CHAPTER 1

INTRODUCTION

1.1 GENERAL

India is a very fast growing economy among the developing nations in the world and has proved its stability during the major world economic recession in 2008. The Indian electricity sector plays a vital role in the economic growth of the country and hence the Indian economic growth rate has reached just above 8%. India has a total installed power generation capacity of 2,74,818 MW as of July, 2015 but there is a gap of 20% between power demand and power generation during the peak hours of power consumption. Power system planning is critical for the electricity sector to have proper generation expansion to bridge this gap and hence the system efficiency and reliability can be improved. The problems in the vertically integrated power market and restructured power market such as Unit Commitment (UC), Economic Dispatch (ED), Emission Dispatch (EmD) and Combined Economic and Emission Dispatch (CEED) are some of the key issues in power system planning.

Economic dispatch is an important optimization problem which aims at scheduling the committed power generating units to meet the load demand at minimum operating cost while satisfying the equality and inequality constraints (Wood & Wollenberg 1984). Though the core objective of the problem is to minimize the operating cost while satisfying the power
demand, several types of physical and operational constraints such as Prohibited Operating Zones (POZ) and Ramp Rate Limits (RRL) make the ED problem highly nonlinear in nature (Arul doss et al 2004).

Power system security analysis is the process of detecting whether the power system is in a secure state or in an alert state. Secure state implies that the load is satisfied and no limit violations occur under the present operating conditions. Economic dispatch with line flow constraint introduces the aspect of system security to the classical economic dispatch by bringing in the line flow and voltage limit constraints.

In this problem, the system reliability and cost efficiency are two conflicting objectives in nature. The solution methodology should find out a compromising solution between these objectives. Security analysis is introduced to the economic study of an electric power system in the form of security constraint which has to be satisfied (AI- Othman et al 2008).

According to the United Nations framework convention on climate change, the Kyoto Protocol is an international agreement for reducing the emission level from 37 industrialized countries. The Kyoto Protocol 1990 has the objective of reducing the emission of greenhouse gases by at least 5% below the value of the base year in the commitment period. The main pollutants emitted into the atmosphere are oxides of nitrogen, oxides of sulphur and oxides of carbon. The Kyoto Protocol offers guidelines for countries to reduce their emission level from sectors like oil, refineries, power generating stations, steel industries, paper mills, cement industries and ceramic companies.

In modern power system operation and control, the economic and emission dispatch problems of thermal generating units and their issues are
given greater importance. Conventionally, electric power plants are operated on the basis of lowest operating fuel cost strategies and less attention is given to the minimum emission strategies. Generating adequate electricity at a least possible cost under a number of constraints is Economic Dispatch (ED). While decreasing the pollution by suitably changing the generation allocation, the cost of generation may be increased deviating from ED. The process of generating power with the objective of minimizing the emission is called Emission Dispatch (EmD). The Combined Economic and Emission Dispatch (CEED) is a multi objective optimization problem which minimizes both fuel cost and emission of pollutants simultaneously, while satisfying the load demand and other operational constraints. The Emission Constrained Economic Dispatch (ECED) is the one in which the emission limit is considered as an additional constraint (Sudhakaran et al 2007).

The power sectors all over the globe underwent restructuring and deregulation and hence the Unit Commitment (UC) problem has taken a new form called “Profit Based Unit Commitment” (PBUC). The objective of the traditional unit commitment problem is to minimize the total production cost while satisfying all the system constraints. However, in a deregulated environment, the traditional unit commitment objective needs to be changed to profit based unit commitment which is a combinatorial optimization problem in which the generation company’s (GENCO’s) objective is to maximize the profit and minimize the effort (Eric H Allen & Marija DIIic 2000). Due to the inclusion of constraints such as prohibited operating zones, ramp rate limits, line flow constraints and emission limitations, these problems become highly nonlinear and hence may not be solved by conventional optimization tools. The power engineers need special optimization tools to analyze and optimize the above nonlinear power system optimization problems.
1.2 LITERATURE SURVEY

A study of literature on the ED problem with POZ and RRL, Economic Dispatch with line flow and voltage limit constraints, the Economic and Emission Dispatch problems and Profit Based Unit Commitment problem reveal that many mathematical programming methods and optimization techniques have been applied to solve these optimization problems. They are Lambda iteration, Linear Programming (LP), Interior Point (IP), Dynamic Programming (DP) and Gradient methods. Recently, with the emergence of artificial and computational intelligence techniques, attention has been given to solve power system planning issues by Evolutionary Computing (EC) techniques. EC techniques like Cuckoo Search (CS), Firefly Algorithm (FA), Artificial Neural Networks (ANN), Genetic Algorithm (GA), Evolutionary Programming (EP), Particle Swarm Optimization (PSO) and hybrid algorithms have been addressed in the literature for solving the above nonlinear power system optimization problems.

1.2.1 Literature Review on ED Problems with POZ and RRL Constraints

Classical Optimization Techniques: Different classical optimization techniques were used to solve the ED problems. In the conventional ED problem, the cost function for each generator was represented by a single quadratic function and was solved using a lot of mathematical programming based optimization techniques.

