UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION
INSTITUE OF SCIENCE AND TECHNOLOGY

OPTIMIZING THE ECONOMIC POWER DISPATCH FOR VARIOUS GENERATION UNITS IN IRAQI NETWORK

MASTER THESIS

Mohammed AL-JUMAILI

THE DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

MASTER THESIS PROGRAM

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Mohammed AL-JUMAILI
25.10.2017

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I express my sincere gratitude to the Iraqi ministry of electricity.

To all these people and to the spirits of the martyrs of Iraq, Dedicate this work.

Thanks to My University THKU

October 2017 Mohammed AL-JUMAILI

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LIST OF ACRONYMS

EPD : Economic Power Dispatch
NBA : Novel Bat Algorithm
BA : Bat Algorithm
PSO : Particle Swarm Optimization
GA : Genetic Algorithm
QP : Quadratic Programming
LD : Load Demand
PL : Power Losses
FA : Firefly Algorithm

ABSTRACT

OPTIMIZING THE ECONOMIC POWER DISPATCH FOR VARIOUS GENERATION UNITS IN IRAQI NETWORK

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The economic power dispatch (EPD) is an integral part of the power system, and the major roles and purpose of its use are for achieving a reliable and efficient operation out of the power system and generation networks, and this operation should be obtained by minimizing the generator fuel cost. Getting optimal solutions to EPD problem requires efficient optimization algorithms.

In Iraqi network, we have 31 generating units, and these units represent all thermal units in Iraq. Firstly, in this thesis, we have employed the optimization methods for a part of generating units (19 units) in order to solve the economic power dispatch for the Iraqi system. We employed the most well-known algorithms, such as the Novel Bat Algorithm (NBA), Particle Swarm Optimization (PSO), Genetic Algorithm (GA) and Quadratic Programming (QP). The aim of this study is to get an optimal solution in reducing the fuel cost of the Iraqi power system as much as possible.

Secondly, Novel Bat Algorithm (NBA) is one of the most recent methods and it has already proven its efficiency and reliability for solving the EPD problem. This study proposes Novel Bat Algorithm (NBA) in order to solve the EPD problem based on the large scale power system. The NBA has proved its efficiency and it gave a perfect performance for small-scale systems compared with the original Bat algorithm (BA), because of considering the Doppler Effect and assumed that bat can move between various habitats. To test the performance of NBA during small and large scale power system, we have applied it to many systems, including 3-thermal units, 6-thermal units, 31-Iraqi thermal units and IEEE 40-thermal units respectively, with transmission losses and generator limits, and we have made a comparison of the obtained results of NBA with other optimization methods.

Keywords: Economic Power Dispatch (EPD), Particle Swarm Optimization (PSO), Novel Bat Algorithm (NBA).

ÖZET

IRAK AĞI'NDA FARKLI KUŞAK BİRİMLERİ İÇİN EKONOMİK GÜÇ GÖNDERİMİNİ EN İYİ HALE GETİRMEK

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Ekonomik güç dağıtımı (EPD), güç sisteminin ayrılmaz bir parçasıdır, onun ana rolü ve amacı; güç sistemi ve üretim ağlarından güvenilir ve verimli bir çalışma elde etmektir ve bu işlem, jeneratör yakıt maliyetini en aza indirgeyerek elde edilmelidir. EPD sorununa en uygun çözümleri elde etmek için verimli optimizasyon algoritmaları gerekir.

Irak şebekesinde 31 üretim birimi vardir. Bu birimler, Irak'taki tüm termik birimleri temsil eder. Birinci olarak, Bu tezde ilk olarak, Irak sisteminin ekonomik güç dağıtımını çözmek için üretim birimlerinde (19 ünite) optimizasyon yöntemleri kullanıldı. Novel Bat Algoritması (NBA), Parçacık Sürüsü Optimizasyonu (PSO), Genetik Algoritma (GA) ve Kuadratik Programlama (QP) gibi en iyi bilinen algoritmaları kullanıldı. Bu çalışmanın amacı: Irak elektrik sisteminin yakıt maliyetini mümkün olduğunca azaltmak ve en uygun çözümü bulmaktır.

İkincisi ise, en güncel yöntemlerden birisi olan Novel Bat Algoritması (NBA) ve EPD sorununu çözmek için, yeterliliğini ve güvenilirliğini kanıtlamıştır. Bu çalışma, büyük ölçekli güç sistemine dayalı EPD problemini çözmek için Roman Bat Algoritması'nı (NBA) önermektedir. NBA verimliliğini kanıtlamış, Doppler Etkisini göz önüne almış ve yarasa çeşitli yaşam alanları arasında hareket edebileceğini varsaydığı için, orijinal Bat algoritması (BA) ile karşılaştırıldığında küçük ölçekli sistemler için mükemmel bir performans sağlamıştır. NBA'nın küçük ve büyük ölçekli güç sistemi sırasında performansını test etmek için, 3-termal üniteler, 6-termik üniteler, 31-Irak termik üniteleri ve IEEE 40-termik üniteler dahil olmak üzere birçok sisteme iletim kayıpları, jeneratör limitleri ve diğer optimizasyon yöntemleri ile NBA`dan elde edilen sonuçlarının karşılaştırmasını yapıldı.

Anahtar Kelimeler: Ekonomik Güç İletimi (EPD), Parçacık Sürüsü Optimizasyonu (PSO), Novel Bat Algoritması (NBA).

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Study the electric power is considered one of the most significant fields currently, because it interferes with our everyday life. The electric power industry is divided into production, transmission and distribution, and all these parts are very expensive especially the production part. The major aim in study the electric power is to deliver the electricity to the consumer in a correct and economic way and without interruptions. There are several sources of electricity production such as nuclear, hydro, thermal, solar, etc. Some of these sources are very expensive such as thermal power plants. Due to the high cost of electricity production, we will focus in this study on the production part of the power industry and especially the thermal power plants, and will try to find an optimal method to reduce the losses of the power system in order to produce electricity in an economic way, taking into consideration the efficiency and reliability of the operations.

Increased complex problems of our real life encouraged the engineers to investigate for efficient and reliable problem-solving techniques to minimize the cost of industrial products. The behavior of any organism such as, bee, ant, bats and others made the investigators working up in order to find optimization algorithms to solve these complicated problems of our life. One of these complicated problems is the Economic Power Dispatch (EPD) problem. Dealing with the cost of electric power production is an important part of studying the electric power system. Engineers have created many optimization algorithms, and the main aim of them is to deal with the fuel cost of electric generation units and minimize it as much as possible considering the efficiency and reliability of the operations.

Solving the EPD problem is one of the most important styles used to operate the power system and control it. The major aim of solving this problem is to reduce the overall cost of electricity production taking into consideration the available operational constraints on the power system. EPD works to solve the problem economically by dealing with the fuel cost equation for each generating unit and it works to cover the load demand at the lowest possible cost of fuel. EPD method has proven its efficiency and reliability in reducing costs of electricity production and saving millions of dollars. The use of EPD methods began after 1975, and those methods were consisting of sets of mathematical orders and decisions that worked to reduce costs and deal with fuel equations for generation units and those conventional methods were considered unconstrained optimization. Those methods proved their efficiency for a long period of time such as a Lambda Iteration method, Linear Programming Based method, the Gradient method and the Interior Point method. The operational constraints in power systems were few in that period, so the unconstrained optimization methods achieved efficient results, and the EPD problem was also considered one of the easiest and linear problems. But then, the operational constraints of power systems gradually began to increase due to the modernity of electric power plants and wide networks. The problem began to turn into a nonlinear problem due to these new operational constraints. Researchers have begun to look for more efficient methods and adapt to these new operational constraints such as valve point effect, transmission loss and prohibited zone. That means that researchers have begun to look for constrained optimization methods and these methods should be adapted to new operational constraints. In fact, researchers have succeeded in finding many optimization algorithms, some of these algorithms have proven its efficiency and reliability and they are working so far such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Firefly Algorithm (FA) and Bat Algorithm (BA).

