CHAPTER-6

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

6.1 INTRODUCTION

This chapter presents the salient and significant contributions of the study undertaken and being presented in this thesis as well as brief statement concerning some recommendations for further research. The significant original contributions are listed and discussed below.

6.2 SIGNIFICANT CONTRIBUTION

The present study is based on solving and optimizing a single area and multi-area; single objective and multi-objective unit commitment optimization problem of electric power system to minimize the overall generation cost while satisfying the time varying load demand subject to physical and technological constraints. In an effort to solve scalar objective single area unit commitment optimization problem of electric power system integrated differential evolution and harmony search, hybrid harmony search and random search and hybrid differential evolution and random search optimization algorithms have been proposed and implemented successfully. Energy is essential for socio-economic development and poverty eradication. Global warming is a crucial issue for the whole world. United Nations formulated an international treaty in 1992 and instructed the countries to reduce green house gases. In the light of this Kyoto protocol was implemented by Japanese government in 1997. Indian government also imposed an effective policy to reduce emission of CO_2. Carbon tax policy is a cost-effective method to reduce emission of gases. However, setting the carbon tax is one of the challenging tasks for policy makers, as it will lead to higher price of emission-intensive sources especially the utility price. India will continue to face power crisis unless various types of energy sources are not explored for different types of consumers. Also, there is a need to reduce energy wastage by improving transmission and distribution networks. In India, the thermal power plants are mainly responsible for releasing of polluting gases like carbon

dioxide, sulphur dioxide and nitrogen dioxide etc. into the atmosphere. These gases are responsible for global warming. Thus, the problem of increasing emission level of pollutant gases in the environment due to fossil fuels of thermal power plants becomes essential. To tackle this crucial situation in Indian power sector, multi objective unit commitment (MOUCP) is employed. In MOUCP status of the generating units and their power outputs are to be determined keeping in view the system load demand. All this is to be optimized for minimal possible cost and minimum emission while operating within the system's and units' various types of equality and inequality constraints. As in view point of global warming, reduction in emission is also an important need of the day therefore it has been undertaken as another objective in addition to operating cost reduction. In this thesis, the multi-objective unit commitment model is proposed with two conflicting objective functions: minimization of the operating cost and lowering of CO_2 emission. In the multi-objective optimization problem, to achieve optimal solution with respect to scalar objective is generally a cumbersome process. Therefore, interactive method is applied to find the 'best' compromised solution among the non-inferior solutions of conflicting objectives. Also, the challenge of supplying the nation with high quality, reliable electrical energy at a reasonable cost, converted government policy into deregulation and restructuring environment. Increase in the electrical energy demand and trends in privatization and deregulation result in overloading impact on electrical grids. The situation necessitates the development of electrical grid at the same pace as there is increase in load demand, but economical commitment and scheduling has the ability to tackle the time-varying power demand and environmental constraints leading to the full exploitation of accessible grid. Inclusion of restructuring into electricity industries brings more choice. As the objective of restructuring in electricity market is to abolish the domination in the power production and trading sectors and introducing opposition at diverse levels. In deregulation, power generation utilities pierce into mutual agreements to supply the generated electricity to power distributors/dealers or volume patrons or sell the power in a pool, where power brokers and patrons can participate. In this energy exchange process, the buyers offer for their demands along with ability/willingness to reimburse and power generation or power trading become free from the conformist policy and turn into spirited environment, as customers/companies are free to buy power, as per

their requirements, either from a federal spot market or unswervingly from marketers or generators through prearranged mutual agreements. However, due to increase in the electrical energy demand and trends in privatization, combined dispatch of electric generation will be beneficial in inter-connected power system areas, which can result in reduced environmental pollution and operational cost savings. The two or more interrelated regions/areas of electric power system are interconnected by means of tie lines. To achieve significant cost savings and minimize environment pollution, multi-objective multi-area unit commitment strategies are employed, whose' objective is to establish optimal commitment and generation schedule for multi-area power system for momentous outfitted cost savings.

The present research study is dedicated to investigate the novel techniques to define, extend and establish optimal unit commitment strategies in scalar and multi-objective framework for single and multi-area unit commitment problem while considering various system and physical constraints. To solve the problem, non-conventional search techniques are explored. Random search algorithm is exploited to improve the exploitation ability and global performance of conventional harmony search and differential evolution algorithms. The following significant contributions result from this study:

1. A Single area single objective unit commitment problem has been formulated to minimize the overall cost of generation subject to physical and technological constraints while satisfying the time varying load demand. It is a large, non-convex, non-linear and mixed integer optimization problem and has been solved by employing heuristic research techniques such as: integrated *differential evolution and harmony search* (DE-HS), hybrid *differential evolution and random search* (DE-RS) and hybrid *harmony search and random search* (HS-RS) algorithms. These algorithms have been implemented to obtain the optimal schedule for operating the generating units in a most economic manner to satisfy the power demand and taking care of the system and physical constraint requirements of a single area power system. In order to obtain the integrated differential evolution and harmony search, harmony search and random search and differential evolution and random search algorithms, the general operators of harmony search algorithm,

differential evolution algorithm and random search algorithm are combined, recursively. Heuristics procedure is adopted to tackle various physical and operational constraints of unit commitment problem. These methods are successfully implemented on various test systems comprising 5-, 6-, 7-, 10, 20- and 40- generating units.

