CHAPTER 1

INTRODUCTION

1.1 GENERAL

Throughout the entire world, the electric power industry has undergone a considerable change to meet out the growing needs of its consumers. The economic and reliable electricity supply are the major needs of the consumers. The increasing electricity demand and decreasing energy sources have necessitated the optimum use of available resources. Scheduling of available generating resources to meet the load demand is an important job of a power system operator to meet the economic needs of the consumers. Economic operation is very important for any power system to achieve the profits on the capital investment. Since price of fossil fuels is continuously rising and its availability is also decreasing, these lead to the conservation of fossil fuels. This scenario gives extra pressure to the electric power industry in order to achieve the maximum possible fuel efficiency.

Economic Dispatch (ED) is an important optimization task in power system operations for allocating generation among the committed units such that all the constraints imposed are satisfied with minimizing the operating fuel cost. Improvements in the scheduling of unit outputs can lead to significant cost saving as given in Wood and Wollenberg (1996). Hence, the economic aspect of the electric power generation itself needs extra importance from the electric power industry.
1.1.1 Optimal Economic Dispatch

The importance of the optimal economic dispatch starts from the time that two or more generating units are committed to meet the power system load demand, whose total generating capacities exceed the system demand. The economic scheduling of generators aims to guarantee at all times the optimum combination of generators connected to the system to supply the load demand. This involves minimizing the costs of fuel, line losses etc.. The basic purpose of the economic dispatch is to schedule the outputs of the online fossil fuel generating units so as to meet the system load demand at least cost.

The traditional ED requires the input-output characteristics curve (millions of Btu per hour against MW) of generating units. These incremental heat rates of the units must be monotonically increasing, smooth and convex curve. In reality, unit incremental heat rate curves do not exhibit the monotonically increasing nature as required by the traditional ED problem. Today’s power systems are highly complex and their operations are unpredictable.

The basic objective of the conventional ED of electric power generation is to schedule the committed generating unit outputs so as to meet the load demand at minimum operating cost, while satisfying system equality and inequality constraints as given in Wood and Wollenberg (1996).

In addition, because of the increasing awareness of the environmental pollution, limiting the emission of pollutants in fossil fuelled power plants is becoming a vital issue in economic power dispatch. The conventional economic power dispatch cannot meet the environmental protection requirements, since it only considers minimizing the total fuel cost. The multiobjective generation dispatch in electric power systems treats
economic and emission impact as competing objectives, which requires some reasonable tradeoff among objectives to reach an optimal solution. This formulates the Combined Economic Emission Dispatch (CEED) problem with an objective to dispatch the electric power considering both economic and environmental concerns.

However, a practical ED must take ramp rate limits, prohibited operating zones, valve point effects, and multiple fuel options into consideration to provide the completeness for the ED formulation. The resulting ED is a non-convex optimization problem, which is most challenging and cannot be solved by the traditional methods.

1.2 LITERATURE REVIEW

In the past five decades, numerous research works have been reported for this ED problem. According to the complexity considered, various objective functions and various solution algorithms have been considered for the ED problem. For this proposed work, only some of the objectives and solution algorithms from the important literature, which are directly related to the present work, are considered. Literature survey made has been presented under the following topics.

1.2.1 Classical Economic Dispatch

The various literature considering convex nature of fuel cost minimization as an objective to the economic dispatch problem are discussed below.

Lee et al (1985) has presented a new method for optimal real and reactive power dispatch for economic operation of a power system. This method has basically coupled the three modules such as optimal dispatch of
real power, optimal allocation of reactive power and finally with load flow module. To solve this optimization problem, gradient projection method has been introduced.

A General survey of papers and reports addressing various aspects of ED problem has been presented by Chowdhury and Rahman (1990). The time period covered is from the year 1977 to 1988. This survey presents clear picture of what is available and hence the researchers in the area of ED can identify problems and seek their solutions.

Farag et al (1995) have described a novel method and algorithm based on the linear programming techniques to obtain the optimal shift in ED problem related to contingency states or overload situations in power system operation and planning phases under various objectives such as economy, reliability and environmental conditions.

