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Economic Load Dispatch Using the Conventional and Intelligent Methods

إرسال الحمل الإقتصادي بإستخدام الطرق التقليدية والذكية

A Thesis Submitted as Partial Fulfillment for Requirements of the Degree of Master of Science in electrical Engineering

(Power**)**

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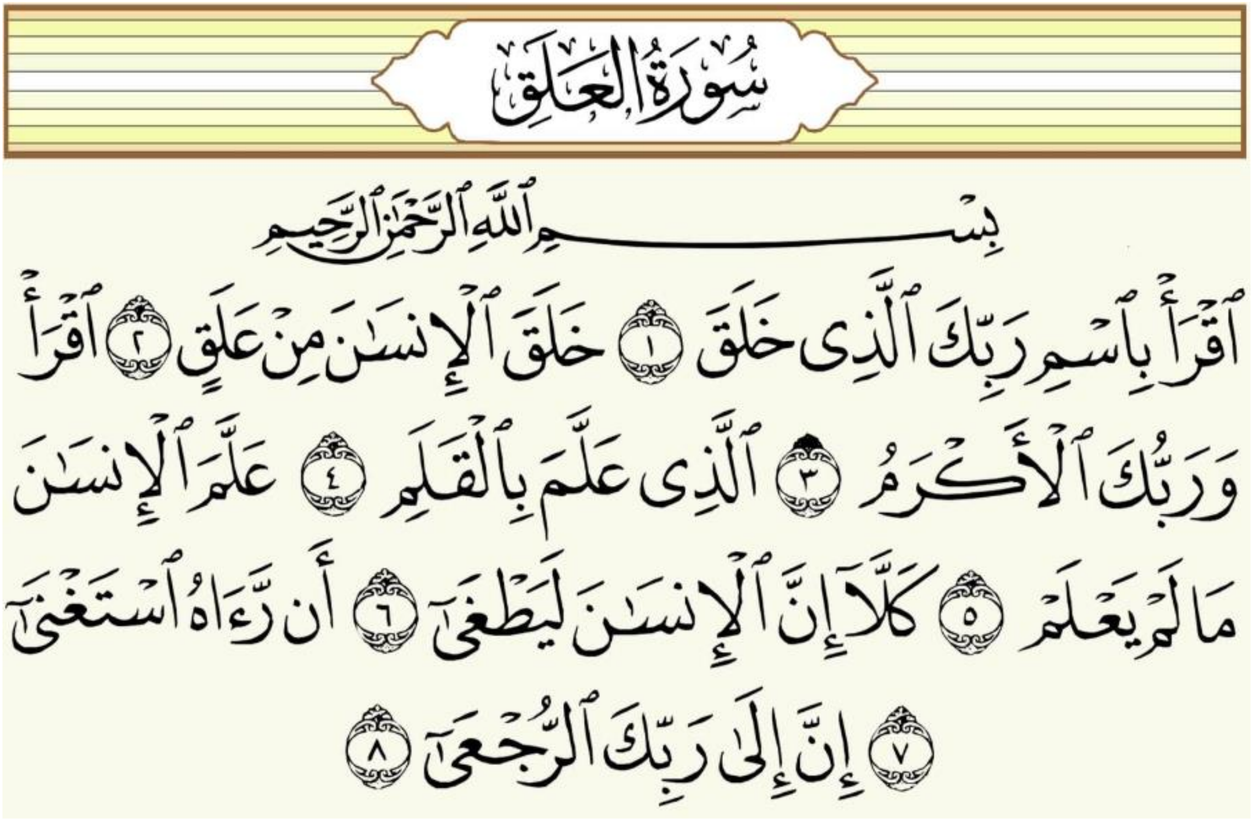

سُورَةُ العَلَق

بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

ٱقْرَأْ بِٱسْمِ رَبِّكَ ٱلَّذِى خَلَقَ ﴿١﴾ خَلَقَ ٱلْإِنسَٰنَ مِنْ عَلَقٍ ﴿٢﴾ ٱقْرَأْ
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صدق الله الهظيم

سورة العلق الايات(1-8)

Dedication

This research is dedicated to both those who supports me and especially my family

Father

Mather

Prather's

Sisters

My wife

Friends

ACKNOWLEDGMENT

First and foremost, I wish to appreciate the Almighty God for His amazing grace throughout my academic life. His love and guidance has propelled me to get this far. I extend my appreciation goes to my supervisor Dr. Alfadil Zackaria yahia for ensuring that I had all the necessary guidance and support during the entire period of this project besides being a great mentor.

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ABSTRACT

This thesis introduces the importance of economic dispatch in a power system. Economic dispatch was the method use in allocate the output power of each generator in order to achieve the optimal dispatch to reduce fuel cost to the minimum. The thesis discusses how the economic dispatch problem can be solved by using the methods of Particle Swarm Optimization (PSO) and Lambda Iteration (LI). These two methods were applied in IEEE-30 busses systems. The system was tested on a few load demands to find out the total fuel cost, power losses and computational time. From the result obtained, comparison was made between (PSO & LI) methods to discover which produced the lower total cost in solving the ED problem. All the analysis was based on the transmission line losses constraint. Besides, the power limit constraint for generators will also be considered. From the results (PSO) able to produce lower fuel cost compared to (LI). As a conclusion, (PSO) was better accuracy in solving Economic Dispatch problem. Means that the use of (PSO) reduces the cost of petroleum fuel, which contributes to protecting the environment from pollution and damage caused by petroleum derivatives

مستخلص

هذه الاطروحة تقدم أهمية التشغيل الإقتصادي لأنظمة القدرة الكهربائية .الإرسال الإقتصادي هو طريقة تخصيص الطاقة الانتاجية لكل مولد من أجل خفض تكلفة الوقود إلى الحد الأدنى . تناقش الإطروحة كيفية حل مشكلة التشغيل الإقتصادي بإستخدام طريقة أساليب السرب وطريقة لامبدا التكرارية, طبقت الطريقتين علي منظومة كهربائية في النظام العالمي يتكون من ستة وحدات و30موصل عمومي بمساعدة برنامج الحاسوب ((ماتلاب).

حيث تم الإختبار علي أحمال كهربائية مختلفة بالطريقتين وتم حساب التكلفة الكلية ,الفقودات الكهربائية وزمن التنفيذ وعمل مقارنة للنتائج بين الطريقتين وتحديد الطريقة الأمثل من حيث دقة الحلول والسرعة . حيث إستند هذا التحليل علي قيود فقودات خطوط النقل والحد الأدني والحد الأقصي للمولدات الكهربائية,وبالنسبة لطريقة اساليب السرب كانت هناك حاجة إلى مجموعة أدوات التحسين التي ستنفذ إلى ماتلاب من أجل تشغيل التشفيرات ومن خلال تحليل النتائج تم التوصل الي ان طريقة تحسين سرب الجسيمات هي الأفضل من حيث تقليل تكلفة الوقود ومفقودات خطوط النقل بالإضافة الي التحسين العام علي المستوي البيئي وحماية الإنسان من المخلفات والمشتقات البترولية.

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List of symbols

W	Weight factor
C_1, C_2	Acceleration constant
R_1 , R_2	Random number
λ	System Lambda
B	Losses coefficient
V_i	Velocity of particle
P_i	Position of particle
$\mathrm{P_{g\ ,Q_g}}$	Real and reactive power generation
$P_{D\ ,Q_D}$	Real and reactive power demand
ν , δ	Bus voltage and phase angle

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

Electrical power systems are designed and operated to meet the continuous variation of power demand. In power system minimization of the operation cost is very important. Economic Load Dispatch (ELD) is a method to schedule the power generator outputs with respect to the load demands, and to operate the power system most economically, or in other words, we can say that main objective of economic load dispatch is to allocate the optimal power generation from different units at the lowest cost possible while meeting all system constraints. Power plants in a practical power system are not located at the same distance from the centre of loads and their fuel costs are different under normal operating conditions, the generation capacity is more than the total load demand and losses. However the fundamental requirements of a system should be secure, economical and reliable [1].

Economical operation is very important for a given power system to return a profit on the capital invested. Power companies are always under constant pressure to achieve maximum possible efficiency due to the rates fixed by the regulatory bodies and the importance of conservation of fuel, the maximum efficiency refers to minimized cost per kilowatt hour to the consumer and the cost of the company delivering that power regardless of the constantly rising prices of lab our, fuel, supply and maintenance. Basically in economic operation in power generation is divided to economic load dispatch which deals with scheduling the outputs of generating units by allocating them. The generating levels hence it aims at economizing the whole generation process to meet the system load demand and losses. This entails proper allocation of power output among the generating units when the cost of production is minimized by satisfying the unit constraints. Many advanced approaches have been developed towards solving the economic dispatch problem. Among the conventional methods include Quadratic Programming (QP), Interior Point method (IP), Linear Programming (LP), Lambda Iteration (LI), gradient method and so, while the intelligent methods include Genetic Algorithm (GA) Anti-colony Optimization method, Particle Swarm Optimization (PSO), Differential Evaluation (DE) and Tabu Search method (TS) [2].

In this project other optimization methods will be discussing but particle swarm optimization and lambda iteration been apply to solve the economic dispatch problem in thermal plant and satisfying the system constraints to minimize the cost of power generator.

The particle swarm optimization algorithm and lambda iteration is implementing using MATLAB code and the standard IEEE-30 busses system data is use, with different load demand.

1.2 Problem Statement

The discrepancy in fuel cost of generators of power system is usually not situated at same distance from the center of load. The output of generators are usually not at the optimum level for demand of load, this will increase the cost of generation. It is important to investigate the power of generators in power system in order to adjust the power in the way of most cost saving. If the generators are not efficient, energy will be lost and the fuel cost to be increased, the extra burning fuel will pollute the environment, and also will increase the burden for both electricity supplier and customers.

1.3 Objectives

(i) To understand what are the economic load dispatch problems, unit commitment, thermal hydro constrains of the systems.

(ii) To schedule the committed generating unit outputs so as to meet the load demand at minimum operating cost while satisfying all units and operational constraints of the power system.

(iii) To understand the intelligent and conventional methods as Particle Swarm Optimization (PSO), Lambda Iteration (LI)) and use it to find the optimal solution for the case of Economic Load Dispatch (ELD).

(iv) To compare the results of fuel cost and power losses that are obtain from Lambda Iteration (LI) and Particle Swarm Optimization (PSO) methods.

1.4 Methodology

In this thesis study will be discussed about the economic load dispatch problem with the consideration of transmission loss. The method of Particle Swarm Optimization (PSO) and Lambda Iteration (LI) will be used to analyze the cost function by investigating the fuel cost of each generators and the total cost needed in order to generate the desired power demand. The software that will be used for analysis is computer programming (MATLAB). It will assist in the mathematical iteration of Particle Swarm Optimization and Lambda Iteration methods. The size of the power system and the amount of generators which are involved in the study will be determined according to the standard case by considering the equality and inequality constraints. The power system will be referred to standard IEEE- 30 busses system.

1.5 Thesis Layout

This thesis consists of six chapters. Chapter 1 discusses the introduction, problem statement, objectives and methodology, chapter 2 discusses the literature reviews, introduction of economic load dispatch problems, solution, characteristics of thermal and hydro power plants, computational methods and Unit commitment, chapter 3 had the conventional and intelligent methods which applied in solving economic load dispatch, chapter 4 discusses Lambda Iteration (LI) and Particle Swarm Optimization (PSO),chapter 5 represent results, discussions, and comparison, after that, chapter 6 will discuss the conclusion and the recommendations of the research based on the analysis part.

CHAPTER TWO

LITERATURE REVIEWAND ECONOMIC LOAD DISPATCH

2.1 Literature review

The progress of optimal dispatch goes far back as the early 1920s, when engineers were concerned with the problem of economic allocation of generation or the proper division of the load among the generating units available. Prior to 1930, various methods were in use such as the base load method where the next most efficient unit is loaded to its maximum capability, then the second most efficient unit is loaded, etc. Best point loading, where units are successively loaded to their lowest heat rate point, beginning with the most efficient unit and working down to the least efficient unit, etc. It was recognized as early as 1930, that the incremental method, later known as the equal incremental method, yielded the most economic results. In 1954, coordination equation was developed for solving economic dispatch problem. A breakthrough in the mathematical formulation of the economic dispatch problem was achieved by Carpentier in the early 1960‟s who treated the entire work in an exact manner. The solution of Carpentier formulation is a non-linear optimization which has been the subject of much study though the present and its implementation in real time remains a challenge.

Presented a several classical optimization techniques for solving economic Load dispatch problem. These are Lambda Iteration Method, Gradient method and Dynamic Programming (DP) method, etc [1].

Presented an effective and reliable particle swarm optimization (PSO) technique for the economic load dispatch problem using the standard 3-

generator and 6-generator systems with and without consideration of transmission losses. The final results obtained using PSO are compared with conventional quadratic programming and found to be encouraging [3].

Presented an application of Genetic Algorithm (GA) to solve Economic Load Dispatch (ELD) problems with smooth and non-smooth fuel cost objective functions. Several cases were tested and verified, among of them, two cases of 6-units and 40-units systems including losses with smooth and non-smooth cost functions. And concluded that GA proves an excellent viability to optimize and solve problems of ELD [4].

Developed Differential Evolution (PDE) technique to solve Multi Objective Economic Dispatch (MOED) problem. The proposed method was implemented on the standard IEEE-30 bus system having six generating units including valve point effects to evaluate its performance and applicability. From the results obtained, the proposed method demonstrated its effectiveness by solving the Multi Objective economic dispatch problem considering security constraints [5].

Presented the economic power dispatch problems using ant colony optimization (ACO) technique which is a meta-heuristic approach for solving hard combinatorial optimization problems. This technique was tested using the standard IEEE 26-Bus and the results revealed that the proposed technique has the merit in achieving optimal solution for addressing the problems. Comparative studies with artificial immune system (AIS) were also conducted in order to highlight the strength of the proposed technique [6].

Presented an effective and reliable particle swarm optimization (PSO) technique for the economic load dispatch problem. Using the standard 3-

generator and 6-generator systems with and without consideration of transmission losses. The final results obtained using PSO are compared with conventional quadratic programming and found to be encouraging [7].

Proposed a method for solving economic dispatch problem using Particle Swarm Optimization (PSO) Algorithm and Simulated Annealing (SA) for the three generating units as a case study. PSO and SA were applied to find out the minimum cost for different power demand. They compared their results with the traditional technique, where PSO displayed better result and better convergence characteristic [8].

Presented the overview of different methods for solving economic load dispatch (ELD) problem using MATLAB. They concluded that lambda iteration method converges rapidly but complexities increases as system size increase. Gradient and Newton methods can only be applied where cost function is much more complex while for the non convex input-output curves, dynamic programming method can be used to solve the economic load dispatch problem [9].

Presented an application of the Genetic Algorithm method (GAMS) to power economic dispatch (PED) problem with Power loss for 3 and 6 generator test case systems. The simulation results show that the proposed GAMS Method outperforms previous optimization methods [10].

Presented lambda iteration method to solve the Economic Load Dispatch (ELD) problem using MATLAB for the three and six generating units with and without transmission losses [11].

Said that particle swarm optimization is an extremely simple algorithm that seems to be effective for optimizing a wide range of functions. PSO method is composed of a set of particles called individuals, which are able to follow a certain algorithm to obtain the best solution for an optimization problem. These particles explore the search space with different velocities and positions [12].

2.2 Economic Load Dispatch (ELD)

Power system operation and planning involves the study of several problems like load flows, Economic Dispatch, Unit Commitment, Reactive Power Control, Power System Stability and Relay Coordination. Among these problems ED and UC are broadly classified as optimization problems and are ranked high among the major tasks in power system operation and planning. Several researchers in the past have attempted to solve these problems by conventional optimization techniques and Heuristic methods. The ED has been usually considered as the minimization of an objective function representing the generation cost. The constraints involved are physical laws governing the power generation transmission systems and operating limitation of the equipment [2].

