UNIVERSITY OF NAIROBI
SCHOOL OF ENGINEERING
DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING

ECONOMIC LOAD DISPATCH USING HIGH ORDER COST FUNCTIONS USING DYNAMIC PROGRAMMING

PROJECT INDEX: 41

SUBMITTED BY
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F17/29261/2009

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PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF

BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING OF THE

UNIVERSITY OF NAIROBI 2015

DATE SUBMITTED: 24th April 2015
DECLARATION OF ORIGINALITY

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FACULTY/SCHOOL/INSTITUTE: Engineering

DEPARTMENT: Electrical and Information Engineering

COURSE NAME: Bachelor of Science in Electrical and Electronic Engineering

TITLE OF WORK: ECONOMIC LOAD DISPATCH USING HIGHER ORDER COST FUNCTIONS USING DYNAMIC PROGRAMMING

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The report has been submitted to the Department of Electrical and Information Engineering, University of Nairobi with my approval as supervisor:

Mr. Peter Moses Musau.

Date:……………………………..
DEDICATION

I dedicate this project to my mum, for always believing in me.
ACKNOWLEDGEMENT

I wish to appreciate the Almighty God for His amazing grace throughout my life. His love and guidance has brought me this far.

I extend my gratitude and thanks to my supervisors Prof. Nicodemus Abungu and Mr. Moses Musau, for their constant support and motivation throughout the course of my project besides them being great mentors. I am indebted to them for always being there to help me shape the problem and provide insights towards the solution. The progress I have made now would have been impossible without their guidance. I also appreciate the teaching staff and non-teaching staff at the University of Nairobi, Department of Electrical and Information Engineering for their selfless effort that enabled me to achieve my academic goals during the entire course of my studies.

I would also like to thank my friends Brian Kiplimo and Samuel Kabutha for their constant encouragement and helpful discussions throughout the course of this work.

Finally I thank my family for their patience and understanding.
ABSTRACT

The modern power system around the world has grown in complexity of interconnection and power demand. The focus has shifted towards the enhanced performance, increased customer focus, low cost, reliable and clean power. In this changed perspective, scarcity of energy resources, increasing power generation cost and environmental concern necessitates economic load dispatch. In reality power stations neither are at equal distances from load nor have similar fuel cost functions. Hence for providing cheaper power, load has to be distributed among the various power stations in a way which results in lowest cost of generation. Practical economic dispatch (ED) problems have highly non-linear objective function with equality and inequality constraints. Conventional methods such as lambda iteration method and gradient method have been applied to solve the Economic Load Dispatch (ELD) problem. However these techniques don’t give optimal solution because they require incremental fuel cost curves which are piecewise linear and monotonically increasing to find the global optimal solution. Techniques like Dynamic Programming (DP) method do give optimal solution. DP is applied to allocate the active power among the generating stations satisfying the system constraints and minimizing the cost of power generated. The ELD problem is solved for IEEE 14, 30 and 57 bus test networks. The results obtained using the higher order DP method is comparable with those of the second order method. For example the fuel cost for a power demand of 600MW 14 bus using higher order DP is $18217.59 /Hr while that of lower order is $18305.91 /Hr. In the case of the 57 bus system for the same power demand, the fuel cost for higher order DP is the power demand is $18216.07 /Hr and that of the lower order DP is $19044.625 /Hr.
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<td>Non Linear Programming</td>
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<td>IC</td>
<td>Incremental Cost</td>
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<td>BTU</td>
<td>British Thermal Units</td>
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<td>ITL</td>
<td>Incremental Transmission Loss</td>
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<td>DP</td>
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<td>ED</td>
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<td>ELD</td>
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<td>GA</td>
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<td>GBEST</td>
<td>Global Best</td>
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<td>IEEE</td>
<td>Institute of Electrical and Electronic Engine</td>
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<td>LP</td>
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<td>MW</td>
<td>Mega Watts</td>
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<td>PBEST</td>
<td>Personal Best</td>
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<td>PSO</td>
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CHAPTER 1

INTRODUCTION

1.1 Economic Load Dispatch Using Higher Order Cost Function

1.1.1 Economic Load Dispatch
Economic load dispatch is a process of allocating generation levels to dispersed generating power plants so that the system is fully supplied in the most economical way, and it is defined as the operation of generation facilities to produce energy at the lowest cost to reliably serve consumers recognizing any operational limits of generation and transmission facilities [1].

For any specified load condition, economic dispatch determines the power output of each plant which will minimize the overall cost of the fuel needed to serve the system load. It focuses upon coordinating the production costs of all power plants operating on the system. The goal of power system economic load dispatch is to maximize system efficiency and minimize system losses that cannot be passed on to consumers [2].

1.1.2 Higher Order
Most ELD problems are solved using quadratic functions. In this project we are expected to solve the ELD problems using an order higher than the second order (quadratic function). In this case we are going to use the third order equations (cubic functions).

1.1.3 Cost Function
Cost function is a financial term used by economists and managers within businesses as a way of expressing how different costs behave under a variety of circumstances. It shows how monetary outputs, everything from overhead and operating expenses to charges and fees change as the levels of an activity relating to those outputs change. There are three basic types of linear cost functions:

✓ Fixed cost functions.
✓ Variable cost functions.
✓ Mixed cost functions.

In a mixed circumstance, the cost will be fixed to a certain point that can be changed based on related activity. Analysts use these sorts of functions to make important predictions about the market place and to inform a variety of decision making tasks [3].

### 1.1.4 Economic load dispatch using higher order cost function

This can be defined as the operation of generation facilities to produce energy at the lowest cost to reliably serve consumers recognizing any operational limits of generation and transmission facilities. [1] This also involves expressing how different costs behave under a variety of circumstances. It shows how monetary outputs, from overhead and operating expenses to charges and fees change as the levels of an activity relating to those outputs change. [3] Unlike in the conventional methods of solving ED problems where the computations are done using quadratic functions, in this project we are going to use cubic functions. Since the computation of such a task is likely to exhibit properties of overlapping sub-problems and optimal substructure we therefore use a method of solving complex problems by breaking them down into simple sub-problems. Generally to solve a given problem we need to solve the different sub-problems and then combine their solutions to get the final overall solution. Once the solution to a given sub-problem has been computed it is simply looked up. This greatly reduces the number of computations [4].

### 1.2 Survey of Earlier Work

Since the cost characteristics of each generating unit is a nonlinear solution to economical dispatch, using conventional methods becomes a big setback as they require incremental fuel cost curves [2]. In order to overcome this problem, several alternative methods have been developed such as:
1.2.1 Nonlinear programming
Power system operation problems are nonlinear. Thus nonlinear programming (NLP) based techniques can easily handle power system operation problems with nonlinear programming problem, the first step in this method is to choose a search direction in the iterative procedure which is determined by first partial derivatives of the equations. Therefore these methods are referred to as the first order methods, such as generalized reduced gradient method. NLP based methods have higher accuracy than linear programming based approaches and also have global convergence, which means that the convergence can be guaranteed independent of the starting point, but a slow convergent rate may occur because of zigzagging in the search direction [5].

