Chapter 7

Conclusions

7.1 General

This thesis has addressed mathematical model of power system with power system stabilizer and thyristor control series capacitor, design of PSS and TCSC using different computational intelligent techniques, design of smart techniques based ancillary controllers with first order and fifth order linear and non linear power system model under restructured electric environment, and linear and non linear analysis of rotor angle stability issue under different operating conditions, contingencies, faults and various DPM.

The main contribution of the thesis include:

The development of the systematic procedure for conversion of non linear mathematical model into linear model of power system with both PSS, TCSC and simultaneous designing of PSS and TCSC as discussed in chapter 2.

The Genetic Algorithm Based control strategies have been developed for designing of PSSs and TCSC damping controller. The PSSs and simultaneous designed TCSC and PSS have been applied to the dynamical power system as discussed in chapter 3.

Adaptive Neuro-Fuzzy inference System and Levenberg-Marquardt Artificial Neural Network algorithm for the development of the control strategy for thyristor control series capacitor Based damping controller and power system stabilizer has been discussed in chapter 4.

Identification method such as Non Linear Auto regressive Moving Average-L2 based controller and hybrid controller such as Genetic Algorithm Based Network Network has been discussed for the development of the control strategy for power system stabilizer , and developed ANFIS Based Thyristor control series capacitor has been suggested in addition to power system stabilizer in chapter 5.

A new control strategy for designing of Ancillary controllers such as power system stabilizers and thyristor control series capacitor in two area deregulated electric market with load frequency control loop with low and higher order power system model has been discussed in chapter 6.

7.2 Summary of Important Findings

Chapter 2 has presented the fourth order non linear mathematical model of the power system with IEEE-ST1 excitation system. The systematic procedure for conversion of non linear model into linear model with both PSS, TCSC and simultaneous designing of PSS and TCSC have been discussed. Using Taylor's series method, a new fourth order linearized model of the power system with exciter has been derived and the equations of machine constant K_1 to K_{10} have been calculated. The linerized mathematical model and state space form of power system with conventional power system stabilizer and a new PID- power system stabilizer have been described. The linearized state space form of power system with individual TCSC and simultaneous CPSS and TCSC have been also derived. The block diagram representation of system with PSSs and TCSC are included.

In chapter 3, genetic algorithm based control strategies have been developed for designing of PSSs and TCSC damping controller. The PSSs and simultaneous designed TCSC and PSS have been applied to the dynamical power system. The small signal stability Analysis and non-linear simulation for the transient stability analysis have been carried out for details investigation of the power system stability issue. Four different operating conditions are taken and the responses of the rotor Angle, rotor speed deviation, terminal voltage and net reactance have been analyzed under different types of the disturbances and faults.

- It has been shown that the eigen values associated to the electromechanical mode are more negative with presence of CPSS and PID-PSS in power system and poles in s-plane are far away from origin. The damping factor has been improved with PSSs compared to that without PSSs, which has shown that the system is more stable and PSSs have provided good damping to oscillation in power system. It has also been also observed that with the simultaneous application of PSS and TCSC in power system, the eigen values are more negative and damping factor has been improved significantly, which shows good stability of system compared to the individual application of PSS and TCSC.

- From the non - linear Analysis, without the application of the controllers in the system, the oscillations in rotor angle, rotor speed deviation have been observed. Under the heavy loading conditions, it has been observed that as the active power and reactive power are increased, the oscillation in rotor angle and speed deviation are continuously growing which creates the instability of the system under the contingencies. While simultaneously designed TCSC and PSS damping controller have significantly diminished oscillations in system, simultaneously application of TCSC and PSS have provided very good damping characteristics compared to the individual application of PSSs or TCSC and almost eliminated the oscillations in system. Application of GA Based TCSC and PSSs have improved the time response parameters such as settling time, rise time and delay time appreciably and also decreased the overshoot in the system.