Lambda Iteration and Lagrange Relaxation Methods: A Lambda iteration method propagated by Wood & Wollenberg (1984) was found useful in solving the ED problem. Since the lambda iteration method requires a consistent problem formulation, it cannot be openly applied to ED
problems with discontinuous prohibited operating zones. In the units with prohibited operating zones, the zones divided the operating region between the minimum and maximum limits into sub-regions to form non-convex sub-regions and the associated ED problem were thus non-convex optimization problems. Thus, it was found that the conventional Lagrange Relaxation approach cannot be directly constructive.

**Dynamic Programming and Quadratic Programming Methods:**
Ringlee et al (1963) proposed a DP method to solve the non-convex ED problem, but had disadvantages, namely, that the computational requirements of the DP based method depended on the size of the distinctive capacity step (10 MW, 20 MW). With a capacity step of 1 MW, which is the common accuracy required in the ED schedule, a number of states at each stage (e.g. a stage i represent the total load served by the first i unit ) are quite large for a small system.

Balamurugan & Subramanian (2008) suggested an Improved Dynamic Programming (IDP) approach to solve the economic power dispatch problem considering the ramp-rate limits, prohibited operating zones and generating capacity limit constraints. In this approach, the transmission losses are augmented with the objective function using price factor and the method is validated on 6, 15 and 40 unit sample systems. Then the proposed method results get compared with the results of the GA and PSO methods reported in the literature concerned. Test results show that the IDP approach can acquire better quality solutions with enhanced performance.

Reid & Hasdorff (1973) proposed the Quadratic Programming (QP) method for solving the economic dispatch problem considering both equality and inequality constraints. In this method, the QP method does not necessitate the use of penalty factors or the determination of gradient step size which can
cause convergence difficulties. The effectiveness of the algorithm was validated on 5, 14, 30, 57 and 118 bus test systems.

Linear Programming and Interior Point Methods: Somuah & Khunaiz (1990) presented the Linear Programming (LP) method to solve the economic dispatch problem taking into consideration of spinning reserve and other security constraints. In this paper, two methods are secondhand in the solution of the problem. The first method is a QP technique combined with a LP re-dispatches technique. The second method uses a LP formulation of the dynamic dispatch problem based on the Dantzig-Wolfe was tested on four different test systems and the results are compared with other methods.

Irisarri et al (1998) reported of an Interior Point (IP) method to solve the economic dispatch problem considering generator limits, reserve constraints, line flow limits and ramp-rate limit constraints. The proposed method was tested on the IEEE-30 bus network over 168 hours and the convenience of the structured interior point formulation was recognized.

Evolutionary Computing Methods: Evolutionary computing techniques are a recent class of algorithms to solve nonlinear optimization problems. Methods such as the genetic algorithm, particle swarm optimization, evolutionary programming, etc. are used by many researchers to solve ED problems.

Particle Swarm Optimization: Zwe-Lee Gaing (2003) suggested a Particle Swarm Optimization (PSO) algorithm for solving the economic dispatch problem considering ramp-rate limits, prohibited operating zones, power balance equation and generator limits constraints. The schedule of the proposed PSO method was tested on three different test systems and the result obtained was compared with the Genetic Algorithm (GA) in terms of the
solution quality and computation efficiency. The experimental result shows that the proposed PSO method was better than GA for solving ED problems.

Mohammadi-Ivatloo et al (2012) presented Iteration PSO with Time Varying Acceleration Coefficients (IPSO-TVAC) for solving non-convex economic dispatch problem taking into consideration the valve-point effects and prohibited operating zones. The proposed IPSO-TVAC method was validated on standard three different test systems and the results were compared with other optimization algorithms which are presented in the references.

Park et al (2005) reported the concept of PSO to an economic dispatch problem with non-smooth cost functions. The recommended method provides high probability solutions for a 3 unit test system and quasi-optimums for a 40 unit test system. The proposed methodology was shown to be superior compared with conventional numerical methods, Artificial Neural Network (ANN) and EP methods.

**Evolutionary Programming:** Hong-Tzer et al (1996) recommended the EP technique to solve economic dispatch problems considering non-smooth fuel cost functions. The recommended method was demonstrated on two example power systems and the results were compared with dynamic programming, simulated annealing and GA methods.

Nidul Sinha et al (2003) solved the ED problem using various EP techniques considering power balance equation, generator limits and valve point loading effects. The main objective of this paper was to expand and study the various EP techniques to ELD problem (i) Classical EP with Gaussian mutation (CEP) (ii) Cauchy-mutation-based EP called fast EP (FEP) (iii) mean of Gaussian and Cauchy mutations with scaled cost (MFEP).
(iv) Gaussian and Cauchy mutations with scaled cost (IFEP). Then the proposed techniques are tested on 3, 13 and 40 unit test systems and the results were compared in terms of solution quality.

Jayabarathi et al (1999) presented the Evolutionary Programming (EP) method to solve ED problem with ramp-rate limits, prohibited operating zones and spinning reserve constraints. The proposed method was implemented for solving the economic dispatch problems. The result obtained by this approach was compared with those obtained using traditional methods. The study results showed that the approach developed was feasible and competent.

**Firefly and Cuckoo Search Algorithms:** Xin-She Yang et al (2012) suggested Firefly Algorithm (FA) for solving non-convex economic dispatch problems considering the power balance equation, ramp rate limits, prohibited operating zones and generation capacity limit constraints. The proposed algorithm was tested on 3, 13, 15 and 40 generating unit test systems and the results obtained were compared with other methods which are presented in the references.

