CHAPTER 1
INTRODUCTION

1.1 PREAMBLE

In this chapter, a general description of the research work is presented. The main objectives of the thesis, contributions of the thesis and an outline of the structure of the thesis are coalesced to build this chapter. The chapter also includes literature reviews in areas that is most related to this research work. Finally, the chapter deals with problem formulation of economic dispatch problems and dynamic economic dispatch problems using novel optimization techniques.

1.2 OVERVIEW OF THE RESEARCH WORK

The electric power system is often referred to as a complex system. The operations of electrical power systems are designed to meet the continuous variation of power demand. In essence, to ensure economic operation, power generation scheduling is performed based on two important tasks, unit commitment and economic dispatch, of which, the latter is the topic of the present research. The power generating units should be run at about full load or the load at which they can give maximum efficiency. The way of deciding the size and number of generating units in the power station is to choose the number of sets to fit the load curve as closely as possible. It is necessary for a power station to maintain reliability and continuity of power supply at all times. In an electric power plant the capital cost of the generating
equipment increases with an increase in efficiency. The benefit of such increase in the capital investment will be realized in lower fuel costs as the consumption of fuel decreases with an increase in cycle efficiency. Scarcity of energy resources, increasing power generation cost and ever-growing demand for electric energy necessitate optimal economic dispatch in today’s power systems. The cost of power generation, particularly in fossil fuel plants, is very high and economic dispatch helps in saving a significant amount of revenue. Therefore, economic dispatch is considered as an optimization problem and its purpose is to allocate generation levels to various generators in the system in order to meet the load demand in the most economic way, while satisfying constraints.

Previous efforts on solving Economic Dispatch Problem (EDP) have employed various mathematical programming methods and optimization techniques. These conventional methods include the lambda-iteration method, the base point and participation factors method, the gradient method, the Newton method, linear programming, non-linear programming, Lagrangian relaxation, quadratic programming and dynamic programming. These numerical methods rely heavily on the convexity assumption of generator cost curves and usually approximate these curves using quadratic or piecewise quadratic monotonically increasing cost functions. These methods follow traditional procedures of either flattening out or ignoring those portions of generator incremental costs that are not monotonically increasing. This assumption does not guarantee an accurate dispatch because the cost functions of modern generators have discontinuities and higher order non-linearity due to valve point loading, prohibited operating zones and ramp rate limits of generators. The practical EDP with above non-linearity translates into a complicated optimization problem having complex and non-convex characteristics, with multiple minima, making the challenge of obtaining the global minima, very difficult. Conventional gradient based optimization
methods fail to model these discontinuities and usually result in inaccurate dispatches causing loss of revenue.

To obtain accurate dispatch results, approaches without restriction on the shape of incremental fuel cost functions are needed. Unlike some traditional algorithms, dynamic programming imposes no restrictions on the nature of the cost curves and therefore it can solve EDP with inherently non-linear and discontinuous cost curves. This method, however, suffers from the “curse of dimensionality” or local optimality. With the development of the computer science and technology, more and more interests have been focused on the application of artificial intelligence technology for the ED problems. Among these methods, some of them are genetic algorithm, evolutionary programming, tabu search, simulated annealing, neural network, particle swarm optimization and ant colony optimization. All these approaches have achieved success to a certain extent.

Static economic dispatch (SED) allocates the load demand which is constant for a given interval of time, among the online generators economically while satisfying various constraints including static behaviour of the generators. Dynamic economic dispatch (DED) is an extension of static economic dispatch problem. It schedules the online generator outputs with the predicted load demands over a certain period of time so as to operate an electric power system most economically. In order to avoid shortening the life of the equipment, plant operators try to keep gradients for temperature and pressure inside the boiler and turbine within safe limits. This mechanical constraint is transformed into a limit on the rate of increase or decrease of the electrical power output. This limit is called ramp rate limit which distinguishes DED from SED problem. Thus, the dispatch decision at one time period affects those at later time periods. DED is the most accurate formulation of the economic dispatch problem but it is the most difficult to
solve because of its large dimensionality. Mathematically, DED problem with valve-point effects can be categorized as a large-scale, dynamic, non-linear and non-convex optimization problem with various complicated constraints, which make finding the optimal dispatch result with efficiency a challenge. DED has been recognized as a more accurate formulation than the traditional SED problem in two aspects: first, the mechanical constraint which keeps the thermal gradients of the generating units within a safe area is translated into a limit on the rate of increase and decrease of the outputs of all generating units to avoid shortening the service lifetime of units; second, the dynamic connections among the system parameters during the dispatch periods are taken into account to assure the exact satisfaction of technical constraints on the dynamics of power generation.