In chapter 4, the smart control strategies based TCSC damping controller and PSS have been designed. The ANFIS and LMNN based PSS, and simultaneous LMNN and ANFIS based TCSC-PSS have been applied to the dynamical power system. The non-linear simulations have been carried out for detail analysis of the stability of the power system. The time responses of speed deviation obtained by intelligent techniques based controller has been compared to the conventional power system stabilizer. Four different operating conditions are taken and the response of rotor speed deviation has been analyzed under different types of the disturbances and faults.

From the non - linear Analysis,

- Without the application of the controllers in the system, the oscillations in rotor speed deviation has been observed. Under the heavy loading condition, it has been observed that if the active power and reactive power are increased; the oscillation in speed deviation is continuously growing which creates the instability of the system. The smart damping controllers have greatly diminished oscillations in system.

- Convention power system stabilizer does't produce satisfactory response under the different operating conditions. Simultaneous application of ANFIS and ANN based TCSC and PSS have provided very good damping characteristics compare to the individual application of PSS and almost eliminated the oscillations in system.

- It has been observed that individual application of ANFIS-TCSC produces better response compared to the individual application of LMNN-TCSC.

- Figures have shown that individual application of ANFIS-PSS produces better response compared to the individual LMNN-PSS.

- Under the heavy loading condition, ANFIS based TCSC-PSS has produced good results compared to the LMNN based TCSC-PSS, and also improved the time response parameters such as settling time, rise time and delay time appreciably and decreased the overshoot in the system.

In chapter 5, the smart control strategies based TCSC damping controller and PSS have been designed. The NARMA-L2 and GA-ANN based PSS, and simultaneously ANFIS-TCSC and PSS have been applied to the dynamical power system. The non-linear simulations have been carried out for detail analysis of the stability of the power system. The time response of speed deviation obtained by intelligent techniques based controller has been compared to the conventional power system stabilizer. Four different operating conditions are taken and the response of rotor speed deviation has been analyzed under different types of the disturbances and faults.

From the non - linear analysis,

- Without the application of the controllers in the system, the oscillations in rotor speed deviation has been observed. Under the heavy loading condition, it is clear that if

the active power and reactive power are increased; the oscillation in speed deviation is continuously growing which creates the instability of the system. The smart damping controllers have greatly diminished oscillations in system.

- Convention power system stabilizer doesn't produce satisfactory response under the different operating conditions, while simultaneously application of ANFIS -TCSC and PSS been provided very good damping characteristics compared to the individual application of PSS and almost eliminate the oscillations in system.

- Figures have shown that individual application of GA-ANN-PSS produces better response compare to the individual NARMA-L2-PSS.

- Under the different loading conditions, It has been observed that simultaneous application of GA-ANN-PSS and ANFIS-TCSC produce better response compare to the simultaneous application of NARMA-L2-PSS and ANFIS-TCSC. Also it has improved the time response parameters such as settling time, rise time and delay time appreciably and decreased the overshoot in the system.

In the section (5.6), different Intelligent techniques based PSS are tested under heavy loading conditions. Simultaneously ANFIS-TCSC with all PSS are also tested under heavy loading conditions. Following results are obtained from details study:

- The GA-CPSS, ANFIS-ANN and GA-ANN have produced better response compared to the LMNN-PSS and NARMA-L2-PSS.

- But GA-CPSS has required different optimized parameters under different operating conditions and GA-ANN needed more time for training of neural network. ANFIS-PSS has provided fast, adaptive and satisfactory response with less number of training data.

- From figures (5.19) to (5.26), it has been observed that the ANFIS-TCSC produces better response with GA-CPSS, ANFIS-PSS and GA-ANN-PSS compared to the NARMA-L2-PSS and LMNN-PSS.

- Finally it has been concluded that simultaneous application of ANFIS-TCSC with ANFIS-PSS produce good damping characteristics under all operating conditions and disturbances in power system.