Economic load dispatch is one of the most important problems to be solved for the economic operation of a power system. Economic load dispatch is to define the production level of each plant so that the cost of fuel is reduced for the prescribed schedule of load. The objective of economic load dispatch is to allocate the generation among the committed units such that the cost of fuel is minimized, while satisfying all the system constraints [2]. Economic Load Dispatch (ELD) is the short term determination of optimal output of power generation facilities to basically meet the system load at the lowest possible cost, while serving power to the demand in a robust and reliable manner [12].

2.2.1 The optimization

Optimization can be defined as the maximization or minimization of a given function with some defined constraints. In engineering perspective the techniques, methodology and procedures are used to decide on the specific solution in a defined set of possible alternatives that will be most suitable to satisfy a selected problem [2]. The main objective of optimization is to obtain the best results subject to restrictions or constraints that are imposed [2].

2.2.2 Problem of the optimum dispatch formulation

The economic dispatch is one sub problem of the Unit Commitment (UC) problem. It is a nonlinear programming optimization one. Practically, while the scheduled combination units at each specific period of operation are listed, the primary concern of an (ELD) problem is the minimization of its objective function. The total cost generated that meets the demand and satisfies all other constraints associated is selected as the objective function [13].

2.2.3 Solution of economic dispatch problem

To solve economic dispatch problem different kinds of constraints and multiple objectives have been incorporated using various optimization techniques. In traditional (ED) problem, the cost function for each generator has been expressed by a simple quadratic function that is solved by conventional methods. In the modern units the input and output characteristics are highly nonlinear with valve point effects and rate limits are having multiple local minimum points in the cost function. In consideration of highly non-linear characteristics of the units requires high robust algorithms to avoid getting stuck at the local optima. These algorithms belong to the larger class of guided random search technique [2].

2.2.4 The steam variables

To analyze the power system network there is a need of knowing the system variables they are [14].

(i) Control variables ($P_{g\ and\ Q_g}$)

The real and reactive power generations are called control variables since they are used to control the state of the system.

(ii) Disturbance variables($P_{D\ and}\ Q_D$)

The real and reactive power demands are demand variables since they are beyond the system control and are hence considered as uncontrolled variables.

(iii) State variables ($v\ and\ \delta$)

The buses voltage magnitude (v) and phase angle (δ) dispatch of the system, these are dependant variables that are being controlled by the control variables [14].

2.2.5 Economic load dispatch –thermal stations

A power system is a mix of different type of generations, out of which thermal, hydro and nuclear power generations contribute the active share. However, economic operation has conveniently been considered by proper scheduling of thermal or hydrogenation only. As for the safety of nuclear station, these types of stations are required to run at its base loads only and there is a little scope for the schedule of nuclear plants in practice Economy of operation is most significant in case of thermal stations, as the variable costs are much higher compared to other type of generations, shown in table (2.1) [15].

Table (2.1) various costs of different stations

Costs	Thermal stations	Hydro stations	Nuclear stations
Fixed costs	20%	75%	70%
Fuel costs	70%	0%	20%
Other operational costs	10%	25%	10%

2.2.6 Generator Operating Cost Curves

The major component of the generator operating cost is the fuel input/hour, while maintenance contributes only to a small extent. The fuel cost is meaningful incase of thermal and nuclear stations, but for the hydro station where the energy storage is “apparently free‟, the operating cost of such is not meaningful [15].

2.2.7 Input-output characteristic of thermal units

The generating unit fuel consumption function or operating cost function for the thermal units are also called the input-output characteristics. In addition to the fuel consumption cost, the operating cost of a unit includes lab our cost, maintenance cost, and fuel transportation cost. It is difficult to express these costs directly as a function of the output of the unit, so these costs are included as a fixed portion of the operating cost. The Thermal unit system generally consists of the boiler, the steam turbine, and the generator. The input of the boiler is fuel, and the output is the volume of steam. The input output curve of a unit can be expressed in million kilocalories per hour or directly in terms of Rs./hour versus output in megawatts. The cost curve can be determined experimentally [16]. A typical curve is shown in the fig (2.1). Where (MW) min is the minimum-loading limit below which it is uneconomical to operate the unit and (MW) max is the maximum output limit. By fitting a suitable degree polynomial, an expression for classical smooth fuel operating cost can be written as.

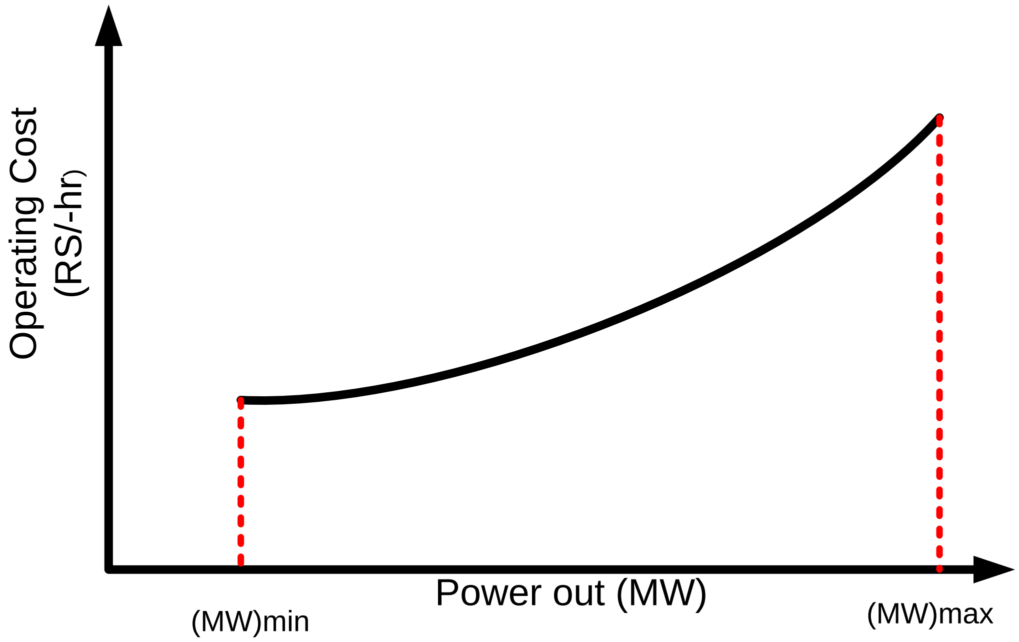

Fig (2.1) Input-Output curve of a generating unit

$$f_i(P_{gi})={}^1/_2\, a_i P^2(g_i) + b_i P(gi) + C_i \qquad (2.1)$$

Where P_{gi} is the power of the i^{th} generating unit, a_i b_i C_i are the fuel cost coefficients of the i^{th} generating unit.

2.2.8 Non-Smooth Fuel Cost Functions including Valve-point Loading Effects

The generating units with multi-valve steam turbines exhibit a greater variation in the fuel cost functions. Since the valve point results in the ripples cost function contains higher order nonlinearity. Therefore, the cost function should be modified to consider the valve-point effects, the ripples like in to take account for the valve-point effects, sinusoidal functions are added to the quadratic cost functions as follows in fig (2.2) [17].

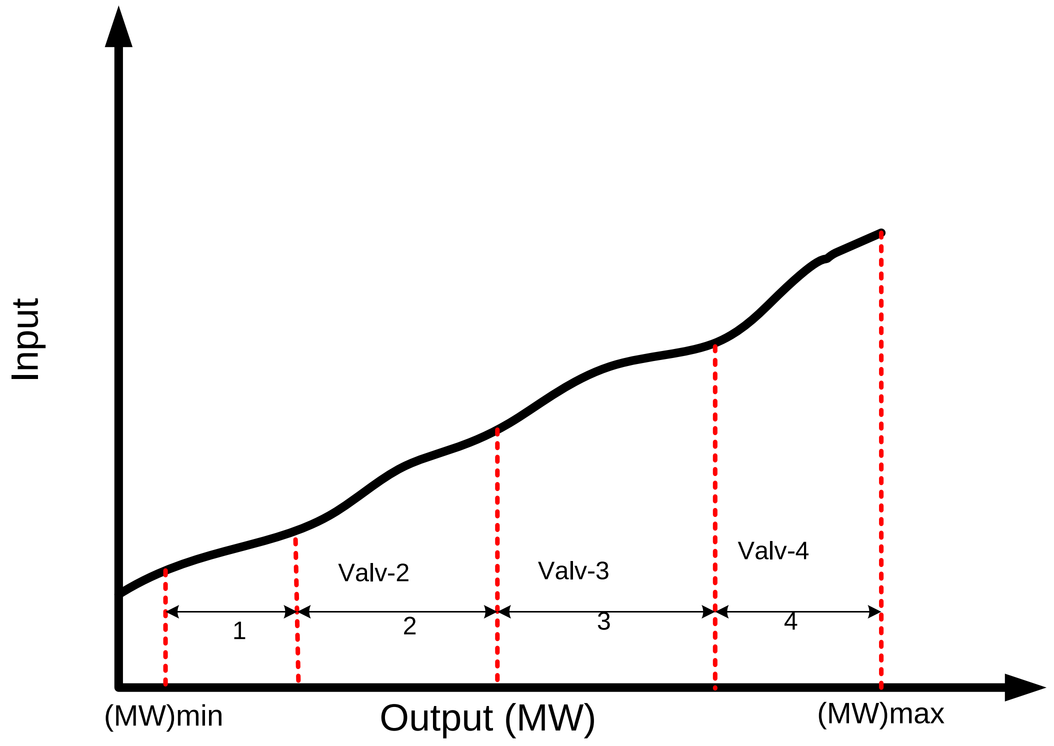

Fig (2.2) non smooth fuel cost function curve

$$PC_i(P_i) = a_i{P_i}^2 + b_i p_i + c_i + \left|e_i * \sin\left(\left(f_i * (P_{imin} - P_i)\right)\right)\right| \qquad (2.2)$$

Where: a_i b_i c_i are the fuel cost coefficients of the $_{i}^{th}$ generating unit and, e_i, f_i , C_i are the coefficients of generator (I) reflecting valve-point loading effects.

These classical and non-classical models either with smooth or non-smoothed fuel cost functions are subjected to the following equality and inequality constraints:

2.2.9 Incremental fuel cost curve

From the input-output curves the incremental fuel cost (IFC) curve can be obtained it is expressed in terms of $(Rs/MWhr)$.

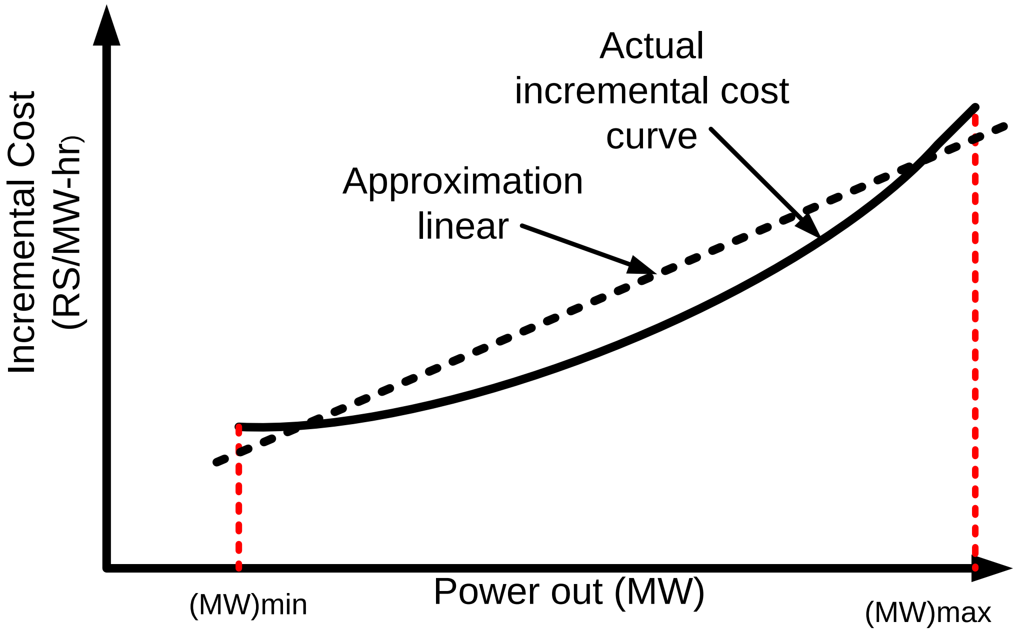

Fig (2.3) incremental cost curve

A typical plot of this curve is shown in fig (2.3) a above For better accuracy incremental fuel cost may be expressed by a number of short line segments (piecewise linearization) alternatively we can fit a polynomial of suitable degree to represent IC curve in the inverse form equation [14]. Significance The curve represents the increase in cost rate per increase in one mega watt output.

2.2.10 Heat Rate Characteristic

Sometimes the unit net heat rate characteristic is also considered important. To obtain this characteristic the net heat rate in

$(K.CAL/KWhr)$ is plotted a against the power output Fig(2.4) The thermal efficiency of the unit is influenced by factors like steam condition, reheat stages, condenser pressure and the steam cycle used. The efficiency of the units in practice is around 30% [1].

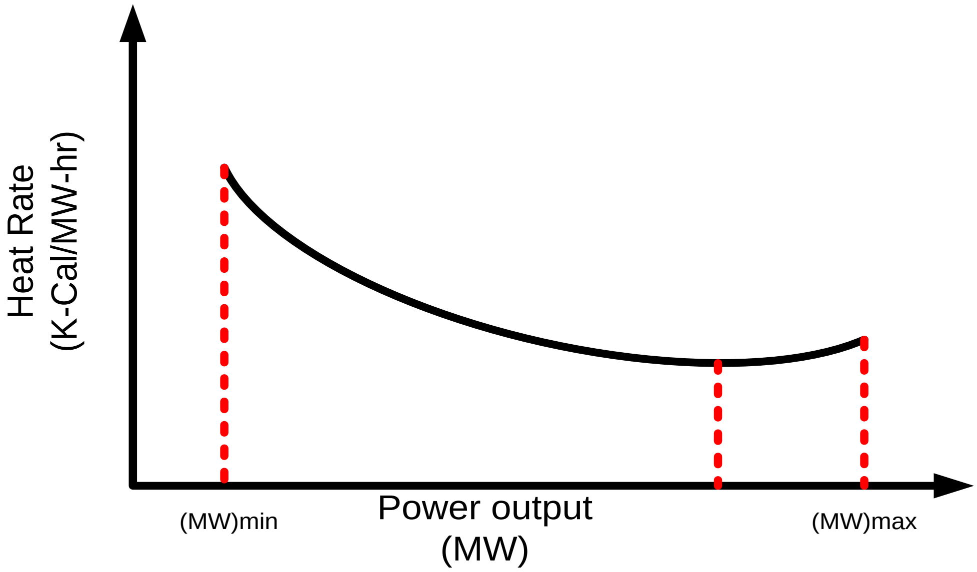

Fig (2.4) Heat rate characteristic

2.2.11 Incremental Production Cost Characteristics

The production cost of the power generated actually depends on several items such as fuel cost, lab-our charges, cost of items such as oil, water and other supplies needed and also the cost of maintenance. It is well known that in thermal generation the fuel cost is by far the largest cost head and is directly related to the power generated. Even the other charges, that is the additional running expenses too are, more or less, related to the amount of generation. Thus, it is a simple practical proposition to assume that, all the additional costs as a fixed percentage of the incremental fuel cost.

The sum of incremental fuel cost and other incremental running expenses is called incremental production cost [16].