Adriane B.S. Serapiao (2013) solved the Economic Load Dispatch (ELD) problem using Cuckoo Search (CS) algorithm considering power balance equation, generator limits and transmission system losses. The effectiveness of the CS algorithm was tested on 3 and 6 unit test systems and the results were compared with other algorithms presented in the reference in terms of solution quality.

**Improved Harmony Search and Water Cycle Algorithms:** Leandro dos Santos Coelho & Viviana (2009) presented an Improved Harmony Search (HIS) algorithm for solving the ELD problem. The proposed
HIS algorithm does not require derivative information, but uses stochastic random search instead of a gradient search. This paper reflected on a new IHS algorithm based on the exponential distribution for solving ED problems is proposed by considering the valve-point loading effects. The proposed IHS algorithm was tested on 13 unit test system and the numerical results show that the proposed method has the fine convergence property.

Mostafa & Hamdi (2014) presented a Water Cycle Algorithm (WCA) to solve the economic load dispatch problem considering the valve point effect and ramp rate limit constraints. The algorithm was tested on a system of 3 and 15 units with a load demand of 850 (MW) and 2630 (MW). The results obtained by the proposed method were compared with other methods presented in the references.

**Hybrid Evolutionary Techniques:** Hybrid techniques integrate two or more optimization techniques in order to unite their strength and conquer one another’s weakness in solving the optimization problems.

**Evolutionary Programming based Levenberg-Marquardt Optimization (EP-LMO):** Manoharan & Kannan (2008) projected the Evolutionary Programming based Levenberg-Marquardt Optimization (EP-LMO) technique to solve the economic dispatch problem considering the value-point effects and multiple fuel options. In this proposed method, the EP method was applied as a base level search to find the direction of the optimal global region and LMO method was used as an excellent tuning to determine the optimal solution. This novel EP approach was applied to two benchmark problems and the results were compared with improved PSO, improved GA, a Modified Hop Field Neural Network and the EP methods.
**Hybrid EP and SQP**: Pathom et al (2002) suggested a hybrid EP and Sequential Quadratic Programming (SQP) method for the solving dynamic economic dispatch with non-smooth fuel cost function. In this proposed approach, the EP was applied as a base level search which could give a good direction to the optional global region and the SQP was used as a fine tuning to determine the optimal solution at the final stage. To reveal the effectiveness of the proposed method, a 10-unit test system was considered and the results obtained were compared with EP and SQP methods.

**Hybrid PSO-SQP**: Arul doss & Ebenezer Jeyakumar (2004) applied the hybrid PSO-SQP method for solving the economic dispatch problem with the value-point effects. In this proposed hybrid method, PSO is the main optimizer and the SQP was used to fine tune every improvement in the solution of the PSO run. The PSO is a derivative free optimization technique which produces results quickly and proves itself fit for solving large-scale complex economic dispatch problems. SQP is a nonlinear programming method which starts from a single searching point and finds a solution using the gradient information. The proposed method was tested on 3, 13, and, 40 unit systems and the results were compared with GA, EP, and other methods.

**Hybrid PSO – DSM**: Chen & Jan (2011) used the hybrid algorithm for the solution of economic dispatch considering valve-point loading effects. The novel hybrid algorithm is a combination of Particle Swarm Optimization (PSO) and Direct Search Method (DSM). In the proposed method, a new inertia weight mechanism was integrated into PSO to advance its search capacity that led to a higher probability of obtaining the global optimal solution. The DSM algorithm was used as a fine tuning to conclude the eventual global optimal solution with a reduced computing time.
The proposed hybrid method was validated with standard 3 and 13 unit test systems.

**Hybrid GA- PSO - SQP:** Alsumait et al (2010) suggested a hybrid GA-PS-SQP method to solve power system problems with value-point effects. In this proposed method, GA was hybridized with Pattern Search (PS) and SQP to overcome the drawback of PS and SQP method that required a suitable starting point by the user. In this hybrid method, the GA generates the initial good solution automatically and PS was used with SQP to fine tune the search. For validating the hybrid method, it was applied to 3, 13 and 40 generators and the results were compared to the EP, EP-SQP, PSO, PSO-SQP, PS and DE methods.

1.2.2 **Literature Review on ED Problems with Line Flow and Voltage Limit Constraints**

**Classical Optimization Techniques:** The following classical optimization methods such as Interior Point method, Successive LP method, Newton-Raphson method and Quadratic Programming method are used to solve ED problem with line flow and voltage limit constraints.

**Interior Point and Successive Linear Programming Methods:** Vargas et al (1993) reported on the application of an Interior Point Method (IPM) for the solution to Security Constrained Economic Dispatch (SCED) problem. A comparison of the proposed method with an efficient complex code was carried out by solving SCED problems of two standard IEEE test systems. The results show that the interior point technique was consistent, precise and more than two times as fast as the simplex algorithm.
Samir & Khaled (2006) solved the economic load dispatch with security constrained problems using Successive Linear Programming (SLP) method. In the proposed method, voltage and line flow constraints were taken as additional constraints and the SLP concept was implemented on the Algerian 59-bus test system. The results proved the potential of the proposed method in real-time implementation of the economic load dispatch problems.