Optimization has turned into one of the most indispensable parts of delineation activity in all major specialties. The major reason of using the optimization methods in solving the problems is to produce economically pertinent services and products where the quality is embedded. Optimization can be proposed to all specialties, and one of them, we utilize it as an optimal solution for the problem of EPD.

1.2 Problem Definition

The EPD is a main and an integral portion of power system and it is embedded under the term of economic operations of power systems. The purpose of EPD is to determine an optimal power output for a generation unit in order to cover the load demand according to the minimum fuel cost for every generation unit and satisfy different operational constraints over finite dispatch period [1].

The problem of EPD considers a complicated problem (nonlinear problem), due to the huge number of operational constraints that are related to this problem. The major aim to solve this problem is to avoid wasting an extra money, where this money can be saved if we make the power system working in an economic way. In the Iraqi network, there are many thermal generating units, and these units are working in a random way. A lot of money is wasted because of this random operation. This system needs to be operated in an economic way in order to reduce the cost of operations. And this status is considered one of EPD problems. To solve this problem, we are going to employ the optimization methods to reduce these extra costs.

Many optimization methods were employed in order to solve the problem of EPD, and one of the most recent and efficient algorithms is the Novel Bat Algorithm (NBA). It was originally proposed in [2-4]. The proposed NBA has given a higher quality performance when it was applied for small scale power systems [3, 4]. The BA performance can be calculated by making comparison with other well-known optimization methods that they proved their efficiency and reliability in solving the EPD problem, such as Genetic Algorithm (GA) [5, 6] and Particle Swarm Optimization (PSO) [7-9], and we will study the performance of NBA by simulation results.

In this study, two part of dataset are used. The first part points to the small-scale power system and it consists of 3-thermal units and 6-thermal units. These networks have been taken from [3, 4]. The transmission loss is considered for these networks, and it is calculated by B-coefficient method. The cost coefficients and generator limits for these networks are presented in the chapter five. The second part of power network indicates to the large-scale power system and it also consists of 31-thermal units of Iraqi network. This data includes the quadratic fuel equations for the electrical thermal units in Iraqi network, and it includes all thermal units in Iraq. This data has been taken from the Planning and Studies Center in Iraqi Ministry of Electricity. The other data is IEEE 40-units. Also the transmission loss is considered and it is calculated by the B-coefficient method. All the transmission line losses are virtual values and we have assumed them for all power systems.

1.3 Motivation

In the Iraqi power system, the thermal generating units represent a large amount of electricity production. This system does not work in an economic way, and a lot of money is wasted randomly. Making this system working economically and reducing this wasted money is our motivation in this thesis.

1.4 Objective

The major objective of our study is to let the electric power system work economically and minimizing all losses as much as possible. Utilizing optimization methods to solve the EPD problem is the optimal way in reducing the cost of system operations, especially in minimizing the fuel cost of generating units and reduce the transmission losses. This economic operation must be achieved by sharing total load demand among all generating units, according to the minimum cost for each unit, taking into consideration the efficiency and reliability of this process. The main target of using this process is to obviate wasting extra money on system operations; in return, this money can be saved.

1.5 Contribution

The power losses are the major problem in all countries and Caused great concern. Minimizing these losses and making systems work within an optimal performance considers a great aim for these countries. In this thesis, firstly, we will solve the problem of economic power dispatch for thermal power plants in the Iraqi network. We will use new and real data for these generation units and this data has been taken from the Iraqi Ministry of Electricity. We will employ several famous algorithms which have proven their high performance previously, and we will make comparisons between the obtained results of these algorithms to determine which one gives the most accurate and optimal results in reducing the cost of electricity production.

Secondly, the Novel Bat algorithm (NBA) has proved its high and accurate performance in solving the problem of economic power dispatch previously, but for a small-scale power system only, including three or five generation units. In this thesis, we will employ the Novel Bat algorithm to solve the problem of economic power dispatch for large-scale power systems, including 31_units of Iraqi thermal plants and IEEE 40-unit system. Then we will monitor the performance of this algorithm by comparing its achieved results with other algorithms.

1.6 Thesis Organization

This thesis has been done in six chapters. Chapter one introduces the introduction of thesis, work objects and the contribution.

Chapter two presents the literature reviews of the thesis subject.

Chapter three explains the main idea of the EPD problem and its details, including the transmission line loss and the interconnection system.

Chapter four represents an explanation of the optimization algorithms that will be used in our study.

Chapter five summarizes the practical work of the thesis, including the cases study with the achieved results.

Chapter six is a conclusion and the summary of the thesis.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter mentions to the literature survey of solving the EPD problems. The EPD problems were solved by classical methods, but these days, many optimization algorithms use to solve the power system. In this chapter, we present the most famous optimization method that used successfully and gave optimal results in minimizing the fuel cost of power generation units.

2.2 Literature Review

2.2.1 Solve the EPD problem using Firefly Algorithm

Jaswantand Wadhwani [10], mainly have used the Firefly Algorithm (FA) to resolve the EPD, also Lambda-iteration method (LIM) was applied for the same purpose. Both of them were applied to know which one will give the most optimal results in minimizing the fuel costs for the generation units. A virtual network has used, including 6 generation units, and the transmission line losses were considered in this work and it was also a virtual data. As a result of this study, the results of the FA were more accurate and gave a more optimal solution than the other method (LIM).

J. Merlin and Nagajothi [11], have employed developed FA as proposal to resolve the EPD and minimizing the cost of the generating units. The proposed algorithm has applied to a data set consisting of the IEEE 30 bus system. Employing the (FA) was the best to minimize the fuel costs of the generation units and it has given the most optimal results compared with the other optimization methods, such as GA and Evolutionary Programming.

Sreelekha and Scaria [12], have employed the FA and Self-Adaptive Differential Evolution algorithms (SDE) to reduce the power generators' costs by solving EPD for 10-generation units with valve point effect and multiple fuel equations for each unit. In short, the comparison between the results of both algorithms showed that (FA) was capable of getting good quality optimal solving non-smooth EPD problems compared with the other algorithm.

2.2.2 Solve the EPD Problem Using Evolutionary Algorithms

M. F. Zaman et al. [13], have employed two evolutionary algorithms to give the optimal generators' output according to the minimum fuel costs and solving the dynamic EPD problems. The self-adaptive differential evolution and real-coded genetic algorithm were the proposed algorithms for a network. A diversity mechanism and constraint handling mechanism have been used to improve the execution of the proposed algorithms. Using those techniques made the algorithm giving better results in solving the dynamic EPD. In the future, these algorithms will apply in solving the dynamic EPD problems, including renewable energy sources with thermal generation units.

Rahmat et al. [14], have utilized the Differential Evolution Immunized Ant Colony Optimization (DEIANT) algorithm in order to solve the EPD problems. The researchers got this cited algorithm by making improvement to the standard Ant Colony Optimization algorithm to get more accurate and efficient results of the power system. The aim of this work was to determine the generators' output at the minimum fuel costs. Many constraints were calculated in this study such as prohibited operating zones, valve loading effect and ramp rate limits. Also, the transmission line losses were counted. These operational constraints made the system more complicated and non-linear. MATLAB program was used to obtain the results. The performance of DEIANT algorithm was superior and accurate in achieving lower fuel costs of the generation units and in decreasing the losses.

Rahmat et al. [15], presented in this study the Differential Evolution Immunized Ant Colony Optimization Technique (DEIANT) to solve the EPD problem and reducing the cost of electricity production for a power system, including prohibited operating zones. The intent of this study was to solve the problem of EPD for the power system economically and make the generation units operating according to the minimum fuel costs and in the same amount of power. The database includes IEEE 30 bus unit system. A comparison has been done between the proposed algorithm DEIANT in a side, with the Differential Evolution (DE) and Ant Colony Optimization (ANT) algorithms in the other side. The numerical results were done by using MATLAB. The proposed algorithm gave a good performance in solving the power system and the comparison indicated that the DEIANT algorithm was the best in term of minimizing the fuel costs of generation units.