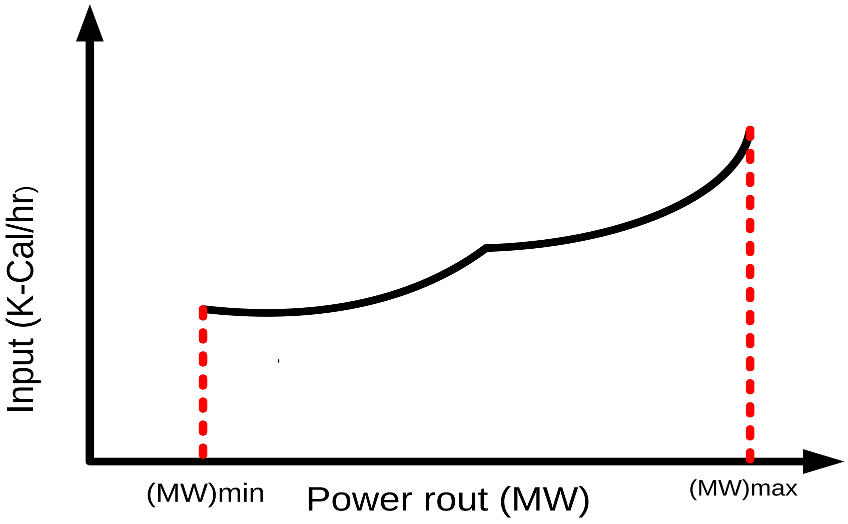

Fig (2.5) incremental production cost

2.2.12 Characteristics of Hydroplanes

The input output characteristics for hydro units can be obtained in the same way as for thermal units on the assumption of constant water head. The input-output characteristic may be as shown in Fig(2.6) The ordinates are water input or discharge in cubic meters per second shown against power output in megawatts. While the water requirement is nearly linear till rated load, after that the efficiency decreases and greater discharge is required to meet the increased load demand [16].

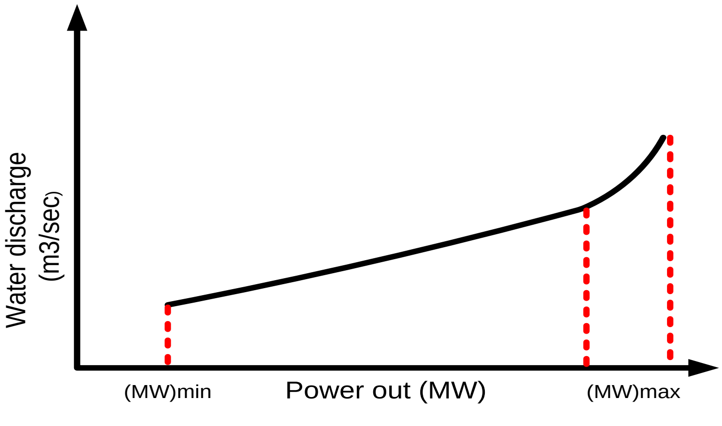

Fig (2.6) Input-output characteristic for hydro unit

It may be noted that, if the head varies the input-output characteristics change. it will move vertically upwards, as head falls and vice versa since the hydro power generated is directly related to the head of the water level and as head falls, higher water discharge is required for the same power generation as shown in fig (2.7).

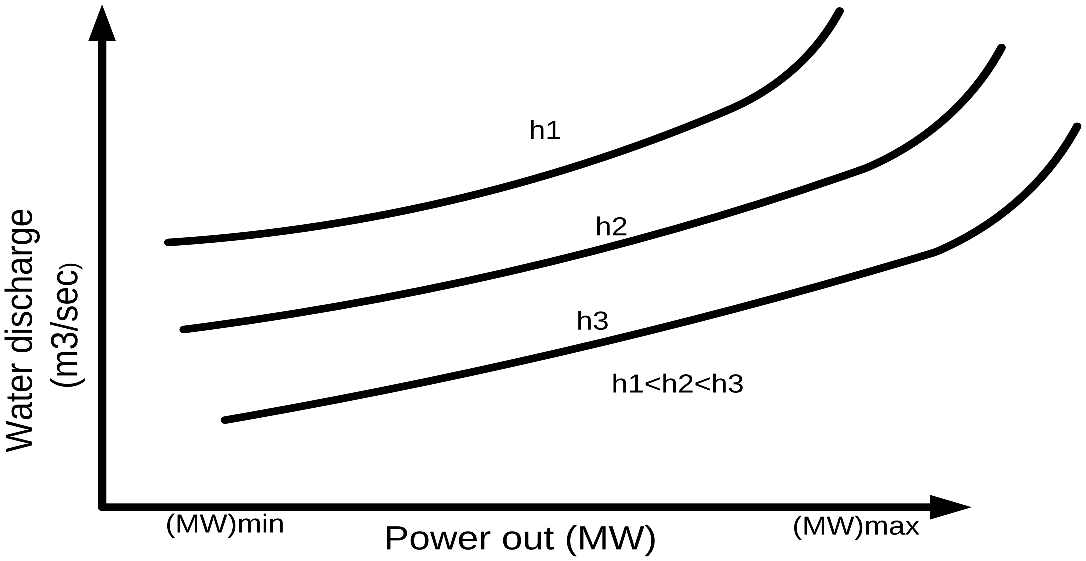

Fig (2.7) Effect of head on discharge for hydro unit

2.2.13 Incremental Water Rate Characteristics

The incremental water rate curve is obtained from the water input-output characteristic in the same way as for thermal units. A typical characteristic is shown in Fig (2.8). As the input-output curve is linear for a greater part, the incremental water rate characteristic is a horizontal line over this region indicating constant slope, and thereafter it rises rapidly. With increase in load, more and more units will have to be brought into service [16].

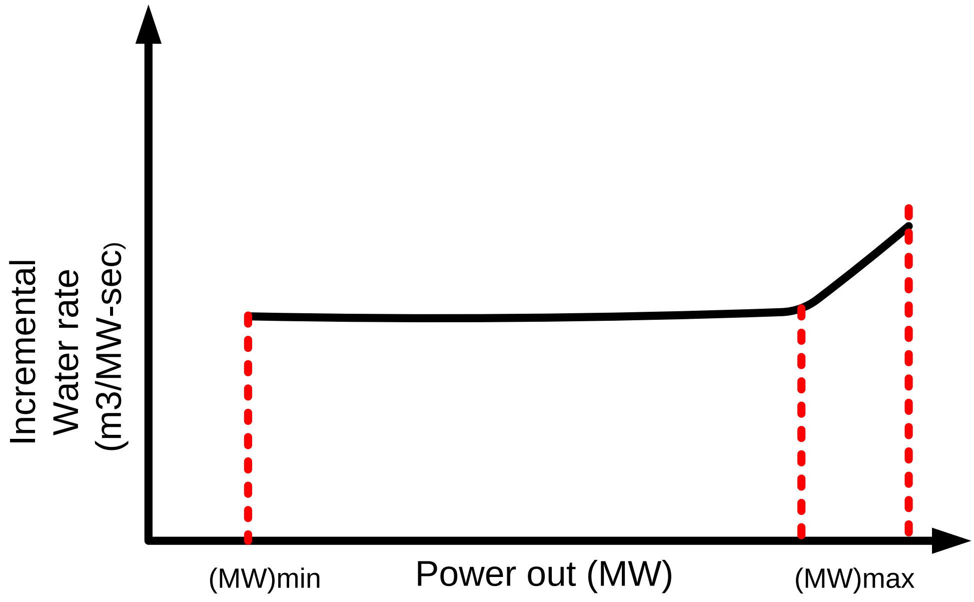

Fig (2.8) Incremental water-rate characteristic

2.2.14 Incremental Production Cost Characteristics

The incremental water rate characteristic can be converted into incremental production cost characteristic by multiplying the incremental water rate characteristic by water rate or cost of water in rupees per cubic meter C_W The incremental production cost characteristic is shown in Fig(2.9) [16] .

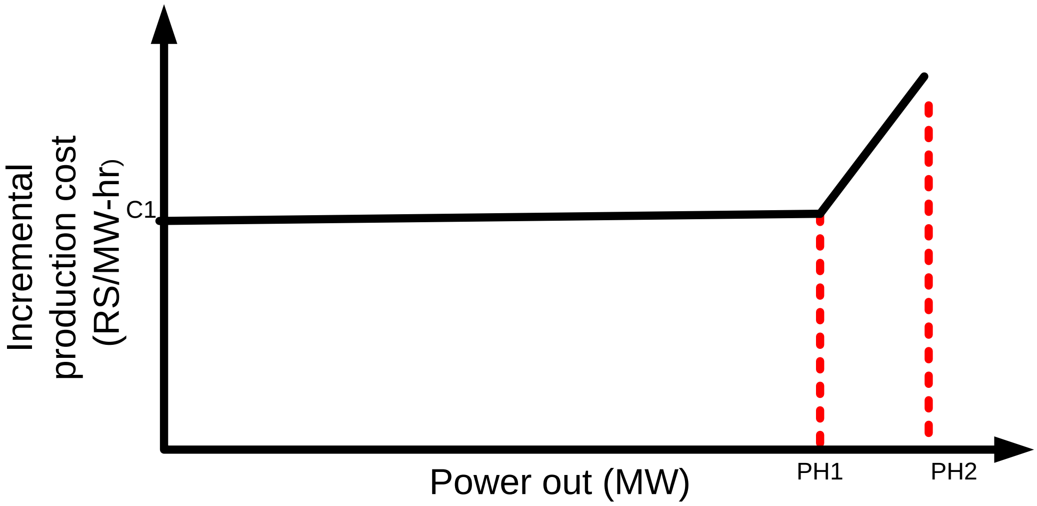

Fig (2.9) Incremental production cost representation

2.2.15 Constraints in hydro-power plants

The following constraints are generally used in hydro-power stations

(i) Water storage constraints

Let Υ_j be the storage volume at the end of interval $\gamma_{\min} \leq \Upsilon_j \leq \Upsilon_{\max}$

(ii) Water spillage constraints

Even though there may be circumstances where allowing water spillage S_{pi}>0 for some interval j assumed that all Sp=0 might reduce the cost of thermal plant.

(iii) Water discharge flow constraints

The discharge flow may be constrained both in rate and in total as

$$q_{min} \leq q_j \geq q_{\max} \quad and \quad \sum_{j=1}^{jmax} n_j q_j = q_{total} \tag{2.3}$$

2.2.16 Optimization problem –mathematical formulation (neglecting the transmission losses)

The optimization problem consists of:

(i) Objective function

The objective function is to minimize the overall cost of production of power generation.

Total cost $C = C1 + C2 + C3 + \cdots \dots \dots \dots \dots . Cn$ OR

$$C = \sum_{i=1}^{n} C_T \tag{2.4}$$

$n: number\ of\ units\ in\ the\ system$,C is cost of power generation of unit i^{th}.The cost of generation of each unit in thermal power plants is mainly a fuel cost the generation cost depends on the amount of real power generated, since the real power increased by increasing the fuel input and the generation of reactive power has negligible influence on the cost of generation. Therefore the total cost of the i^{th} unit is function of real-power generation of that unit.

$$C = C_1(P_{G1}) + C_2(P_{G2}) + C_3(P_{G3}) \dots \dots \dots \dots \dots \dots C_n(P_{Gn}) \qquad (2.5)$$

This objective function consists of the summation of the terms in which each term is a function of separate independent variables.

This type called a separable objective function the optimization problem is to allocate the total load demand (P_D) among the various generating units such that the cost of generation is minimized and satisfies the following constraints [11]

(i) Constraints equations

The economic power system operation needs to satisfy the following types of constraints.

a. Equality constraints

The sum of real-power generation of all the various units must always be equal to the total real-power demand on the system

$$P_D = \sum_{i=1}^{n} P_{Gi} \quad or \quad \sum_{i=1}^{n} P_{Gi} - P_D = 0 \qquad (2.6)$$

Where $\sum_{i=1}^{n} P_{Gi}$ total real-power generation

P_D is total real-power demand

b. Inequality constraints

These constraints are considered in an economic power system operation due to physical and operational limitations of the units and components, this classified as.

(i) According to the nature

According to the nature the inequality constraints are classified further into the following constraints:

a. Hard-type constraints: - these are definite and specific in nature. No flexibility will take place in violating these types of constraints

(Range of tapping of a no-load tap-changer)

b. Soft-types constraints**:** - these have some flexibility with them in violating (magnitudes of node voltage and the phase angle between them)

(ii) According to power system parameters

The inequality constraints are classified further into the following categories:

a. Output-power constraints: - each generating unit should not operate above its rating or blow some minimum generation. This minimum value of real-power is determined form the technical feasibility.

$$P_{Gi(min)} \leq P_{Gi} \leq P_{Gi(max)} \text{ \& } Q_{Gi(min)} \leq Q_{Gi} \leq Q_{Gi(max)} \qquad (2.7)$$

$$for\ i = 1,2,3 \dots\dots..n$$

b. Voltage magnitude and phase angle constraints**:** -from maintaining better voltage profile and limiting overloading it is essential that bus voltage magnitudes and phase angles at various buses should vary within the limits. These can be illustrated by imposing the inequality constraints on bus voltage magnitudes and their phase angles.

$V_{i(min)} \leq V_i \leq V_{i(max)}$ And $\delta_{ij(min)} \leq \delta_{ij} \leq \delta_{ij(max)}$ (2.8)

For $i = 1,2,3 \ldots\ldots..n \quad ,j = 1,2,3 \ldots\ldots.m$

c. Dynamic constraints: this considers when fast changes in generation are required for picking up the shedding down or increasing the load demand.

$$\left|\frac{dPG(t)}{dt}\right|_{min} \leq \left|\frac{dPG(t)}{dt}\right| \leq \left|\frac{dPG(t)}{dt}\right|_{max} \& \left|\frac{dQG(t)}{dt}\right|_{min} \leq \left|\frac{dQG(t)}{dt}\right| \leq \left|\frac{dQG(t)}{dt}\right|_{max} \qquad (2.9)$$

d. Spare capacity constraints: these are required to meet the following criteria.

- Errors in load prediction
- The unexpected and fast changes in load demand
- Unplanned loss of scheduled generation, the forced outages of one or more units on the system.

The total power generation at any time must be more than the total load demand and system losses by an amount not less than a specified minimum spare capacity (P_{sp}).

$$P_G \geq (P_D + P_l) + P_{sp} \qquad (2.10)$$

Where$P_G$total power generation, $(P_D + P_l)$: total load and system losses

And $P_{sp} is\ the\ specified\ minimum\ spare\ power$

e. Transmission line constraints: the active and reactive power generating flowing through the transmission line is limited by the thermal capability of the circuit $TC_i \leq TC_{i(max)}$

Where $TC_{i(max)}$ is the maximum loading capacity of the i^{th} lines?

f. Security constraints: Power system security and power flows between certain important buses are also considered for the solution of an optimization problem. If the system is operating satisfactorily, there is an outage that may be scheduled or forced but some of the constraints are naturally violated .it may be mentioned that consideration of each and every possible branch for an outage will not be a feasible proportion.

2.2.17 Computational methods

Different types of computational methods for solving the above optimization problem:

(i) Analytical methods

The mathematical equations representing the incremental fuel cost (IFC) of each unit can be determined from the cost of generation of that unit see equation (2.1)

When the number of unit is small (2or 3) the incremental cost curves are approximated as a linear or quadratic variation and no discontinuities are present in the incremental cost curves.