Classical economic dispatch techniques involve the use of advanced calculus method relying on the LaGrangian function. The LaGrangian function is added to the constraint function and is also multiplied by an unknown constant variable with the objective function. Many classical techniques such as gradient, Newton, linear programming and interior point applied to solve this well behaved formulation has been reported in Wood and Wollenberg (1996).

Song and Chou (1997) have formulated the classical ED problem with the quadratic form of fuel cost function as an objective and solved it based on the lambda iteration method with the help of advanced engineered conditioning genetic approach.

Ciornei and Kyriakides (2012) have provided a detailed account of papers published after 1990, the year that witnessed the beginning of major
transformations in the power system organization. A comprehensive survey on mathematical formulations and a general background of methods, analyses and developments in the field of economic dispatch have been presented for the past 20 years based on more than 150 publications. A database of the most common test systems used in the literature is also provided to test different economic dispatch methodologies.

1.2.2 Non-convex Economic Dispatch

Many of the previous researchers have considered the non-convex form of objective functions by incorporating valve point effect and multiple fuel options along with fuel cost function. Those non-convex ED related literature are discussed below.

To model the effects of valve points, a recurring rectified sinusoid contribution is added to the input-output equation by Walters and Sheble (1993), which illustrates the multi model solution space in the ED problem created by the valve point effects.

Jayabarathi and Sadasivam (2000) have proposed a classical evolutionary programming methods for the ED problem with piecewise quadratic cost function and the results are compared with Hopfield neural network approach. Park et al (2005) and Chiang (2005) both have initiated the modelling of realistic ED problem by considering both valve point effects and multiple fuels, which always exist in real power systems simultaneously.

Selvakumar & Thanushkodi (2007) have considered the ED problem as a non-convex optimization problem by including the practical operating conditions such as valve point effect, multiple fuels, prohibited operating zones and generation ramp rate limits.
Coelho and Mariani (2008, 2010) and Amjadi & Sharizadeh (2010) have considered the valve point effects by incorporating the sinusoidal function in the quadratic natured fuel cost function. Bhattacharya and Chattopadhyay (2010) have formulated the convex and also a non convex ED problem by considering the valve point effect and multiple fuel options. Khamsawang and Jiriwibakorn (2010) formulated the ED problem with three types of fuel cost functions such as ED with valve point effect, ED with valve point effect and multiple fuels and finally ED with prohibited operating zones.

Tsai et al (2011) have proposed the Novel Stochastic Search (NSS) method and Cai et al (2012) have proposed a hybrid of chaotic Particle Swarm Optimization (PSO) and Sequential quadratic programming based algorithm and both solved the non convex ED problem. The spread of the obtained optimal solution by the proposed algorithm has also been analysed by Tsai et al (2011).

1.2.3  Environmental Constrained Economic Dispatch

Researchers dealing with the environmental constrains along with fuel cost minimization are presented in this section.

Heslin and Hobbs (1989) have presented a model to accurately evaluate the fuel costs and emission with the help of modern probabilistic production costing methods. The weighting method is utilized to create a single objective by summing the multiple objectives.

Dhillon et al (1993) have solved a problem on CEED by a stochastic approach that takes into account uncertainties in the system cost and nature of load demand. A weighted min-max method is used to obtain the non-inferior solutions of the multi-objective ED problem.
Ramanathan (1994) has proposed an efficient emission constrained dispatch technique that minimizes the operating cost and also satisfies the emission constraints. This paper has proposed two methods. In the first method, an efficient technique is developed to add the emission constraints in the standard classical ED problem and to produce a rapid convergence to Kuhn-Tucker conditions. In the second method, partial closed form solutions are used to arrive at the Kuhn-Tucker conditions.

A summary of work in the area of Environmental Economic Dispatch (EED) is given by Talaq et al (1994). The summary includes several techniques intended to reduce emission in the atmosphere due to electric power generation.