2.2.3 Solve the EPD Problem Using Hybrid Algorithms

Yamina et al. [4], have make hybridization between the most well-known algorithms, including FA and Bat algorithm (BA) in order to solve the EPD and minimizing the fuel cost of the generation units. The aim of making this hybridization was to have the best results to reduce the fuel cost of generating units and minimize the random effect of both algorithms that are above-mentioned. In short, the new approach really has given excellent results compare to using those algorithms separately.

Raul et al. [7], proposed in this paper a developed algorithm by mixing between the two famous algorithms in solving the EPD: PSO and GA. The hybrid developed algorithm has employed based on 3, 13 and 20 generation units respectively. The hybrid algorithm results were normal in the first case and they were better in the other studies. Also, a comparison between the hybrid algorithm and the original algorithms (PSO and GA) results has been worked and it showed the new method was higher quality than the other algorithms. The simulation results have been done by using the MATLAP program.

Dipankar et al. [9], have utilized in this paper a new hybrid algorithm in order to solve the convex and non-convex EPD problems. The algorithm was a combination of PSO and ACO algorithms. The PSO-ACO algorithm has been applied on a small-scale network, which it has 3 thermal units and 5-bus system. The operational constraints represented by valve point effect, prohibited operating zones and ramp rate limits. In addition, the transmission line losses were considered for all case studies. The aim of this hybridization was to avoid the weakness of PSO in getting stagnated in local loop before reaching the optimal solution. The performance of the PSO-ACO algorithm was really inspiring compared with the other hybrid algorithms, especially when it bases for 3 generators and 5-bus system. The simulation results have been obtained by MATLAB program.

2.2.4 Solve the EPD Problem Using Genetic Algorithm

Fahad et al. [5], proposed in this paper the GA to solve the EPD problem. The unit system included two sources of energy: renewable energy unit (one wind power plant) and six thermal generators. The aim of this study was how to mix between the two energy sources and avoid the constraints correctly to solve the EPD and getting optimal results for the generators' output according to the minimum fuel cost. For this work, the GA has applied and the results have shown optimal ranges for the thermal units against the probabilistic wind power unit.

Muhammad et al. [6], have applied the developed GA on a data set, including 6-generation units with Quadratic Equations of fuel cost for solving the EPD problem and getting a satisfactory result of generators' output, according to the minimum fuel cost. The GA has mixed up with Priority list. The intention of that hybridization was to give a better result and control the multi-constrained nonlinear EPD problem. The hybrid GA has gotten laudable choice to solve EPD problem and it gave an excellent huge optimization in improving the efficiency of the EPD results.

2.2.5 Solve the EPD Problem Using Particle Swarm Optimization

Jun et al. [16], have employed a new developed optimization to solve the EPD. This algorithm is called the random drift particle swarm optimization (RDPSO). Three case studies were taken, and the simulation results of those cases showed that the (RDPSO) performed higher quality results and good convergence properties compared with the other algorithms that they have used such as PSO, GA and others.

Zetty et al. [17], have employed extension of particle swarm optimization (E-PSO) in solving the EPD problems for the continuous non-linear power system. This algorithm is an improved approach of standard PSO. The data set included 6 generating units, and the generators power limits and the transmission line losses were considered in this study. The simulation results showed that the E-PSO could solve the power system in a better way compared with the standard PSO and it was able to satisfy the equality and inequality constraints. The obtained numerical results have been done by MATLAB program.

2.2.6 Solve the EPD Problem Using Bat Algorithm

Gauthaml and Rajamohan [4], have used in this paper the Novel Bat Algorithm (NBA) to solve the EPD problem and get satisfactory generators' outputs at a minimum fuel cost. The novel algorithm has been achieved by using Doppler Effect and foraging of the bat between various habitats. Two test cases were used, including 5 and 6 thermal generation units respectively. The first case was without transmission line losses and the valve loading effect was considered, and in the other case, transmission line losses were considered but without valve loading effect. The proposed algorithm has proved that it is the best in getting optimal results at minimum fuel costs compared with the other algorithms. The comparison was between the proposed algorithm in a side and the standard BA and the PSO algorithm in other side. The simulation results have been achieved by MATLAB program.

Julia Jose [18], has employed in this study the Bat algorithm (BA) to solve the EPD problems and minimize the fuel costs of generation units as much as possible. Mixed power networks were applied, including thermal generation units and wind power unit. Two study cases were used, one with a wind generator and the other without, and the results of BA have been compared with PSO algorithm. The proposed algorithm was able of achieving higher quality solutions. The obtained results of algorithms have been done by MATLAB program.

2.2.7 Solve the EPD Problem Using Other Optimization Methods

J. P. Zhan et al. [19], have applied a new EPD method and it is called a Fast Lambda Iteration method. This method has been developed from its main method (LIM). This new method has employed on a 15-unit system and 140-unit system of Korea country. The results have been getting by using a numerical solution, and this method performed very well in both cases in 15-unit system and 140-unit system of Korean network and gave the optimal solution.

Mahesh et al. [20], have made improvement for the general Bees algorithms to achieve a better EPD optimization and get good results in minimizing the fuel cost. In this study, Improved Bees Algorithm (IBA) has used to be employed in solving the dynamic EPD for prohibited operation zones. IBA has applied to a power network, including (6) generation units with nonlinear characteristics and the constraints of ramp rate limits, also the transmission line losses were considered in this work. The purpose of using IBA is to satisfy the operational constraints represented by spinning reserve, transmission losses, load demand, prohibited operation zone and ramp rate limits. By studying the results, IBA has given a better performance and it was more efficient compared with the other algorithms, such as PSO, GE and General BA. In addition, the IBA has proved that it is an excellent algorithm in satisfying the constraints.

Ehsan and Farsangi [21], have introduced a developed algorithm to solve the EPD problem and it is called Improved Adaptive Shuffled Frog Leaping Algorithm (IASFLA). The enhancement and the good performance of SFLA have been done by suggesting a new adaptive frog leaping rule. This new algorithm applied based on 40 thermal generation units. This new algorithm has applied successfully for non-smooth EPD problem with ramp rate limits and prohibited operating zones and it showed more accurate result than the general algorithm (SFLA).

Seyyed et al. [8], have presented in this paper an effective new hybrid algorithm to solve the EPD problems with valve point effect. The work aim was scheduling the generators output limits in order to cover the load demand, according to the minimum fuel costs for each generation unit. Clonal Selection Algorithm (CSA) used the positive properties of other optimization methods, Gases Brownian Motion Optimization (GBMO) and Particle Swarm Optimization (PSO). The new hybrid PG-Clonal algorithm showed activeness and it has solved the EPD problem efficiently. In addition, it was fast and reliable in getting the results of generators' output. This algorithm has been employed to minimize the fuel costs for 13 thermal generation units. The simulation results have been done by MATLAB program.

Uguret et al. [22], presented in this paper the Symbiotic Organisms Search (SOS) as an optimization algorithm to solve the EPD problems. This algorithm was suitable and efficient to solve the EPD problem which it has operational constraints, such as ramp rate limits, prohibited generating zones and valve point effect. The algorithm has been employed to solve the EPD problem for a power network which is consisting of 38 units. Three cases were used: 3, 15 and 38 generation units respectively, with non-convex and discontinuous fuel cost functions. The achieved results showed that the SOS algorithm was able to give an optimal solution in small iteration number and it was reliable and good optimization algorithm to solve the classical EPD and non-convex EPD problems. The simulation achieved results has been done by using the MATLAB program.

Bratati et al. [23], have employed an influential hybrid Krill Herd algorithm (HKHA) in order to solve the non-convex EPD problems. The mentioned algorithm applied on thermal generation units with inequality constraints such as valve point loading and prohibited operating zones. The transmission line losses have been considered in this study. The obtained results showed that the performance of HKHA has high quality and fast speed of convergence in all compared with the previous algorithms which they have used in this paper and the mentioned algorithm can be used as a one of the most efficient algorithms to solve the complicated EPD problems. The simulation results have been done by MATLAB program.