2. Results obtained by proposed hybrid algorithms are compared with those obtained by other well-known evolutionary, heuristics and meta-heuristics search algorithms. By performing comparison, it has been observed that proposed hybrid HS-RS and hybrid DE-RS algorithms yield better feasible solutions as compared to integrated DE-HS algorithm. The overall generation cost in hybrid DE-RS algorithm is better than hybrid HS-RS algorithm due to self-adaptive mutation and parallel processing nature of Differential evolution algorithm. However, hybrid DE-RS algorithm lacks in computational efficiency due to the requirement of large number of fitness evaluations.
3. The objective of gaseous emission reduction has also been added in addition to the aim of cost reduction in the next chapter to solve single area unit commitment problem of electric power system. Consideration of both the operating cost and gaseous emission (CO_2) objectives make the unit commitment problem multi-objective one. Both of these objectives are conflicting in nature and so non-inferior solution set is generated by employing weighting method. To select the compromised solution from the non-inferior domain, decision maker plays important role. In order to determine the overall Pareto front from a large set of multi-objective solution points, a strategy has been implemented, which split the given objective set into several smaller groups and then, the Pareto fronts of each group are combined together to determine the overall Pareto front.
4. The proposed integrated DE-HS, hybrid HS-RS and hybrid DE-RS algorithms are extended to solve the multi-objective unit commitment problem of single area power systems comprising of 5-, 6-, and 7- generating units. Heuristic procedure is adopted to handle the operational and physical constraints of the problem. It has been concluded that performance of hybrid DE-RS algorithm is better than conventional differential evolution, harmony search, integrated DE-HS and hybrid

HS-RS algorithms. The hybrid DE-RS algorithm outperforms due to direct search capability of random search algorithm and greediness of differential evolution algorithm. However, hybrid DE-RS algorithm is computationally less efficient as it needs large number of fitness evaluation.

5. To tackle inter regional power generation, multi-area unit commitment strategies are employed, whose objective is to establish optimal commitment and generation schedule for multi-area power systems. To achieve significant cost savings and emission reduction, integrated DE-HS, hybrid HS-RS and hybrid DE-RS optimization techniques are again utilized to solve the formulated multi-objective unit commitment and scheduling problem of multi-area electric power systems. Two different test models of multi area power system are taken into consideration for proposed research. To select an optimal compromised solution from a large set, two efficient algorithms have been implemented.
6. From the experimental results of hybrid DE-RS algorithm for multi area unit commitment optimization problem, it is observed that emission in area-1 is less as compared to area-2 and area-3. Thus, to achieve environment protection goal, the power from area-1 should be exported to area-2 and area-3. However, to achieve optimal value of generation cost, area-2 should be operated to export power to area-3 and area-1. With consideration of an effectual tie-line constraint checking procedure, it has been found that the proposed method reduces the total operating cost and gaseous pollutant's emission of the plant. The proposed Hybrid DE-RS gives better results than hybrid HS-RS algorithm.
7. Comparison of simulation results shows that proposed algorithms have prospective to optimize multiple objectives in single and multi-area unit commitment problems with import and export constraints. It has been observed that performance of proposed hybrid DE-RS algorithm is much better than simulated annealing (SA), genetic algorithm (GA), gravitational search algorithm (GSA), particle swarm optimization (PSO) and other recently developed evolutionary and heuristic search algorithms undertaken for comparison in the thesis. From simulation results, it is clear that proposed hybrid DE-RS algorithm is able to determine satisfactory commitment schedule in a reasonable computational time. Also, it has been found

that proposed hybrid HS-RS and hybrid DE-RS algorithms yield better feasible solutions in comparison to integrated DE-HS algorithm. The overall generation cost in hybrid DE-RS algorithm is lower than hybrid HS-RS algorithm, because differential evolution algorithm uses self-adaptive mutation and processes many solutions simultaneously called parallel processing.

8. Results can be summarized as
   - The hybrid DE-RS method is promising. It is able to obtain near-global, optima for the unit commitment optimization problems.
   - The functioning of hybrid HS-RS algorithm is superior to integrated DE-HS algorithm and other variants of harmony search algorithms.
   - Hybrid DE-RS algorithm is substantially better than Hybrid HS-RS algorithm.
   - For higher dimensions, hybrid DE-RS and integrated DE-HS algorithms accelerate DE in general.
   - Wilcoxon's Rank sum test shows that hybrid DE-RS and Hybrid HS-RS algorithms are better than other meta-heuristics algorithms. Hybrid DE-RS algorithm is highly competitive than the hybrid HS-RS and integrated DE-HS algorithms for similar testing functions.
   - Hybrid DE-RS and Hybrid HS-RS algorithms balance the exploration and the exploitation because poor solutions are able to get information from good ones. Also good solutions are prevented from destroying during evolution. Therefore hybrid HS-RS algorithm is better than the original HS algorithm for unimodal and multi-modal benchmark functions.

6.3 SUGGESTIONS FOR FUTURE WORK

Possible future research directions are listed below:

- The profit may be taken as objective function instead of generation cost.
- Maintenance cost can also be considered in the objective function.
- The problem can be converted to hydrothermal unit commitment problem.
- The combined operations of conventional and non-conventional energy sources can be included in the study.

- Combined cycle plants, that is, production of heat along with power can be undertaken for further course of study.
- Newly emerging search techniques such as Grey wolf optimizer (GWO), Ant Lion Optimizer (ALO), Moth Flame Optimizer etc. can be tried which may prove to be faster for on-line and off-line implementation. A suitable combination of Evolutionary and conventional methods may prove to be better option.
- Artificial intelligence (AI) based hybrid models can be utilized to explore a wider search space. AI based systems can solve large scale systems in reasonable time.