CHAPTER 7

CONCLUSION

7.1 INTRODUCTION

This research work focuses on developing the optimal controller using soft computing techniques for multi source multi area hydro thermal system. For the controller action, perturbed mathematical model of single source multi area hydro thermal system was considered and the modeling was further extended towards multi source multi area hydro thermal system. The limitation of the governor droop left the hydro thermal system with the frequency and tie-line power deviation, in terms of transient oscillations and steady state error. To remove the offset, appropriate secondary controller was used. PI controller is the effective conventional controller which improves the system response.

In this thesis, the parameters of the secondary PI controller were tuned using ZN, GA and FGS methods for its effective operation. Increasing the gains of the PI controller produced sustained oscillations for a period with high peak value which was resolved using VSS Controller. The predominance of switching from P to PI controller during the transient and steady state period suffices the relevance of the VSS Controller over conventional PI controller. The tuned gain values of the conventional PI controller were used in VSS Controller. Appreciable system response was achieved by using ZN and GA tuned VSS controller gains.
The inherent nature of gain variations by FGS was made much more effective by using VSFGS controller in single source multi area and multi source multi area hydro thermal system. Much fine betterment in the system performance subjected to load variation was achieved along with the FACTS devices.

In this thesis, refined FACTS devices were selected for improving the system response. SMES, UPFC and SSSC were used for controlling the frequency and tie-line power deviations along with VSFGS controller in the power plants. SMES was connected across the power system to control the frequency variation subjected to load disturbance in single source and multi source multi area hydro thermal power systems.

UPFC and SSSC were provided in series with the tie-line whose effectiveness of either FACTS device operation was judged by using performance indices. ISE, ITAE and ITSE performance indices were used for judging the effective performance of the system in using all the controller operation including with the FACTS devices. On comparing the responses, the appropriate choice of controller and FACTS device was identified.

7.2 MAJOR CONCLUSIONS

7.2.1 Modeling of Hydro Thermal System

The transfer function model of thermal and hydro power plants were derived from the literature survey.

Due to the drooping characteristics of the governor in both hydro and thermal power plant without secondary controller, there is a steady state error in frequency when the system is subjected to unit step load disturbance of 0.01 p.u.
Thermal based power system and the hydro based power system were connected using tie-line to form single source multi area hydro thermal system.

When the single source multi area hydro thermal system without secondary controller was subjected to unit step load disturbance of 0.01 p.u., the tie-line power and area frequencies have steady state error.

Later, the control area was modeled with both hydro and thermal power plants. This forms multi source control area. Such two control areas were interconnected by means of tie-line to form multi source multi area power system.

The multi source multi area hydro thermal system without secondary controller was subjected to unit step load disturbance of 0.01 p.u. Due to non-availability of secondary controller and drooping characteristics of governor, there exists the steady state error in tie-line power and area frequencies.

There is a need for secondary controller in both single source multi area and multi source multi area hydro thermal systems to remove the offset in area frequencies and tie-line power.

7.2.2 PI Controller for Hydro Thermal System

The PI secondary controllers, for single source multi area and multi source multi area hydro thermal systems have been tuned using ZN method.

The ZN tuned PI controller for single source multi area hydro thermal system settles the frequency of both the areas and tie-line power without steady state error.
The ZN tuned PI secondary controller removes the offset in frequency and tie-line power of multi source multi area hydro thermal system.

Though, the ZN tuned PI controller yielded good steady state response, their transient responses is not giving satisfactory results. There is a need for a tuning methodology to yield the optimal value. It was done by GA.

GA was used for tuning the PI controller with population size of 10, crossover fraction of 0.8, mutation probability of 0.05 and Integral Squared Error as the fitness function.

The GA tuned PI controller improved both the steady state response and transient response of single source multi area and multi source multi area hydro thermal systems than the ZN tuned PI controller.

The disadvantage of the Genetic Tuned PI controller is the fixed gain values. The gain values of the PI controller should vary based on the system conditions. It is possible by FGS. The FGS was developed with ACE and change in ACE as inputs. The outputs are the gain values of PI controller.

The inputs were divided into seven linguistic variables. The membership functions are symmetrical and triangular shaped except the extremes which are trapezoidal. Since the two inputs have seven membership functions each, the total number of rules written was forty nine. As far as output is concerned, there are seven linguistic variable of symmetrical and triangular shaped except the extremes which are trapezoidal shaped. Centre of gravity method was used for defuzzification. The Fuzzy Gain Scheduled (FGS) controller improves the transient and steady state response of single source multi area and multi source multi area hydro thermal systems than GA tuned PI controller.
For the justification of the controller performance, performance indices namely, ISE, ITSE and ITAE were calculated. The ISE value of ZN tuned, GA tuned and FGS controllers are 0.001211, 0.0006861 and 0.0002312 respectively for single source multi area hydro thermal system. Similarly, it is 0.001077, 0.0009056 and 0.0001611 respectively for multi source multi area hydro thermal system.