1.2.2 Tabu search
The Tabu Search (TS) algorithm is a general heuristic optimization approach designed for finding optimal solution to optimization problems. It has a flexible memory to keep the information about the history search and employs it to create and explore the new solutions in the search space. The two main components of TS are the tabu list and the aspiration criterion. The tabu list stores all tabu moves that are not permitted to be applied to the current solution. The tabu list records the move direction, frequency and regency. Aspiration criterion is employed to determine which move should be free in such a case, that is, if a certain move criterion is satisfied, it is then set to be allowable. In general terms, TS is an iterative improvement procedure that starts from some initial feasible solution and attempts to determine a better solution in the manner of a great decent algorithm. TS permits backtracking to previous solutions which may ultimately lead via a different direction, to better solutions. However, TS is characterized by an inability to escape local optima, which usually causes simply descent algorithms to terminate, by using a short term memory of simple solutions [6, 7].
1.2.3 Particle swarm optimization
Particle swarm optimization (PSO) is a population based stochastic optimization technique inspired by the social behavior of flocks of birds or schools of fish. In PSO the potential solutions called particles, fly through the problem space by following the current optimum particles. The particles change their positions by flying around in a multidimensional search space until a relatively unchanged position has been exceeded [6]. A particle bases its search not only on its personal experiences but also by the information given by its neighbours in the swarm. Each particle keeps track of its coordinates in the problem space, which is associated with the best solution fitness it has achieved so far. The fitness value is also stored. This value is called P best. Another best value that is tracked by the particle swarm optimizer is the 1 best value obtained thus far by any particles in the neighbours of the particle. This location is called 1 best. When a particle takes the whole population as its topological neighbours, the best value is a global best and is called g best. The main advantages of PSO are: easy implementation, single concept, robustness to control the parameters and less computational time compared to other optimization techniques [1, 6].

1.2.4 Newton’s Method
Newton’s method requires the computation of the second order partial derivatives of the power flow equation and other constraints (the hessian) and is therefore called a second – order method. The necessary conditions of optimality commonly are the Kuhn –Tucker conditions. Newton’s method is favoured for its quadratic convergence properties [5].

1.2.5 Hybrid algorithms
Hybrid algorithms try to make use of the merits of different methods. Hence the aim is to improve the performance of algorithms that are based on a single method. The main aim of proposing an algorithm as a hybrid of two or more methods is to speed up the convergence and to get better quality of solutions
than that obtained when applying the individual methods. A new algorithm integrating Tabu search (TS), Simulated Annealing (SA) and Genetic Algorithm (GA) can be used to solve an economical dispatch problem. The core of the algorithm is based on GA. TS is used to generate new population members in the reproduction phase of the GA. SA method is used to accelerate the convergence of the GA by applying the SA for all the population members. In the TS part of the algorithm a simple short danger of entrapment at a local optimum and the premature convergence of the GA [6].

1.2.6 **Quadratic programming**
Quadratic programming (QP) is a special form of nonlinear programming. The objective function of QP optimization method is quadratic and the constraints are in linear form. Quadratic programming has higher accuracy than linear programming based approaches. Especially the most often used objective function in power system optimization is the generator cost function which generally is a quadratic. Thus there is no simplification for such objective function for a power system optimization problem solved by QP [5].

1.2.7 **Simulated annealing (SA)**
Simulated annealing is the physical process of heating up a solid until it melts followed by cooling it down until it crystallizes into a state with perfect lattice [8]. During this process, the free energy of the solid is minimized. If the temperature is reduced at a very fast rate, the crystalline state transforms to an amorphous structure, a metastable state that corresponds to a local minimum of energy. Therefore the main point of the process is slow cooling, that leads to crystallized solid state which is a stable state, corresponding to a minimum energy. This is the technical definition of annealing and it is essential for ensuring that low energy state will be achieved SA algorithm is a probabilistic meta-heuristic method for global optimization problems emulating the process of annealing. Starting from an initial point the algorithm takes a step and the function is evaluated. Since the algorithm makes very few assumptions regarding the function to be optimized it is quite robust with respect to non-
quadratic surfaces. In economic dispatch problem it’s used for determination of the global or near global optimum dispatch solution. The disadvantage of SA is its repeated annealing with a schedule is very slow especially if the cost function is expensive to compute [6, 8, 9].

1.2.8 Genetic algorithm
Genetic algorithm (GA) is a multi-objective search technique based on principles inspired from the genetic and evolution mechanisms observed in natural systems and populations of living beings. Its basic principle is the maintenance of a population of solutions to a problem in the form of encoded information individuals that evolve in time. GA is a search method based on the mechanics of natural selection and natural genetics. It combines survival of the strongest among string structured yet random information exchange. In every generation a new set of artificially developed strings is produced using elements of the strongest of the old. An occasional new element is experimented with for enhancement [10].

The algorithm identifies the individuals with the optimizing fitness values and those with lower fitness will naturally get discarded from the population. But there is no assurance that a genetic algorithm will find a global optimum. Also the genetic algorithm cannot assure constant optimization response times. These unfortunate genetic algorithms properties limit the genetic algorithms use in optimization problems [8].

1.2.9 Dynamic Programming
Dynamic programming is a method of solving complex problems by breaking them down into simpler sub problems. It is applicable to problems exhibiting the properties of overlapping sub problems and optimal substructure. When applicable the method takes far less time than naïve methods which don’t take advantage of the sub problem overlap. The idea behind DP is quite simple. In general, to solve a given sub problem, we need to solve different parts of the problem, and then combine the different parts of the solution to get an overall
solution. Often when using a more naïve method, many of the sub problems are generated and solved many times. DP approach seeks to solve each sub problem only once, thus reducing the number of computations. Once the solution to a given sub problem has been computed it is stored. The next time the same solution is needed it is simply looked up. The approach is especially useful when the number of repeating sub problems grow exponentially as a function of the size of the input [4].