Based on the year 1990 amendments to the clean air act, Lamont and Obessis (1995) have renewed emphasis on emission dispatching strategies and presented with a set of dispatching algorithms along with solution algorithms. In that, Lamont and Obessis (1995) have proposed a strategy to minimize the total operation cost and to estimate the SO\(_2\) emission allowance as defined by the 1990 amendments to the clean air act. It also presented a new emission dispatch solution algorithm that achieves a minimum cost solution by curtailing those generating units with the highest ratio of incremental emission to incremental cost.

Srinivasan and Tettamanzi (1997) have presented an integrated framework for modelling and evaluating the economic impacts of environmental dispatching and fuel switching. The heuristics guided evolutionary algorithm has been employed to solve the proposed ED model.

Dhillon and Kothari (2000) have solved a problem on EED using \(\varepsilon\)-constraint methods to generate non-inferior solutions along with the trade off function between the conflicting objectives. Surrogate worth trade off
Huang and Huang (2003) have described a novel approach that combines abductive reasoning network and a technique for order preference by similarity to ideal solution decision approach in order to achieve real-time EED and the best compromise solution. The test results revealed that the proposed approach outperforms the artificial neural networks method.

Selvakumar et al (2003) and Kumarappan & Mohan (2004) have used the price penalty factor to convert the bi-objective EED problem into a single objective CEED problem. Venkatesh et al (2003) have proposed a modified penalty factor approach to convert the bi-objective CEED problem into single objective CEED problem. AlRashidi and El-Hawary (2006, 2006a) have presented with trade off solutions for the multiobjective EED problem by converting it as a single objective EED problem using the weight factor or utility factor.

Singh et al (2006) have formulated the multiple criteria load dispatch problem as a scalar optimization single objective EED problem with weighting method. The fuel cost and atmospheric pollutants such as NO\textsubscript{X}, SO\textsubscript{X}, CO\textsubscript{X} caused by fossil fuelled thermal generating units are considered as four different objectives. Singh et al (2006) have mainly focused a solution methodology to compute the best compromised solution by evaluating weights for each objective.

Bharathi et al (2007) have formulated the bi-objective EED problem as single objective CEED with the help of price penalty factor approach. Singh & Dhillon (2008) have proposed a solution methodology with the best weight pattern approach to optimize the real and reactive power in power systems.
Hemamalini and Simon (2008) have solved the CEED problem as single objective problem with the help of weighted sum method using PSO. In this, a linear weight factor has been assigned for different objectives based on its importance.

Hota et al (2010), Chatterjee et al (2012) and Rajasomashekar et al (2012) have modelled the multi objective CEED problem as a single objective CEED problem by incorporating the compromise factor and price penalty factor while adding the cost and emission objectives.

Güvenç (2012) has also utilized the price penalty approach to convert the bi-objective CEED problem in to a single objective CEED problem. While the fuel cost function is considered in the CEED problem, the valve point effect is incorporated. Özyön et al (2012) have solved the EED problem as single objective optimization problem by using weighted sum method.

1.2.4 Multiobjective Economic Dispatch

Many researchers have proposed the multiobjective economic dispatch problem by considering more than one conflicting objectives and they have also presented with Pareto optimal solutions instead of single optimal solution.

Yokoyama et al (1988) have formulated the optimal load flow problem as a multiobjective optimization problem and solved by the $\varepsilon$-constrained technique to obtain a set of non inferiority solutions among the various objectives such as, economy, reliability and minimum emission.

Abido (2003, 2003a, 2006 and 2009) has formulated the basic EED problem as a nonlinear constrained Multi Objective Environmental Economic
Dispatch (MOEED) problem where fuel cost and environmental impact are treated as competing objectives.

Ah King (2003, 2005) has also formulated the EED problem as a multiobjective problem with fuel cost and emission as conflicting objectives. Three conflicting objectives such as fuel cost, NO$_X$ emission and SO$_2$ emission are considered by Ah king (2003).

Zhuang and Cai Guo-wei (2009) have structured EED problem as multi objective model of power generation dispatch based on ideal point method in goal programming. Gong et al (2010) and Basu (2011) both have solved the highly constrained EED problem as MOEED problem with conflicting objectives.