In chapter 6, a performance and role of ancillary controllers such as PSS and TCSC have been analyzed in two area control system under restructured electric market. Low order power system model and higher order power system model have been considered for depth Analysis of two area system with Ancillary controllers. The small signal stability analysis and non-linear simulation for the transient stability analysis have been carried out for investigation of the power system stability issue. Two different operating conditions are taken with consideration of various DPM and load variation in two control area. The rotor speed deviation and change in tie line power have been analyzed under different types of DPM and variation of load in control area.

From first order power system model :

It has been shown that the eigen values associated to the electromechanical mode are more negative with presence of TCSC in two area system and poles in s-plane are far away from origin as shown in Table 6.1. The damping factor has been improved with TCSC compared to that without TCSC, which has shown that the LFC system is more stable and TCSC has been provided good damping to oscillation in power system. The effect of various DPM and variation of load have been clearly observed in the simulation results of speed deviation and change in tie line power. The simulation results have shown that the frequency oscillation and tie line power oscillation have been controlled through GA and ANFIS based TCSC in two area system. The ANFIS based TCSC has reduced oscillation in speed deviation and tie line power compared to the GA based TCSC. The time response parameters such as settling time and overshoot have been improved using ANFIS based TCSC compared to the GA Based TCSC in both control area.

From higher order power system model :

1. GA and ANFIS based control strategies have been developed for designing of multiple PSS and TCSC damping controller. The multiple PSS and simultaneous designed TCSC and PSS have been applied to the dynamical two area power system.

2. It has been shown that the eigen values associated to the electromechanical mode are more negative with presence of multiple PSS and TCSC' in multi area power

system and poles in s-plane are far away from origin. The damping factor has been improved with PSSs compared to that without PSSs, which has shown that the system is more stable and PSSs have provided good damping to oscillation in power system. It has also been observed that with the simultaneous application of multiple PSS and TCSC in power system, the eigen values are more negative and damping factor has been improved significantly, which shows good stability of system compared to the individual application of PSS and TCSC.

3. From the non - linear analysis, without the application of the controllers in the system, the oscillations in rotor speed deviation and tie line power have been observed. Under the heavy loading conditions in restructured environment, the oscillation in speed deviation are continuously growing which creates the instability of the restructured electric system. While simultaneously designed TCSC and PSS damping controller have significantly diminished oscillations in system. Simultaneous application of TCSC and PSS have provided very good damping characteristics compared to the individual application of PSSs or TCSC and almost eliminated the oscillations in system. Application of ANFIS based TCSC and PSSs have improved the time response parameters such as settling time, rise time and delay time appreciably and also decreased the overshoot in the system compared to the GA based Ancillary controllers.

7.3 Scope of Future Research

As consequence of investigations carried out in this thesis, the following aspects are being suggested as future research work to be carried out.

Modeling of PSS and TCSC controller with fifth order power system has been presented. However, the modeling of system can be extended for other FACTS controllers for stability analysis and sensitivity of power system.

Chapter 3 has been restricted to genetic algorithm based controllers. The different evolutionary algorithms such as cultural, ant colony, and hybrid algorithms can be applied for designing of PSS and different FACTS controllers for parameters optimization.

The highly dynamic power system, the recurrent dynamic neural network with non linear

system identification techniques can be applied for PSS and FACTS controllers. Neural network based system identification for non linear power system is new research area for designing of PSS and FACTS controllers. The non linear power system stability also can be analyzed using non linear Liyapunov's stability method.

The work presented by chapter 6 can be extended for three and four areas power system with four GENCOs and four DISCOs in each area. The optimized location of PSS and FACTS controllers can be identified using evolutionary algorithms in multi area power system. Considering dynamical situation in power system, the adaptive neural networks based ancillary controllers can be developed for stability issues and tie line power control in restructured electric market. The concept described by chapter 6 can be applied to large integrated hybrid power system.