We know that the (IFC) of i^{th} unit for an optimal solution, the (IFC) of all the units must to be the same (no- transmission losses)

(ii) Graphical method

For obtaining the solution in this method the following procedure is required**:-**

Consider the incremental cost curves of all units

$$(IC)_i = a_i P_{Gi} + b_i \tag{2.11}$$

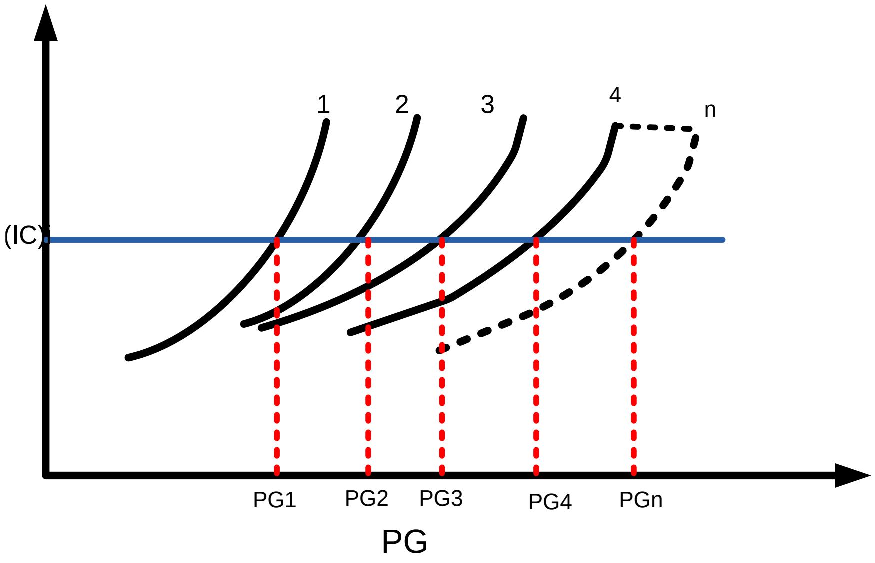

Fig (2.10) Real-power generation in (MW)

Step1 draw the graph between PG and (IC) as shown above

Step2: choose the particular value of λ and Δλ

Step3: determine the corresponding real-power generation of all units

Step4: compute the total real-power generation $=\sum_{i=1}^{n} P_{Gi}$

Step5: check the real-power balance

If $\sum_{i=1}^{n} P_{Gi} - P_D = 0$ than the λ is optimal solution and the incremental cost of all units become equal.

If $\sum_{i=1}^{n} P_{Gi} - P_D < 0$ increas λ by Δλ and repeat step5

If $\sum_{i=1}^{n} P_{Gi} - P_D > 0$ decrease λ by Δλ then repeat step5

Step6: this process is repeated until $\sum_{i=1}^{n} P_{Gi} - P_D \leq \epsilon$

(iii) Using Digital Computer

When the number of units is more the gradient or lambda iteration methods are used.

2.3 Unit Commitment

Economic operation of power system is very important to return profit on the capital invested and to sub side a part of investment itself through proper planning. More significantly it is important from the perspective of conserving the irreplaceable fossil fuels. Economic operation results in maximizing the operating efficiencies which in turn minimize the cost per kilowatt-hour. Total load on power system varies at every instant of time, generally being higher during the daytime and early evening when industrial loads are high, lights are on, and so forth, and lower during the late evening and early morning when most of the population is asleep [1]. In addition, the use of electric power has a weekly cycle, the load being lower over weekend days than weekdays. Therefore, the option of turning ON enough units and leave them online, so that the variable load demand is met at all times is not viable due to the costs involved. This causes some of the units to operate near their minimum capacity at times, resulting in lower system efficiency and increased economics. Thus, if the operation of the system is to be optimized, units must be shut down as the load goes down and must be brought online as it goes up again [1].

Electric utilities have to plan their generation to meet this varying load in advance, as to which among their available generators are to start-up and when to synchronize them into the network as well as the sequence in which the operating units must be shut down. The process of making this decision is well known as ‘Unit Commitment’ [18]. The word ‘commit’ refers to ‘turn ON’ a unit. Thus, the problem of Unit Commitment is to schedule the ON and OFF times of the generating units with the overall minimum cost while ensuring the unit’s operational constraints like minimum up/down times, ramp rate limits, maximum and minimum power generation limits .

Out of the cost incurred in generation, major component is the cost of fuel input per hour for all the generators, while maintenance cost contributes only to a small extent. This fuel cost evaluation is more important for thermal and nuclear power stations, which is not the case with hydro stations where the energy is obtained from storing water in dams built for irrigation purpose and is apparently free. Fuel cost savings can be obtained by proper allocation of load among the committed units. But the problem of UC minimizes the total cost which includes both production cost i.e., the fuel cost and costs associated with the start-up and shutdown of units. Start-up cost and shut down cost are categorized by unit type. A fixed cost is incurred with the shut-down of a unit while the start-up cost is dependent on the length of time the unit has been down prior to starting. When performing the unit commitment scheduling a variety of operating constraints and spinning reserve requirements are observed [18].

2.3.1 Economic Dispatch versus Unit Commitment

At this point, it may be as well to emphasize the essential difference between the unit commitment and economic dispatch problem. The economic dispatch problem assumes that there are N_{gen} units already connected to the system. The purpose of the economic dispatch problem is to find the optimum operating policy for these N_{gen} units. This is the problem that we have been investigating so far in this text. The unit commitment problem, on the other hand, is more complex. We may assume that we have N_{gen} units available to us and that we have a forecast of the demand to be served. The question that is asked in the unit commitment problem area is approximately as follows.

Given that there are a number of subsets of the complete set of N_{gen} generating units that would satisfy the expected demand, which of these subsets should be used in order to provide the minimum operating cost? This unit commitment problem may be extended over some period of time such as the 24 h of a day or the 168 h of a week. The unit commitment problem is a much more difficult problem to solve. The solution procedures involve the economic dispatch problem as a sub problem.

2.3.2 Constraints in Unit Commitment

Many constraints can be placed on the unit commitment problem. The list presented here is by no means exhaustive. Each individual power system, power pool, reliability council, and so forth may impose different rules on the scheduling of units, depending on the generation makeup, load-curve characteristics, and such. Spinning Reserve

Spinning reserve is the term used to describe the total amount of generation available from all units synchronized on the system, minus the present load and losses being supplied. Spinning reserve must be carried so that the loss of one or more units does not cause too far a drop in system frequency, if one unit is lost, there must be ample reserve on the other units to make up for the loss in a specified time period [1]

2.3.3 Thermal Unit Constraints

Thermal units usually require a crew to operate them, especially when turned on and turned off. A thermal unit can undergo only gradual temperature changes, and this translates into a time period of some hours required to bring the unit on-line. As a result of such restrictions in the operation of a thermal plant, various constraints arise, such as.

(i) Minimum uptime: once the unit is running, it should not be turned off immediately.

(ii) Minimum downtime: once the unit is recommitted, there is a minimum time before it can be recommitted.

(iii) Crew constraints: if a plant consists of two or more units, they cannot both be turned on at the same time since there are not enough crew members to attend both units while starting up.

In addition, because the temperature and pressure of the thermal unit must be moved slowly, a certain amount of energy must be expended to bring the unit on-line. This energy does not result in any MW generation from the unit and is brought into the unit commitment problem as a start-up cost.

The start-up cost can vary from a maximum “cold-start” value to a much smaller value if the unit was only turned off recently and is still relatively close to operating temperature. There are two approaches to treating a thermal unit during its down period. The first allows the unit’s boiler to cool down and then heat back up to operating temperature in time for a scheduled turn on. The second (called banking) requires that sufficient energy be input to the boiler to just maintain operating temperature. Up to a certain number of hours, the cost of banking will be less than the cost of cooling as is illustrated in Figure(2.10) [12].

Start-up cost function:

$$C_{cold} = H_{cold}\left(1 - e^{-t_{shunt-\frac{down}{\alpha}}}\right)F_{fuel} + C_{fixed} \qquad (2.12)$$

Banking cost function:

$$C_{bank} = H_{bank} * F_{fuel} * t_{shunt-down} + C_{fixed} \qquad (2.13)$$

Where: C_c: cold-start cost M Btu, F: fuel cost

C_{fixed} Fixed cost includes crew expense, maintenance expenses (in $)

α: Thermal time constant for the unit, t: time the unit was cooled

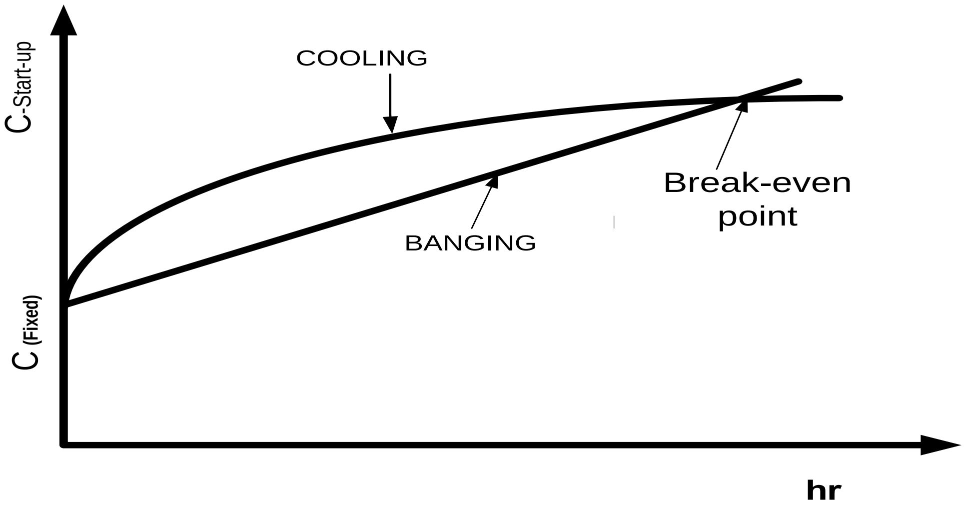

Fig (2.11) Time-dependent start-up costs

(iv) Must Run

Some units are given a must-run status during certain times of the year for reason of voltage support on the transmission network or for such purpose supply of steam for uses outside the steam plant itself.

2.3.4 Fuel Constraints

A system in which some units have limited fuel, or else have constraints that require them to burn a specified amount of fuel in a given time, presents a most Challenging unit commitment problem[12].

2.3.5 Unit commitment techniques

UC is a highly non linear optimization problem in power system operation. Given the highest priority to the reliability of power supply a UC schedule which lays emphasis on the economic and secure operation is necessary. With the increase in system size, UC problem becomes more combinatorial and exhaustive. Several methodologies have been proposed to solve UC problem and increase potential savings in power system operation. In the operation, system security also plays a major role and thus a great amount of research work is carried towards the security constrained UC.

Techniques applied to solve UC problem can be broadly classified into deterministic and stochastic. Deterministic approaches include methods like Priority List (PL), Integer Programming (IP), Mixed Integer Programming (MIP), Dynamic Programming (DP), Lagrangian Relaxation (LR) and the Branch and Bound (BB). These methods are simple but they suffer from drawbacks like numerical convergence, solution quality and execution time. On the other hand stochastic search algorithms which are inspired by artificial intelligence include Artificial Neural Networks (ANN), Genetic Algorithms (GA), Evolutionary Programming (EP), Simulated Annealing (SA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) and Tabu Search (TS). These are able to overcome the shortcomings of traditional optimization techniques and can handle complex nonlinear constraints assuring high quality solutions.

CHAPTER THREE

CONVENTIONAL AND INTELLIGENT METHODS

3.1 Solution of economic load dispatch problem

To solve Economic Load Dispatch ELD problem different kinds of constraints and multiple objectives have been incorporated using various optimization techniques. In traditional ELD problem, the cost function for each generator has been expressed by a simple quadratic function that is solved by both conventional computation methods and intelligent methods. Artificially intelligent methods are preferred due to their flexibility, adaptability, less development time and faster convergence. These methods are discussed below [19].

3.2 Conventional techniques

Most mathematical based algorithms can guarantee reaching an optimal solution, while do not necessarily guarantee reaching a global optimum. Global optimality may be only reached, checked or guaranteed for simple cases. On the other hand, many practical optimization problems do not fall in strict forms and assumptions of mathematical based algorithms [15]. Moreover, if the problem is highly complex, we may not readily be able to solve them, at all, through mathematical algorithms. Besides, finding global optimum is of interest, as finding a local one would be a major drawback. These drawbacks are tackled by employing heuristic techniques [19] [20].

3.2.1 Linear Programming (LP)

The Linear Programming (LP) - based technique is used to linearize the nonlinear power system optimization problem, so that objective function and constraints of power system optimization have linear forms. The simplex method is known to be quite effective for solving LP problems. The LP approach has several advantages. First, it is reliable, especially regarding convergence properties. Second, it can quickly identify infeasibility. Third, it accommodates a large variety of power system operating limits, including the very important contingency constraints [21]. The disadvantages of LP - based techniques are inaccurate evaluation of system losses and insufficient ability to find an exact solution compared with an accurate nonlinear power system model. However, a great deal of practical applications shows that LP - based solutions generally meet the requirements of engineering precision. Thus LP is widely used to solve power system operation problems such as security - constrained economic dispatch, optimal power flow, steady - state security regions, and reactive power optimization [21].

3.2.2 Non-Linear Programming (NLP)

Power system operation problems are nonlinear. Thus nonlinear programming (NLP) based techniques can easily handle power system operation problems such as the OPF problems with nonlinear objective and constraint functions. To solve a nonlinear programming problem, the first step in this method is to choose a search direction in the iterative procedure, which is determined by the first partial derivatives of the equations. Therefore, these methods are referred to as first - order methods, NLP - based methods have higher accuracy than LP - 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 [12].

3.2.3 Quadratic Programming (QP)

Quadratic Programming (QP) is a special form of nonlinear programming. The objective function of QP optimization model is quadratic, and the constraints are in linear form. Quadratic programming has higher accuracy than LP – 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 [21].

3.2.4 Newton-Rapson Method (NR)

Newton's method requires the computation of the second - order partial derivatives of the power flow equations and other constraints and is therefore called a second - order method. The necessary conditions of optimality commonly are the Kuhn – Tucker conditions. Newton's method is favored for its quadratic convergence properties [21].

3.2.5 Interior Point Methods (IP)

The Interior Point (IP) method is originally used to solve linear programming. It is faster and perhaps better than the conventional simplex algorithm in linear programming. IP methods were first applied to solve OPF problems in the 1990s, and recently, the IP method has been extended and improved to solve OPF with QP and NLP forms [21].

3.2.6 Mixed-Integer Programming (MIP)

The power system problem can also be formulated as a Mixed - Integer Programming (MIP) optimization problem with integer variables such as transformer tap ratio, phase shifter angle, and unit on or off status. MIP is extremely demanding of computer resources, and the number of discrete variables is an important indicator of how difficult an MIP will be to solve. A decomposition technique is generally adopted to decompose the MIP problem into a continuous problem and an integer problem [21].

3.2.7 Network Flow Programming (NFP)

Network Flow Programming (NFP) is special linear programming. NFP was first applied to solve optimization problems in power systems in 1980s. The early applications of NFP were mainly on a linear model. Recently, nonlinear convex network flow programming has been used in power systems optimization problems. NFP - based algorithms have the features of fast speed and simple calculation. These methods are efficient for solving simplified OPF problems such as security - constrained economic dispatch, multi area systems economic dispatch, and optimal reconfiguration of an electric distribution network [21].

3.3 Intelligent techniques

Heuristic search methods are robust and have a faster development time while tend to be insensitive to noise and missing data [21].

3.3.1 Genetic Algorithm (GA)

Genetic Algorithm (GA) is based on conjunction of natural selection (survival for the fittest) and genetics. (GA) was developed by John Holland in 1960's. The decision variables to be found are in the form of string of genes. This string is called the problem chromosome, selected from a set of population. The objective function calculated for this chromosome is called problem fitness function. Next population (off-springs) is generated from initial chromosomes (parents).This regeneration results in chromosomes with a better fitness value [21]. GA depends on selection, crossover and mutation. Population of chromosomes is initially generated. Then two chromosomes are considered as parents based on the fitness value. Crossover is used to generate off- springs from the two parents by interchanging the value of genes at specific positions. Mutation curds the drawback of the value of a given gene not changing during crossover. Mutation operator tries to alter the value of a gene randomly [21].