Sivasubramani and Swarup (2011) have handled the MOEED problem with two competing objectives such as quadratic form of fuel cost function and emission function with exponential term in it.

Javad and Ghasemi (2012) have formulated the MOEED problem as nonlinear constrained multiobjective problem with three competing objectives such as fuel cost, emission and systems loss.

1.2.5 Application of Single Objective Optimization Algorithms

Traditional and Evolutionary algorithm based methods have been applied to solve the economic dispatch problems. Those single objective optimization methods are reported here.

Walters and Sheble (1993) have proposed the genetic algorithm based solution to an ED problem with valve point discontinuities. The results of the Genetic Algorithm (GA) based solutions have been compared with the Dynamic Programming (DP) technique solutions. Bakirtzis et al (1994) have

Lin et al (2002) have developed an improved Tabu search algorithm and modified the Tabu search algorithm for ED problem with non continuous and non smooth cost functions. Gaing (2003) has employed the PSO method to solve the ED problem with nonlinear generator characteristics such as ramp rate limits and prohibited operating zone. The results reveal that the proposed PSO method could avoid the shortcoming of premature convergence of GA method and could obtain high quality solutions.

Various modifications to the basic EP algorithm have been proposed with a view to enhance speed, robustness and the relative performance of the proposed algorithms on real world ED problems with non-convex cost curves by Sinha et al (2003). Zeynelgil et al (2003) have examined the EED with transmission losses in the power plant using the conventional Hopfield Neural Network.

Improved GA has been proposed to solve the ED problem with valve point effect. New genetic operator has been introduced in improved GA. Ling et al (2003) has claimed that the improved GA performs more efficiently and provides a faster convergence than other GA methods. Venkatesh et al (2003) have proposed a non linear scaling factor included EP to solve the single objective CEED problem with and without line flow constraints. In addition to the EP, GA and micro GA are also used to solve the CEED problem and the results conclude with the effectiveness of EP over other algorithms.
Selvakumar et al (2003, 2007) have proposed PSO and modified PSO to solve the ED problem with emission constraints and ED problem with Non smooth cost functions respectively. Kumarappan and Mohan (2004) have proposed a hybrid method with GA and Tabu Search to solve the price penalty factor based single objective CEED problem.

Chiang (2005) has proposed an Improved GA with Multiplier Updating (IGA_MU) to solve the realistic ED problem. The comparative results reveal that the proposed IGA_MU algorithm possess merits such as, easy implementation, better effectiveness than other methods and better efficiency for solving the real world ED problem.

Park et al (2005) have suggested the modified PSO mechanism to deal the equality and inequality constraints in the ED problem. Moreover, a dynamic search-space reduction strategy has been devised to accelerate the optimization process. Kar et al (2005) have first optimized the CEED problem with Lagrange multiplier technique and the results are utilized to train the artificial neural network to solve the CEED problem. It is found that this algorithm has produced more accurate results with reduced time compared to the conventional methods.

Jayabarathi et al (2005) have explored the performance of the different Evolutionary Programming (EP) techniques for various kinds of ED problems such as ED with prohibited operating zones, ED with piecewise quadratic cost functions and CEED problem. Somasundaram and Kuppusamy (2005) have demonstrated the chronological development and successful application of EP to the solution of security constrained ED. Somasundaram et al (2006) have proposed a modification in EP based algorithm for solving the ED problem. In the fast EP, the search region is progressively reduced and generates only effective offsprings.
Jeyakumar et al (2006) describe a successful adaptation of PSO algorithm to solve ED problems in power systems such as ED with prohibited operating zones, ED with multiple fuel options and CEED problem. The results obtained are compared with classical EP method and it reveals that the PSO outperforms the EP in solving the ED problems. AlRashidi and El-Hawary (2006, 2006a) have proposed the PSO to solve the single objective EED problem with quadratic nature of objective functions.

Liu (2007) has proposed a deterministic approach called filled function method to solve the multimodal ED problem. Bharathi et al (2007) have solved the CEED problem with the help of GA and Ant Colony Search Algorithm (ACSA). Comparison of results reveals that the ACSA outperforms GA in terms of objective functional value.