Rabih et al (2000) proposed a Linear Programming (LP) method for solving Security Constrained Economic Dispatch (SCED) problem considering power balance equation, generator limits and line flow limit constraints. An important feature of the optimizing interior point LP algorithm was that it could detect infeasibility of the SCED problem reliability. The proposed approach was validated on the standard IEEE -24 bus test system and a practical 175 bus network. The results obtained were compared with the predictor corrector point algorithm.

**Newton-Raphson and Quadratic Programming Methods:** Jiann-Fuh & Shin-Der (1997) suggested Newton-Raphson method to solve the power system, Multi- objective Power Dispatch (MPD) problem with line flow constraints. In this proposed approach, two conflicting objectives, together with minimization of fuel cost and emission were considered. The Jacobian matrix was formulated by the incremental transmission loss in terms of the sensitivity factors, line flows and line resistances. The sensitivity factors were obtained from line flow solutions based on a DC load flow model. The usefulness of the proposed method was tested on the IEEE- 14 and 30 bus test systems. The results obtained from the proposed method were put up without the advantage of computation rapidity and solution accuracy over that of the AC load flow method and the conventional B-coefficients methods.
Ji-Yuan & Zhang (1998) used Quadratic Programming (QP) method for solving real time economic dispatch problems. The proposed method formulates the problem with a quadratic objective function based on the limits cost curves on quadratic forms. The goal programming techniques were also incorporated in the problem formulation which guaranteed the best available solution even under infeasible conditions. The support of the proposed method was documented by an example power system problem.

**Evolutionary Computing Methods:** The Evolutionary computing techniques such as Pattern search, Evolutionary programming, Genetic algorithm and PSO methods have been used to solve ED problem with line flow and voltage limit constraints.

**Pattern Search Method:** AI-Othman & EL-Nagger (2008) proposed the Pattern Search (PS) method to solve the power system Security Constrained Economic Dispatch (SCED) problem. In this proposed approach, the Pattern Recognition (PR) technique was used first to rightly use dynamic security. Linear classifiers are used to establish the stability of electric power system were presented and added to other system stability and operational constraints. The proposed method was tested 2 machines-5 bus 6 line test system and the results were compared with GA and QP methods.

**Evolutionary Programming:** Somasundram & Kuppusamy (2005) offered an EP method to solve SCED problem. In the proposed method, the controllable system quantities in the base case were optimized to some defined objective function to diminish the total fuel cost subject to the constraints recognized in the problem. The recommended method was tested on a 10 bus system and the IEEE-30 bus test system.
**Particle Swarm Optimization:** Pancholi & Swarup (2004) proposed a PSO method for SCED problem. In this problem the range of minimum and maximum velocity limit is quite large which makes the approach slow in the rate of convergence, takes more computational time and leads to local convergence.

Swarup & Rohitkumar (2006) presented a new approach called Attractive and Repulsive Particle Swarm Optimization (ARPSO) algorithm for solving economic dispatch with security constraints. In this paper the line flow and bus voltage constraints, which are so important for any practical implementation of ED, were taken into consideration. The proposed approach was implemented on the IEEE-14, 30 and 57 bus test systems and the results were compared with LP, QP and GA methods.

**Genetic Algorithm:** Hosam K. Youssef & Khaled (2000) reported the application of Genetic Algorithm (GA) for the security constrained power system economic dispatch problem. In this approach, the pattern recognition technique was used to handle the dynamic security and linear classifiers were used to determine the stability of electric power systems. Finally GA was used to solve this constrained nonlinear optimization problem.

**Hybrid Evolutionary Techniques:** Some of the hybrid evolutionary techniques which are formed by integrating an evolutionary computing technique with either conventional or another evolutionary computing technique for solving nonlinear optimization problems are discussed.
**EP- LR Method:** Somasundram et al. (2005) suggested the hybrid algorithm based on EP and LP to solve the security constrained economic dispatch problem. In the proposed algorithm, the EP was used as base level search which could give a good direction in the optimal global region and the LP concept was applied to determine the best possible solution. A 10 bus and 66 bus Indian utility systems were considered to demonstrate the effectiveness of the proposed method.

**SA- PSO Method:** Kuo (2008) presented the combined SA-PSO hybrid algorithm to solve practical economic dispatch problem, considering the power balance equation, ramp-rate limits, prohibited operating zones, generation limits and line flow constraints. In this proposed method, the PSO was combined with SA to create an innovative approach capable of generating high quality solutions with greater stability in convergence characteristics and reduced calculation time. The proposed hybrid method was tested on 6, 13, 15 and real TAI-POWER system consisting of 40 units and the results were compared with other methods.