The recursive algorithm is used to compute the minimum cost in hours t with feasible state I, that is:

\[ F_{tc}(t, I) = \min_{\{L\}} [F(t, I) + S_c(t - 1, l \rightarrow t, I) + F_{tc}(t - 1, I)] \]  

(1.1)

Where:

- \( F_{tc}(t, I) \) – The total cost from initial state to hour t state I
- \( S_c(t - 1, l \rightarrow t, I) \) – The transition cost from state \((t - 1, l)\) to state \((t, I)\)
- \( \{L\} \) – The state of feasible states at hour \((t - I)\)
- \( F(t, I) \) – The production cost for state \((t, I)\)

The following constraints should be satisfied for the unit commitment problem solved by dynamic programming.

\[ \sum_{i=1}^{n} p_{Gi}^{t} = p_D^{t} \]  

(1.2)

\[ X_i^{t} p_{Gimin}^{t} \leq p_{Gi}^{t} \leq X_i^{t} p_{Gimax}^{t} \]  

(1.3)

Where:

- \( p_D^{t} \) – The system load at hour t
- \( p_{Gimin}^{t} \) – The lower limit of the unit power output
- \( p_{Gimax}^{t} \) – The upper limit of the unit power output
$X_i^t$ – the 0-1 variable [5]

1.2.10 Summary
Economic dispatch problem is a multi-objective problem. Dynamic programming has therefore been chosen owing to its advantages over other optimization techniques. For instance when applicable the method takes far less time than naïve methods which don’t take advantage of the sub problem overlap. Dynamic programming has higher accuracy than linear programming based approaches. The most often used objective function in power system optimization is the generator cost function which generally is quadratic. However in this project we are going to use cubic cost function and compare its accuracy to the quadratic cost function. It is also one of the objective problems in the project [5].

1.3 PROBLEM STATEMENT
The main purpose of the project is to understand in detail the theory and working of economic load dispatch, to formulate and solve economic load dispatch problem using higher order cost function such as a cubic function and dynamic programming.

Dynamic programming operators are to be understood in detail and used to write a software program in MATLAB programming using higher order cost function unlike the normally used Quadra cost function, to solve the economic load dispatch problem

1.3.1 OBJECTIVES
The objectives of the project can be stated as:

✓ To find a solution to economic load dispatch problem using higher order cost function.
✓ To obtain a solution to a higher order cost function using dynamic programming.
1.4 Organization of Report

In Chapter 1, the definition of ELD and various methods which have been employed to solve the ELD problem have been discussed. It also covers the problem statement, objective of the project and the simulation method which will be used to solve the ELD problem.

In Chapter 2, a review of economic load dispatch and DP method has been discussed. DP concept is explained, its benefits over conventional methods are briefed. Basic parameters of DP are looked at in order to understand its working especially in relation to higher order cost function.

In Chapter 3 the implementation of higher order economic dispatch problem using DP is discussed in detail. The flowchart and the algorithm are provided.

In Chapter 4, the simulation results obtained from programming in MATLAB are and discussed. These results are compared with a quadratic cost function using DP algorithm from published work.

In Chapter 5, the conclusions are presented and recommendations for further work stated.
CHAPTER 2
LITERATURE REVIEW

2.1 Literature Review on Economic Load Dispatch

2.1.1 Economic load dispatch
Economic load dispatch (ELD) can be defined as the process of allocating generation levels to the generating units so that the system load is supplied entirely and most economically [1]. That is, to determine the generations of different plants such that the total operating cost is minimum and at the same time the total demand and the losses at any instant are met by the total generation. For an interconnected system it’s necessary to minimize the expenses. The economic load dispatch is used to define the production level of each plant so that the total cost of generation and transmission is minimum for a prescribed schedule of load. The objective of ELD it to minimize the overall cost of generation. The method of ELD for generating units at different loads must have total fuel cost at the minimum point [2, 11].

2.1.1.1 Necessity of load dispatch
The operation of a modern power system has become very complex. It is necessary to maintain frequency and voltage within limits in addition to ensuring reliability of power supply and for maintaining the frequency and voltage within limits it is essential to match the generation of active and reactive power with the load demand. For ensuring reliability of power system it is necessary to put additional generation capacity in to the system in the event of outage of generation equipment at some station.

Over and above, it is also necessary to ensure the cost of electric supply is at the minimum. The total interconnected network is controlled by the load dispatch centre. The load dispatch center allocates the megawatt (MW) generation to each grid depending on the prevailing MW demand in that area. Each load dispatch center controls load and frequency of its own by matching generation
in various generation stations with total required MW demand plus MW losses. Therefore the work of load control center is to keep the exchange of power between various zones and systems frequency at desired values.

2.1.1.2 Thermal power plant
A thermal power plant is a power plant in which its prime mover is driven by steam. Water is the working fluid. It is heated at the boiler and circulated with energy to be expanded at the steam turbine. To give work to the rotor shaft of the generator. After it passes through the turbine, it is condensed in a condenser and then pumped to feed the boiler where it is heated. For simplification, thermal power plants can be modeled as a transfer function of energy conversion from fossil fuel to electricity as described in figure 2.1.

![Energy conversion diagram for a thermal power plant](image)

**Figure 2.1:** Energy conversion diagram for a thermal power plant

The thermal unit system generally consists of the boiler, steam turbine and generator [11]. The input of the boiler is fuel and the output is steam. The relationship of the input and output can be expressed as a convex curve. The input of the turbine – generator unit is the volume of steam and the output is electrical power, the overall input-output characteristic of the whole generation unit can be obtained by combining directly the input-output characteristics of the boiler and the input-output characteristic of the turbine-generator unit.

2.1.1.3 Generator operating cost
The total cost of operation includes the fuel cost, cost of labour, supplies and maintenance. Generally, cost of labour, supplies and maintenance are fixed percentages of incoming fuel cost. Other factors influencing power generation are operating efficiencies of generators and transmission losses. The total cost
of generation is a function of the individual generation of the sources which can take values within certain constraints. The problem is to determine the generation of different plants such that total operating cost is minimum. The input of the thermal plant is generally measured in Btu/hr and the output power is the active power in MW. A simplified input – output curve of a thermal unit is known as heat – rate curve and it’s shown in figure 2.2 [2, 13].

**Figure 2. 2:** Heat rate curve

2.1.1.4 Fuel efficiency
This is the ratio of energy output in megawatt hours (MWh) to fuel input measured in millions of British Thermal Units (BTU). The criterion of distributing the load between any two units is based on whether increasing the load in one unit as based on whether increasing the load in one unit as the load is decreased on the other unit by the same amount results in the increase or decrease in total load [2].

2.1.1.5 Incremental cost (IC)
This is the limit of the ratio of increase in cost of fuel input in dollars per hour to corresponding increase in power output in megawatts as the increase in
power output approaches zero. Incremental cost is the slope of the fuel cost curve, and the unit of IC is in dollars per megawatt hour (MWh).

IC tells us how much it will cost to run a generator to produce an additional 1MW of power. All units in power plant must operate at the same incremental fuel cost for minimum cost in dollars per hour \[2, 12\].

2.1.1.6 Transmission loss as a function of plant generation

Although the incremental fuel cost at one bus may be lower than that of another plant for a given distribution of load between plants, the plant with the lower incremental cost at its but may be much further from the load center. The losses in transmission from the plant having lower incremental cost may be so great that economy may dictate lowering the load at the plant with the lower incremental cost and increasing it at the plant with the higher incremental cost.

