7.1. CONCLUSIONS

For fluctuations in load and operating conditions of the systems, there always remains a mismatch between instant by instant generation and the load. So surplus or deficiency in the generation will cause frequency fluctuations. The deterioration and fluctuations in frequency affects consumer’s equipments & power system as a whole in an adverse manner. Therefore, it is necessary to regulate the frequency at its nominal value within a short span of time. Further, due to depleting natural resources and negative impact of fossil fuel burning, a lot of interest in the power industry has grown to replace the later with RER based power generation. However, the integration of these unconventional generators has posed several new technical challenges related to voltage and frequency stabilization. The objective of this work is to improve the frequency regulation of interconnected power system with RER, limiting the focus of the work only towards integration of DFIG based WECS and hydro power generators to the grid.

When the DFIG based WECS are connected to the existing grid, the frequency deviation is more due to the decreased value of overall inertia of the system. But a modified inertia control of the DFIG capitalizes the stored kinetic energy of rotational mass to facilitate and enhance the frequency support capability of the system. The response of the conventional generators is considerably slower than that of the wind turbine equivalent generation when the frequency support capability is available from the later. In this regard, the work in chapter-2 aim to optimize the controller gains of DFIG and the integral gains of the AGC, in a coordinated manner. The fast response capability associated with electronically-controlled PD control loop of DFIG based
WECS is utilized to improve the transient performance of frequency regulation of power system. Integrated with thermal systems, a coordinated tuning of the PD controllers of DFIGs along with those of integral controllers of AGC in a two area system is found to be beneficial. The controllers tuned with CSA are found to give better dynamic performance compared to similar controllers optimized with some previously published modern conventional and heuristic optimization techniques i.e., LP, GA and PSO, in terms of their robustness. The new controllers depict better ability of disturbance rejection, when system parameters and operating conditions are varied. Looking at the efficiency of CSA, it is decided to further test the same in some other similar problems with other RER sources in the integrated system and try to improve upon its optimization performance later.

As far as other sources of RER are concerned, the ones based on hydro sources have been in service of the power sector since long. Being a renewable resource, the effect of its integration with the wind thermal system requires to be investigated. In this regard, the comparison in performance of mechanical and electro-hydraulic (electrical) governor is analyzed in this work, for SLP in different areas. The electrical governor of hydro-generators in a hydro-thermal (H-T) system has an advantage of providing initial real power surge in the case increased power demand. Therefore, the frequency regulation performance improves. With the electrical governor, a H-T system having the same capacity with an two area thermal system, provides better frequency regulating capability due to the presence of higher inertia of the available water column.

The impact of DFIG participation for frequency control of the two-area interconnected H-T power system is evaluated in chapter-3. Compared to the thermal area, wind power penetration in hydro area improves the frequency regulation
characteristics, when the controller parameters of PD controllers of wind generators and integral controllers of H-T system are optimized with CSA simultaneously.

The thermal power plants operate with large numbers of operational constraints, particularly in an integrated system. The level of real and reactive power reserve with only contribution from rotor inertia of generators provides a very small margin of maneuverability in system operation. The use of ESS and FACTS devices solves the problem to a large extent particularly in larger interconnected system. Further, the nature of randomness and uncertainty in the availability of renewable resources also require extra storage system for grid reliability. In this regard, a comparative analysis of a coordinated operation of the controllers of FACTs devices along with those of SMES has been done in Chapter-4. The relative performance of CSA optimized controllers of SMES–SMES, SSSC–SMES and TCPS–SMES, is compared and it is found that, the performance of SMES-SMES scheme results in best performance among all of them. The same tuned controllers of SMES-SMES depict good robustness in their performance even with modified parameter and operating conditions. In summary, a coordinated operation of CSA optimized controllers of SMES along with active power support from DFIG based WECS in both the areas of a two area system, improves the dynamic response of the T-T systems during load fluctuations. Even though the settling time and MDR values with DFIG-SMES has reduced marginally compared to only SMES alone, but the overall dynamic response has improved as witnessed in the waveforms. Therefore, in a wind integrated thermal power system with the uncertain nature of wind flow, investing in SMES in both the areas may be advantageous.