**PSO- DE Algorithm:** Vaisakh et al. (2012) solved, the Dynamic Economic Dispatch (DED) problems with security constraints using bacterial foraging PSO- DE algorithm. The proposed hybrid method eliminated the problem of stagnation of solution with the inclusion of the PSO and DE operators in the original bacterial foraging algorithm. It achieved global cost by selecting the bacterium with good foraging strategies. The bacteria with good foraging strategies are obtained in the updating process of every chemotactic step by the PSO operator. The DE operator fine tuned the solution obtained through bacterial foraging and PSO operator. The feasibility of the presented approach was demonstrated on various standard test systems.
HGA-PSO Method: Abdelmalek Gacem & Djilani Benattous (2014) suggested a Hybrid Genetic Algorithm and Particle Swarm Optimization (HGAPSO) for solving the optimal power flow problem with non-smooth cost function and subjected to limits on generator real, reactive power outputs, bus voltages, transformer taps and power flow of transmission lines. In this proposed hybrid method the individuals in a new generation were created not only by crossover and mutation operators, as in GA but also by PSO. The effectiveness of this algorithm was tested on the standard IEEE-30 bus system with 6 units. The results of the proposed algorithm were compared with the PSO and other methods reported in the literature.

1.2.3 Literature Review on Economic and Emission Dispatch Problems

Classical Optimization Techniques: The classical methods available in the literature for solving economic and emission dispatch problems are discussed as follows.

Newton-Raphson and Lagrangian Relaxation Methods: Jiann-Fuh & Shin-Der (1997) presented a N-R method to solve the multi-objective Power Dispatch (MPD) problem with line flow constraints. The recommended method was used to solve the bi-objective optimization problem one was minimization of fuel cost and another was minimization of emission. The Jacobian matrix was formulated by the incremental transmission loss in terms of the sensitivity factors, line flows and line resistances. The usefulness of the proposed method was tested on the IEEE-14 and 30 bus test systems.

The proposed algorithm has the ability to handle a large number of various types of linear and nonlinear environmental constraints. The proposed method was tested on a large size power system.

Hemamalini & Simson (2012) presented Maclaurin series based Lagrangian method to solve Emission Constrained Economic Dispatch with valve-point effect. In this paper two conflicting functions (fuel cost and emission) were considered and formulated as a single objective optimization problem by the weighted sum method. The feasibility of the proposed method was validated on the IEEE -30 bus test system and ten unit test systems. The results obtained with the proposed method were compared with GA.

**Quadratic Programming and Linear Programming Methods:**
Ziane et al (2014) suggested Quadratic Programming (QP) method for solving Dynamic Economic Load Dispatch (DELD) problem with minimum emission. This problem determines the optimum power generation schedule while minimizing gas emission. To validate the effectiveness and the feasibility of the proposed approach, it was tested on 3, 6, and 10 unit test systems and the results were compared with the other methods. The comparison confirmed the superiority, fast convergence of the proposed method.

EI Keib & Ding (1994) solved the economic dispatch problem in view of the Clean Air Act Amendment (CAAA) of 1990. In this approach, there are two strategies to solve the problem subject to environmental constraints—one is linear programming using the gradient projection method to guarantee the feasibility of solution and another one is based on a provision in the act that is designed to facilitate compliance.
**Evolutionary Computing Methods:** The Evolutionary computing techniques available in the literature for solving economic and emission dispatch problems are addressed as follows:

**Evolutionary Programming:** Venkatesh et al (2003) applied Evolutionary Programming (EP) techniques to solve the Economic Load Dispatch (ELD) and Economic Emission Dispatch (EED) problems to get hold of the optimum fuel cost and optimal emission of generating units respectively. The Combined Economic Emission Dispatch (CEED) problem is obtained by considering both the fuel cost and emission objectives. The bi-objective CCED problem is converted into a single objective function using a function price penalty factor approach. The CEED problem with using EP was tested on the IEEE-14, 30 and 118 bus systems with and without line flow constraints. The solution obtained was practically encouraging and useful in the economic emission environment.

**Particle Swarm Optimization:** Abido (2007) described the CEED problem using the novel multi-objective PSO method subjected to generation limits and power balance constraints. The proposed approach extends the single objective PSO by proposing the new definitions of the local and global best individuals with multi objective optimization problems.

Selvakumar et al (2003) suggested a PSO to solve the multi-objective Combined Economic Emission Dispatch (CEED) problem. In this problem, there are two contradictory objectives (emission and economic cost) which are combined by using price penalty factor which blends the emission cost with normal fuel cost.

Umayal & Kamaraj (2005) proposed the PSO method to solve the multi objective CEED problem. The paper was formulated by the multi-
objective problem considering the various competitive objective fuel cost, NO$_2$, SO$_2$, CO$_2$ and variation of generation mismatch. All objectives were weighed as per significance and added to form the final objective function.

Anurag et al (2012) presented the PSO method to solve Combined Economic Emission Dispatch (CEED) problem of thermal units, while satisfying the constraints such as generator capacity limits, power balance and line flow limits. The objective was to minimize the total fuel cost of generation and environmental pollution caused by fossil based thermal generating units. The bi-objective problem was converted into a single objective problem by introducing the price penalty factor to maintain an acceptable system performance in terms of limits on generator real power outputs and transmission losses with minimum emission dispatch. The proposed approach was evaluated on an IEEE 30-bus test system with six generators. The results obtained with the proposed approach were compared with the results of genetic algorithm and other techniques.