To coordinate transmission loss in the problem of determining economic loading of plants, we need to express the total transmission loss of a system as a function of plant loading. Present day utility systems serve over a vast area of relatively low density. The transmission loss may vary from 5 to 15% of total load. Therefore it is essential to take into account transmission loss in economic dispatch calculations \[2, 11, 13\].

The general form of the loss formula using the loss coefficient is:

\[
P_l = \sum_{i=1}^{NG} \sum_{j=1}^{NG} P_{gi} B_{ij} P_{gj}
\]  

(2.1)

Where

\(P_{gi}\) and \(P_{gj}\) are the real power generations at \(i^{th}\) and \(j^{th}\) buses respectively

\(B_{ij}\) are the loss coefficients or \(B\) coefficients

2.1.1.7 Formulation of economic dispatch problem

Economic load dispatch problem assumes that the amount of power supplied by a given set of units is constant for a given interval of time and attempts to
minimize the cost by supplying this energy subject to constraints of the generating units. The objective is to minimize the total cost of generating real power at various stations while satisfying real power at various stations while satisfying the loads and losses in the cost as the only variable cost since generally the costs of labour, supply’s and maintenance are fixed percentages of fuel cost [11]. The fuel cost is meaningful in the case of thermal and nuclear plants, but nuclear plants are operated at constant output levels and for higher stations where the energy cost is apparently free, the operating cost is not that meaningful. Hence only thermal plants are considered in this project.

For fuel cost curve it is assumed that the fuel cost curve of each generating unit is given. The fuel cost curve specifies the input energy rate \( F_i(P_{gi}) \) or cost fuel used per hour \( C_i(P_{gi}) \) as a function of the generator output \( P_{gi} \).

The fuel cost curve takes up a quadratic form:

**Figure 2.3:** Fuel cost curve
\[ C_i(P_{gi}) = a + bP_{gi} + CP_{gi}^2 \]  

(2.2)

Where

\( g_i \) = generator i

\( P_{gi} \) = real power generation

\( C_i(P_{gi}) \) = operation cost of unit in $/h

\( P_{gi\ min} \) = minimum loading limit below which operating the unit proves to be uneconomical

\( P_{gi\ max} \) = maximum loading output limit

2.1.1.8 Power balance constraints

This constraints is based on the principle of equilibrium between the total system generation and the total system loads (\( P_0 \)) and the loses (\( P_1 \)) which must be equal. The cost function is also not affected by the reactive power demand. So full attention is given to the real power balance in the system

\[ \sum_{i=1}^{NG} P_{gi} - (P_0 + P_1) = 0 \]  

(2.3)

Where;

\( i \) – The generator

\( P_0 \) – Real power demand

\(+P_1\) – Power loss

\( P_{gi} \) – Power generation at generator i

\( NG \) – Number of generator plants
2.1.1.9 The generator constraints
The maximum active power generation \((P_{gi \ max})\) is limited by thermal consideration and also minimum power generation \((P_{gi \ min})\) is limited by flame instability of a boiler. If the power output of a generator for optimum operation of the system is less than a pre-specified value. The unit is not put on the bus bar because it’s not possible to generate that low value of power from the unit. So the output power of each power generating unit has a lower and upper bound and unit power lies between these bounds.

\[
P_{gi \ max} \leq P_{gi} \leq P_{gi \ min}
\]  

(2.4)

Where

\(P_{gi \ max}, P_{gi \ min}\) = minimum and maximum output power generation respectively of the \(i^{th}\) unit

2.1.1.10 Economic load dispatch without losses
In this case transmission losses are neglected. Therefore the total load demand is the sum of all generations. A cost function \(C_i (P_{gi})\) is assumed to be known for each plant hence the problem is to find the real power generation \(P_{gi}\) for each plant such that the total operating cost \(C (P_{gi})\) is minimum and the generation remains within the lower generation \(P_{gi \ min}\) and upper generation \(P_{gi \ max}\) [2, 11, 12].

Suppose there is a station with NG generators committed and the active power load demand \(P_0\) is given the real power generation \(P_{gi}\) for each generator has to be allocated to as minimize the total cost. The optimization problem can therefore be stated as:

\[
\text{minimise } C (P_{gi}) = \sum_{i=1}^{NG} C_i (P_{gi})
\]

(2.5)

subject to the constraints.
Power balance constraints

\[ \sum_{i=1}^{NG} (P_{gi}) = P_0 \]  \hspace{1cm} (2.6)

Inequality constraints

\[ P_{gi \ min} \leq P_{gi} \leq P_{gi \ max} \]  \hspace{1cm} (2.7)

The above constraint optimization problem is converted into an unconstrained optimization problem language multiplier is used in which a function is minimized or maximized with side conditions in the form of equality constraints. Using the method an argument function is defined as:

\[ L(P_{gi}, \lambda) = C(P_{gi}) + \lambda \left( P_0 - \sum_{i=1}^{NG} P_{gi} \right) \]  \hspace{1cm} (2.8)

Where \( \lambda = \) Lagrange multiplier

A necessary condition for a function \( C(P_{gi}) \), subject to the power balance constraint to have a relative minimum point \( P_{gi} \) is that the partial derivative of the Lagrange function is defined by \( L = L(P_{gi}, \lambda) \) with respect to each of its arguments must be zero.

\[ \frac{\delta L(P_{gi}, \lambda)}{\delta P_{gi}} = \frac{\delta C(P_{gi}) - \lambda}{\delta P_{gi}} = 0 \]  \hspace{1cm} (2.9)

\[ \frac{\delta L(P_{gi}, \lambda)}{\delta P_{gi}} = P_0 - \sum_{i=1}^{NG} P_{gi} = 0 \]  \hspace{1cm} (2.10)

From equation (2.9)

\[ \frac{\delta C(P_{gi})}{\delta P_{gi}} = \lambda \]  \hspace{1cm} (2.11)
This is called coordination equation

Where \( \frac{\delta C(p_{gi})}{\delta p_{gi}} \) is the incremental fuel cost (marginal cost) of the \( i^{th} \) generator.

Optimal loading of generators corresponds to the equal incremental cost point of all generators.