Mandal and Chakraborty (2008) have studied the effect of parameter settings in Differential Evolution (DE) algorithm in solving the single objective CEED problem with valve point effect and transmission losses. This study reveals that the optimal setting of the control parameters in DE algorithm heavily influences the success rate of DE.

Hemamalini and Simon (2008) have proposed the PSO to solve the CEED problem considering fuel cost function with valve point effect and emission function with exponential term in it. Coelho and Lee (2008) have proposed the Gaussian probability distribution and also chaotic sequences in PSO approaches to solve the ED problem with generator constraints. The results conclude that the methods combining PSO with Gaussian and chaotic signal are very effective and outperform the other methods reported in literature in solving ED problem.

Coelho and Mariani (2008) present a Quantum- inspired version of the PSO (QPSO) using Harmonic oscillator potential well (HQPSO) to solve
the ED problem. The tested HQPSO results show its merits when compared with PSO and QPSO for solving ED problem with valve point effects.

Kumar et al (2009) have provided a bee optimization algorithm based solution methodology for the ED problem with convex and non convex objective functions. Coelho and Mariani (2010) have proposed and implemented a stochastic optimization algorithm named Self Organising Migrating Algorithm combined with a Cultural algorithm (CSOMA) for solving the ED problem with valve point effects. It is observed that the CSOMA results are slightly better than the other solvers reported in literature.

Khamsawang and Jiriwibhakorn (2010) have proposed hybrid approach called distributed Sobol PSO and Tabu Search Algorithm to solve the ED problem with nonsmooth and noncontinuous cost functions. Simulation results prove that the proposed method converges to the global solution regardless of the form of cost functions such as discontinues and non smoothness in the cost functions. Neyestani et al (2010) have proposed modified PSO algorithm to solve the ED problem with non smooth objective functions. By the above algorithm, the diversity of the population is controlled thereby avoiding premature convergence.

The positive characteristics of DE, PSO, GA, and Simulated Annealing (SA) are combined in Amjady and Sharifzadeh (2010), to create a new Modified Differential Evolution algorithm for the application of non convex ED problem. Shaw et al (2010) have offered the seeker optimization algorithm for the solution of the constrained ED problems in different power systems considering various non linear characteristics of generators.

Gravitational Search Algorithm (GSA) method has been proposed and implemented to solve the ED problem with valve point effects by
Duman et al (2010). The comparison of results confirms the effectiveness of the GSA approach over the other techniques in terms of solution quality.

Hota et al (2010) have presented a newly developed optimization approach involving a Modified Bacterial Foraging Algorithm (MBFA) applied for the solution of the CEED problem. In addition, a fuzzy set theory has been implemented to derive a solution efficiently from the set of trade off solutions.

Bhattacharya and Chattopadhyay (2010, 2011, 2011a) have proposed and implemented a hybrid technique by combining DE with Biogeography Based Optimization (BBO) algorithm (DE/BBO) to both convex and non convex ED problem. This DE/BBO gives better performance compared to BBO.

Niknam et al (2011) have modified the PSO with the fuzzy tuned inertia weight and new mutation. This proposed new adaptive PSO approach is applied to solve the EED problem. Cai et al (2012) have presented a hybrid method by integrating the Chaotic PSO (CPSO) with the Sequential Quadratic Programming (SQP) (CPSO-SQP) for solving the ED problem with valve point effects. The results show the capability and effectiveness of the proposed hybrid CPSO-SQP for the practical ED problems.

Chatterjee et al (2012) have utilized the opposition based learning concept to accelerate the convergence rate of harmony search algorithm and proposed a approach called opposition-based harmony search for solving the CEED problem with valve point effect in the fuel cost objective.

Güvenç et al (2012) have proposed the GSA method and Özyön et al (2012) have accustomed the charged system search algorithm to find the solution for single objective CEED problem and the results obtained show
that the proposed algorithms are more powerful than other algorithms. Rajasomashekar et al (2012) have presented a best compromised solution strategy for CEED problem using Biogeography based optimization.