3.3.2 Simulated Annealing (SA)

In statistical mechanics, annealing is often performed in order to relax the system to a state with minimal free energy. The free energy of matter corresponds to objective function while the state of statistical physics corresponds to solution in optimization problem. The basis of (SA) is metropolis algorithm. Metropolis algorithm works on the principle of generating a new state, for given initial state with a given energy level. The new state is obtained by a small permutation of the original state using Monte Carlo method to choose the particle to move. Thus (SA) consists of two methods vies generation of alternatives (states) and acceptance rule. (SA) is effective in network configuration problems for large scale distribution systems and its search capability becomes more significant as system size increases. Advantages of simulated annealing include ability to optimize functions with arbitrary degrees of non linearity, stochasticity, boundary conditions and constraints and that it is statistically guaranteed to find an optimal solution. Disadvantages of (SA) include the fact that efficiency depends on the nature of surface one is trying to optimize and that the algorithm is slow. However these cons have been mitigating by supercomputing resources [22].

3.3.3 Tabu Search Method (TS)

Tabu is derived from the word taboo meaning prohibited, not allowed. Tabu search was developed by Glover in 1987 who was motivated by the randomness of human behavior given similar situations. Glover argued that such deviance from consistence might be to some advantage. Thus, Tabu search operates this way except that the new courses are not chosen randomly. Tabu search proceeds to elude that there's no point in accepting a new solution unless it’s to avoid a path already chartered. This ensures that the whole problem space will be investigated as we move away from local minima to alternatively find the desired solution. Tabu search has advantages ,Ability to avoid the entrapment of local minima, Employs a flexible memory system in contrast to (SA) and (GA) which are memory less ,(TS) has better performance than(GA& SA) in terms of computational time and solution quality [22].

3.3.4 Ant Colony Optimization (ACO)

Ant colony is a combinatorial optimization technique developed in the 1990s from the study of ant’s food hunting behavior of finding the shortest route from food to their nest. Ants use pheromones to communicate with one another, and therefore leave a trail of the chemical as they crawl. The ant that finds food first (shortest route) returns to the nest sooner and redeposit’s pheromone as it returns to the nest. The path will be richer with pheromone other ants recognize it as a promising path [21].

3.3.5 Differential Evolution (DE)

Differential Evolution (DE) is a stochastic search algorithm that was originally motivated by the mechanism of natural selection, DE effectively solves optimization problem with non-smooth objective functions. This is so because (DE) does not require derivative information. It differs from conventional genetic algorithms in the use of perturbing vectors-being the difference between two parameter vectors, chosen randomly. This concept is borrowed from the simplex optimization technique. The fundamental idea behind (DE) is a scheme by which it generates trial parameter vectors. In each step, (DE) mutates vectors by adding weighted random vector differentials to them. If the trial vector is better than that of the target, the target vector is replaced by the trial if the cost of the trial vectors in the next generation [24].

Differential Evolution includes Evolution Strategies (ES) and conventional Genetic Algorithms (GA). Since it's a population based search algorithm, DE is therefore an improved version of Genetic Algorithm. The convergence characteristics and the few control parameters in (DE) make it one powerful algorithm for Evolutionary computation. The first generation is first initialized randomly and the proceeding generations evolve sequentially through application of a certain evolutionary operator up to where a stopping criterion is reached [21]. Advantages of Differential Evolution Method. It has ability to find the true global minimum regardless of the initial parameters, fast and simple with regard to application, the algorithm requires few control parameters; it is capable of providing multiple solutions in a single run. Disadvantages of Differential Evolution Method. The algorithm does not always give an exact global optimum due to premature convergence; the algorithm requires tremendously high-computation time [21].

CHAPTER FUOR

LAMBDA ITERATION AND PARTICLE SWARM OPTIMIZATION METHODS

4.1 Lambda Iteration Method (LI)

The Economic Load Dispatch (ELD) is an important function in modern power system like unit commitment, Load Forecasting Available Transfer Capability (ATC) calculation, Security Analysis, Scheduling of fuel purchase etc. A bibliographical survey on (ELD) methods reveals that various numerical optimization techniques have been employed to approach the (ELD) problem.

Electrical power systems are designed and operated to meet the continuous variation of power demand. In power system minimizing, the operation cost is very important. Economic Load Dispatch (ELD) is a method to schedule the power generator outputs with respect to the operate the power system most economically, and load demands, or in other words, we can say that main objective of economic load dispatch is to allocate the optimal power generation from different units at the lowest cost possible while meeting all system constraints many efforts have been made to solve the (ELD) problem, over the years, incorporating different kinds of constraints or multiple objectives through optimization techniques and various mathematical programming[25].

Lambda Iteration method (LI) is introduced in solving optimization problem such as ED problem in order to find the best fuel cost and also the generators output power. Lambda, λ which is also known as the Lagrange multiplier which is the condition for optimal dispatch and scheduling [26]. Lambda Iteration (LI) is able to solve the (ELD) problem by using hand calculation, but if the system is big, hand calculation is impossible to solve the problem [27].

4.1.1 Economic dispatch problem without loss

The simplest economic load dispatch problem is the case when transmission line losses are neglected due to this the total demand P_D is the sum of all generations. A cost function $F_i(P_{gi})$ is assumed to be known for each plant the problem is to be find the real-power generation P_{gi} for each plant such that the total operating cost $F_i(P_{gi})$ is minimum and the generation remains within the lower generation ${P_{gi}}^{min}$ And upper generation ${P_{gi}}^{max}$ suppose there is a station with NG generators committed and the active power load demand P_D is given the real power generation P_{gi} for each generators has to be allocated so as to minimize the total cost . In the power system, if it does not consider any losses then the output of the generator is similar to the demand of power. That is indicating the system does not care about the line impedance and other losses such as transmission line losses, as shown in figure (4.1) [28].

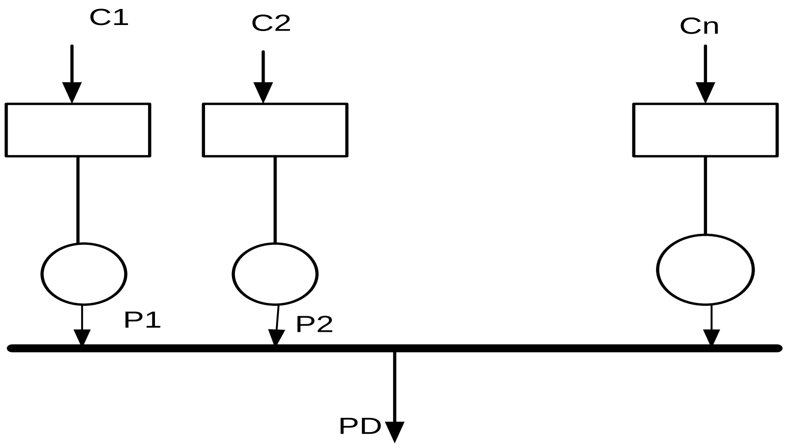

Fig (4.1) Sample of generator power system

By considering the power limit constraint, $\mathrm{P_i^{(min)}}) \leq \ P_i \leq \ \mathrm{P_i^{(max)}}$ at where the Total cost C_i is equal to the sum of each generator fuel cost

$$C_t = \sum_{i=1}^{n} C_i = \sum_{i=1}^{n} c_i + b_i\, P_i + aiP^2{}_i \tag{4.1}$$

Where: Pi Is the i^{th} power generator output?

PD Is the total demand and n is the total number of generators

a_i , b_i and c_i are constant of objective function

The optimization problem can be stated as Minimize:

$$F_i\left(P_{gi}\right) = \sum_{i=1}^{n} F_i\ (P_{gi}) \tag{4.2}$$

The energy balance equation is

$$\sum_{i=1}^{n} P_i = P_D \tag{4.3}$$

The inequality constraints

$$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max} \tag{4.4}$$

Where

P_{gi} Is the decision variable real power generation

P_D Is real power load demand, NG is number of generation plants

P_{gi}^{min} $is\ the\ lower\ permissible\ limit\ of\ real\, power$ generation

P_{gi}^{max} $is\ the\ upper\ permissible\ limit\ of\ real\, power$ generation

$F_i\left(P_{gi}\right) is\ the\ operating\ fuel\ cost\ of\ the\ i^{iH}\ \ plants$ The quadratic equation is

$$F_i(P_{gi}) = a_i P^2 g_i + b_i P g_i + c_i \qquad RS/h \tag{4.5}$$

The above constrained optimization problem is converted into an unconstrained optimization problem. Lagrange multiplier is used in which a function is minimized or maximized with side conditions in the form of equality constraints. Using the method an augmented function is defined.

$$L(P_{gi}, \lambda) = F_i\left(P_{gi}\right) + \lambda(P_D - \sum_{i=1}^{n} P_i) \qquad (4.6)$$

Where λ is the Lagrange multiplier

A necessary condition for a function $F_i\left(P_{gi}\right)$ subject to energy balance constraints to have a relative minimum at point $\left(P_{gi}\right)$ is that the partial derivation of the Lagrange function defined by

$L = L(P_{gi}, \lambda)$ With respect to each of arguments must to be zero. So the necessary conditions for optimization problem are

$$\frac{\partial L(P_{gi},\lambda)}{\partial P_{gi}} = \frac{\partial F_i\left(P_{gi}\right)}{\partial P_{gi}} - \lambda = 0 \quad i = 1,2,3 \ldots\ldots\ldots\ldots\ldots . n \qquad (4.7)$$

$$\frac{\partial L(P_{gi},\lambda)}{\partial \lambda} = P_D - \sum_{i=1}^{ng} P_{gi} = 0 \qquad (4.8)$$

For equation (4.7)

$$\frac{\partial F(P_{gi})}{\partial Pi} = \lambda \qquad (4.9)$$

Where the $\frac{\partial F(P_{gi})}{\partial Pi}$ is the incremental fuel cost of the i^{th} generation

Optimal loading of generators corresponds to the equal incremental cost point of all the generators the Eq. (4.9) is called coordination equations numbering Ng are solved simultaneously with the load demand to yield a solution for Lagrange multiplier λ and the optimal generation of NG generators considering the cost function given by Eq. (4.5) the incremental cost can be defined as [28].

$$\frac{\partial F(P_{gi})}{\partial P_{gi}} = b_i + 2a_i P_{gi} \tag{4.10}$$

Substituting the incremental cost in Eq. (4.9)

$$b_i + 2a_i P_{gi} = \lambda \tag{4.11}$$

$$P_i = \frac{\lambda - b_i}{2a_i} \tag{4.12}$$

Substitute the value of P_i in Eq. (4.8) we get

$$\sum_{i=1}^{n} \frac{\lambda - b_i}{2a_i} = P_D \tag{4.13}$$

Rearranged in form

$$\lambda = \frac{P_D + \sum_{i=1}^{n} \frac{bi}{2a_i}}{\sum_{i=1}^{n} \frac{1}{2a_i}} \tag{4.14}$$

Equation (4.14) will be substituted into equation (4.12) to get the Pi.

By using the Taylor‟s series, equation (4.13) can be expressed as

$$f(\lambda) = P_D \tag{4.15}$$

By expanding the Taylor‟s series with the operating point, we get

$$F(\lambda)^{(k)} + \left(\frac{df(\lambda)}{d\lambda}\right)^{(k)} \Delta\lambda^{(k)} = P_D \tag{4.16}$$

$$\Delta\lambda^{(k)} = \frac{\Delta Pi^{(k)}}{\sum_{i=1}^{n} \frac{1}{2ai}} \tag{4.17}$$

Where $\frac{1}{2ai}$ get from the Eq.(4.8) as

$$\Delta\lambda^{(k)} = \frac{\Delta Pi^{(k)}}{\left(\frac{dF(\lambda)}{d\lambda}^{(k)}\right)} \tag{4.18}$$

$$\lambda^{(K+1)} = \lambda^{(k)} + \Delta\lambda^{(k)} \tag{4.19}$$

4.1.2 Economic dispatch problem with loss

In the power system, the losses of transmission can sometimes be ignore due to the distance of transmission is short and the generators are not located at the area which far from the load centre. However, if the generators are far from then load centre, then it has to consider that transmission losses as an important factor as this may take a significant effect on the dispatch system. The general form of the losses using B-coefficients is:

$$P_L = \sum_{i=1}^{NG} \sum_{j=1}^{NG} P_{gj} B_{ij} P_{gi} \quad {}_{MW} \tag{4.20}$$

Where: B_{ij} Is the loss coefficients or B-coefficients

$P_{gi}\ and\ P_{gj}$ Are the real power generations at $i^{th}\ \ and\ j^{th}\ busses$

The transmission loss formula, of Eq. (4.20) using the Lagrange multiplier λ

$$L(P_{gi}, \lambda) = F_i(P_{gi}) + \lambda(P_D + PL - \sum_{i=1}^{n} Pg_i) \tag{4.21}$$

As the minimum of the unconstraint function can be located at the point where the partials of the function are equal to zero.

$$\frac{\partial L(P_{gi}, \lambda)}{\partial Pi} = 0 \qquad \& \qquad \frac{\partial L(P_{gi}, \lambda)}{\partial \lambda} = 0 \tag{4.22}$$

$$\frac{\partial fi(P_{gi})}{\partial P_{gi}} = \frac{\partial f_i(P_{gi})}{\partial P_{gi}}$$

Then, the condition for optimum dispatch is:

$$\frac{\partial L(P_{gi}, \lambda)}{\partial Pi} = \frac{\partial f_i(P_{gi})}{\partial P_{gi}} + \lambda\left(\frac{\partial PL}{\partial Pi} - 1\right) = \qquad i = 1,2, \ldots..NG \tag{4.23}$$

$$\frac{\partial f_i(P_{gi})}{\partial P_{gi}} = \lambda\left(1 - \frac{\partial PL}{\partial Pi}\right) \text{ OR } \frac{\partial f_i(P_{gi})}{\partial P_{gi}} + \lambda\left(\frac{\partial PL}{\partial Pi}\right) = \lambda \tag{4.24}$$

Where $\frac{\partial PL}{\partial Pi}$ Is an Incremental Transmission Loss (ITL)

$\frac{\partial f_i(P_{gi})}{\partial P_{gi}}$ Is incremental fuel cost (IFC)

$$\lambda = \left(\frac{1}{1-\frac{\partial PL}{\partial Pi}}\right)\frac{\partial fi(P_{gi})}{dPi} \tag{4.25}$$

$$L_i = \left(\frac{1}{1-\frac{\partial PL}{\partial Pi}}\right) \quad or\ L_i\left(\frac{\partial fi(P_{gi})}{dPi}\right) = \lambda$$

Where : L_i is penalty factor of the i^{th}generators

$$L_i = \left(\frac{1}{1-\frac{\partial PL}{\partial Pi}}\right) \tag{4.26}$$

The equation (4.25) shown that the minimum cost is obtained when the incremental cost of each plant multiplier by its penalty factor is same for all plants .equation (4.23) is also written in

$$(IC)i = \lambda[(1-(ITL)_i] \tag{4.27}$$

This equation is referred to as exact coordination equation thus it is clear that to solve the economic load dispatch problem it’s necessary to compute (ITL) for each plant and therefore functional dependence of transmission line losses on real powers of generators plant must to be determined . There are several methods approximate and exact for developing a transmission losses model. One of the most important simple but approximate methods of expressing transmission losses as function of generators powers through B-coefficient this model is reasonably adequate for treatment of loss coordination in economic scheduling of load between plants.