Considering the cost function (2.2) the incremental cost can be defined as:

\[
\frac{\delta C(p_{gi})}{\delta p_{gi}} = 2 \alpha_i p_{gi} + B_i = \lambda (i = 1, 2, \ldots, NG) \quad (2.12)
\]

2.1.1.11 Economic load dispatch with losses

In a large interconnected network where power is transmitted over long distances, transmission losses are a major factor and affect the optimum dispatch of generation. [2, 11] The economic load dispatch problem considering the transmission power loss \( P_2 \) for the objective function is thus formulated as:

\[
\text{minimise } C(p_{gi}) = \sum_{i=1}^{NG} C_i(p_{gi}) \quad (2.13)
\]

Subject to:

Power balance constraint

\[
\sum_{i=1}^{NG} (p_{gi}) = P_0 + P_l \quad (2.14)
\]

Inequality constraint

\[
p_{gi\min} \leq p_g \leq p_{gi\max} (i = 1, 2, 3, \ldots, NG) \quad (2.15)
\]

Using the langrange multiplier \( \lambda \) the augmented function is

\[
L(p_{gi}, \lambda) = C(p_{gi}) + \lambda \left( P_0 + P_l - \sum_{i=1}^{NG} p_{gi} \right) \quad (2.16)
\]
For minimization of augmented function

\[
\frac{\delta L(P_{gi}, \lambda)}{\delta P_{gi}} = 0
\]  

(2.17)

\[
\frac{\delta L(P_{gi}, \lambda)}{\delta \lambda} = 0
\]

(2.18)

\[
\frac{\delta C_i(P_{gi})}{\delta P_{gi}} = \frac{\delta C(P_{gi})}{\delta P_{gi}}
\]

(2.19)

Using conditions given by equations (2.18) and (2.19)

\[
\frac{\delta L(P_{gi}, \lambda)}{\delta \lambda} = \frac{\delta C(P_{gi})}{\delta P_{gi}} + \lambda \left( \frac{\delta P_2}{\delta P_{gi}} - 1 \right) = 0
\]

(2.20)

\[
\frac{\delta C(P_{gi})}{\delta P_{gi}} = \lambda \left( 1 - \frac{\delta P_2}{\delta P_{gi}} \right)
\]

(2.21)

\[
\frac{\delta C(P_{gi})}{\delta P_{gi}} + \lambda \left( \frac{\delta P_2}{\delta P_{gi}} \right) = \lambda
\]

(2.22)

Where

\[
\frac{\delta C(P_{gi})}{\delta P_{gi}}
\]

is the incremental cost of generator \( I (IC) i \)

\[
\left( \frac{\delta P_i}{\delta P_{gi}} \right)
\]

is the incremental transmission loss (ITL) associated with the \( i^{th} \) generation unit.

\[
\lambda = \frac{\delta C(P_{gi})}{\delta P_{gi}} \left( \frac{1}{1 - \frac{\delta P_i}{\delta P_{gi}}} \right)
\]

(2.23)

\[
\lambda = L_i \left( \frac{\delta C(P_{gi})}{\delta P_{gi}} \right)
\]

(2.24)

Where \( L_i \) is the penalty factor of the \( i^{th} \) plant given by;
\[ L_i = \left( \frac{1}{1 - \frac{\delta P_i}{\delta P_{gi}}} \right) \] (2.25)

Fuel cost is minimum with the incremental cost of each plant multiplied by its penalty factor is same for all plants

\[ IC_i = \lambda (1 - (ITL)_i) \] (2.26)

This is the exact coordination equation

When transmission losses are included and coordinated, the following points must be kept in mind for economic load dispatch problem:

- Whereas incremental transmission cost of production of a plant is always positive, the incremental transmission losses can be both positive and negative
- The individual generators will operate at different incremental costs of production
- The generation with highest positive incremental transmission loss will operate at the lowest incremental cost of production.

2.2 Literature Review on Dynamic Programming

The dynamic programming approach is one of the most widely employed methods for the solution of the non convex economic power dispatch problem. Unlike the Lambda iteration approach, the dynamic programming method has no restrictions on generator cost function and performs a direct search of solution space. However, for a practical sized system, the fine step size and the large unit number often causes the ‘curse of dimensionality’ problem or local optimality in the dynamic programming solution process. In the scheduling of power generation systems, DP techniques have been developed for the economic dispatch of thermal systems, the solution of hydrothermal economic-scheduling problems and the practical solution of the unit commitment problem. If valve points are considered in the input-output curve, the possibility of non-convex curves must be accounted for if extreme accuracy
is desired. If non convex input-output curves are to be used, an equal incremental cost methodology cannot be used since there are multiple values of MW output for any given value of incremental cost. Under such circumstances, there is a way to find an optimum dispatch which uses dynamic programming (DP). The dynamic programming solution to economic dispatch is done as an allocation problem. Using this approach, not just a single optimum set of generator MW outputs is calculated for a specific total load supplied—rather a set of outputs are generated, at discrete points, for an entire set of load values[5,19].

2.2.1 Dynamic Programming without losses
The dynamic programming solution to the above economic dispatch problem neglecting losses is represented by the following recursive relationship[16]:

$$C_n^*(D) = \min_{P_n} \{ C_{n-1}^*(D - P_n) + C_n(P_n) \}$$  \hspace{0.5cm} (2.27)

Where:

- $C_n^*(D)$ = minimum total cost of supplying a demand of D MW with units n, n-1, n-2, .....1
- $P_n$ = real power output of generator n, MW
- $C_n(P_n)$ = operating cost of unit n
- D = total demand MW

It is assumed that each generator cost function is given at discrete MW steps with step size $\Delta$. Also, the demand D is divided into discrete MW steps, with the same step size $\Delta$, over the following range:

$$\sum_{n=1}^{N} P_{n.min} \leq D \leq \sum_{n=1}^{N} P_{n.max}$$  \hspace{0.5cm} (2.28)

Where:

- $P_{n.min}$ = minimum output of unit n, MW
- $P_{n.max}$ = maximum output of unit n, MW
- N = total number of units on economic dispatch

The dynamic programming solution is characterized by stages, where each generating unit is associated with a stage. The units are arbitrarily ordered,
and the first stage ($n=1$), using only unit 1, is simply a list of unit 1 operating costs for each discrete output $P_1$. For outputs outside its operating range, the cost is assumed infinite.

The second stage, using units 1 and 2, is given by (2.27) with $n=2$. This can be represented by a two-dimensional matrix, where the value within the brackets of (2.27) is computed for each discrete value of demand $D$ and for each unit 2 output $P_2$. A search through this matrix gives the stage 2 minimum cost $C_2^*(D)$ and optimum unit 2 output $P_2^*$ for each discrete demand step $D$.

The $n$th stage, using units 1, 2, ..., $n$, is also represented by a two-dimensional matrix. Again, the value within the brackets of (2.27) is computed for each discrete value of demand $D$ and unit $n$ output $P_n$. A search through this matrix gives the stage $n$ minimum cost $C_n^*(D)$ and optimum unit $n$ output $P_n^*$ for each demand step $D$.

When $n=N$, all units are considered, and the dynamic programming solution is completed. The actual demand $D$ is then selected, and a search through the final matrix gives the minimum cost and optimum unit $N$ output $P_N^*$. Also optimum unit $n$ output $P_n^*$ for each $n$ is obtained from previous stage $n[17]$.

**2.2.2 Dynamic Programming including losses**

During the first iteration where $i=1$, an initial dynamic programming solution neglecting losses is computed. Then using initial generator outputs from this first solution, transmission line losses $L$ and penalty factors $PF_n$ are computed.