Nagendra Singh & Yogendra Kumar (2015) suggested a new PSO called Moderate Random search PSO (MRPSO) for the solution of economic load dispatch as well as environmental emissions of the thermal power plant considering power balance and generation limit constraints. The new approach was used to solve bi-objective function. One was minimization of fuel cost and the other was environmental emission minimization. MRPSO enhances the capability of particles to explore in the search spaces more efficiently and increases their convergence rates. The proposed approach was tested for the IEEE-30 bus test system and the results obtained by MRPSO algorithm show their efficiency.
Genetic Algorithm: Rajkumar et al (2013) presented a multi-objective optimization algorithms, in particular None dominated Sorting Genetic Algorithms-II (NSGA-II) and Modified NSGA-II (MNSGA-II) for solving the CEED problem with a valve-point loading. In this proposed approach, the reference pareto-front was generated by means of multiple runs of Real Coded Genetic Algorithm (RCGA) with a weighted sum of objectives. To authenticate the proposed approach, the IEEE-57 and IEEE-118 bus test systems were taken and the performance was compared with respect to various statistical performance measures such as convergence metric, diversity metric and an inverted generational distance metric.

Neural Network: Benhamida & Belhanchem (2013) solved the Dynamic Constrained Economic/Emission Dispatch (DEED) problem using Flexible Hopfield Neural Network (FHNN) method considering the system load demand, spinning reserve capacity, ramp rate limits and prohibited operating zones constraints. The viability of the FHNN method was applied to three power system networks and the results were compared with other methods in terms of solution quality and computation efficiency.

Cuckoo Search Algorithm: Nguyen Thi Phuong Thao & Nguyen Trung Thang (2014) employed a Cuckoo Search Algorithm (CSA) to solve Environmental Economic Load Dispatch (EELD) with the quadratic fuel cost function. The effectiveness of the proposed algorithm was validated on 3 and 6 unit test systems with different loads. The obtained results, including fuel cost, emission and computation time from the CSA were compared to other methods reported in this paper. The comparison results indicated the proposed CSA as a very competent method for solving EELD problems.

(ODEA) for solving Dynamic Economic Emission Load Dispatch (DEELD) with emission constraints and valve point effects. The recommended algorithm has unique features such as self-tuning of its control parameters, self acceleration and migration for searching. The effectiveness of the algorithm was validated through four standard test cases and the results obtained are compared with previous studies.

**Hybrid Methods:** The hybrid methods addressed in the literature for solving economic and emission dispatch problems are as follows:

**GA based Fuzzy Logic:** Dhillon & Jain (2011) presented GA based fuzzy logic for the multi-objective generation and emission dispatch problem involving different combinations of fuel cost, oxides of nitrogen, sulfur and carbon, which were solved using a Non-dominated Sorting Genetic Algorithm (NSGA-II). The approach uses a crowding distance technique to add diversity to the converging solutions. The final result is a single best compromise solution of all the required objectives such as reduction of fuel cost and emission. The algorithm was tested on a system of 6 generating units.

**1.2.4 Literature Review on Profit Based Unit Commitment Problem**

**Classical Optimization Techniques:** The conventional optimization techniques addressed for solving PBUC problem are explained as follows:

**Mixed Integer Programming and Dynamic Programming Methods:** Tao Li & Mahammad (2005) suggested Mixed Integer Programming (MIP) method to solve Price Based Unit Commitment (PBUC) problem. The proposed method was applied to a PBUC solution for a
generating company (GENCO) with thermal, combined-cycle, cascaded-hydro, and pumped-storage units. The PBUC solution by utilizing MIP was compared with that of Lagrangian-relaxation (LR) method. Test results on the modified IEEE-118 bus test system show the efficiency of MIP formulation and advantages of the MIP method for solving the PBUC problem.

**Mixed Integer Linear Programming Method:** Smajo et al (2010) presented a Mixed Integer Linear Programming (MILP) method for solving unit commitment problem in a deregulated environment. The proposed method allows precise modeling of non-convex variable cost, non-linear start up cost, ramp-rate limits and minimum up and minimum down time constraints. The effectiveness of the proposed method was tested on 15 unit test system.

**Lagrangian Relaxation Method:** Takayuki & Isamu (2007) proposed a Lagrangian Relaxation (LR) method for solving PBUC problem. This article develops a stochastic programming model which incorporates power trading. A stochastic integer programming model was proposed in which the objective was to maximize expected profits. In this model, ON/OFF decisions for each generator are made in the first stage. The approach to solving the problem is based on Lagrangian relaxation and dynamic programming methods.

**Evolutionary Computing Methods:** The evolutionary computing techniques available in the literature for solving the PBUC problems are discussed as follows:

**Particle Swarm Optimization:** Jacob Ragled et al (2010) reported the application of PSO to solve the PBUC problem under a deregulated environment considering generation, spinning reserve, non-spinning reserve
and system constraints. This paper presents a new approach of GENCOs profit based unit commitment using the PSO technique in a day ahead competitive electricity market. The PBUC problem was solved using various PSO techniques such as chaotic PSO (CPSO), new PSO (NPSO) and dispersed PSO (DPSO) on IEEE-30 bus test system with 6 units as an individual GENCO. The results obtained are quite encouraging and useful in a deregulated power market.

Sam Harrison & Sreerengaraja (2013) investigated the application of swarm intelligence to the solution of PBUC problems with emission limitations. In this paper, two incompatible objectives are taken into consideration - one is maximizing profit and the other is minimizing emission. The binary PSO is used to solve the PBUC problem and real-valued PSO (RPSO) is used to solve the economic dispatch which is a sub problem of PBUC. A 6 and 11 generating unit test systems were taken and the proposed algorithm was applied to solve it for the PBUC with emission limitations. From the comparison of results, the capability of the proposed algorithm was demonstrated in the aspects of solution quality and computational efficiency.