In the measurement of ITAE, ZN tuned, GA and FGS have 1.499, 0.5069 and 0.4454 respectively for the single source multi area hydro thermal system. The ITAE values ZN tuned, GA and FGS controller of multi source multi area hydro thermal system are 1.185, 0.5412 and 0.1605 respectively.

The ITSE values of single source multi area hydro thermal system with ZN, Genetic and Fuzzy tuned controllers are 0.003726, 0.001658 and 0.0005609 respectively. Similarly for multi source multi area, the ITSE values are 0.002858, 0.00123 and 0.0001548 respectively.

From all the ISE, ITAE and ITSE values, it was found that Fuzzy Gain Scheduled (FGS) controller provided better response for both single source multi area and multi source multi area hydro thermal systems.

7.2.3 VSS Controller for Hydro Thermal System

The problem of PI controller was the effect of P controller during steady state response and I controller during transient response. The P controller improved transient response and disturbed the steady state response. Similarly, I controller improved steady state and affected transient. This was overcome by using VSS controller.
The VSS controller switches between P and PI based on system error. This concept was applied to ZN, GA and FGS controller and applied to single source multi area and multi source multi area hydro thermal systems.

The performance index ISE for single source multi area hydro thermal system with VSS based ZN, Genetic and Fuzzy are 0.00120, 0.0006037 and 0.0002156 respectively. Similarly for ITAE, the values are 1.482, 0.4987 and 0.4188 respectively. For ITSE, the values are 0.003646, 0.001311 and 0.0005023 respectively.

For the multi source multi area hydro thermal system, the ISE values for VSS based ZN, Genetic and Fuzzy are 0.000956, 0.0008813 and 0.0001545 respectively. The ITAE values are 0.738, 0.5391 and 0.1559 respectively. The ITSE values are 0.001463, 0.001189 and 0.000151 respectively.

From the performance index values, it was identified that VSS based FGS controller is the optimal secondary controller for both single source multi area and multi source multi area hydro thermal systems.

7.2.4 FACTS Devices for Hydro Thermal System

FACTS devices like SMES, UPFC and SSSC were used for the LFC of hydro thermal system in this thesis work. SMES is used for controlling the frequency in the control area. SSSC and UPFC are used for the control of tie-line power flowing between the areas.

SMES unit has superconducting inductive coil which stores the energy in the form of magnetic field and discharges large amount of power for a short duration of time. This property is used for controlling the frequency in control area. The SMES was connected in both the areas of
single source multi area and multi source multi area hydro thermal systems. It improved the system performance with less peak value and less settling time.

UPFC has the ability to control the line impedance, bus voltage and angle which ultimately controls the power flow. It is used for controlling the power flow in tie-line. When UPFC was connected to the tie-line, it improved the response of tie-line power with \(-2.77\times10^{-5}\) p.u. of peak value and 0.41 sec of settling time in single source multi area hydro thermal system. Similarly, in multi source multi area hydro thermal system, it reduced the peak over shoot of tie-line to \(-3.36\times10^{-5}\) p.u. with settling time of 0.55 sec.

SSSC controls the active power of the tie-line by connecting it in series with the tie-line of the system. It improved the tie-line power response of single source multi area hydro thermal system with \(-1.86\times10^{-5}\) p.u. of peak over shoot and 0.4 sec of settling time. In multi source multi area hydro thermal system, the SSSC improved the tie-line power oscillations with peak value and settling time to \(-2.43\times10^{-5}\) p.u. and 0.525 sec respectively.

On comparing all the responses of FACTS devices it was found that the optimal response is achieved with SMES in both the areas, SSSC in tie-line and VSS based FGS as secondary controller.

Both the hydro thermal systems with FACTS devices and optimal VSS based FGS controller were tested with speed governor dead band, boiler system and reheat turbine. It was tested on non-identical power system, and then finally on the system with random load variations.

All the testing methods proved that VSFGS secondary controller along with SMES in both the control areas and SSSC in tie-line yields best optimal LFC action for both single source multi area and multi source multi area hydro thermal systems.
7.3 MAJOR CONTRIBUTION OF THE WORK

Single source multi area and multi source multi area hydro thermal system is modeled and connected with VSFGS as secondary controller, SMES across the power system and SSSC in series with the tie-line. The systems were subjected to unit step load disturbance of 0.01 p.u. The validation of the results using performance indices ISE, ITAE and ITSE had shown improved results in terms of reduced overshoots and attained faster settling time when compared with VSFGS. Considering practical approach, the system performance was also tested and validated with better response including the non-linearities, governor dead band and boiler dynamics in the thermal system being interconnected with the hydro system as single source multi area and multi source multi area.

7.4 SCOPE FOR FUTURE WORK

- In this thesis, multi source model was created only with hydro and thermal power plant. By using the transfer function model of gas turbine, wind and solar, it can be extended further.

- The PI controller can also be tuned using hybrid soft computing optimization techniques for the multi source multi area hydro thermal systems. And, Hybrid controller can also be integrated with VSS.

- When the multi source multi area system is used in deregulated environment, the control techniques will be different. It is based on contract. A suitable control strategy can be developed.

- Subsequently, the optimal secondary controller for the multi source multi area system with various generations can be developed under deregulated environment.