During the second iteration where $i=2$, each cost function is multiplied by its penalty factor to obtain modified cost functions. Then using the same dynamic programming method that neglects losses, the next solution including losses is obtained with these modified cost functions and with $D$ replaced by $(D + L)$.

During further iterations $i=3, 4$, etc., line losses $L$ and penalty factors $PF_n$ are updated after each dynamic programming solution is computed. The demand $D$ is replaced by $(D+L)$, and generator cost functions are modified for the next solution, as follows:

$$C_{n,i} = C_n PF_{n,i-1}$$

(2.29)

where $PF_{n,i-1}$ is the penalty factor computed during iteration $(i-1).$ The iterations continue until a specified tolerance $\varepsilon$ is obtained.
Note that the shape of each modified cost function does not change. Instead, each cost function is increased by an amount equal to its computed penalty factor. The objective is to ensure that \( \lambda \) given by (2.30) is the same for each unit that is not operating at its minimum or maximum output, a requirement for an optimal solution.

\[
PF_n \frac{dC_n}{dP_n} = \lambda \quad n=1,2 \ldots N
\]

(2.30)

Where \( PF_n \) is the penalty factor of unit \( n \) given by:

\[
PF_n = \frac{1}{1 - \frac{\partial L}{\partial P_n}}
\]

(2.31)

Note also that a variety of transmission loss representations can be used with this solution method, including penalty factor computation from an ac load flow. The only requirement is that generator penalty factors need to be calculated from the losses [18].

### 2.2.3 Advantages of Dynamic Programming

Dynamic Programming offers the following advantages compared to other optimization techniques [16]:

- Unlike the traditional lagrangian multiplier method which requires generator incremental cost curves that are monotonically increasing, the dynamic programming method has no restrictions on generator cost functions. Any analytical or empirical cost function versus real power output may be used. Dynamic programming avoids traditional procedures of either flattening out or ignoring those portions of generator incremental costs that are not monotonically increasing; such procedures do not guarantee an accurate dispatch.
- Where short-term load forecasting is available, the dynamic programming method can solve the economic dispatch for present and short-term future demands. Dynamic programming easily handles generator rate constraints, as well as generator minimum/maximum outputs and other power system constraints.
- Computer monitoring of generator fuel input and megawatt output to provide on-line updating of generator cost curves has been proposed. As generator output varies over its operating range, weekly or even daily updates in cost functions can improve economic dispatch accuracy.
CHAPTER 3

Solution To Economic Dispatch Problem Using DP

3.1 Economic Load Dispatch Problem Formulation
The principal objective of the economic load dispatch problem is to find a set of active power delivered by the committed generators to satisfy the required demand subject to the unit technical limits at the lowest production cost. The optimization of the ELD problem is formulated in terms of the fuel cost expressed as[20],

\[ F_T = \sum_{i=1}^{n} F_i(P_{Gi}) = a_i P_{Gi}^3 + b_i P_{Gi}^2 + c_i P_{Gi} + d_i \]  

Subject to the equality constraint,

\[ \sum_{i=1}^{N} P_{Gi} = P_D + P_L \]  

Subject to the inequality constraint,

\[ P_{Gi_{\min}} \leq P_{Gi} \leq P_{Gi_{\max}} \]  

3.2 Principle of Dynamic Programming
The research objects of dynamic programming are multi-stage decision problems. When the dynamic programming method is applied, the first step is to divide a practical issue into stages, describe the state of each stage and define decision variables and indicators. The optimization direction of dynamic programming is from the terminal point \( n \) to the starting point. At terminal point \( n \), the best index function is \( F_n(x_n) \):

\[ F_n(x_n) = \min \{ f_n(x_n, \mu_n(x_n)) \} \]  

Where \( x_n \) is the state of stage \( n \) and \( \mu_n(x_n) \) is the decision variable of this stage. Add the values of the best index functions in the correct order, the best index function value from stage \( n \) to stage \( k \) should be calculated as follows:

\[ F_k^*(x_k) = \min \left\{ f_k(x_k, u_k(x_k)) + F_{k-1}(x_{k-1}) \right\} \]  

Formula (3.5) is also the basic function of dynamic programming. It identifies the recursion relations of index functions.
3.3 Dynamic Programming To Economic Dispatch

The process of building the dynamic programming model to solve economic dispatch is as follows: In a system consisting of \( n \) units, there are \( n \) stages. The \( n \) units were numbered with 1, 2, 3, ..., \( n \). Where \( s_i \): load assigned to the \( i \)-th unit, \( Q_i \): load assigned to the \( i \)-th unit, \( S_i + 1 = S_i - Q_i \): load assigned to the \( i+1 \)-th unit to the \( n \)-th units, \( C_i(Q_i) \): cost of the \( i \)-th unit when its load is \( Q_i \). \( f_i(s_i) \): minimum cost of the \( i \)-th units when their load are \( s_i \). The back stepping expressions are as follows:

\[
\begin{align*}
    f_i(s_i) &= \min_{0 \leq Q_i \leq s_i} \left\{ C_i(Q_i) + f_{i+1}(s_i - Q_i) \right\} \\
    f_n(s_n) &= 0 \quad i = n, n-1, ..., 2, 1
\end{align*}
\]

(3.6)

First, obtain the minimum fuel consumption by calculating backward from the end. Then calculate forward step by step to get the load distributed to each unit. In this way, the problem can be solved [19].

3.4 Proposed Algorithm

The steps taken in solving DP based higher order ED are as follows [21].

**Step 1**: Read input data i.e. cost coefficients, power demand and generator unit maximum and minimum real power constraints.

**Step 2**: Initialize the recursive process for a given demand neglecting the transmission losses. Calculate the optimum generation of each generating unit for the given load demand.

**Step 3**: Using the optimal generation schedule, calculate the total transmission loss of the system.

**Step 4**: Obtain the modified form of self-coefficients. These are coefficients in which losses have been included.

**Step 5**: Find the modified cost equation for each unit using price factor and modified loss coefficients for inclusion of the transmission loss.

**Step 6**: Calculate the total generation required using relation:

\[
\sum_{i=1}^{n} P_i = (\text{Demand + Losses}) = P_{\text{Desired}}
\]
Step 7: Using generalized recursive equation, calculate the generation of each unit for new demand $P_{Dnew}$.

Step 8: Determine the total transmission loss of the system using the new generation schedule.

Step 9: Check if,

$$\sum_{i=1}^{n} P_i - (Demand + Losses) \leq \varepsilon$$

If this equation is satisfied stop the above procedure, otherwise proceed to step 4.
3.5 Flow Chart

Figure 3. 1: Flow chart for DP based ED
CHAPTER 4

Results and Analysis

4.1 Results
To verify the feasibility and effectiveness of the higher order DP a 5-machine 14-bus, a 6-machine 30-bus and a 7-machine 57-bus IEEE Bus systems are used. Economic dispatch with transmission losses for the generators is computed and the results compared with quadratic cost function DP method from [16]. B-loss coefficients matrix of the power system network has been employed to calculate the transmission loss. The software has been written in the MATLAB-programming language.