Accurate modelling with the inclusion of valve-point loading effects makes the solution space of DED non-convex with many local minima. Therefore, DED becomes a highly non-linear and non-convex optimization problem, which cannot be solved by traditional techniques. In recent years, many purebred and hybrid metaheuristic algorithms have been proposed to solve DED with valve-point effects. Mathematical properties such as differentiability, convexity, and linearity are of no concern for these algorithms.

Thus in this research work an attempt is made to solve the non-smooth EDP and DED problems using differential evolution (DE) algorithm. DE, proposed by Price and Storn, is one of the latest global optimization methods. Compared with other evolution algorithms, DE is a simple yet powerful optimizer with fewer parameters. In the recent years, DE has gradually become popular and has been applied successfully to solve power system optimization problems due to its strong global search ability, causing widespread concern among scholars. DE is very effective for solving
optimization problems with non-smooth objective functions, since it does not require derivative information. To solve the EDP, DE with variable neighbourhood search (DE-VNS) method, DE with random scale factor (DE-RSF) and DE with neighbourhood search operation are used. However, to solve the DED problem, DE with neighborhood based mutation is used.

Figure 1.1 Optimization methods for EDP and DED problems

1.3 THE POWER GENERATION SCHEDULING PROBLEM

In this section, the various problem formulations of EDP and DED problems, to be solved using novel optimization techniques are discussed. The modeling aspects of EDP with a view to develop different evolution models to solve convex economic dispatch problem and non-convex economic dispatch due to valve point effects. EDP is an important optimization task in power
system operation. The main objective of EDP is the allocation of power generation to different generating units so as to minimize the operating cost while satisfying various physical constraints. This makes the EDP a large-scale non-linear constrained optimization problem. The cost function of each generator has been modeled considering the valve-point effects and multiple fuels. This would often introduce more complex function into the problem formulation of EDP.

Because of physical limitations of the power generators, a generating unit may have prohibited operating zones between the minimum and maximum power outputs. Generators that operate in these zones may experience amplification of vibrations in their shaft bearings, which should be avoided in practical application. On the other hand, due to the fact that unit generation output cannot be changed instantaneously, the unit in the actual operating processes is restricted by its ramp rate limit. Moreover, the units of real input–output characteristics include higher order non-linearities and discontinuities owing to the valve point effect, which has been modeled as a circulating commutated sinusoidal function in it. The EDP with the above considerations is usually a non-smooth/non-convex optimization problem.

The DED occupies a prominent place in the power system operation and control. It aims to determine the optimal power outputs of on-line generating units in order to meet the load demand subject to satisfying various operational constraints over finite dispatch periods. Similar to most real-world complex engineering optimization problems, the nonlinear and non-convex characteristics are more prevalent in the DED problem. Therefore, it is possible that computational methods may not yield a global solution as many local solutions may be encountered. And, in this case of obtaining a truly optimal solution presents a challenge. The problem formulation considers non-convex fuel cost function and such problems are
non-linear, non-convex and non-smooth optimization problem with multiple minima, which is hard, if not impossible, to solve using traditionally deterministic optimization algorithms.

1.3.1 Economic Dispatch Problem

Economic Dispatch Problem is vital and essential daily optimization procedure in the power system operation. It is a constrained nonlinear optimization problem. In reality the load demand changes with respect to time. Therefore, the whole dispatch stage is divided into number of subintervals and EDP is utilized for each stage. The objective of EDP is proper allocation of the real power demand among the on-line generating units entirely and economically without violating any system constraints.

