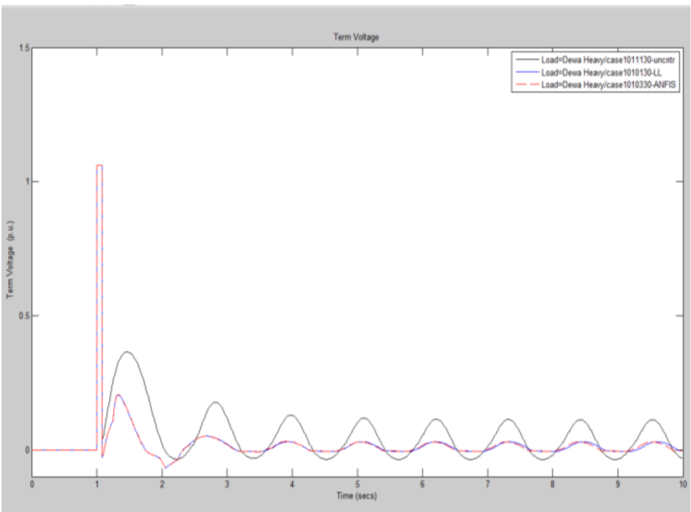

Figure 3.6: DEWA (Heavy) Term Voltage

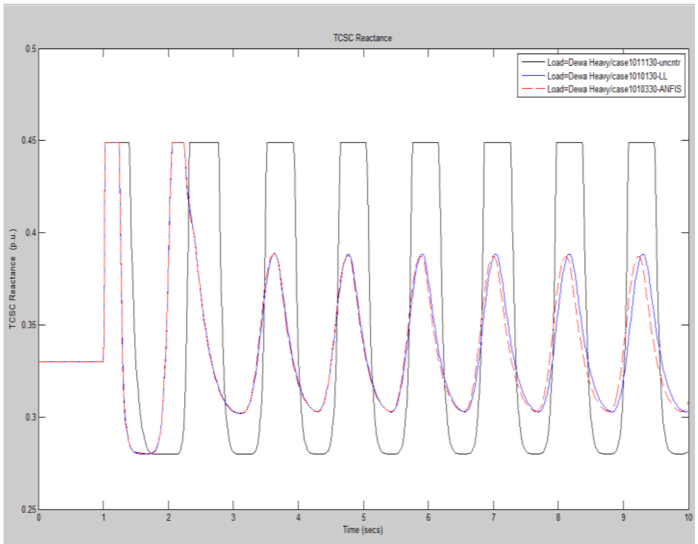

Figure 3.7: DEWA (Heavy) TCSC Reactance

13. Explanation of Dewa Heavy Loading Results:

The TCSC fuzzy controller for the heavy Loading results performs well from figure 3.2 to 3.7 improves dynamic stability of system under consideration than compared to lead-lag controller. The TCSC fuzzy controller suppresses the line power swings, caused by unwanted disturbances.

14. Method to be used for Improvement

We can improve it further to make it stable for much heavier loading cases example by modifying the program to work for Dewa Extra heavy case as an example Table 3 below

Table 3

Dewa Extra Heavy Case

Pe (Real Power)	1.6
Qe (Reactive Power)	0.3

After running the Running the main program we will see the program producing stabilized graph results for Pe=1.6 and Qe=0.3 in this manner we can improve to make it work for 4 cases, with the fourth case being the extra heavy case