Junqing et al. [24], have introduced in this study Pareto-based chemical reaction optimization (PCRO) algorithm in solving the EPD problems and minimizing the fuel cost of the generating units. The aim of this study was to get the optimal solution in minimizing the fuel generation costs and emission. A novel encoding mechanism has been designed to improve the algorithm execution. The obtained results showed that this algorithm has a good performance in solving multi area EPD problems compared with the other optimization techniques. The PCRO algorithm has been applied to a power network consisting of 6 generating units and the transmission line losses was considered. The simulation results have been executed by MATLAB program.

Sulaiman and Mohamed [25], presented in this paper a proposed Cuckoo Search algorithm (CS) in order to solve the EPD problems. This algorithm has been employed to control the valve loading effect with other practical constraints such as prohibited operating zones and the power limits of generators. Two test systems have been used in this study, 40-unit system and 15-unit system. From the simulation results, the proposed algorithm (CS) showed that it is the best one in minimizing the fuel costs of generation units comparing with other algorithms presented in this paper. The simulation results have been achieved by MATLAB program.

Weiye et al. [26], have applied the fully distributed algorithm to solve multi area EPD problems. The algorithm used based on three IEEE test systems, 30 bus system, 69 bus system and 276 bus system, and the effectiveness of transmission line for active distribution network has been taken during these tests. The numerical results of proposed algorithm have been compared with two other well-known distributed algorithms, Lagrangian relaxation and auxiliary problem principle. The achieved results of the proposed algorithm showed the speed and accuracy of the fully distributed algorithm in solving the EPD problem and giving an optimal solution, they also showed the effectiveness of the transmission line loss model.

Wong et al. [27], have presented in this work an optimization method in order to solve the EPD problems, and this method is called Grey Wolf Optimizer (GWO). This algorithm has been applied to a power network, including 20-generation units. The simulation has been done by using MATLAB program. The final results have been verified by making a comparison between them and the most popular optimization algorithm and methods of EPD such as, lambda-iteration method, Artificial Bee Colony (ABC), Firefly algorithm (FA), Hopfield model based approach (HM) and some others. The GWO was able to solve the EPD problem successfully, and find the optimal results according to minimize the fuel cost of generation units. Also, it has given competitive results compared with the other famous optimization methods.

Subramanian et al. [28], newly presented in this paper a novel proposed algorithm in solving the EPD problems, and this method is called TANAN's Algorithm (NTA). The objective of that was to minimize the fuel cost of the generation units and find the optimal solution for that. The operational constraints were including the power limits of generation units and the transmission line losses. The NTA is a numerical and a random search approach founded on a parabolic TANAN function. The NTA has solved the problem successfully and it has outperformed the previous optimization methods such as GA, PSO and BBO and it gave the best results in all cases according to the minimum fuel costs of generation units.

Rani et al. [29], proposed in this paper the Modified Artificial Bee Colony (MABC) algorithm in order to minimize the fuel cost of the generation unit and solve the EPD problem. The MABC algorithm was selected in solving the EPD due to its superiority over the other optimization methods. The MABC algorithm has the least number of control parameter and its execution of exploration and exploitation phases during the search of optimal solution. This algorithm has been applied for IEEE 30-

bus system and wind generator. 6 generators were used in this study and the sixth one has been replaced by wind generation unit. The transmission line losses were embedded in the calculation of the optimal solution and they have been calculated by using B-loss matrix. The operational constraints were including the valve loading effect, the prohibited operating zones and ramp rate limits. From the study of simulation results, the MABC performance had higher quality compared with the standard ABC algorithm and it was better in all tests in finding the optimal solution for the EPD problem according to the minimum fuel costs of generation units. The simulation results have been calculated by MATLAB program.

Surender and Momoh [30], have made an improvement to Artificial Neural Network (ANN) algorithm to get the proposed algorithm Improved Hopfield Neural Network (IHNN) algorithm. This new algorithm has faster convergence and it is more efficient than the standard algorithm. The mentioned algorithm was used to solve the EPD problems with prohibited operation zones and active power constraints. It has applied based on 3, 6 and 20 generation units respectively. The MATLAB program has used to achieve the simulation results. The IHNN results have been compared with the Lambda Iteration method and Particle Swarm optimization. The performance of IHNN was good, especially in the convergence speed.

Ming et al. [31], have employed the Hysteretic noisy chaotic neural network (HNCNN) algorithm in order to solve the EPD problem for a power system and minimizing the operational costs for a network, including 3 thermal plants with transmission line losses and valve point effect. The aim of the study was to solve the system economically and minimize the fuel costs for the generation units as much as possible. The numerical results have been obtained by MATLAB and they have been compared with other optimization method such as Genetic algorithm (GA) and Ant Colony Optimization. The mentioned algorithm HNCNN proved that it is one of the best algorithms in solving the EPD and it gave an optimal solution in minimizing the fuel costs of generation units.

2.3 Summary

From the literature review, it is found that many optimization algorithm has been employed in order to solve the EPD problems and some of them have been developed to give a more efficient solution. Many constraints have been used in the various studies such as generator limits, valve loading effect, prohibited operating zone and transmission line losses. From the numerical results of the algorithms, we found that many optimization algorithms gave global solutions and they have proved that they are the best in term of minimizing the fuel cost of the generation units, such as PSO, GA, NBA, FA and others.

CHAPTER THREE

ECONOMIC POWER DISPATCH

3.1 Introduction

In this chapter, we will first explain the problem of economic power dispatch in the power systems for the thermal generation units, and we will discuss the constraints related to this problem. Second, we will discuss the available solutions to this problem and the classical method used to solve the problems of economic power dispatch.

Economic operations in power systems have taken an important and essential site globally, especially in thermal generation units, due to the high fuel costs of electricity production relatively. After the rise in fuel prices globally, a lot of economic studies in the field of electric power began to appear and develop gradually. The aim of these studies is to produce electricity, according to the lowest fuel cost, taking into consideration the available constraints in power systems. The most important solutions reached by the researchers are the economic power dispatch method, which is one of the reliable and adopted methods currently. The economic power dispatch also has begun gradually to develop by electrical engineers, and new algorithms emerged to solve the problem of economic power dispatch as optimization algorithms.

The major aim of studying and solving the problem of economic power dispatch in thermal generation units is to achieve the minimum cost of electricity production and delivery the electricity to the consumer at the lowest cost taking into consideration the quality and reliability in the delivery of energy. The study has been developed significantly in recent times, due to countries need to reduce the cost of electricity production to the minimum and optimal status. In addition, there is a significant need to study operational constraints in power systems so as to maintain the safety of the power system and to operate it optimally, thus not causing the system to break down due to unexpected circumstances.

The EPD determines the optimum output of a set of power plants to cover the electrical load demand by a specific area, taking into consideration the reliability and high efficiency of the electrical power delivery. The problem of EPD can be solved by software programs and these programs should take into consideration the processes and operational constraints of power systems to avoid sudden system crashes. The problems of EPD have resolved previously by many methods based on mathematical integration and differentiation methodology, as found in the method of Lagrangian multiplier [32], and these methods have linear Characteristics of curves. But these methods may not be able to resolve the problem of EPD in the modern power systems, so that electrical engineers started to look for new methods to solve power systems economically, due to increasing of power plants and increasing the operational constraint, in addition to that the modern power plants have non-linear Characteristics.

The increasing in power plants, increasing the operational constraints in power systems and the nonlinear characteristics of modern power plants, all of them are among the major reasons why electrical engineers resorted to find new methods for solving the EPD problem. Many optimization algorithms were discovered by researchers, and these algorithms have been developed to give better and more accurate results than the old methods. As that these algorithms take into consideration the increasing of operational constraints in power systems and nonlinear characteristics of modern power plants. The optimization techniques have been used to improve the performance and efficiency of the electrical power systems and have achieved the ultimate target ultimately. It has been widely used in whole industries and especially in the electrical industry. These algorithms have helped to improve decision making and give the system a higher performance and reliability more than the previous methods.