1.3.2 Classical Economic Dispatch Problem

The traditional formulation of the EDP is the minimization of summation of the fuel costs of the individual dispatchable generators subject to the real power balanced with the total load demand as well as the limits on generators outputs. The most simplified cost function of each generating unit \(i\), can be represented as a quadratic function as:

Minimize

\[
F_T = \sum_{i=1}^{N} F_i(P_i) \tag{1.1}
\]

\[
F_i(P_i) = \sum_{i=1}^{N} \left( a_i P_i^2 + b_i P_i + c_i \right) \tag{1.2}
\]

where \(a_i\), \(b_i\), \(c_i\) are the fuel cost coefficients of the \(i\)th generating unit, \(N\) is the number of generating units, \(P_i\) is the real power output of the \(i\)th unit in MW, \(F_i\) is the fuel cost function of \(i\)th unit in $/h, \(F_T\) is the total fuel cost in $/h.
The total power output of generators must be always equal to the sum of the power demands and the transmission losses. This is expressed as:

$$\sum_{i=1}^{N} P_i = P_D + P_L$$

(1.3)

where $P_D$ is the total power demand in MW, and $P_L$ is the total transmission loss in MW.

Since power plants are spread out geographically, transmission network losses must be taken into account to achieve true economic dispatch. Transmission loss is a function of unit generation. To calculate transmission losses, the B-coefficient method is commonly used by the power utility industry. It can be expressed as a quadratic function, as shown in the following:

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{oi} P_i + B_{oo}$$

(1.4)

where $B_{ij}$, $B_{oi}$ and $B_{oo}$ are the loss coefficients.

- **Real power generation limits**

  The real power output of each generating unit is limited by the maximum and minimum power limit of the units. The maximum power generation of a generating unit is limited by thermal consideration and the minimum power generation is limited by the flame instability of a boiler. If the power output of a generator for optimum scheduling of the system is less than a pre-specified value $P_{\text{min}}$, the unit is not synchronized with the bus bar because it is not possible to generate that low value of power from that unit. Hence, the generator power cannot be outside the range stated by the inequality as in Equation. (1.5).
\[ P_{i_{\text{min}}} \leq P_i \leq P_{i_{\text{max}}} \] (1.5)

Where \( P_{i_{\text{min}}} \) and \( P_{i_{\text{max}}} \) are the minimum and maximum real power generation limits of the \( i \)th generating unit.

1.3.3 EDP with Valve-Point Effect

In most of the classical EDP, the fuel cost function is a smooth quadratic function, where the valve-point effect is sacrificed during the formulation. The theoretical cost curve of EDP is as shown in the Figure. 1.2. However, large steam turbine generators having steam admission valves exhibits a greater variation in input–output characteristic functions compared with the smooth cost function. The sequential valve opening process of multivalue steam turbine produces a ripple-like effect in the heat rate curve of the generators with higher order linearity. This is known as valve-point effect.

![Theoretical cost curve of economic dispatch problem](image_url)
which makes the cost function discontinuous and non-convex with multiple minima. For accurate modelling, the valve point effect is refined by a sine function. The EDP cost objective function, considering the valve-point effects, is generally described as superposition of sinusoidal function and quadratic function mathematically.

\[
F_i(P_i) = a_i P_i^2 + b_i P_i + c_i + |e_i \sin(f_i(P_{\text{min}} - P_i))|
\]  

(1.6)

where \(a_i, b_i, c_i\) are the fuel cost coefficients of the \(i\)th generating unit, \(e_i, f_i\) are the valve-point coefficients of the \(i\)th unit, \(P_{\text{min}}\) is the minimum generation limit of the \(i\)th unit in MW, \(P_i\) is the power output of the \(i\)th unit in MW, \(F_i\) is the fuel cost function of the \(i\)th generating unit in $/h. Now, the modified objective function for the EDP is to minimize the function given in Equation (1.6) subject to the constraints given in Equations (1.3 and 1.5). Figure 1.3 shows the valve point effect is incorporated in traditional EDP by superimposing the sine component model on the quadratic cost curve.