Sajjadi et al (2012) have proposed a gumption approach, Yang et al (2012) have proposed Firefly Algorithm (FA) and Zare et al (2012) have proposed a Modified Group Search Optimizer (MGSO) algorithm. All the above three have solved the ED problem with non smooth cost function.

Kim et al (2013) have suggested an improved mean variance optimization algorithm with Kuhn-Tucker condition and swap process for the non-convex ED problems with heavy constraints. Wang and Li (2013) have formulated a hybrid algorithm by combining the mechanisms of both harmony search and differential evolution. The effectiveness of the proposed hybrid approach is demonstrated with the help of ED problem with valve point effects, multiple fuels and prohibited operation zones.

1.2.6 Application of Multi Objective Optimization Algorithms

Many researchers have solved the multiobjective economic dispatch problem with various multiobjective evolutionary algorithms.

Ah King (2003, 2005), has applied an elitist multiobjective evolutionary algorithm based Non dominated Sorting Genetic Algorithm –II (NSGA-II) to the MOEED problem. Simulation results reveal that the NSGA-II algorithm can identify the Pareto optimal front with a good diversity for the MOEED problem with two objectives and also for three objectives.

A Niched Pareto Genetic Algorithm (NPGA) based approach to solve the multiobjective environmental/economic dispatch (EED) problem is presented in Abido (2003). The NPGA based approach handles the problem
as a multiobjective problem with competing and non-commensurable cost and emission objectives. The above approach also has a diversity-preserving mechanism to overcome the premature convergence problem.

Abido (2003a) has proposed a new Strength Pareto Evolutionary Algorithm (SPEA) based approach to solve the MOEED problem. In addition, a fuzzy set theory has been introduced to derive a compromised solution from the Pareto optimal solutions for the utilization of decision makers. Zhang (2004) has presented the fuzzy multi objective genetic algorithm and solved the MOEED problem. In this, a fuzzy evaluation factor is employed as correction to the fitness function of multi objective genetic algorithm.

Zhao and Cao (2005) have proposed a Multi Objective Particle Swarm Optimization (MOPSO) approach for MOEED problem with three non commensurable objectives such as fuel cost, emission and system loss. A diversity preserving mechanism using an external memory and a geographically based approach to find widely different Pareto optimal solutions are integrated in the proposed MOPSO algorithm.

Abido (2006) has made a comparative study among the Multi Objective Evolutionary Algorithm (MOEA) techniques to solve the real world MOEED problem. In this study, the considered MOEAs are Non dominated Sorting Genetic Algorithm (NSGA), NPGA and Strength Pareto Evolutionary Algorithm (SPEA). The final results conclude that the SPEA has provided better performance compare to others.

Mendoza (2006) has presented NSGA and SPEA to solve the multiobjective design of the power distribution system, to select the optimal size and layout of substations and feeders. In these proposals, a diversity preserving mechanism is applied to find widely different Pareto optimal solutions. Guesmi et al (2006) have used the NSGA-II approach to solve the
MOEED problem in real time according to a forecasted load curve. In order to determine variations of power according to level of load, the neural networks with radial basis function has also used. The obtained NSGA-II results are compared with NPGA, NSGA, SPEA and weighted sum method.

Wang and Singh (2008) have applied the MOPSO algorithm to a bi objective ED problem considering wind penetration with objectives such as operational costs and security impacts. Abido (2008) has also proposed the MOPSO technique for solving multiobjective optimal power flow.

Hazra and Sinha (2008) have proposed the Multi objective Bacteria Foraging Optimization algorithm to solve the MOEED problem with load flow constraints. Bandyopadhyay et al (2008) have developed the Archived Multi Objective Simulated Annealing (AMOSA) algorithm for the application of multiobjective optimization problem. Based on the test system results, it has been proved that the performance of the AMOSA is superior to that of NSGA-II.