Mathematical optimization in power systems is a set of related decisions and orders that lead to a precise and rapid decision. The purpose of the optimization is to reduce the total cost and control to a specific power system in order to deliver electricity to the consumer in an efficient way and less losses as much as possible. The problem of EPD is one of the most important optimization in power systems, which is considered a difficult and a nonlinear problem. The difficulty reason of EPD problem and making it a nonlinear problem is the many operational constraints in the power system such as transmission losses, valve point effect, wide network, prohibited loading zones and others. Previously, the well-known classical methods have been employed in order to solve the EPD problem such as lambda iteration method [33], linear programming based method [34],the gradient method [35], and the interior point method [36], but because of the new constraints mentioned and the modern generation units, these methods began to record inefficient results relatively. Researchers began to look for new and more efficient methods and actually several optimization algorithms have been discovered recently. The new optimization algorithms really gave amazing and optimal results compared to conventional methods. Some of the new optimization algorithms have proved their high efficiency and outstanding performance, such as PSO, BA and GA.

3.2 Economic Power Dispatch

3.2.1 Generalized EPD Problem

As we mentioned previously, the EPD method can be defined as the operations that occur on a group of electric power plants to produce electricity at the lowest cost by the dealing with fuel cost equations for each generating unit, taking into consideration all operational constraints in these units. The EPD problem is based on the efficient and economical allocation of power generation units in a specific network to meet the load demand in order to deliver electricity to consumers in the correct and optimal way. Therefore, the main objective of solving the EPD problem is to reduce the cost of production of the electric power plants optimally. The system shown in Figure 3.1 represents multiple thermal generation units [37]. These units are all linked to a single bus-bar that covers the load demand. The (F1) symbol represents the cost rate of the generator (1), and the total cost of the system is calculated by the summation of the cost rate (F) for each generator separately.

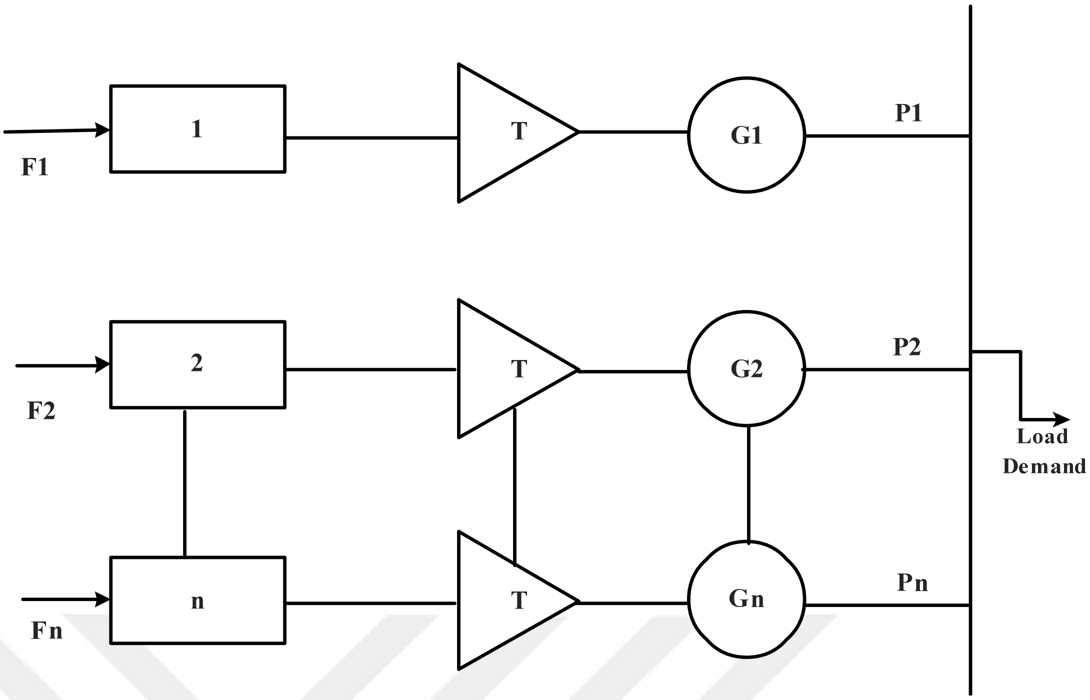

Figure 3.1: N-thermal generation units linked to cover load demand.

3.2.2 Fuel Cost Function

Energy sources are many types and diverse such as (fuels, wind, tides, hydro, nuclear, etc.). There are three types of energy that are frequently used in power plants, which include nuclear plants, hydro-plants and fossil plants (oil, gas and coal). The cost of producing electricity in hydro power units is very low and these plants depend on the availability of water. The nuclear power plants always cover a base load and it is still ON. Therefore, the cost of fossil stations such as thermal stations is considered in economic dispatch procedures. There is a containment of the costs for fuel, operational staff and maintenance on the electricity production, and since the costs of maintenance and operational staff are fixed and did not change, then the cost of fuel is only that take into consideration in the economic dispatch. The Figure 3.2 is expressed a simple model of fossil unit (thermal unit).

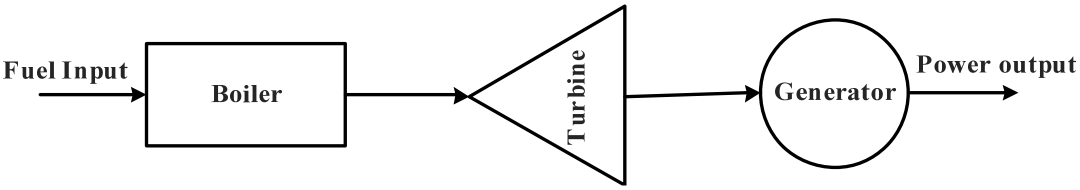

Figure 3.2: simple model of thermal unit.

In thermal generation units, the input of the unit is read as (Btu / hr), while output is taken as (MW). In fact, the fuel cost in thermal units usually is taken as a function in quadratic form. This quadratic function can be expressed mathematically as follows:

$$F_i(P_i) = a_i + b_i P_i + c_i P_i^2 \tag{3.1}$$

Where ai, bi and ci are expressed the cost coefficients for generation thermal unit (i), and (Fi) is representing the total fuel cost for unit (i). There is also a direct proportion between the value of fuel cost with the increase in unit production, it means if the (MW) increases, the fuel cost will increase too. The Figure 3.3 shows the relationship between fuel cost and unit production.

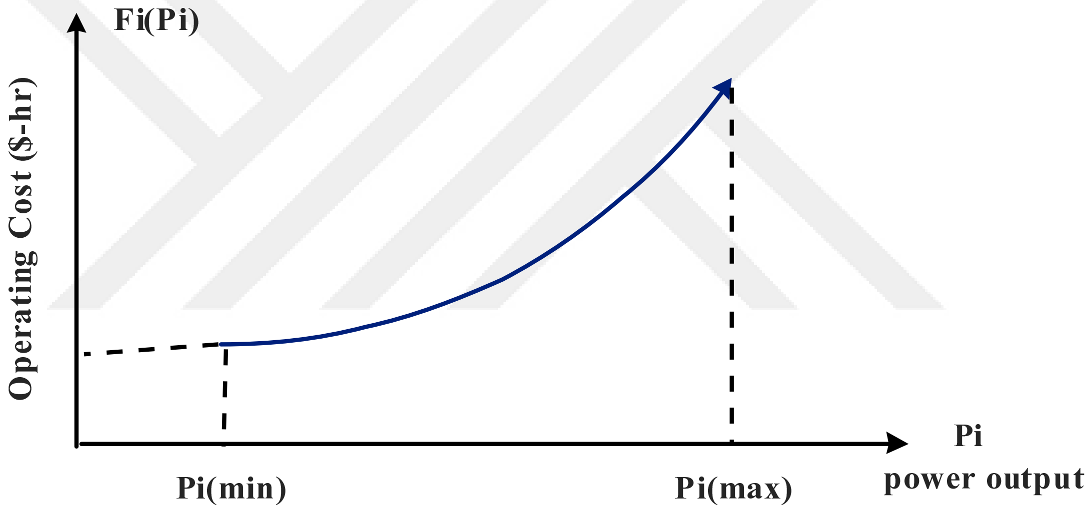

Figure 3.3: Cost curve of thermal generation unit.