4.1.1 Case Study: IEEE 14 Bus System

![Figure 4.1: One line diagram of IEEE 14 bus system](image)

The optimal generation of the five generating units and the optimal costs for both higher order DP and quadratic cost function DP is shown in table 4.1 for the system demands of 600MW.
Table 4.1: Optimal generations using 14 bus system for higher order ED and second order ED using DP, Demand=600MW.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{G1}$</td>
<td>150.00</td>
<td></td>
<td>200.00</td>
<td></td>
</tr>
<tr>
<td>$P_{G2}$</td>
<td>168.20</td>
<td></td>
<td>174.10</td>
<td></td>
</tr>
<tr>
<td>$P_{G3}$</td>
<td>113.25</td>
<td></td>
<td>55.22</td>
<td></td>
</tr>
<tr>
<td>$P_{G4}$</td>
<td>90.21</td>
<td></td>
<td>85.00</td>
<td></td>
</tr>
<tr>
<td>$P_{G5}$</td>
<td>78.59</td>
<td></td>
<td>88.84</td>
<td></td>
</tr>
<tr>
<td>Total Output (MW)</td>
<td>600.25</td>
<td>603.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Losses (MW)</td>
<td>0.25</td>
<td>3.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Generation Cost ($/hr)</td>
<td>18217.59</td>
<td>18305.91</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.1.2 IEEE 30 Bus System

Figure 4. 2: One line diagram for IEEE 30 bus system

The optimal generation of the six generating units and the optimal costs for both higher order DP and quadratic cost function DP is shown in table 4.2 for the system demands of 600MW.
Table 4.2: Optimal generations using 30 bus system for higher order ED and second order ED using DP, Demand=600MW.

<table>
<thead>
<tr>
<th>Unit Power Output (MW)</th>
<th>Proposed Higher Order DP method</th>
<th>Second Order DP method [22]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{G1}$</td>
<td>150.00</td>
<td>23.84</td>
</tr>
<tr>
<td>$P_{G2}$</td>
<td>147.91</td>
<td>10.00</td>
</tr>
<tr>
<td>$P_{G3}$</td>
<td>82.85</td>
<td>95.57</td>
</tr>
<tr>
<td>$P_{G4}$</td>
<td>97.47</td>
<td>100.52</td>
</tr>
<tr>
<td>$P_{G5}$</td>
<td>67.26</td>
<td>202.78</td>
</tr>
<tr>
<td>$P_{G6}$</td>
<td>54.73</td>
<td>181.52</td>
</tr>
<tr>
<td>Total Output (MW)</td>
<td>600.22</td>
<td>614.23</td>
</tr>
<tr>
<td>Losses (MW)</td>
<td>0.22</td>
<td>14.23</td>
</tr>
<tr>
<td>Total Generation Cost ($/hr)</td>
<td>18216.68</td>
<td>18641.88</td>
</tr>
</tbody>
</table>
4.1.3: **IEEE 57 bus system**

**Figure 4.3:** One line diagram for IEEE 57 bus system

The optimal generation of the seven generating units and the optimal costs for both higher order DP and quadratic cost function DP is shown in table 4.3 for the system demand of 600MW.
Table 4.3: Optimal generations using 57 bus system for higher order ED and second order ED using DP, Demand=600MW.

<table>
<thead>
<tr>
<th>Unit Power Output (MW)</th>
<th>Proposed Higher Order DP method</th>
<th>Second Order DP method [22]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{G1}$</td>
<td>150.00</td>
<td>200.00</td>
</tr>
<tr>
<td>$P_{G2}$</td>
<td>129.80</td>
<td>80.00</td>
</tr>
<tr>
<td>$P_{G3}$</td>
<td>103.38</td>
<td>46.01</td>
</tr>
<tr>
<td>$P_{G4}$</td>
<td>52.29</td>
<td>35.00</td>
</tr>
<tr>
<td>$P_{G5}$</td>
<td>50.00</td>
<td>30.00</td>
</tr>
<tr>
<td>$P_{G6}$</td>
<td>64.73</td>
<td>106.89</td>
</tr>
<tr>
<td>$P_{G7}$</td>
<td>50.00</td>
<td>129.59</td>
</tr>
<tr>
<td><strong>Total Output (MW)</strong></td>
<td><strong>600.20</strong></td>
<td><strong>627.50</strong></td>
</tr>
<tr>
<td><strong>Losses (MW)</strong></td>
<td><strong>0.2</strong></td>
<td><strong>27.50</strong></td>
</tr>
<tr>
<td><strong>Total Generation Cost ($/hr)</strong></td>
<td><strong>18216.07</strong></td>
<td><strong>19044.625</strong></td>
</tr>
</tbody>
</table>

4.2 Analysis

From tables 4.1, 4.2 and 4.3 we see that power loss decreases as we move from 14 bus system to 57 bus system in the higher order DP as compared to the second order DP, which loss increases as we move to larger buses. This shows that the higher order DP is better suited for systems with larger buses. The losses are also significantly lower for higher order DP than lower order DP signifying a higher level of accuracy.

Optimal fuel costs for the same power demand decreases as we move from the 14 bus system to the 57 bus system in the higher order DP method, as compared to the second order DP method where under the same conditions the fuel cost increases. This is due to lower loses in the higher order method leading to lower power being generated thus lower fuel cost.
CHAPTER 5

CONCLUSION AND RECOMMENDATION FOR FURTHER WORK

5.1 Conclusion
The project applied higher order DP method for the solution of ELD. The objectives of the project were to establish the accuracy of the proposed method and also to minimize the generation costs while taking into account generator constraints and transmission losses. The superiority of the proposed method was demonstrated when it was tested on an IEEE 30 bus system and the results compared with published work. The simulation results show that the proposed method offered a more cost effective production cost with negligible computational time. The proposed method also has the ability to give high quality solutions reliably with fast convergence characteristics. It gives the same optimal solution for different trials and it can be implemented for a system consisting of a greater number of generating units.