Abido (2009) has proposed and implemented a new MOPSO technique to solve the MOEED problem. Both the results demonstrate the capability of the proposed MOPSO technique to generate a set of well distributed Pareto optimal solutions in one single run. Wang and Singh (2009) have derived the multi area EED problem formulation and applied MOPSO to find the set of Pareto optimal solution between the operational cost and pollutant emissions. Rabbani et al (2010) have proposed a multiobjective PSO with a creative approach to identify and keep the best global and personal solutions to distinguish Pareto front. Four different multi objective performance metrics are evaluated to validate the proposed algorithm, such as number of non dominated solutions, quality metric, diversity metric and spacing metric.
Qu et al. (2010) have constructed a fast multi objective EP algorithm by introducing the summation of normalized objective value for sorting instead of using the rank obtained by non dominated sorting. Diversified selection is also implemented in the proposed algorithm.

Gong et al. (2010) have proposed and applied a Hybrid Multi Objective optimization algorithm based on PSO and DE (MO-DE/PSO) to the MOEED problem. The solution quality of the proposed MO-DE/PSO method has been evaluated with few multiobjective performance metrics and its statistical results are also presented.

Wu et al. (2010) and Basu (2011) have proposed and applied the Multi Objective Differential Evolution (MODE) algorithm to the MOEED problem. Three competing objectives such as fuel cost, emission and system loss are considered by Wu et al. (2010). The results have provided the competitive performance when compared with NSGA, NPGA SPEA, NSGA-II, SPEA-2 and MOPSO.

Sivasubramani and Swarup (2011) have extended the harmony search algorithm by including the non dominated sorting and ranking with dynamic crowding distance strategy. The multi objective harmony search application to the MOEED problem shows the ability to produce well distributed Pareto optimal solution than NSGA-II method.

Modified adaptive \( \theta – \) PSO algorithm for the MOEED is presented by Niknam and Mojarrad (2011). Fuzzy based clustering to control the size of the repository is also proposed in this study. Niknam and Mojarrad (2011) have also utilized three multi objective algorithm performance metrics to evaluate the Pareto output of the proposed algorithm.
Javad and Ghasemi (2012) have presented a multi-objective honey bee mating optimization algorithm to solve the MOEED problem with three competing objectives such as fuel cost, emission and systems loss. The comparison with reported results of other multi objective algorithms reveals the superiority of the proposed approach.

1.2.7 Glowworm Swarm Optimization

During the last decade, nature inspired intelligence has become increasingly popular among researchers. They have provided novel problem solving techniques based on swarm intelligence for solving difficult real world problems. Following this tradition, Krishnanand and Ghose (2005) have proposed Glowworm Swarm Optimization (GSO) algorithm to find the multiple optima of the multimodal function. GSO is a derivative free and meta-heuristic algorithm and it also mimics the glow behaviour of glowworms. The algorithm shares some common features with Ant Colony Optimization (ACO) and with PSO, but with serval significant differences.

Krishnanand et al (2006a) have applied the GSO algorithm to multiple source localization tasks that has been demonstrated through real-robot experiments, Where four wheeled mobile robots are collaborated with GSO algorithm to achieve a sound source localization task.

Krishnanand and Ghose (2006, 2009, 2009a) have implemented a large class of benchmark multimodal functions to test against the capability of GSO in capturing multiple optima. Numerical simulation results show the algorithm’s efficacy in capturing multiple peaks of a wide range of multi-modal functions.
Krishnanand and Ghose (2008) have also described theoretical foundations involving local convergence results for a simplified GSO model. Liao et al (2011) have proposed a sensor deployment scheme based on GSO, which can maximize the coverage of the sensors with limited movement after an initial random deployment.

Wu et al (2012) have presented Improved GSO (IGSO) algorithm, which is incorporated with Artificial Bee Colony algorithm (ABC) and PSO. The IGSO algorithm is proposed with two new modifications in changing the position of the glowworms. The results obtained from the bench mark functions show that the IGSO is more effective than classical GSO in finding the better optimal solutions.

Yang and Feng (2012) have presented a GSO approach for the parameter optimization of support vector machine which is a kind of machine learning method in the statistical learning theory. It has been widely used in signal processing.

1.2.8 Technique for Order Preference by Similarity to Ideal Solution

Multi Criteria Decision Making (MCDM) methods have received much attention from researchers and decision makers in evaluating, assessing and ranking alternative across diverse industries. Among the various MCDM methods, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a popular one.