3.3 Operational Constraints of Power Systems

The mathematical constraints are defined as conditions that exist in optimization problems, and the available solution to this problem must be satisfied for these constraints and take them into consideration in order to avoid collapse of the system. The power system is similar to any other system and has a lot of operational determinants which they must be considered in the solution of the problem. The constraints in the power system can be classified into equality constraints, inequality constraints and other, and we will explain them below.

3.3.1 Equality Constraints

In power systems and EPD studies, the cost functions of the generating units do not depend on the required reactive power (VAR), so the attention must be for the real power (MW), and this real power should always be in balance state [38]. This condition is an important constraint in the study of EPD and can be represented mathematically as follows:

$$P_D = \sum_{i=1}^{N} P_i \tag{3.2}$$

Equation (3.2) represents the balance state for real power between the produced power and the load demand, but in this mathematical function the losses of transmission lines have been neglected. If we add these losses into the consideration, there will be a slight change to this equation and it will be as follows:

$$P_D + P_L = \sum_{i=1}^{N} P_i \tag{3.3}$$

Where, the (PD) represents the load demand for the system, and (PL) are the total transmission losses of the power system which can be calculated by the B-coefficient method.

3.3.2 Inequality Constraints

The inequality constraints are also important, and they are taken into consideration in solving the EPD problem. These constraints can be classified as follows:

Generator constraints: the loading of (KVA) must be within pre-defined and specified limits and does not overcome the value specified previously, in order not to cause rising the temperature to the unacceptable high value, and as a result this high temperature can do damage to the generator.

The higher and lower values of the real power (MW) for each generation unit are determined according to special considerations. The maximum value (Pi max) is taken according to the thermal considerations in the generating unit, and the minimum value (Pi min) is determined according to the intensity of the boiler flame. Each generator has upper and lower determinants as shown in Fig. 3.3. These inequality constraints are represented mathematically in the following equation:

$$P_{i\min} \le P_i \le P_{i\max} \tag{3.4}$$

In a similar way for the reactive power (MVAR), which must not exceed the pre-assumed and specified values, avoiding the high temperatures which result the losses in the rotor part of the generator, and this value can be expressed in the following equation:

$$Q_{i\min} \le Q_i \le Q_{i\max} \tag{3.5}$$

Also the inequality constraints include the constraints of transmission lines for the system, and these constraints shortly depend on the power flow through the transmission lines and this power flow is determined by thermal capability of the system circuit. This constraint led to that system loss (transmission line loss) must be greater than zero, and that means, there are always losses in the power system.

$$P_{loss} \rangle 0 \tag{3.6}$$

3.3.3 Constraints of Unit Commitment

Unit commitment is the process of running the generating unit and connecting it to a specific network and making it synchronous. In other words, the generation unit can deliver electrical power to the grid. There are a lot of available constraints in the field of unit commitment and we will mention some of them.

A. Spinning Reserve:

The spinning reserve is defined as the total amount of generating power in a specific and synchronous network, minus the total amount of both the power delivered to load demand and the transmission line losses. Spinning reserve is important in the synchronous power networks, to compensate the lost power suddenly, in order not to cause so far drops in the system by the effect of this lost power, especially the drop in frequency. In other words, if one of the generating units is turned off suddenly, there must be a reserve capacity to compensate this lack in the power in the synchronized network. The spinning reserve must be distributed among fast-responding units and low-responding units, due to the control system of generation can automatically and quickly compensate for losses and restore the frequency value.

The spinning reserve should not be distributed among generating stations in suitable way only, but it should have fast-responding to be turned on and connect it to the network. So spinning reserve must be selected from special kinds of generating plants such as gas plants, high-speed diesel plants or hydro power plants, in order to make a quick response to compensate the power lack of the synchronized network, and restore the frequency. Therefore, the spinning reserve can be calculated within the network, according to the response speed of these power plants and the compensation of losses quickly.

B. Thermal Unit Constraints:

As well known, thermal generating units require a large functional staff to operate and synchronize them to the network, especially in turn on and turn off cases. The thermal power plants need several hours to be connected to the synchronized grid. Because of these operations, several constraints have been generated from the thermal units such as:

1. Minimum up-time: in this case, the thermal power plant need for a time period to be turned on, and another period to be turned off, and that means, if the thermal unit is running, it will require time period to make it turned off, and it should not turn off immediately.
2. Minimum down-time: if thermal unit does not commit to a network, there will be a minimum time before connecting it to the network synchronized.
3. Crew constraints: if there are a lot of thermal units in a plant, these units cannot be committed at the same time to the network, due to this operation requires enough staff to make all units in committed status.

In thermal generation units, the increasing of unit temperature relatively is slow, and this operation consumes the amount of energy to reach the required limit in order to commit the thermal unit into the network, and this consumed energy does not give any MW to the network. This status is considered one of unit commitment problems and it is called start-up cost.

The value of a start-up is different relatively, and it is calculated among the range of cold start value (maximum) and minimum value. These values depend on the status of the thermal unit. If the unit has turned-off recently and it still keeps a portion of its temperature, the unit does not need to high start-up cost, and vice versa. There are two types of processes that treat this problem and reduce the cost of start-up: first, by making the boiler cool-down to a certain level and then making the boiler restore its the required temperature by backup heat to run at a specified time for the scheduled turn-on. The second is called banking, and this requires energy to enter into the boiler sufficiently in order to restore the boiler heat and re-run the unit. The following equations show the start-up cost in both cases:

$$cooling - \cos t = (1 - \varepsilon^{-t/\alpha}) \times F + C_f \tag{3.7}$$

$$banking - \cos t = C_t \times t \times F + C_f \tag{3.8}$$

Where:

Cc is the cost of cold start-up (MBtu).

F is the fuel cost.

Cf is a constant cost, including crew and maintenance expenses in ($).

α is thermal time constant.

t is the cooled period time in (h).

Ct is the maintaining cost of the unit at operating temperature in (MBtu / h).

The cooling cost is greater than the banking cost for a certain number of hours, as shown in Figure 3.4.

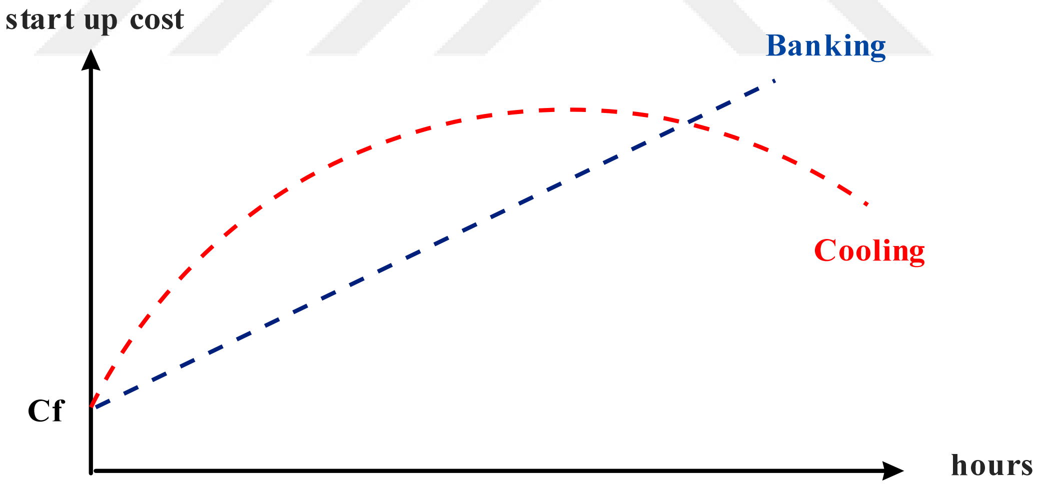

Figure 3.4: Time dependent of start-up cost.