Figure 1.3 Practical cost curve of economic dispatch problem
### 1.3.4 EDP with Ramp Rate Limit

One of the unpractical assumptions that prevailed for simplifying the problem in many of the earlier research is that the adjustments of the power output are instantaneous. Even though this assumption simplifies the problem, it does not reflect the actual operating processing of the generating unit. However, under practical circumstances ramp rate limit restricts the operating range of all the online units for adjusting the generator operation between two adjacent operating periods. The generation may increase or decrease with corresponding upper and downward ramp rate limits. Figure 1.4 shows the model of Ramp-rate limits. So, the power output of a practical generator cannot be varied instantaneously beyond the range as it is shown in the following:

\[
\begin{align*}
P_i - P_{0i} &\leq UR_i \text{ if generation increases} \\
P_{0i} - P_i &\leq DR_i \text{ if generation decreases}
\end{align*}
\]  

(1.7)

where \(P_{0i}\) indicates the active power output of generating unit \(i\) in the previous hour, \(UR_i\) and \(DR_i\) represent ramp up and down rate limits of unit \(i\) respectively. Combining Equations (1.5 and 1.7), ramp rate constrained operation limits of units can be represented as follows:

\[
P_{i_{\text{min,r}}} \leq P_i \leq P_{i_{\text{max,r}}}
\]  

(1.8)

where

\[
P_{i_{\text{min,r}}} = \max\{P_{i_{\text{min}}}, P_{0i} - DR_i\}
\]  

(1.9)

\[
P_{i_{\text{max,r}}} = \min\{P_{i_{\text{max}}}, P_{0i} + UR_i\}
\]  

(1.10)
1.3.5 EDP with Prohibited Operating Zone

The generating units may have certain ranges where operation is restricted on the grounds of physical limits of machine components or instability, e.g. due to steam valve or vibration in shaft bearings. Consequently, discontinuities are produced in cost curves corresponding to the prohibited operating zones. For a prohibited zone, the unit can only operate above or below the zone. The prohibited zones result in two disjoint convex regions which form a non-convex set. However, in practice, the shape of the input-output curve in the neighborhood of the prohibited zone is difficult to be determined by actual performance testing or operating records. In actual operation, the best economy is achieved by avoiding operation in these areas. This feature can be included in the EDP formulation as follows:

\[
P_i = \begin{cases} 
P_{\text{min}} \leq P_i \leq P_{i,j} & \\
P'_{i,j-1} \leq P_i \leq P'_{i,j} & j = 2,...,n_i \\
P''_{i,n_i} \leq P_i \leq P_{i,max} 
\end{cases}
\] (1.11)

where \(P_{i,j}\) and \(P''_{i,j}\) are the lower and upper bounds respectively of the \(j^{th}\) prohibited zone of unit \(i\) and \(n_i\) is the number of prohibited zones in unit \(i\). Figure 1.5 clearly shows the Prohibited operating zones modeled in the cost curve.
1.3.6 EDP with System Spinning Reserves Constraints

To maintain system reliability, in a unit with prohibited operating zones, these zones strictly limit the unit’s ability to regulate system load because load regulation may result in its falling into certain prohibited operating zones. Therefore the system spinning reserve requirement must be supplied by way of regulating the units without prohibited zones.

\[
\sum_{i=1}^{N} S_i \geq S_R \tag{1.12}
\]

\[
S_i = \begin{cases} 
\min \left( \left( P_{i_{\text{max}}} - P_i \right) S_{i_{\text{max}}} \right) & \text{for units without prohibited zones} \\
0 & \text{otherwise} 
\end{cases}
\tag{1.13}
\]
1.3.7 EDP with Multiple Fuel Option

The generators that are supplied with multiple fuel sources lead to an optimization problem of determining the economic fuel to burn. In the case of these generators, unlike the conventional cost function, the cost function of each unit should be presented with a few piecewise functions reflecting the effects of fuel type changes and each segment of the hybrid cost function implies some information about the type of fuel being burned or the operational characteristics of the unit. The input-output characteristics and incremental fuel curve for generating units with multiple fuel options are shown in Figure 1.6.