The general form of losses formula Using B-coefficient when $B_{ij} = B_{ji}$

$$\frac{\partial PL}{\partial P_i} = \sum_{j=1}^{n} 2BijPj \tag{4.28}$$

The incremental cost equation is

$$\frac{\partial f_i(P_{gi})}{\partial P_i} = b_i + 2a_iP_{gi} \tag{4.29}$$

By substituting $\frac{\partial P_i(P_{gi})}{\partial P_i}$ and $\frac{\partial P_i}{\partial P_i}$ into equation (4.2)

$$b_i + 2a_iP_i + \lambda(\sum_{j=1}^{n} 2B_{ij}Pgj) = \lambda\ , \quad i = 1,2 \ldots\ldots NG \tag{4.30}$$

Collecting all terms of P_{gi} and solve for P_{gi}

$$\left(2a_i + 2\lambda B_{ij}\right)P_{gi} = -\lambda(\sum_{\substack{j=1 \\ j\neq i}}^{n} 2B_{ij}P_{gi}) - b_i + \lambda \tag{4.31}$$

OR

$$P_{gi} = \frac{\left(1-\frac{b(i)}{\lambda}\right)-2\sum_{j\neq i}^{n} B_{ij}P_{gj}}{(\frac{ai}{\lambda})+2B_{ij}} \tag{4.32}$$

$$\sum_{j\neq 1}^{n} \frac{\sum_{i=1}^{n} \lambda^k(1-B_{0i})-b_i-2\lambda^k \sum_{j\neq i}^{n} B_{ij}Pj^k}{2(a_i+\lambda^k B_{ii})} = P_D + {P_L}^K \tag{4.33}$$

OR

$$F(\lambda)^k = P_D + {P_L}^K \tag{4.34}$$

By using the Taylor's series and ignore the higher order of the terms,

$$F(\lambda)^k + \frac{dF(\lambda)^K}{d\lambda}\ \Delta\lambda^K \quad = P_D + {P_L}^K \tag{4.35}$$

Then

$$\Delta\lambda^K = (\frac{\Delta P^{(k)}}{\frac{dF(\lambda)}{d\lambda}})^{(K)} \tag{4.36}$$

$$\lambda^{(K+1)} = \lambda^{(k)} + \Delta\lambda^{(k)}$$

4.1.3 Steps of implementing lambda iteration (LI)in ELD

The detailed Algorithm for solving the economic load dispatch problem using lambda iteration method is given below [15].

Step1: Read data namely cost-coefficients, B-coefficients, P limits and power demand.

Step2: Make an initial guess λ and Δλ for the Lagrange multiplier.

Step3: Calculate the generations based on equal incremental production cost.

Step4: Calculate the generations at all buses using the equation

$$P_i = \frac{\left(1-\frac{b(i)}{\lambda}\right)-2\sum_{j\neq i}^{n} B_{ij}P_j}{(\frac{\gamma i}{\lambda})+2B_{ii}}$$

Step5: For each unit, check the generation limits and impose the limits in case of violation.

$$if \qquad P_i > P_{imax} \qquad set\ P_i = P_{imax},$$

$$if \qquad P_i < P_{imax} \qquad set\ P_i = P_{imax}$$

Step6: Check if the difference in power at all generator buses between two Consecutive iterations is less than a prespecified value. If not, go back to step 3.

Step 7: Calculate the loss using the relation

$$P_L = \sum_{i=1}^{n} P_j B_{ij} P_i$$

And calculate mismatch between generator power and demand plus losses.

$$\Delta P = |\Sigma\, P_G - P_L - P_D|$$

Step 8: Check if ΔP is less than ϵ (a specified value)

If yes, stop calculation and calculate cost of generation with these values of powers. Otherwise, go to step 9.

Step 9: Increase λ by $\Delta\lambda$ (a suitable step size); if $\Delta P < 0$ or

Decrease λ by $\Delta\lambda$ (a suitable step size); if $\Delta P > 0$

And repeat from step 4.

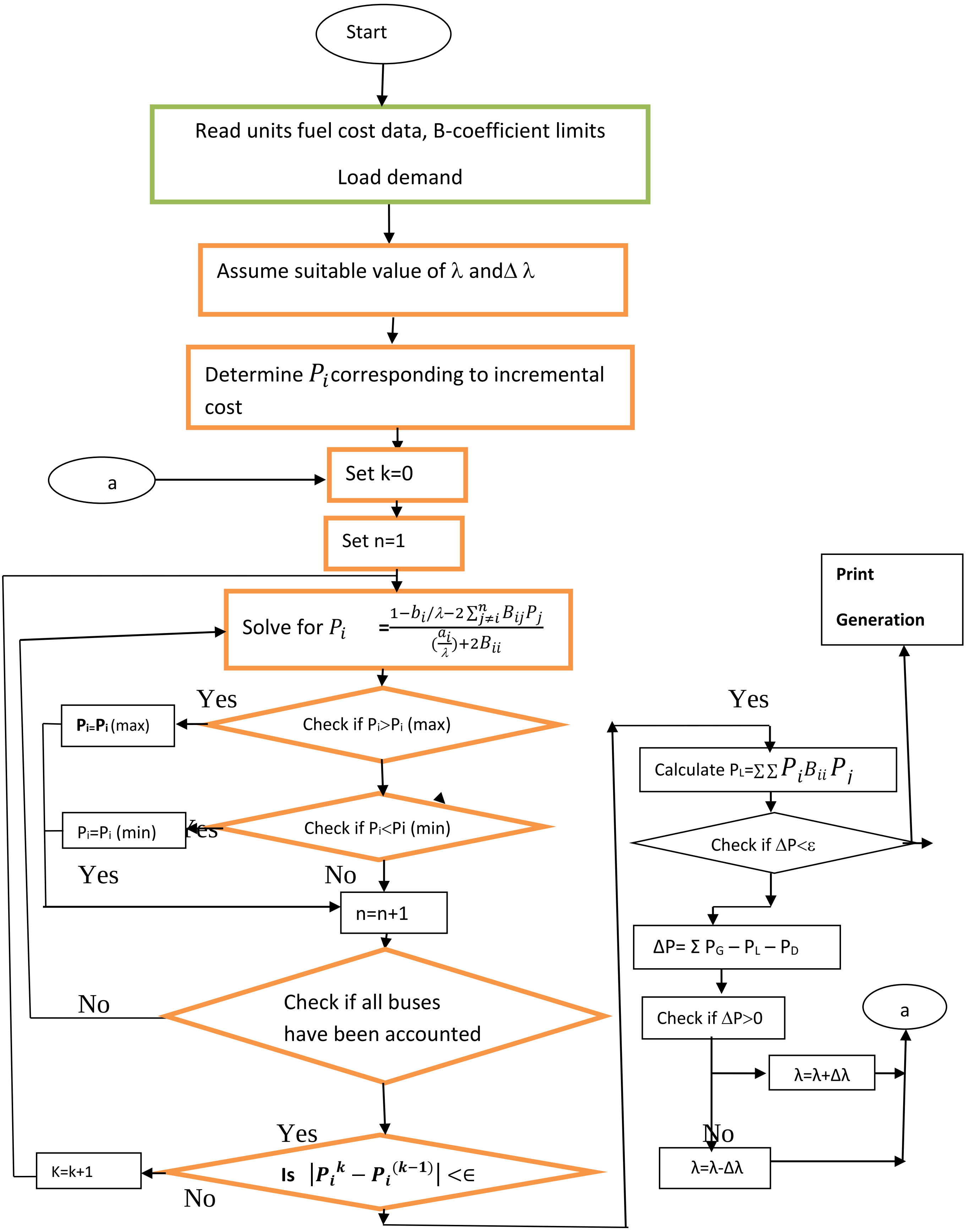

Fig (4.2) flow chart for (LI) base on economic dispatch

4.2 Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) is one of the modern heuristic algorithms, which can be effectively used to solve nonlinear and non-continuous optimization problems. It is a population-based search algorithm and searches in parallel using a group of particles similar to other Al-based optimization techniques [29].

Eberhart and Kennedy suggested a Particle Swarm Optimization (PSO) based on the analogy of swarm of bird and school of fish In (PSO), each individual makes its decision based on its own experience together with other individual's experiences [29]. Particle swarm optimization is a population-based stochastic optimization technique, inspired by simulation of a social psychological metaphor instead of the survival of the fittest individual. In (PSO) the system (swarm) is initialized with a population of random solutions (particles) and searches for optima using cognitive and social factors by updating generations. The particles are drawn stochastically toward the position of present velocity of each particle their own previous best performance and the best previous performance of their neighbors, (PSO) has been successfully applied to a wide range of applications, mainly in solving continuous nonlinear optimization problems [30].

There is a new method in solving the economic dispatch problem with non-smooth cost functions by applying the Particle Swarm Optimization (PSO) technique which can cope the equality and inequality constraints in the economic dispatch, The constraint treatment mechanism is developed in the form that dynamic process inherent in the conventional PSO is maintained. Besides, dynamic search space reduction strategy is used to speed up optimization process. (PSO) is being used to simulate economic dispatch problems by separate it in smooth cost functions and non smooth cost functions by taking consideration of the valve-point effects and multi-fuel problems [31]. (PSO) was proved to be better compared to the conventional numerical method but able to give a quite similar outcome [32] [33]. Generally economic dispatch problem is solved by not considering the transmission constraints but in the unregulated power system environment it is necessary to consider the constraints. (PSO) technique was used for solving the complex optimization situation. However, the premature convergence can be minimized by adjusting the PSO parameters [34] [35].

Nowadays, economic dispatch problem was solved by programming techniques such as genetic algorithm, particle swarm optimization and others dynamic programming methods. Economic problem in practical system have equality and inequality constraints, so it is hard to be solved by conventional mathematical method. However, PSO has been treated as one of the most powerful solution that is able to be applied to the practical problem [33], [34].

Previously, by using conventional method Lambda Iteration was not capable to solve the ED problem effectively and will take longer time to solve in large units system. Thus, new method such as PSO was being introduced by researchers in solving various kinds of problem such as, electronics and electromagnetic, antenna design, economic load dispatch, finance and economics and etc [34], [35].

4.2.1 Basic particle swarm optimization

Particle swarm optimization has roots in two main component methodologies. Perhaps more obvious are its ties to artificial life (A-life) in general, and to bird flocking, fishing schooling and swarming theory in particular. It is also related, however to evolutionary computation, and has ties to both genetic algorithms and evolution strategies particle swarm optimization comprises a very simple concept, and paradigms are implemented in a few lines of computer code. It requires only primitive mathematical operators, and is computationally inexpensive in terms of both memory requirements and speed [30].

Every particle is represented by two vectors the position of each particle is P_i, and also its velocity is expressed by V. Each particle knows its best value so far ($Pbest$) and its position moreover each particle also knows the best value so far in the group (($gbest$), among $Pbest$ [29]. The modified velocity and position of each particle can be calculated using the current velocity and the distance form best previous position of each particle the equation of the PSO velocity and position of particle were shown below:

$$V_i^{(r+1)} = WV_i^{(r)} + C_1R_1\left(Pbi^{(r)} - P_i^{(r)}\right) + C_2R_2(Gi^{(r)} - Pi^{(r)}) \quad (4.37)$$

$$P_i^{(r+1)} = P_i^{r} + Vi^{(r+1)}, \quad (4.38)$$

v_i is the velocity of i^{th}particle at r^{th} iteration?

$v_{i(min)} \le v_i^{r} \le v_{i(max)}$

Where: $P_i{}^{r}$ is the current position of it particle at i^{th} iteration?

w is the weighing function or inertia weight factor

C_1 and C_2 IS the acceleration constant, normally are 2

R_1 &R_2 is the random number between 0 and 1

Every particle will refer the current and best value of the position of other particles and track the best one in order to regulate the movement of its own in the search space. Iteration process keep going in order to get the optimum of the fitness function like the swarm of birds which finding the only food in the search space when there is only one food.

Assume that every position of the particle is the solution to the problem, and then the best position will be stored as the p-best which is considered to be the best value for next iteration. Thus the value will be updated by using the formula:

$$P_i^{(new)} = P_i^{(r)} + V_i^{(new)} \tag{4.39}$$

While the new velocity and position is

$$V_i^{(new)} = WV_i^{(r)} + C_1R_1\left(Pb_i^{(best)} - P_i^{(r)}\right) + C_2R_2(G_i^{(best)} - P_i^{(r)})$$

For the weight factor or inertial weight it can be represented as

$$W = W_{MAX} - \frac{W_{MAX} - W_{MIN}}{IT_{MAX}}(IT) \tag{4.40}$$

Where:

IT_{max} is the maximum number of iterations

IT is the current number of iterations

The weight factor or inertial weight actually is very crucial in better manipulation of the stability of the function. Researchers have concluded that the larger value of the weight factor at the first setting will give the most accurate result and then slowly reduce the value of weight factor to a smaller value. Proper weight factor is able to reduce the number of iteration in searching of solution. However, the best value of weight factor is related to the values of C_1 and C_2, the acceleration constant. Therefore, weight factor, w and acceleration factor C_1, C_2 are quite important in maintaining the stability of the (PSO).This is due to acceleration factor play the role in attracting particles toward the P-best and G-best [32]. Advantages of (PSO) it is easy to implement the coding, able to produce high quality solutions, less sensitive to the objective function compared to conventional mathematical methods, less negative impact toward the solutions, less divergence and less parameter to control. Disadvantages, it is insufficient in mathematical foundation and need a longer computation time compared to the mathematical methods [36].

4.2.2 Representation of an individual population

For an efficient evolutionary method the representation the population is important. Since the decision variables of the (ELD) problems are real power generations the generation power output of each unit is represented as a gene, and many genes comprise a particle in the swarm. Each particle within the population represents a candidate solution for an (ELD) problem.

4.2.3 Outline of the basic Particle Swarm Optimization

This project presents a quick solution to the constrained ED problem using the PSO algorithm to search for optimal or near optimal generation quantity of each unit. The search procedures of the proposed method were as shown below [15].

Step1: Specify the upper and lower bound generation power of each unit, and calculate f_{max} andf_{min}. Initialize randomly the individuals of the population according to the limit of each unit including individual dimensions, searching points, and velocities. These initial individuals must be feasible candidate solution that satisfies the practical operation constraints.

Step2: To each individual Pg of the population, employ the B-coefficient loss formula to calculate the transmission lossesP_L.

Step3: Calculate the evaluation value of each individual P_{gi} in the population using the evaluation function f given by (4).

Step4: Compare each individual’s evaluation value with its Pbest. The best evaluation value among the Pbests is denoted as gbest.

Step 5: Modify the member velocity v of each individual P_{gi}according to (5 $V_{id}{}^{(r+1)}$= w $V_i{}^r$ $+C_1$*R_1* $(\mathrm{pbest}_{id} - P_{gid}{}^{(t)} + C_2 * R_2 *$ $(\mathrm{pbest}_{id} - \mathrm{p}_{gid}{}^{(t)}\ )$

$i = 1,2,3 \ldots\ldots n$; $d = 1,2,3 \ldots..m$ Where n is the population size, m is the number of units and the w value is set by (3).

Step 6: $if\ V_{id}{}^{(r+1)} > V_d{}^{(max)}$ than $V_{id}{}^{(r+1)} = V_d{}^{(max)}$

$if\ V_{id}{}^{(r+1)} < V_d{}^{(min)}$ than $V_{id}{}^{(r+1)} = V_d{}^{(min)}$

Step 7: Modify the member position of each individual P_{gi}according to (6)

$$Pg_{id}{}^{(t+1)} = P_{gid}{}^{(t)} + V_{id}{}^{(t+1)}$$

$Pg_{id}{}^{(t+1)}$ Must satisfy the constraints, namely the prohibited operating Zones and ramp rate limits.

If $Pg_{id}{}^{(t+1)}$ violates the constraints the $Pg_{id}{}^{(t+1)}$ must be modified toward the near margin of the feasible solution.

Step8: If the evaluation value of each individual is better than the previous pbest, the current value is set to be P-best. If the best pbest is better than gbest, the value is set to be best.

Step 9: If the number of iterations reaches the maximum, then go to step 10. Otherwise, go to step 2.

Step10: The individual that generates the latest gbest is the optimal generation power of each unit with the minimum total generation cost.