Xiaohui et al (2005) prescribed an Improved discrete binary Particle Swarm Optimization (IPSO) to solve PBUC problem. In this IPSO method, the position of particles (x2) can take on values of 0 or 1 only and the velocity (vi) will determine a probability threshold. Then the proposed approach was tested on 10 units with a forecasted spot price for 24 hour period. Then the results were compared with a hybrid approach (LR-EP). The result showed that the profit using the IPSO approach was 0.2% more than that of the hybrid method between LR and EP.
**Evolutionary Programming:** Padmini et al (2013) suggested an Evolutionary Programming based hydro-thermal commitment scheduling problem of maximizing the profit of GENCOS considering the effect of reserve in a deregulated energy market. The proposed method was applied to hydrothermal scheduling for 3 thermal and 4 hydro unit test system.

**Genetic Algorithm:** Ritcher & Sheble (2000) used a Genetic Algorithm (GA) to solve PBUC in the competitive environment. In this proposed method, the authors made accessible a PBUC formulation which considers the softer demand constraint and allocates fixed and transitional costs to the scheduled hours. The proposed GA method was validated on 2 units 14 hours case and 10 units 48 hour case. Senthilkumar & Mohan (2009) formulated GA for solving security constrained unit commitment problem in which the line flow limit violations have been properly handled by GA.

**Muller Method:** Chandram et al (2008) used the Muller Method (MM) for solving PBUC problem. The proposed method was implemented in two stages. In the first step the determination of the units to be committed was obtained through Non-Linear Programming (NLP) method and the economic dispatch was solved by the proposed muller method. The main advantage of this method is diminishing the computation time through the initial allocation.

**Shuffled Frog Leaf Algorithm:** Venkatesan & Sanavullah (2013) presented Shuffled Frog Leaf Algorithm (SFLA) to solve the PBUC problem in a deregulated market with emission limitation. The twin objective function is formulated as a maximization of profit and a minimization of the emission output of the thermal units. The effectiveness of the algorithm was validated on the IEEE -39 buses with 10 unit test system.
Sample Average Approximation Method: Qianfan Wang et al (2013) proposed the Sample Average Approximation (SAA) method to solve the PBUC problem in a deregulated power market in which chance constraints to ensure wind power utilization was incorporated. The problem has a two stage stochastic optimization problem with the first stage decision includes UC and quantity of electricity submitted to day-ahead market and second stage decision include generation dispatch, actual usage of wind power and the amount of energy imbalance between day-ahead and real time markets. The SAA algorithm gives a solution in which the sensitivity of the total profit as the requirement of wind power utilization changes.

Memetic Algorithm: Dionisios et al (2011) suggested a new Memetic Algorithm (MA) approach for solving the price based unit commitment problem. The main contributions of the proposed method are (i) an innovative two-level tournament selection (ii) a new multiple window crossover (iii) a novel window in window mutation operator (iv) an innovative local search scheme called elite mutation (v) new population initialization algorithm that is specific to PBUC problem and (vi) new PBUC test systems including ramp up and ramp down constraints so as to provide new PBUC benchmarks for future research. The proposed memetic algorithm was applied to 4, 10, 60 and 110 units and the results showed that in every case examined the proposed MA converged to higher profit PBUC schedules than the GA, SA and the LR methods.

Hybrid Methods: The hybrid methods addressed in the literature for solving PBUC problem are as follows:

LR-EP Method: Pathom et al (2003) investigated a hybrid method (LR-EP) to solve the PBUC problem. The proposed algorithm for helping GENCOs decides as to how much power and reserve should be sold in energy
and ancillary markets in order to receive the maximum profit. Based on forecast data, PBUC is solved by considering power and reserve generation simultaneously. In the proposed hybrid method, EP is used to update Lagrange multipliers in the traditional LR method. Two reserve payment methods were simulated using 3 and 10 unit systems and the results obtained were compared with the traditional Unit Commitment (UC) method.

**LR-PSO Method:** Rampriya & Mahadevan (2010) suggested the LR-PSO method to solve scheduling of generating units and maximizing the profit of GENCOs under deregulated environment. The purpose of PSO used to update the Lagrangian multipliers in an effective manner so that it can handle various constraints and provides a faster solution. The comprehensive search property of PSO was included in this method, thereby improving the performance of the traditional LR method. The proposed hybrid method was tested on 3 unit 12 hours data and the results were compared to LR-gradient search, muller method and LR-EP methods.

**LR-FA Method:** Rampriya et al (2012) suggested the hybrid method (LR-FA) to solve PBUC problems in a restructured power system. In this hybrid approach, the performance of the traditional LR method was improved by FA. The proposed hybrid method generates a feasible unit commitment schedule, and total profit gained by GENCOs. The algorithm was tested on a 10 unit 24-hourly data and the results were compared with the other methods.

**Artificial Immune System based GA:** Lakshmi & Vasantharathna (2013) presented a hybrid Artificial Immune System (AIS) based GA algorithm to solve the PBUC problem. The proposed hybrid method was developed during the adaptive search inspired by the Artificial Immune System and GA to carry out profit maximization of generation companies.
The proposed algorithm was tested on 3, 10 and 36 units and the results were compared with the other methods.