![Figure 1.6 Multiple fuel option for economic dispatch problem](image)

For a power plant with $N$ generators and $K$ fuel options for each unit, the cost function of the $i$th generating unit with valve point effect is expressed as,
1.3.8 Dynamic Economic Dispatch Problem (DED)

EDP which includes inter-temporal dynamic connection is termed as dynamic economic dispatch problem (DED). DED is considered as one of the most important steps to obtain a complete generation scheduling solution. DED aims to schedule the online generators outputs with the predicted load demands over a certain period of time in order to operate an electric power system most economically within its security limits. DED is always considered as an extension of EDP.

1.3.9 DED Problem with valve-point effect

Mathematically, DED problem is considered as a second-order dynamic optimization problem that takes into account the constraints imposed on the system by the generator ramp rate limits. The cost function and associated constraints of the DED problem can be formulated as follows.

Minimize,

\[ F_T = \sum_{h=1}^{H} \sum_{i=1}^{N} F_{ih}(P_{ih}) \]  

\[ (1.15) \]
Generally, the generator cost function is usually expressed as a quadratic polynomial as:

\[ F_{ih}(P_{ih}) = a_i P_{ih}^2 + b_i P_{ih} + c_i \]  

(1.16)

For an accurate non-convex model of the cost function, the DED with valve point effects has to be considered by superimposing a rectified component in the traditional quadratic fuel cost function as formulated below:

\[ F_{ih}(P_{ih}) = a_i P_{ih}^2 + b_i P_{ih} + c_i + \left| e_i \sin \left( f_i \left( P_{ih, \text{min}} - P_{ih} \right) \right) \right| \]  

(1.17)

where \( a_i, b_i, c_i \) are the fuel cost coefficients of the \( i \)th unit, \( e_i, f_i \) are the valve-point coefficients of the \( i \)th unit, \( h \) is the hour, \( N \) is the number of generating units, \( P_{ih, \text{min}} \) is the minimum generation limit of the \( i \)th unit in MW, \( P_{ih} \) is the power output of the \( i \)th unit at time \( h \) in MW, \( F_{ih} \) is the fuel cost function of the \( i \)th unit in $/h at hour \( h \), \( F_T \) is the total fuel cost in $/h, \( H \) is the number of intervals in the entire dispatch period.

**1.3.10 DED Problem with Multiple Fuel Option**

The generators that are supplied with multiple fuel sources lead to an optimization problem of determining the economic fuel to burn. In the case of these generators, unlike the conventional cost function, the cost function of each unit should be presented with a few piecewise functions reflecting the effects of fuel type changes and each segment of the cost function implies the type of fuel being burned or the operational characteristics of the unit.

For a power plant with \( N \) generators and \( K \) fuel options for each unit, the cost function of the \( i \)th generating unit with valve point effect is expressed as, in Equation (1.18).
where $a_{i,k}$, $b_{i,k}$ and $c_{i,k}$ are the fuel cost coefficients, $e_{i,k}$ and $f_{i,k}$ are the valve-point coefficients of the $i$th generating unit using fuel type $k$.

The fuel cost functions for the DED problem are expressed as in Equation (1.18) is subjected to following equality and inequality constraints.

$$F_i(P_i) = \begin{cases} 
    a_{i,1}P_{ih}^2 + b_{i,1}P_{ih} + c_{i,1} + |e_{i,1}\sin(f_{i,1}(P_{ih\text{min}} - P_{ih}))|, & \text{fuel1}, \ P_{ih\text{min}} \leq P_{ih} \leq P_{ih1} \\
    a_{i,2}P_{ih}^2 + b_{i,2}P_{ih} + c_{i,2} + |e_{i,2}\sin(f_{i,2}(P_{ih\text{min}} - P_{ih}))|, & \text{fuel2}, \ P_{ih1} \leq P_{ih} \leq P_{ih2} \\
    \vdots \\
    a_{i,k}P_{ih}^2 + b_{i,k}P_{ih} + c_{i,k} + |e_{i,k}\sin(f_{i,k}(P_{ih\text{min}} - P_{ih}))|, & \text{fuelk}, \ P_{ih,k-1} \leq P_{ih} \leq P_{ih2} 
\end{cases}$$  

(1.18)

- Real power balance constraint

The power output from all the generating units must satisfy the total demand and the transmission losses of the system. It is expressed as,

$$\sum_{i=1}^{N} P_{ih} = P_{Dh} + P_{Lh}$$  

(1.19)

where $P_{Dh}$ is the total load demand in MW at hour $h$, $P_{Lh}$ is the total transmission loss in MW at hour $h$.