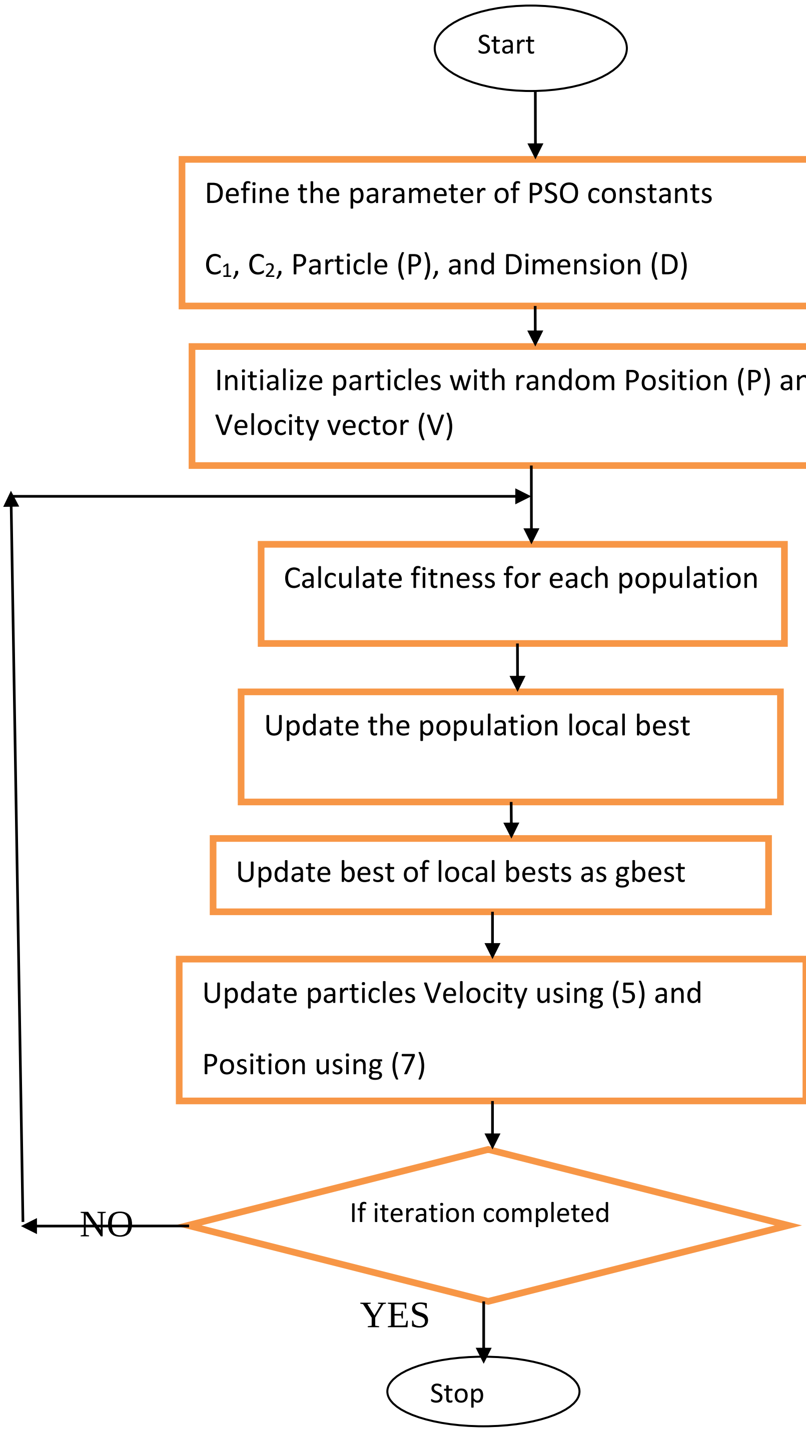

Fig (4.3) flow chart for PSO base on economic dispatch

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Results

In This section the results of economic load dispatch after the implementation the proposed lambda iteration (LI) and particle swarm optimization PSO methods are discussed, the programs are implemented in MATLAB, in solving Economic Dispatch problem according to their Cost, power dispatches and computational time. The developed algorithms for (ELD) problem based on (PSO) and (LI) have been discussed in chapter 4. The main objective is to minimize the cost of generation of plants using (LI) and (PSO) methods. the performance is evaluated with consideration transmission losses The test was done on standard system IEEE 30 bus system under varies power demands(500, 700, 1000, 1300 and 1450) MW respectively.

5.1.1 Definition - What does Institute of Electrical and Electronics Engineers (IEEE) mean?

The Institute of Electrical and Electronic Engineers (IEEE) is a global association and organization of professionals working toward the development, implementation and maintenance of technology-centered products and services.

IEEE is a nonprofit organization founded in 1963. It works solely toward innovating, educating and standardizing the electrical and electronic development industry. It is best known for its development of standards such as IEEE. The tests were carried out in 30 Busses system with the highest global standards agreed upon by IEEE.

IEEE primarily in innovates new electronic products and services, designs the standards that govern them and imparts, publishes and promotes industry knowledge through publications, conferences and partnering with academic institutes. The prime areas of focus for IEEE are electrical, electronics, computer engineering, computer science, information technology and most of their related disciplines.

IEEE in computing is widely popular for the development of standards for computer networking and its suite of services. IEEE develops many different standards, such as IEEE and provides ongoing innovation, amendments and maintenance services for these standards. IEEE also maintains thousands of student and professional chapters globally, has numerous focus societies and sponsors regular conferences and seminars. While the organization is US-based, its standards often become internationally accepted.

5.1.2The system data's

Power plants consisting of several generating units are constructed investing huge amount of money. Fuel cost, staff salary, interest and depreciation charges and maintenance cost are some of the components of operating cost. Fuel cost is the major portion of operating cost and it can be controlled. An additional to transmission line losses the system fuel cost coefficients and real -power limit are shown in Appendix-A table (5.4)[37].

5.1.3 Transmission Losses Coefficients IEEE- 30 bus Systems

Generally in a power system, several plants are situated at different places. They are interconnected by long transmission lines. The entire system load along with transmission loss shall be met by the power plants in the system. Transmission loss depends on, line parameters, bus voltages and, power flow .Determination of transmission loss requires complex computations. However, with reasonable approximations, for a power system with N number of power plants the transmission line losses coefficients of IEEE-30-Busses shown in Appendix-A [18].

5.1.4 Lambda Iteration Results

In the Table (5.1), the system lambda was obtained for 6 generators 30 bus system during the analysis using Lambda Iteration method. Every generator must have the same lambda value in order to have optimal dispatch. (LI) method using less Computational time in every analysis of different power demands, during the analysis of economic dispatch using MATLAB programming. From the table below, it was shown the dispatch power for each generator, losses in transmission, fuel cost, system Lambda and also computational time under different power demand.

Table (5.1) Results of Lambda Iteration method with losses of IEEE-30 busses system

No	PD (MW)	P1(MW)	P2(MW)	P3(MW)	P4(MW)	P5(MW)	P6(MW)	PL(MW)	Cost $/h	Comp Time/s	Lam $/MWhr
1	500	216.3878	50	85.7029	50	50	50	1.9924	6107.1	0.0688	10.110
2	700	312.282	73.420	159.487	50	59.14	50	4.1642	8288.8	0.1576	11.520
3	1000	391.5567	132.14	220.812	93.78	122.0434	50	8.127	11957	0.1609	12.700
4	1300	454.381	178.59	269.624	145.1	171.282	92.4263	13.0854	15862	0.1576	13.660
5	1450	497.1135	200	300	150	200	120	16.7391	17980	0.1637	14.280

5.1.5 Particle Swarm Optimization (PSO) Result

In the particle swarm optimization analysis in Table (5.2), the number of particles was set to 100. Besides, the weight factor was between the ranges of 0.4 to 0.9, the (PSO) was able to search for larger space and discover the G-best. The constants were set to be 2. Then, the number of iteration was set as 1000 iterations to avoid the analysis complete. Before it was really done the iteration, Error was set as e-6, so if the error was less than this value, the iteration process will terminate after 5000 iterations. During the analysis, the B-coefficient was considered to calculate the losses in transmission line for more accurate result. Besides, the generators power limit constraint was also involved in the analysis. The computational time was obtained by using the MATLAB.

Table (5.2) Results of PSO method with losses of IEEE 30 busses system

No	PD (MW)	P1(MW)	P2(M)	P3(M)	P4(M)	P5(MW)	P6(MW)	PL (MW)	Cost $/h	Comp Time/s
1	500	216.3295	50	85.662	50	50	50	1.9916	6106.07	2.91
2	700	312.223	73.383	159.456	50	59.100	50	4.1622	8286.89	2.995
3	1000	391.002	131.731	220.399	93.3474	121.6150	50	8.094	11929.2	3.04
4	1300	454.7530	178.860	269.893	145.337	171.56	92.713	13.11	15885.8	3.04
5	1450	496.7303	200	300	150	200	120	16.730	17974.8	3.05

The analysis for IEEE generators 30 bus system was done in five different power- demands which were, 500, 700, 1000, 1300 and 1450 MW. The convergence of each analysis was shown in the graphs below. The number of iterations where it started to converge can be obtained in the Figure (5.1).

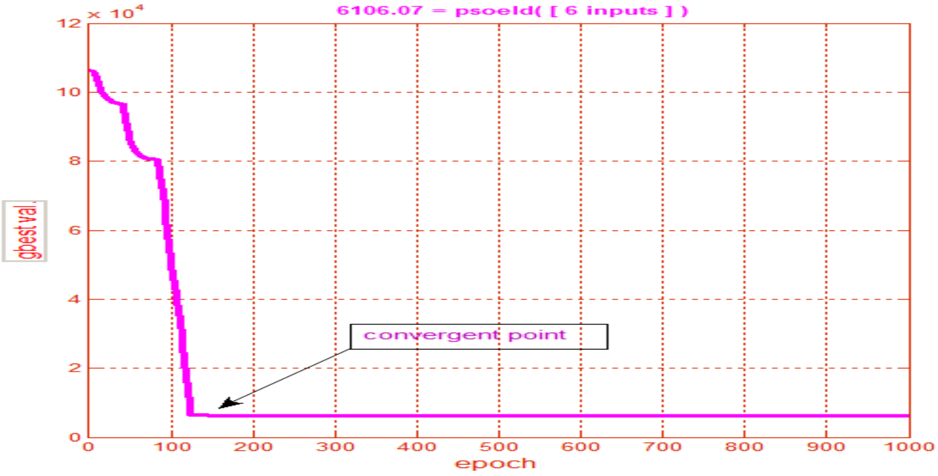

Figure (5.1a) Graphs of G-best against of iterations at P_D=500 MW

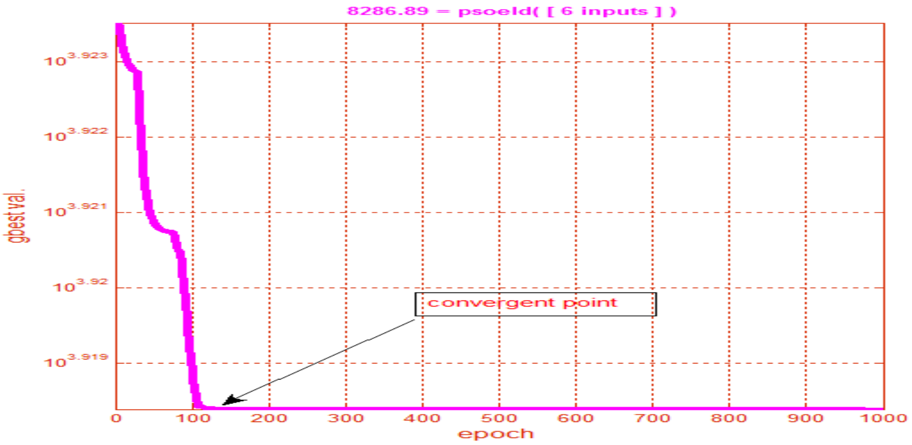

Figure (5.1b) Graphs of G-best against of iterations at P_D=700 MW

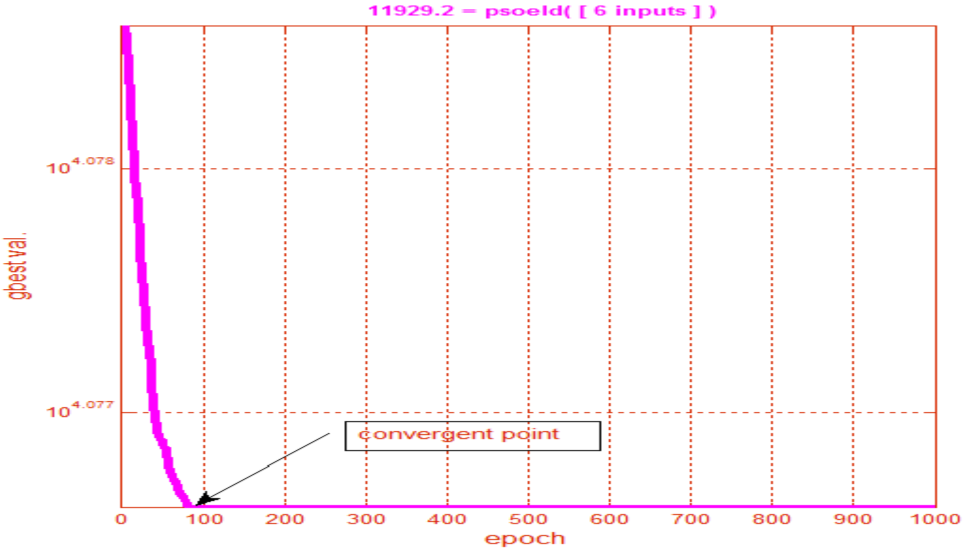

Figure (5.1c) Graphs of G-best against of iterations at P_D=1000MW

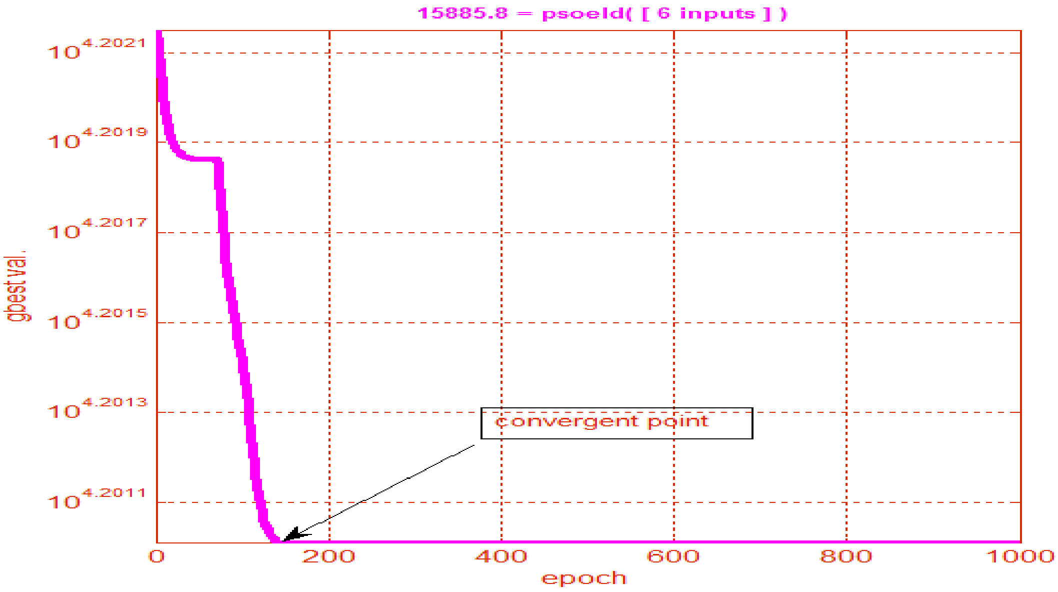

Figure (5.1d) Graphs of G-best against of iterations at P_D=1300 MW

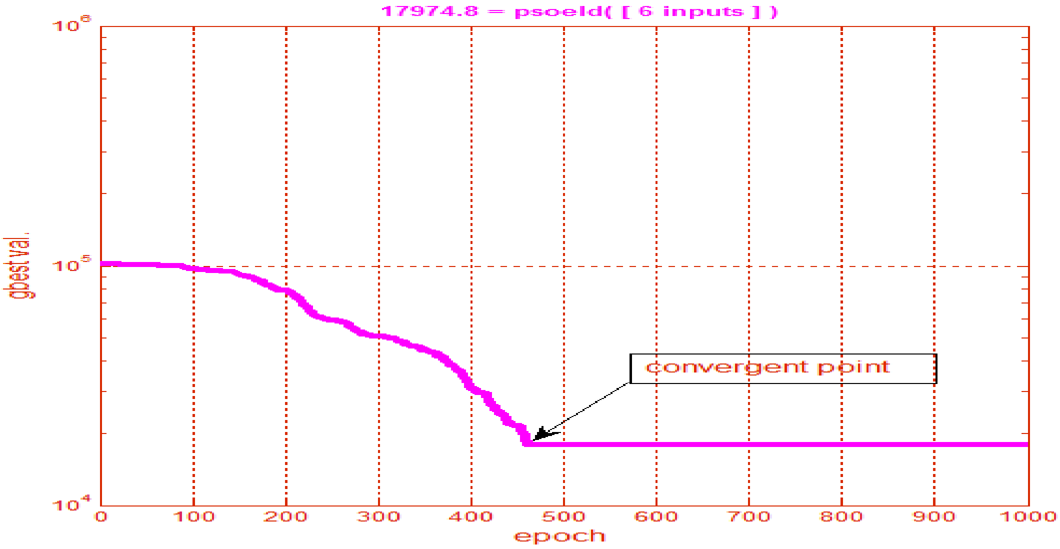

Figure (5.1e) Graphs of G-best against of iterations at P_D=1450 MW

5.1.6 Comparison between (LI and PSO)

The table (5.3) described the comparison between lambda iteration results and particle swarm optimization results, including varies load demands, costs, power losses and computation time columns. It was found that the (PSO) method is more accuracy in side of fuel cost and power losses compared to the (LI) method. Besides, the (LI) method losses also higher than (PSO) method, it will cause the cost increase.