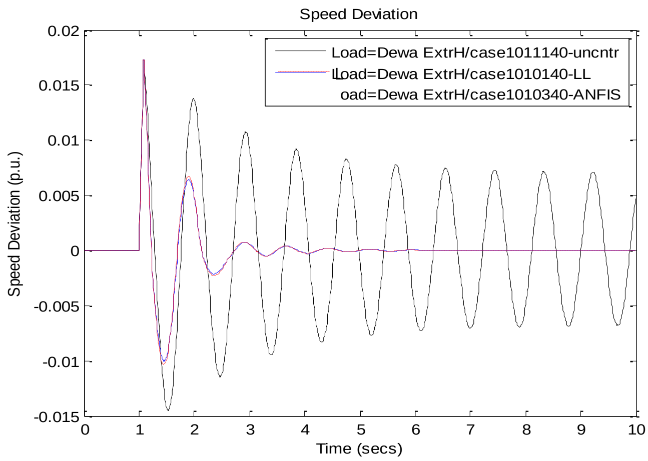

Fig 3.8: DEWA (Extra heavy) Speed deviation

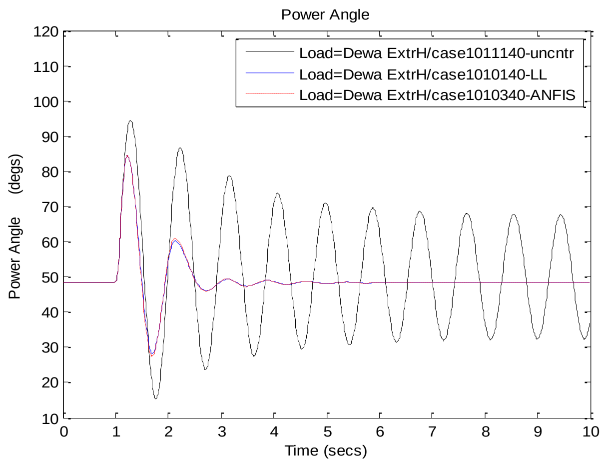

Figure 3.9: DEWA (Extra Heavy) Power Angle

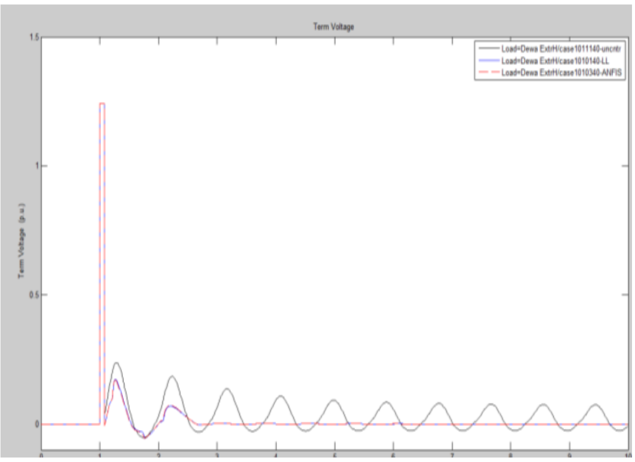

Figure 4.2: DEWA (Extra Heavy) Term Voltage

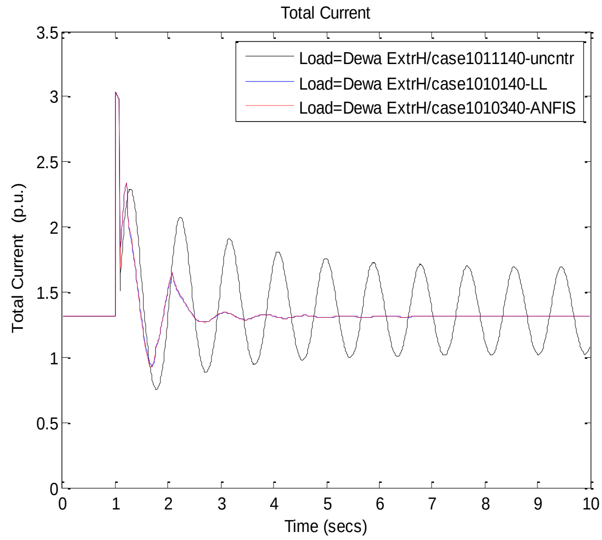

Figure 4: DEWA (Extra Heavy) Total Current

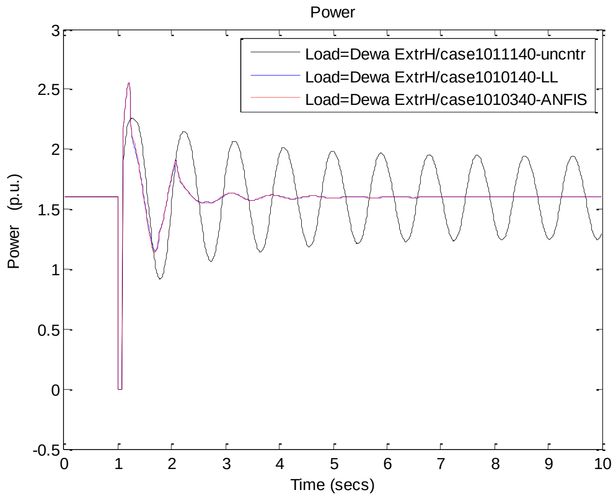

Figure 4.1: DEWA (Extra heavy) Total Power

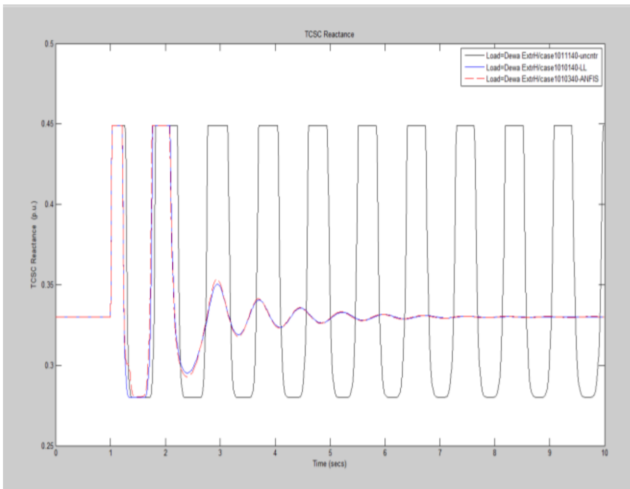

Figure4.3: DEWA (Extra Heavy) TCSC Reactance

15. Conclusion

The investigation was to find the most suitable configurations of the Anfis controllers for FACTS devices. The dynamic performance of proposed TCSC controller under various loading and disturbance conditions are analyzed and compared. The proposed ANFIS controller for TCSC is more superior in the improvement of dynamic stability of the system under consideration compared to the classical lead-lag controller. The proposed control strategy suppresses the line power swings, caused by the unwanted disturbances due to adaptive nature of ANNs .The suggested controller can be easily implemented due to its simple structure, powerful capabilities and lower cost.

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