- Real power generation limit

The real power output of each generating unit is limited by their maximum and minimum power limits.

$$P_{i\text{min}} \leq P_{ih} \leq P_{i\text{max}}$$  

(1.20)

where $P_{i\text{min}}$ and $P_{i\text{max}}$ are the minimum and maximum generation limit of the $i$th unit in MW.
1.3.11 DED Problem with RAMP RATE LIMITS

\[ P_{ih} - P_{i(h-1)} \leq UR_i \quad \text{if generation increases} \]
\[ P_{i(h-1)} - P_{ih} \leq DR_i \quad \text{if generation decreases} \]

Using Equations (1.21 and 1.20) is modified as

\[ \max\left(P_{i(h-1)} - DR_i\right) \leq P_{ih} \leq \min\left(P_{ih}, P_{i(h-1)} + UR_i\right) \] (1.22)

where \( P_{i(h-1)} \) is the power generated by the \( i \)th unit at the \( (h-1) \)th hour. \( UR_i \) and \( DR_i \) are the up and down ramp rate limits of \( i \)th unit in MW/h.

1.3.12 DED Problem with Prohibited Operating Zones

For unit \( i \) with prohibited operating zones, the feasible operating zones can be described as follows:

\[ P_i = \begin{cases} 
P_{ih} & P_{ih} \leq P_{i,1} \\
\left(P_{ih} \leq P_{i,j} \right) & j = 2, \ldots, n_i \\
P_{ih} & P_{ih} \leq P_{i,1} 
\end{cases} \] (1.23)

1.3.13 DED Problem with Spinning Reserve Constraints

In a unit with prohibited operating zones, these zones strictly limit the unit’s ability to regulate system load because load regulation may result in its falling into certain prohibited operating zones. Therefore the system spinning reserve requirement must be supplied by way of regulating the units without prohibited zones.

\[ \sum_{j=1}^{N} S_{ih} \geq S_{Rh} \quad h = 1, 2, \ldots, H \] (1.24)
\[
S_{ih} = \begin{cases} 
\min \left( \left( P_{\max} - P_h \right) S_{i_{\max}} \right) & \text{for units without prohibited zones} \\
0 & \text{otherwise} 
\end{cases}
\]

where \( S_{ih} \) is the spinning reserve of unit \( i \) at the \( h \)th time interval, \( S_{Rh} \) is the system spinning reserve requirement at the \( h \)th time interval and \( S_{i_{\max}} \) is the maximum spinning reserve of unit \( i \).

1.4 OBJECTIVES AND CONTRIBUTION OF THE THESIS

Two essential problems, economic dispatch problems (EDP) and dynamic economic dispatch (DED) are presented in this research work. These two problems are solved for cost minimization,

The main objectives of this work are:

- Implementation of a population based search approach to solve EDP, DED problems with non-smooth cost functions.
- Investigation and validation of the applicability of the proposed algorithms to generation scheduling problems.

The main contributions in this work are:

- The differential evolution (DE) technique is combined with variable neighbourhood search (VNS) to solve the EDP with minimal constraints to improve the quality of the solution and convergence speed.
- The DE technique is enhanced with neighbourhood search operation (NSO) to solve the economic dispatch problem. In the NSO-DE method the DE functions as the main optimizer and NSO as a local optimizer, thus making DE to handle more complex constraints.
Similarly the differential evolution technique is improvised with neighborhood based mutation (DE-NM) technique for solving dynamic economic dispatch (DED) problem with several practical constraints and a real-time power system also.