As far as optimization algorithm is concerned, the proposed CSA has relative smaller numbers of control variables and therefore it is suitable for different types of
optimization problems in power system. However, any possible modification of the algorithm either through the process of hybridization with other similar evolutionary algorithms, or by altering the algorithm into multi objective optimization domain may result in improving its efficiency. So, in subsequent chapters, multi objective optimization methods were considered for further improvement in the performance of wind integrated T-T power system.

In chapter-5, the controller parameters of DFIG ($K_{pf}$, $K_{df}$) and AGC ($K_i$) are optimized using a multi-objective optimization using the algorithm NSGA-II. The main motivation of optimizing the gains of wind and thermal systems using NSGA-II, was to examine the efficacy of the same for tuning the gains of two systems having different characteristics of inertial response. The performance of optimized set of controllers show non domination and improve many performance indices without deteriorating others. The NSGA-II optimized controllers are found to be better compared to similar controllers optimized with CSA, GA, PSO, in terms of their performance and robustness. Further, these set of controllers depict better ability of disturbance rejection, when system parameters and operating conditions are varied.

The primary objective in Chapter-6, was to test the efficacy of utilizing the method of non dominated sorting in the better performing CSA, instead of GA. The process of hybridization between NSGA-II and CSA modifies the crossover and mutation operators of GA in NSGA-II, by replacing them with the concept of Lévy flight and abandonment considered in CSA. The modified algorithm NSCS uses the non-dominated sorting and crowding distance used in the original version of NSGA-II, but improves on the search power by utilizing the Lévy flights. The performance of the controllers obtained both with NSCS$_1$ and NSCS$_2$ (which keeps an archive of
Chaine S. (2016) Improvement of Frequency Regulation of Power System having Renewable Energy Resources

Chapter 7 solutions), has been found better compared to similar controllers optimized with some NSGA-II, CSA, GA and PSO, in terms of their robustness. The process of archiving with niche count carried out in NSCS2 has resulted in a marginally faster convergence characteristics compared to the NSCS1 result, without compromising on the quality of global solution.

The work justifies the fact that a better evolution strategy of CSA, when combined with proper choice of non dominated Pareto optimal set of solutions, the performance improves further.

Highlights and key contributions of the work are as follows

1. The CSA as an optimization tool has been able to provide better optimized controllers of both wind and thermal systems.

2. Hydro based power system with electrical governors is a good renewable alternative for its integration with thermal system to improve frequency regulation when its controller gains are tuned simultaneously with those of thermal systems. Moreover, the contribution of DFIG based WECS in further improvement of frequency regulation is found better when the penetration of the same is provided in hydro area in place of thermal area.

3. Among SMES and series FACTs devices of TCPS and SSSC, the frequency regulation capability of the former is better when placed in both the areas compared to any other combination of devices in the two areas.

4. The nature of giving non dominating solution by NSGA-II, has managed to provide better solution of optimized gains of the controllers.

5. The optimization efficiency of NSCS1 and NSCS2 are found to be better than NSGA-II and other algorithms, as the weaker evolutionary structure of GA is replaced with CSA.
In summary the frequency regulation characteristics of power system integrated with different mix of RER based power sources can be improved by proper study of the characteristics of the individual systems. Further, to avoid the conflicting nature of their behavior in operation, a multi objective Pareto based solution of important optimized controllers may be obtained utilizing algorithms like the NSCS.

7.2. RECOMMENDATIONS FOR FUTURE RESEARCH

The components of the research reported in this thesis have completed some fundamental aspects of frequency control in conventional power system of hydro and thermal types integrated with wind system having an artificial inertial support mechanism within the optimisation domain. Some important future works of research are logical extension of this work to better understand the system operation. Some of them are as follows

1. Frequency control capability of WECS can be improved if some additional real power margin of WECS may be kept deliberately by operating the same in a sub optimal power point widely known as the deloaded operating of WECS.

2. In the energy mix of wind-thermal and hydro systems, some other very important power sources in the forms of Solar-PV, Gas, Nuclear systems with proper modelling, may be studied to get a more comprehensive picture.

3. Future research in the domain of AGC may be extended to study the concept of autonomous demand response in a hybrid power source environment.

4. The proposed optimization algorithms of NSCS may be tested for optimization efficiencies to optimize several controllers in a multimachine power system within the domain of AGC.