Thus, (PSO) was better to be applied in the economic dispatch problem in order to get the most optimum dispatches for each generator and have lowest losses while satisfying the power demand.

Therefore, it was proven that the (PSO) method able to help in reducing the generation cost in a more efficient way while satisfying the load demand. (PSO) method had made it contribution in the aspects of cost saving and reducing environmental pollution as less fuel was wasted. (PSO) is more advantaged compared to (LI) method.

Table (5.3) Comparison of losses and cost between LI and PSO of IEEE system

No	Load Demands(MW)	Costs($/h)		Power losses(MW)		Comp-time/s	
	Methods	PSO	LI	PSO	LI	PSO	LI
1	500	6106.07	6107.1	1.9916	1.9924	2.91	0.0688
2	700	8286.89	8288.8	4.1622	4.1642	2.995	0.15759
3	1000	11929.2	11957	8.094	8.127	3.0189	0.16085
4	1300	15885.8	15862	13.11	13.0854	3.038	0.15755
5	1450	17974.8	17980	16.730	16.7391	3.0579	0.16379

5.2 Discussion

According to the result in Table (5.3) ,it can be concluded that the (PSO) method was able to produce a better fuel cost compared to the (LI) method. However, the result of (LI) ranges from 1000 to 1450MW was not so accurate but for the 500 to 700MW it was acceptable. From this result, it can be found that (LI) had certain limit in solving the economic dispatch problem as the fuel cost it produced may not be accurate in the larger system load demands. (LI) method was unable to provide an accurate and consistent result compared to (PSO). Particles Swarm Optimization had ability in solving the economic dispatch by considering sophisticated constraints such as generation limits, losses and large system effectively. Thus, (PSO) was better in the analysis of economic dispatch compared to LI method. (PSO) was able in generating better quality of solution and much stable in convergence compared to (LI). Although, (PSO) method was taken more computational time, it produces the desired result for the dispatcher. Therefore, by taking the consideration of cost and environmental issues, it can be concluded that (PSO) had made a contribution for it.

In addition, it has total power losses of any loads produced by (PSO) less than that by the (LI). means that the use of (PSO) reduces the cost of petroleum fuel, which contributes to protecting the environment from pollution and damage caused by petroleum derivatives, which resulting in a clean environment free from diseases and a society in need. Figures (5.1 .a-b-c-d& e) are a plot number of iteration against objective function value (total fuel cost).It can be generally noted that total fuel cost drops with increasing iteration values. This is the concept of convergence to global minima. Its corresponding the vary load 500,700,1000,1300,1450 MW respectively. For example fig (5.1a) at load demand =500MW the best value of cost is 6106.7 $/MW-hr at almost 120 iteration.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

In this chapter the conclusion will be made according to the result and discussion that obtained above. From the analysis of IEEE 30-busses generators system. Besides, recommendations will be suggested in improving the result for future research.

6.1 Conclusion

The purpose in doing this thesis was due to the importance of economic dispatch in the power system. Economic dispatch was the method or strategy in saving the fuel cost and minimizing the pollution in the environment. Economic dispatch was meant to manage the generators output in producing the lowest total cost while considering the satisfaction for operating constraints and power demand.

Economic dispatch was playing an important role in economy and environment. Thus, in order to achieve a more effective dispatch, two methods were used to solve, IEEE 30 busses generators power system. The methods were Particle Swarm Optimization (PSO) and Lambda Iteration (LI). These two methods were analyzed using the MATLAB software by running the codes for each of the methods.

From the analysis of IEEE 30 busses generators system with transmission losses, it was found that (PSO) method was able to produce a better accuracy in fuel

cost and power losses compared to the (LI) method. For each of the power demand, (PSO) was able to produce less cost than (LI). Besides, the losses produced by (PSO) for each power demand according to the B-coefficient was smaller than (LI) produced. As we know, higher losses will result in the consumption in fuel and increase the fuel cost. Thus, it was very important to get the optimal dispatch in reducing losses. As shown in table above .As a result, (LI) was using less computational time in the analysis compared to (PSO) method. The computational time of LI method was affected by the increasing of number of generators. However, the computational time of the (PSO) method will not be increased due to increment of generator amount. Although, (PSO) was using more time in analyzing the result, because the process including analysis and plotting convergent point. It produces better result than the LI method. (PSO) was also possessed steady convergence characteristic which result in accuracy and consistency in the result.

As a conclusion, (PSO) method was more suitable to be used in solving the economic dispatch problem due to its ability in producing lower fuel cost, losses, and accuracy. Since, (PSO) was able to perform more efficient, that will be a great help in saving the generation cost by reducing the fuel consumption. Moreover, pollution to the environment also can be minimized as less fuel was used in satisfying the power demand.

6.2 Recommendations

For the future research, other methods could be added in to find out if there any better solution other than Particle Swarm Optimization. For example, GA, neural network, tabu search and other type of PSO methods that can be used based on the system that had been analyzed. It was possible to get better result or fuel cost and satisfying the power demand.

Furthermore, bigger system may be introduced in the analysis in order to find out which method was able to produce the best result no matter how big the system was. Systems such as IEEE 40 buses, IEEE 50 generators and so on could be applied in the analysis by using different methods. Since, the system had become large, the accuracy and limit of the methods can be identified. Some of the methods may not be able to solve large power system.

Software beside MATLAB may be introduced if it is able to be applied in solving the ELD problem. Besides, B-coefficient also can be obtained by using load flow analysis if it was not given in some of the system. The B-coefficient can be obtained through the MATLAB by applying the B-loss program.

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Appendixes

Appendix-A

Table (5.4) Fuel cost coefficients data and real-power limits for generators

Gen-No	**ϒ**	**β**	**α**	**P(min)**	**P(max)**
1	0.0070	7	240	100	500
2	0.0095	10	200	50	200
3	0.0090	8.5	300	80	300
4	0.0090	11	150	50	150
5	0.0080	10.5	200	50	200
6	0.0075	12	120	50	120

Transmission Losses Coefficients IEEE- 30 bus Systems

$$B = \begin{bmatrix} \mathit{0.000017} & \mathit{0.000012} & 0.000007 & -0.000001 & -0.000005 & -0.000002 \\ 0.000012 & 0.000014 & 0.000009 & 0.000001 & -0.000006 & -0.000001 \\ 0.000007 & 0.000009 & 0.000031 & 0.000000 & -0.000010 & -0.000006 \\ -0.000001 & 0.000001 & 0.000000 & 0.000024 & -0.000006 & -0.000008 \\ -0.000005 & -0.000006 & -0.000010 & -0.000006 & 0.000129 & -0.000002 \\ -0.000002 & -0.000001 & -0.000006 & -0.000008 & -0.000002 & 0.000150 \end{bmatrix}$$

Appendix-B

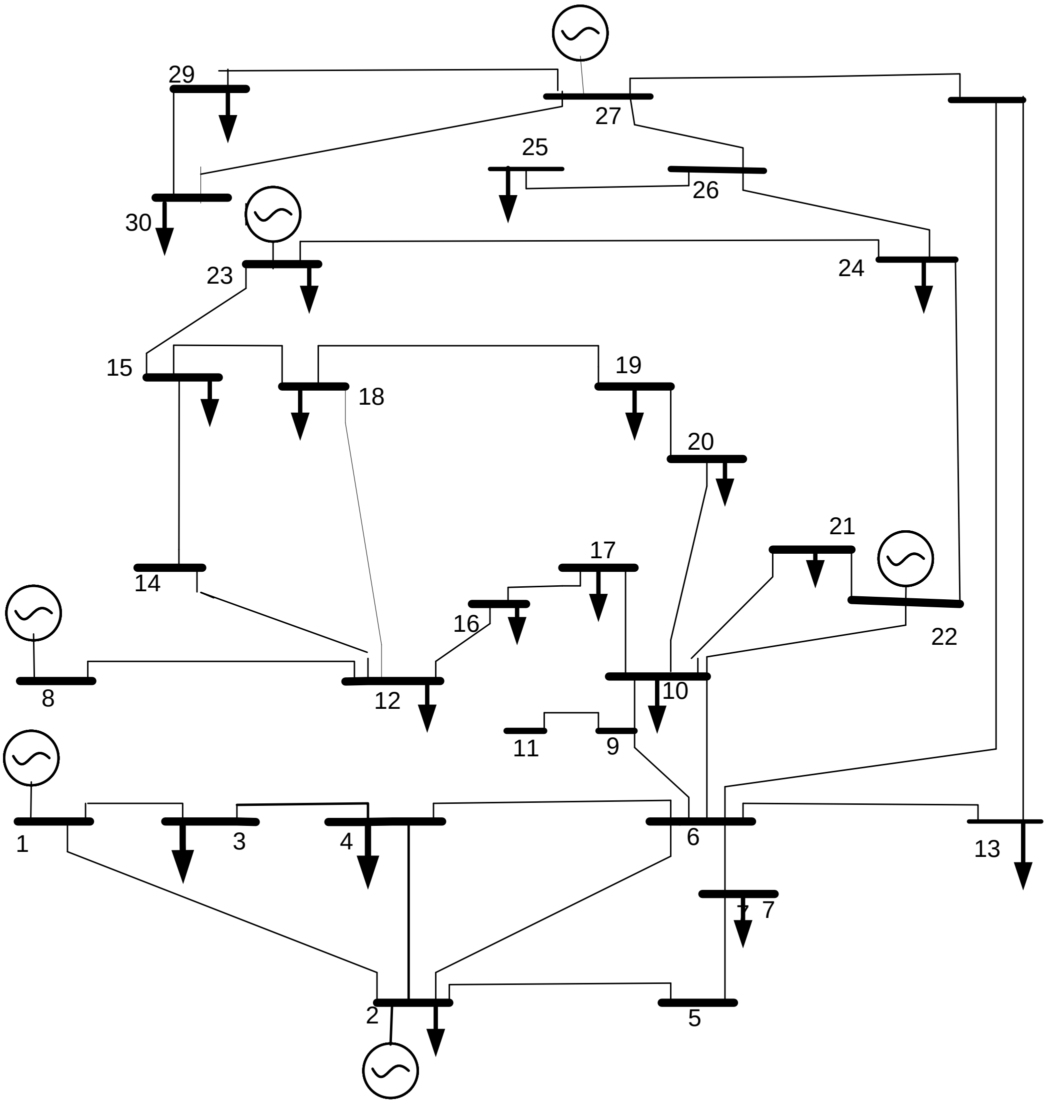

Fig (6.1) Diagram of IEEE-30 Busses System

Appendex-C

LAMBDA ITERATION CODE

```
clear all
clc
KKKKKKKKKKKKKKKopf=open('lamb_eco.doc','w+');KKKKKKKKKKKKKKK
no units=6;
Pd= 500;
a=[0.0070 0.0095 0.0090 0.0090 0.0080 0.0075];
b=[7 10 8.5 11 10.5 12];
c=[240 200 300 150 200 120];
Pmax=[500 200 300 150 200 120];
Pmin=[100 50 80 50 50 50];
B=[ 0.000017  0.000012  0.000007 -0.000001 -0.000005 -0.000002
     0.000012  0.000014  0.000009  0.000001 -0.000006 -0.000001
     0.000007  0.000009  0.000031  0.000000 -0.000010 -0.000006
    -0.000001  0.000001  0.000000  0.000024 -0.000006 -0.000008
    -0.000005 -0.000006 -0.000010 -0.000006  0.000129 -0.000002
    -0.000002 -0.000001 -0.000006 -0.000008 -0.000002  0.000150 ];
itermax=1500;
epsilon=0.1
alpha=2*a
Pg=zeros(no_units,1)
lambda = 0.7
del_lambda=0.01
tic;deltaP=10;iter=0
KKKKKKKKKKKKKK while abs(deltaP)>epsilon && iter< itermax KKKKKKKKKKKKKK
iter=iter+1
for i=1:no_units
sigma=B(i,:)*Pg-B(i,i)*Pg(i)
```

```
Pg(i)=(1-(b(i)/lambda)-(2*sigma))/(alpha(i)/lambda+2*B(i,i))

if Pg(i)<Pmin(i)

Pg(i)=Pmin(i)

end

if Pg(i)>Pmax(i)

Pg(i)=Pmax(i)

end

end

P_loss=Pg'*B*Pg

Pt=sum(Pg)

deltaP=Pt-Pd-P_loss

error(iter)=deltaP

if deltaP>0

lambda=lambda-del_lambda

end

if deltaP<0

lambda=lambda+del_lambda

end

end

Ft=0.0;

for i=1:no_units

   F(i)=c(i)+b(i)*Pg(i)+a(i)*Pg(i)*Pg(i);

Ft=Ft+F(i);

end

tic

 runtime=toc
```

Appendix-D

Code for particle swarm optimization

```
% Particle swarm optimization
% the data matrix should have 5 columns of fuel cost coefficients and plant  limits.
% 1.a ($/MW^2) 2. b $/MW 3. c ($) 4.lower limit(MW) 5.Upper limit(MW)
clear
clc;
opf=fopen('pso_eco.doc','w+');
format long;
global data B  Pd
data=[0.0070  7  240      10        125
0.0095  10        200       10        150
0.0090  8.5       300       35        225
0.0090  11        150       35        210
0.0080  10.5      200       130       325
0.0075  12        120       125       315];
B=[0.000017  0.000012  0.000007 -0.000001 -0.000005 -0.000002
  0.000012  0.000014  0.000009  0.000001 -0.000006 -0.000001
      0.000007  0.000009  0.000031  0.000000 -0.000010 -0.000006
     -0.000001  0.000001  0.000000  0.000024 -0.000006 -0.000008
     -0.000005 -0.000006 -0.000010 -0.000006  0.000129 -0.000002
     -0.000002 -0.000001 -0.000006 -0.000008 -0.000002  0.000150];
Pd=700; l=data(:,4)'; u=data(:,5)'; ran=[1' u']; n=length(data(:,1));
Pdef = [50 1000 10 2 2 0.9 0.4 1500 1e-6 5000 NaN 0 0];
 kkkkkkkkkkk[OUT]=pso_Trelea_vectorized('psoeld',n,1,ran,0,Pdef);kkkkkkkkkkkk
 out=abs(OUT) ; P=out(1:n)
  [F P Pl]=psoeld(P')
  [P1 Fcost1 Pl1]=eld(data,B,Pd)
```