1.5 ORGANISATION OF THE THESIS

The research work carried out has been summarized in six chapters. Chapter 1 highlights the brief introduction of economic dispatch, dynamic economic dispatch and the related topics of the problem. This chapter also includes the objective of the thesis. Chapter 1 also presents the literature review, which has necessitated the scope of the research work. Here, literature reviews regarding the modelling of non-smooth cost functions are dealt first. Then, the modelling of EDP with valve point loadings, EDP with prohibited operating zones was discussed. The existing solution techniques to solve the EDP problems are reviewed and presented. Then the review regarding DED was modelled, and then DED with valve point loadings, DED with prohibited operating zones, DED with multiple fuels and spinning reserve were discussed. Also the existing solution techniques to solve the DED problems are reviewed and presented. Although most of the deterministic and heuristic algorithms successfully obtained some solutions to EDP and DED problems, they have their own drawbacks. Therefore combination of more than one technique has been proposed in the literature. EDP and DED solved with deterministic, stochastic and hybrid methods were reviewed separately.

The chapter 2 describes the formulation of EDP considering non-linearities like valve-point effect, prohibited operating zones, ramp rate limits and system spinning reserve constraints to model the fuel cost function of generating units. The dynamic dispatch problem formulation for generating units exhibiting valve-point effects, prohibited operating zones and multiple
fuel options are also presented. Here equality and inequality constraints including spinning reserve and ramp rate constraints of generating units are considered.

Chapter 3 deals with the development of a new approach to solve EDP with non-smooth cost function using differential evolution technique. The DE technique is combined with variable neighbourhood search (VNS) to improve the quality of the solution and convergence speed. DE is first introduced to find the locality of the solution and then VNS is applied to tune the solution. To validate the performance of the proposed method, test cases like 3-unit system, 10-unit system, 15-unit system and 40-unit system are considered. In addition to the DE-VNS method, DE with random scale factor (DE-RSF) is also developed to solve the EDP with non-smooth cost function. The DE-RSF technique is tested with 3-unit, 13-unit, 15-unit and 40-unit systems to validate its feasibility.

In the chapter 4, differential evolution technique enhanced with neighbourhood search operation (NSO) is implemented to solve the economic dispatch problem. The NSO-DE method incorporates DE as the main optimizer and NSO as a local optimizer. A more realistic EDP is formulated by considering non-linear generator characteristics such as valve point effect, ramp rate limits, prohibited operating zones, multiple fuels and spinning reserve. The performance of the NSO-DE method is validated using various standard test systems consisting of 10, 13 and 15 thermal units and a 19 unit Indian utility system. The robustness and effectiveness of the NSO-DE is compared with other strategies of DE based on the quality of the final solution obtained.

Chapter 5 discusses the differential evolution with neighborhood based mutation (DE-NM) technique for solving dynamic economic dispatch (DED) problem with valve point effects, prohibited operating zones, spinning reserve and multiple fuel options. The performance of the DE-NM is tested on
a standard IEEE 10-unit test system and a real public Indian utility system with 19 generating units. Both the test systems are illustrated under different load patterns.

Chapter 6 contains the comprehensive summary of conclusions obtained throughout this research work is evidently presented. Simulation results on the various test cases validate the effectiveness of the proposed techniques based on the quality of the final solution obtained. The problem formulation and the results presented in this thesis will be the main perspectives for further research resulting from this thesis.

1.6 SUMMARY

The major non-convex EDP are a) economic dispatch with rectified sine term superimposed in the cost function to model valve-point effect, b) economic dispatch with piecewise quadratic cost function, c) economic dispatch with prohibited operating zones and d) EDP with spinning reserve. Later for DED the above non-convex problems considering valve point loading, prohibited operating zones, multiple fuel options and spinning reserve are modeled in the problem formulation. A need for optimality exists in the highly non-linear and computationally difficult power system operation environment. Thus this chapter presented various EDP and DED problem formulation considering the non-smooth characteristics in the fuel cost functions and constraints to validate practical situation existing in real-time power system. This chapter also presented the objectives, contribution and organization of the thesis.