5.2 Recommendations for Further Work
   1. Hybrid methodology is the useful tool for efficient solution by exploiting the strengths of DP with the powers of other techniques. By appropriate integration of both approaches to solve ELD problems, better results can be obtained with less computational time.
   2. Instead of using purely thermal generating units, renewable sources of energy such as solar and wind, could be used instead.
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APPENDIX

Table 1: Generator Data For IEEE 30 Bus System

<table>
<thead>
<tr>
<th>Unit</th>
<th>$a_i$(MW/$$)</th>
<th>$b_i$(MW/$$)</th>
<th>$c_i$(MW/$$)</th>
<th>$d_i$(MW/$$)</th>
<th>$P_{imin}$(MW)</th>
<th>$P_{imax}$(MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0016</td>
<td>2.00</td>
<td>150.0</td>
<td>756.798</td>
<td>100</td>
<td>500</td>
</tr>
<tr>
<td>2</td>
<td>0.0100</td>
<td>2.50</td>
<td>250.0</td>
<td>451.325</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>3</td>
<td>0.0625</td>
<td>1.00</td>
<td>0.0</td>
<td>1049.997</td>
<td>80</td>
<td>300</td>
</tr>
<tr>
<td>4</td>
<td>0.0083</td>
<td>3.25</td>
<td>0.0</td>
<td>1243.531</td>
<td>50</td>
<td>150</td>
</tr>
<tr>
<td>5</td>
<td>0.0250</td>
<td>3.00</td>
<td>0.0</td>
<td>1658.559</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>6</td>
<td>0.0250</td>
<td>3.00</td>
<td>0.0</td>
<td>1356.659</td>
<td>50</td>
<td>120</td>
</tr>
</tbody>
</table>

Table 2: B-Coefficient Matrix

\[ \mathbf{B} = \begin{bmatrix}
0.000140 & 0.000017 & 0.000015 & 0.000019 & 0.000026 & 0.000022 \\
0.000017 & 0.000060 & 0.000013 & 0.000016 & 0.000015 & 0.000020 \\
0.000015 & 0.000013 & 0.000065 & 0.000017 & 0.000024 & 0.000019 \\
0.000019 & 0.000016 & 0.000017 & 0.000071 & 0.000030 & 0.000025 \\
0.000026 & 0.000015 & 0.000024 & 0.000030 & 0.000069 & 0.000032 \\
0.000022 & 0.000020 & 0.000019 & 0.000025 & 0.000032 & 0.000085 \\
\end{bmatrix} \]
clear;
clc;
global objfun D ub lb data B Pd
% 1.a ($/MW^2) 2. b $/MW 3. c ($) 4.lower lomit(MW) 5.Upper limit(MW)
%no of rows denote the no of plants(n)
data = [ 1 0.0016 2.00 150 100 500; 2 0.0100 2.50 25 50 200; 3 0.0625 1.00 0.0 80 300; 4 0.0083 3.25 0.0 50 150; 5 0.025 3.00 0.0 50 200; 6 0.025 3.00 0.0 50 120;];
B = 0.001*[ 0.0017 0.0012 0.0007 -0.0001 -0.0005 -0.0002; 0.00014 0.0009 0.0001 -0.0006 -0.0001; 0.0007 0.0009 0.0031 0.0000 -0.0010 -0.0006; -0.0001 0.0001 0.0000 0.0024 -0.0006 -0.0008; -0.0005 -0.0006 -0.0010 -0.0006 0.0129 -0.0002; -0.0002 -0.0001 -0.0006 -0.0008 -0.0002 0.0150;];
Pd=600;
lb=data(:,5)';
ub=data(:,6)';
D=length(data(:,1));
NP=20;
FoodNumber=NP/2;
limit=100;
maxCycle=1000;

runtime=1;

runABC;
R=GlobalParams;
[ F P1 Pl]=abceld1(R)
global objfun D ub lb
GlobalMins=zeros(1,runtime);
for r=1:runtime

Range = repmat((ub-lb),[FoodNumber 1]);
Lower = repmat(lb, [FoodNumber 1]);
Foods = rand(FoodNumber,D).*Range + Lower;

ObjVal=feval(objfun,Foods);
Fitness=calculateFitness(ObjVal);
%reset trial counters
trial=zeros(1,FoodNumber);

BestInd=find(ObjVal==min(ObjVal));
BestInd=BestInd(end);
GlobalMin=ObjVal(BestInd);
GlobalParams=Foods(BestInd,:);

iter=1;
while ((iter <= maxCycle)),

    for i=1:(FoodNumber)

        Param2Change=fix(rand*D)+1;
        neighbour=fix(rand*(FoodNumber))+1;

            while (neighbour==i)
                neighbour=fix(rand*(FoodNumber))+1;
            end;

        sol=Foods(i,:);

        sol(Param2Change)=Foods(i,Param2Change)+(Foods(i,Param2Change) - Foods(neighbour,Param2Change))*(rand-0.5)*2;

        ind=find(sol<lb);
        sol(ind)=lb(ind);
        ind=find(sol>ub);
        sol(ind)=ub(ind);

        %evaluate new solution
        ObjValSol=feval(objfun,sol);
        FitnessSol=calculateFitness(ObjValSol);

        if (FitnessSol>Fitness(i))
            Foods(i,:)=sol;
            Fitness(i)=FitnessSol;
            ObjVal(i)=ObjValSol;
            trial(i)=0;
        else
            trial(i)=trial(i)+1;
        end;

    end;

%%%%%%%%%%%%%%%% CalculateProbabilities %%%%%%%%%%%%%%%%%

prob=(0.9.*Fitness./max(Fitness))+0.1;
i=1;
t=0;
while (t<FoodNumber)
    if (rand<prob(i))
        t=t+1;
        Param2Change=fix(rand*D)+1;

        neighbour=fix(rand*(FoodNumber))+1;

        while (neighbour==i)
            neighbour=fix(rand*(FoodNumber))+1;
        end

        sol=Foods(i,:);

        sol(Param2Change)=Foods(i,Param2Change)+(Foods(i,Param2Change)
- Foods(neighbour,Param2Change))*(rand-0.5)*2;

        ind=find(sol<lb);
        sol(ind)=lb(ind);
        ind=find(sol>ub);
        sol(ind)=ub(ind);

        %evaluate new solution
        ObjValSol=feval(objfun,sol);
        FitnessSol=calculateFitness(ObjValSol);

        if (FitnessSol>Fitness(i))
            Foods(i,:)=sol;
            Fitness(i)=FitnessSol;
            ObjVal(i)=ObjValSol;
            trial(i)=0;
        else
            trial(i)=trial(i)+1;
        end
    end
i=i+1;
if (i==(FoodNumber)+1)
i=1;
end
end;

ind=find(ObjVal==min(ObjVal));
ind=ind(end);
if (ObjVal(ind)<GlobalMin)
    GlobalMin=ObjVal(ind);
    GlobalParams=Foods(ind,:);
end;

ind=find(trial==max(trial));
ind=ind(end);
if (trial(ind)>limit)
    Bas(ind)=0;
    sol=(ub-lb).*rand(1,D)+lb;
    ObjValSol=feval(objfun,sol);
    FitnessSol=calculateFitness(ObjValSol);
    Foods(ind,:)=sol;
    Fitness(ind)=FitnessSol;
    ObjVal(ind)=ObjValSol;
end;

fprintf('Iter=%d ObjVal=\%g\n',iter,GlobalMin);
iter=iter+1;
end

GlobalMins(r)=GlobalMin;
end; %end of runs

save all