C. Other Constraints:

1) Must-run Constraint:

There are some generation units which they must run at specific times during the year in order to support the voltage on the transmission system, or to provide the steam in order to use outside unit steam.

2) Fuel Constraints:

This constraint is related to fuel existence, and some generation units have fuel, but in limited amount, or other generation units have some constraints which demand them to burn a specific size of fuel at a certain time, and this constrained status presents a challenge for the unit commitment.

3) Hydro-unit Constraints:

The hydro generation units are considered so economic units and their costs are so small compared to other unit such as thermal plant, and if these units (hydro) should not be separated from the synchronous network and scheduling production, due to if we separated them, we would not get optimal and economic solutions.

3.4 EPD for Thermal Units Neglecting the Transmission Losses

The total cost (FT) for a number of thermal generation units can be calculated mathematically according to the following equation:

$$\begin{aligned} F_T &= F_1(P_1) + F_2(P_2) + .. + F_n(P_n) \\ &= \sum_{i=1}^{n} F_i(P_i) \end{aligned} \tag{3.9}$$

When the transmission line loss (Ploss) is not considered for the system, the total generation should be equal to the total load demand of the system (PD) according to the equality constraints that we mentioned.

$$\sum_{i=1}^{n} P_i = P_D \tag{3.10}$$

As mentioned previously, the problem of EPD is a constrained optimization which can be solved by the Lagrange multiplier method as shown in the following equation:

$$L = F_T + \lambda\phi \tag{3.11}$$

$$\phi = P_D - \sum_{i=1}^{n} P_i \tag{3.12}$$

The symbol (λ) is presented the incremental fuel cost and it should be the same for all units. The important condition for making the total cost minimum is by derivation of the Lagrange equation for the independent variables and makes them equal to zero.

$$\frac{\partial L}{\partial P_i} = \frac{\partial}{\partial P_i}\left\{\sum_{i=1}^{n} F_i(P_i) + \lambda(P_D - \sum_{i=1}^{n} P_i\right\} \tag{3.13}$$

$$= \frac{\partial F_i}{\partial P_i} - \lambda = 0$$

$$\frac{\partial L}{\partial \lambda} = 0 \tag{3.14}$$

$$\frac{\partial F_i}{\partial P_i} = \lambda \tag{3.15}$$

By offsetting equation (3.1) in equation (3.15), we will get the following:

$$\frac{\partial F_i}{\partial P_i} = 2c_i P_i + b_i = \lambda \tag{3.16}$$

$$P_i = \frac{\lambda - b_i}{2c_i} \tag{3.17}$$

Substituting (Pi) from the equation (3.10) above, we will get:

$$P_D = \sum_{i=1}^{n} \frac{\lambda - b_i}{2c_i} \tag{3.18}$$

Or

$$\lambda = \left[\frac{P_D + \sum_{i=1}^{n}\left(\frac{b_i}{2c_i}\right)}{\sum_{i=1}^{n}\frac{1}{2c_i}}\right] \tag{3.19}$$

To minimize the fuel cost, we must find the value of (λ) firstly, then we will calculate the output values of (Pi), finally we will calculate the fuel cost for the system.

3.5 EPD for Thermal Units Considering the Transmission Losses

In this case, the total load demand must be distributed between the generating units economically, taking into consideration the power transmission network and the resulted losses by this network. Figure 3.5 shows a scheme of such system.

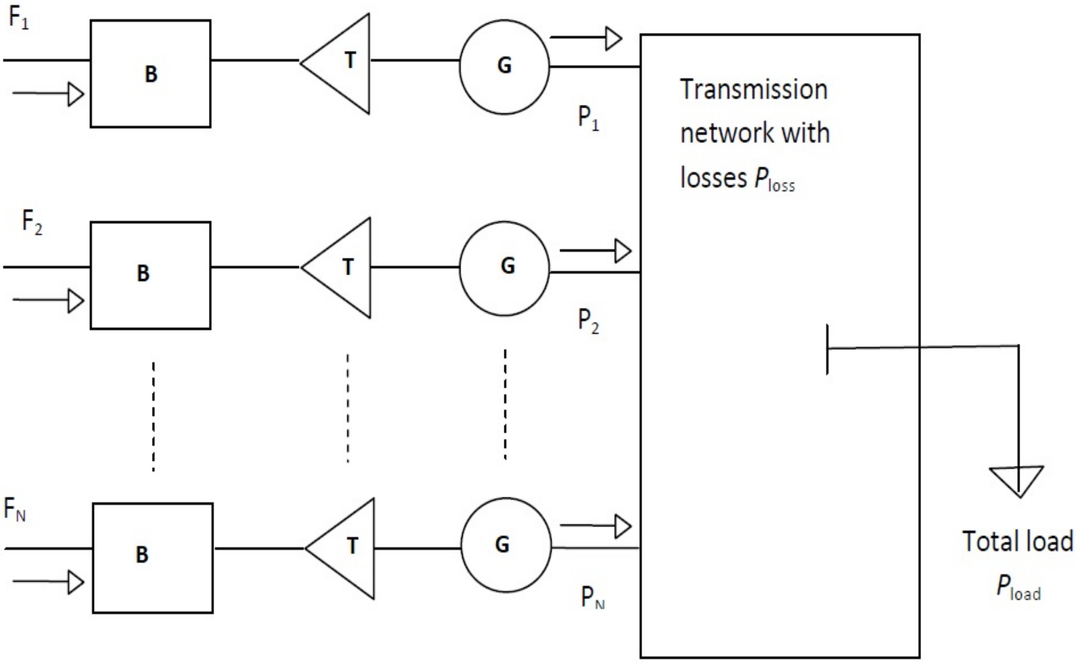

Figure 3.5: N-thermal units serving P_D with transmission loss.

As we mentioned, the total fuel cost can be expressed as follows:

$$F_T = F_1(P_1) + .. + F_n(P_n) = \sum_{i=1}^{n} F_i(P_i) \tag{3.20}$$

According to the equality constraints that we mentioned previously, the transmission loss will be considered here. So the balance of power will be as follows:

$$\phi = P_L + P_D - \sum_{i=1}^{n} P_i = 0 \tag{3.21}$$

The PL is presented the total loss of transmission lines. The problem here is to determine the values of (Pi) which will minimize the total fuel cost and find the optimal solution for the system. Also by using the Lagrange method, the equation will be as follows:

$$L = F_T + \lambda\phi \tag{3.22}$$

And (ϕ) has been given in equation (3.12) previously. The important condition is minimizing the fuel cost, according to the following equation:

$$\frac{\partial L}{\partial P_i}\left[\sum_{i=1}^{n} F_i(P_i) + \lambda(P_L + P_D - \sum_{i=1}^{n} P_i)\right] = 0 \qquad (3.23)$$

Or

$$\frac{\partial L}{\partial P_i} = \frac{\partial F_i}{\partial P_i} + \lambda(\frac{\partial P_L}{\partial P_i} - 1) = 0 \qquad (3.24)$$

By rearranging the equation (3.24) above,

$$\lambda = \frac{\frac{\partial F_i}{\partial P_i}}{1 - \frac{\partial P_L}{P_i}} \qquad (3.25)$$

$$\lambda = p_{fi} \frac{\partial F_i}{\partial P_i} \qquad (3.26)$$

Where (p_{fi}) is expressed the penalty factor for the power plant and it is calculated as the following equation:

$$p_{fi} = \frac{1}{1 - \frac{\partial P_L}{\partial P_i}} \qquad (3.27)$$

3.6 Transmission Losses and B-Coefficients

The transmission loss is considered in our study and it is calculated by using the B-coefficient method. There are several methods to calculate the transmission losses. The B-coefficient is the most efficient method and it is the simplest one that used to calculate the losses through the power transmission systems. PL function is called Kron's formula and it can be expressed as follows:

$$P_L = P^T B\ P + B_0^T P + B_{00} \qquad (3.28)$$

Where:

P represents a vector related to all generators outputs for the buses net.