1.3 MOTIVATION FOR THE RESEARCH

Power system optimization problems are complex and highly nonlinear with several equality and inequality constraints. There are two ways, namely conventional and evolutionary methods, by which the problems can be solved. The conventional optimization methods are Gradient, Linear programming, Interior point, Newton’s and Dynamic programming methods. Similarly, evolutionary optimization methods are Genetic Algorithms (GA), Evolutionary Programming (EP), Particle Swarm Optimization (PSO), Simulated Annealing (SA), Tabu Search Algorithm (TSA), and Cuckoo Search Algorithms (CSA) etc.

Conventional optimization methods require complete objective functional information and the characteristic equations of the system might be differentiable in nature. When the conventional methods are useful for the solution of nonlinear power system problems, they end with sub-optimal solutions. The evolutionary computing techniques need only information about the objective function and the characteristic equation need not be differentiable in nature. They solve the nonlinear optimization problems efficiently. For the highly nonlinear and combinatorial optimization problems, the single evolutionary computing techniques to identify the high performance region of the solution space but are stuck with a local optimal solution.

Therefore, there is a need for new and better optimization technique for the solution of power system optimization problems. These motivating factors have prompted to search for an improved optimization algorithm that
could overcome the shortcomings of both the conventional and single evolutionary optimization methods. In recent years, combinations of two or more different optimization methods were introduced by many researchers to improve their earlier results. Hybrid methodology deals with the synergistic integration of two or more evolutionary optimization methods. The objective of hybridization is to conquer the weakness of one approach during its application with the strengths of the other by integrating them.

1.4 OBJECTIVE OF THE THESIS

The objective of the thesis is to develop a new hybrid evolutionary algorithm by combining the best features of the EP and PSO to solve the nonlinear power system optimization problems. The conventional EP and PSO algorithms have their own merits and demerits. The conventional PSO algorithm has many control parameters and attentive tuning of the parameters is very important for locating the optimal solution. In order to enhance the convergence pattern and to avoid local optimality, the best features of the EP and PSO are blended to develop a new Hybrid Particle Swarm Optimization (HPSO) algorithm. The proposed HPSO algorithm eliminates the demerits of individual PSO and EP algorithms.

In this research work, the proposed HPSO algorithm is applied to solve:

i. Economic dispatch problems considering constraints such as prohibited operating zones, ramp rate limits, generator capacity limits and power balance equation.

ii. Economic dispatch problems with power balance equation, generator capacity limits, line flow limit and bus voltage limit constraints.
iii. Economic and Emission Dispatch problems such as Combined Economic and Emission Dispatch and Emission Constrained Economic Dispatch.

iv. Profit Based Unit Commitment problem with and without emission limitations in a deregulated power market.

1.5 OUTLINE OF THE THESIS

In chapter 1, general overview about the Indian power sector scenario is been briefed. Moreover certain salient issues regarding the present research is also highlighted. In the following part of the chapter 1, a detailed literature survey regarding Economic dispatch problems considering constraints such as POZ, RRL, generator capacity limits and power balance equation, Economic dispatch problems with power balance equation, generator capacity limits, line flow limit and bus voltage limit constraints, Economic and Emission Dispatch problems such as Combined Economic and Emission Dispatch and Emission Constrained Economic Dispatch and Profit Based Unit Commitment problem with and without emission limitations in a deregulated power market is been done. Consequently, the motivation for the research is been discussed and objective of the thesis is framed.

In chapter 2, the EP, PSO and the proposed HPSO algorithms are successfully applied to solve the ED problems with power balance equation, generator limits, prohibited operating zones and ramp-rate limit constraints. The proposed HPSO algorithm has superior features, high quality solutions and stable convergence characteristics and its results are reasonably encouraging. Nonlinear characteristics of the generators such as ramp-rate limits and prohibited operating zones constraints are taken from the practical
generator operations in the proposed algorithm. The results obtained by the proposed HPSO algorithm are compared with EP, PSO and other methods.

In chapter 3, the EP, PSO and the proposed HPSO algorithms are tested on IEEE-14, 30 and 57 bus test systems. The voltage and line flow constraints, which are most significant for any practical execution of ED problems, are taken into the consideration. The results obtained from the proposed HPSO algorithm is compared with EP, PSO and other methods presented in reference.

Chapter 4 deals with the application of the EP, PSO and proposed HPSO algorithms for solving the economic and emission dispatch problems such as Economic Dispatch, Emission Dispatch, Combined Economic and Emission Dispatch and Emission Constrained Economic Dispatch. The IEEE-30 bus system with 6 generating units has been taken as the representative problem and the results obtained by the proposed algorithm is compared with EP, PSO and other methods which are taken from the relevant references.

In chapter 5, the proposed HPSO algorithm has been validated for solving Profit Based Unit Commitment (PBUC) problem with and without emission limitations. The bi-objective optimization problem is formulated to maximize the profit of the generating companies and minimizing the emission level by satisfying all the system constraints. The proposed algorithm is tested on the standard IEEE-39 bus test system having 10 generating units for 24 hour load pattern.

In chapter 6, the conclusion of the research work has been listed out and the scope for future work has been proposed.