TOPSIS is developed by Hwang and Yoon (1981) as simple ranking method in conception and applications. Behzadian (2012) has conducted a state of the art literature survey to taxonomies the researches on TOPSIS applications and methodologies.
1.3 RESEARCH GAP IDENTIFIED FROM LITERATURE REVIEW

From the extensive literature review, the following three findings are identified. First, several heuristic solution algorithms for solving non-convex ED problem are reported in the literature, but all of them are tracking behind the global optimal solution alone instead of searching both the global optimal and local optimal solutions which can avoid the premature convergence of the algorithm.

Next, numerous single objective optimization algorithms for the EED problem are also reported in the literature review, but most of them handled the fitness function as scalar addition of all the objective values instead of evaluating all the objectives with its own real weights provided by the decision makers. Finally, various multi objective evolutionary algorithms are applied to solve the MOEED problem, but performance can be improved in certain aspects.

This research aims at covering these gaps by solving the non convex ED problem with a novel algorithm which searches both the global and local optimal solutions, solving the EED problem with Multi Criteria Decision Making tool incorporated optimization algorithm and solving the MOEED problem with new multi objective algorithm with easy implementation and better performances.

1.4 OBJECTIVES OF THE RESEARCH

After identifying the research gap through an extensive literature review, the following objectives have been outlined for this research work. The specific objectives of this work are:
To optimize the ED problem with realistic cost characteristic of a plant with valve point effect.

To optimize the ED problem with more realistic cost characteristic of a plant with valve point effect and multiple fuels.

To implement the new GSO approach and to compute the optimal results for the above mentioned non convex ED problems.

To optimize the EED problem with more realistic evaluation approach for the considered two objectives and three objectives.

To propose and implement a novel GSO with TOPSIS approach for solving the EED problem with two objectives and three objectives.

To optimize the MOEED problem with two objectives and three objectives.

To formulate and implement a new, Multi Objective Evolutionary Programming (MOEP) approach for solving the MOEED problem and to compare the obtained results with real coded MOPSO approach for the considered two objectives and three objectives of the MOEED problem.

1.5 ORGANISATION OF THE THESIS

The thesis is organised as follows. A detailed review of the literature regarding the researches, which have been carried out related to this work, is presented in the first chapter. The primary objectives of the thesis are also discussed in detail in the first chapter.
The second chapter gives a brief introduction to the single objective evolutionary algorithms, multi objective evolutionary algorithms and a MCDM technique which is used in this thesis. An overview about EP, PSO and GSO algorithms are given in this chapter under single objective optimization algorithm. The fundamentals of each optimization method, which are used in this research work are expressed. A brief overview about the multi objective optimization methods such as MOEP, MOPSO and MCDM technique named TOPSIS is also presented.

The application of GSO to the ED problem with valve point effect and multiple fuels is explained in the third chapter. Problem formulation section portrays the non convex ED problem with valve point effect and multiple fuels. This chapter also describes in detail about the implementation procedures of the proposed GSO approach to the non convex ED problem. The computational results of the GSO on the test systems and comparisons of the obtained results with other methods reported in the literature are provided at the end of this chapter.

The fourth chapter elaborates the application of GSO with TOPSIS approach to the EED problem with two objectives, three objectives and four objectives. This chapter starts with problem formulation details about the EED problem and also describes the implementation procedure of GSO with TOPSIS approach for the EED problem. Test results and comparison of simulation results with other literature reported are also presented.

The fifth chapter deals with the application of MOEP to the MOEED problem with two objectives and three objectives. After the MOEED problem formulation, the implementation procedures of the MOEP and MOPSO to the MOEED problem have been presented. Then, the fuzzy-based mechanism to obtain best compromise solution and the multi objective
performance metrics are elaborated. Test system results and comparative analysis are presented at the end of this.

Finally, conclusions, contributions of this proposed research work, discussions, future work directions and suggestions are presented in the sixth chapter. Complete database of the various test systems considered in this thesis are given in Appendices.