B is a square matrix.

B0 is the length vector.

B00 is a constant.

B term is the loss coefficients, and it is also called B-coefficients which consist of a symmetrical matrix. The PL according to B-coefficients can be expressed as the following equation:

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{i0} P_i + B_{00} \tag{3.29}$$

According to the equality constraints that we mentioned previously, the equation above will be rewritten as follows:

$$\phi = P_D + \left[\sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{i0} P_i + B_{00}\right] - \sum_{i=1}^{n} P_i \tag{3.30}$$

3.7 Interconnection in Power System

Interconnection means gathering many systems and making them work together in a coherent way, according to specific and constrained rules and as a result, getting a single and comprehensive system that can be controlled in a simpler way. The power systems also consist of several generation units their components, and these components all should be interconnected according to certain basics, because the interconnected system is more reliable than the systems that operate separately. The exchange of power during interconnected systems has proved its efficiency for working and it is more organized and more economical. The interconnection in power system has many benefits such as:

1. Interconnection makes the power system more reliable and efficient, due to the loss of generating unit can be compensated by the spinning reserve from other generating unit among the interconnected utilities.
2. The interconnected power system generally needs to spinning reserve that less than the separated power systems.
3. Interconnected system can give better economic operations compared to the separated system.
4. Interconnected system can give the system fast-responding with the faults that occur in the power system such as the unexpected loss of generation.

These reasons above make the interconnected system more efficient and more reliable system and all the power system in the world are interconnected. The Figure 3.6 express an example of interconnection.

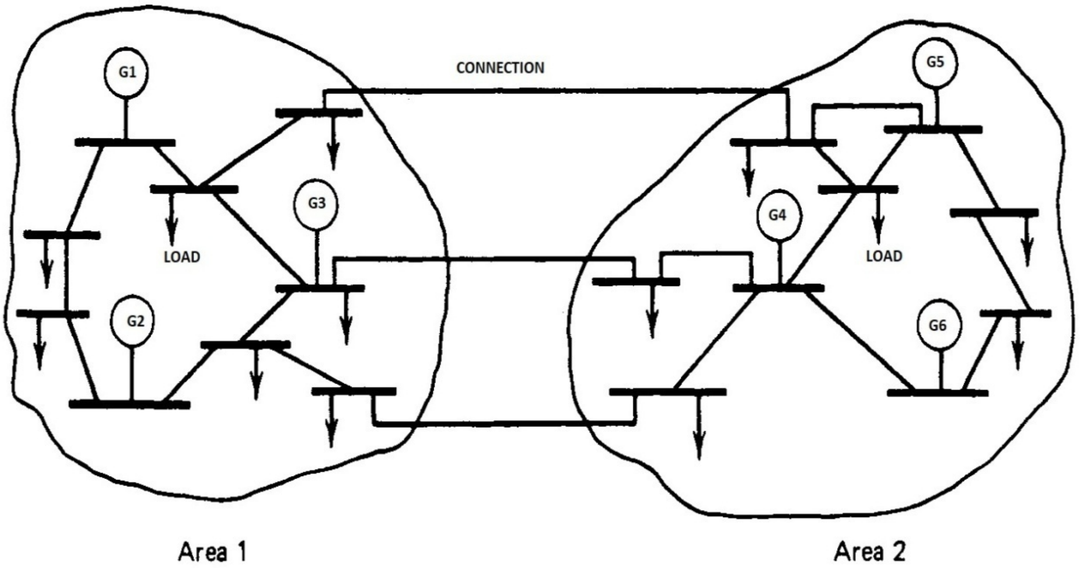

Figure 3.6: Example of interconnected areas.

3.7.1 Interconnection Types

3.7.1.1 Capacity interchange

Usually, the power system has an available spinning reserve and this reserve is used in status of peak load times and the sudden outages of units. If this power system does not have this capacity of power, the system can make interconnection with another neighboring system, and this neighboring system must have this required capacity. The neighboring system sells electricity to the other system in the peak load times and buys the power in the other times according to an agreement between the both systems. The capacity reserve agreement does not grant extra energy to the power purchaser, but it sells the energy to another system in the emergency status only.

3.7.1.2 Diversity interchange

In some cases, the peak load demand between two neighboring systems may be different. For example, the peak period of the first system may be delayed from the second system by two hours. In this case, there could be an agreement between the two neighboring systems. The first system provides the power in peak-time of the second system, and the second system returns this power at the peak time of the first system. This type of power exchange is called daily diversity interchange.

3.7.1.3 Energy banking

This type of power exchange often occurs between two different systems in the type of power source. For example, if we have a interconnection between a hydro power system and a thermal-system, the hydro-system provides the power to the thermal-system at a specific time of year when the water level is high, due to the hydro-system may have a spare energy. Vice versa, the thermal system returns this energy to the hydro-system at another time, especially when the water level is low.

3.7.1.4 Emergency power interchange

At some times, emergency breakdowns may occur in a specific system and these breakdowns cause the electrical plants to get out of operating, and the load demand will not be covered. In such this case, the system must import and purchase the electrical power from a neighboring system to cover its required load. Such agreements often are considered so expensive and uneconomical, because the purchase of energy will be unilateral and this agreement may occur at inappropriate and uneconomic times.

3.7.1.5 Inadvertent power exchange

The AGC (Automatic Generation Control) is not an ideal control system. There may be some errors in the energy exchange between two systems. Because of these errors, this type of power exchange is called Inadvertent Power Exchange. The total amount of Inadvertent energy between the systems is often calculated yearly or monthly and it can be solved by calculating the cost of this electrical energy and returning it to the other system in another time.

3.7.2 Power Pool

When there are several systems that are neighboring to each other, making agreements with each system separately can be a waste of time, and these agreements may not be perfect in finding the optimal cost of electricity production. In such a case, a central office can be established and this office can organize the sale and purchase the electrical energy between these neighboring systems. This central office is called the power pool. This power pool has several advantages such as:

1. It can maximize the efficiency of operation and reduce the production costs.
2. It reduces the high cost of emergency power interchange.
3. It can give a perfect performance for unit commitment.
4. It works to share the spinning reserve; as a result, the costs will be minimized.

3.8 Summary

This chapter presents the EPD formulation in detail and how to reduce the operational costs of power systems, especially the cost of fuel used in the thermal power plants. It also presents the operational constraints of power systems and their impact in reducing operation costs. Then an explanation has been shown about how to calculate the losses of transmission lines in power systems. Finally the exchange of electrical energy between neighboring systems has presented to avoid the high costs of electricity production.

CHAPTER FOUR

OPTIMIZATION ALGORITHMS

4.1 Introduction

This chapter shows the optimization techniques that are used to solve the EPD problem in our thesis. Also, we will present the optimization algorithms which will be considered in our thesis in order to solve the problem of EPD. We will explain the algorithms used in details, and how they work to minimize the operational costs in electricity production.

4.2 Optimization

Optimization technique has turned into one of the most necessary fields of delineation activity in all major specialties. The main reason for utilizing the optimization techniques in solving the problems is to get economically pertinent services and products where the quality is embedded. Optimization can be proposed to all specialties, and one of them, we utilize it as an optimal solution for the problem of EPD in order to minimize the operational costs of electricity production.

We can define the optimization as a set of mathematical orders work to choose the best element from a set of candidate choices, taking into consideration all constraints must be satisfied [39]. The Optimization technique can give the optimal solution of specific function and all function constraints must be satisfactory. For the EPD problem, we can define the optimization as follows:

$$(\min imize)\, F_T = \sum_{i=1}^{n} F_i(P_i) \tag{4.1}$$

4.3 Optimization Algorithms

The Optimization technique can give the optimal solution of specific function and all function constraints must be satisfactory. The optimization methods can be classed into two groups: stochastic and deterministic algorithms. The Figure 4.1 shows the classification of optimization algorithms [40].

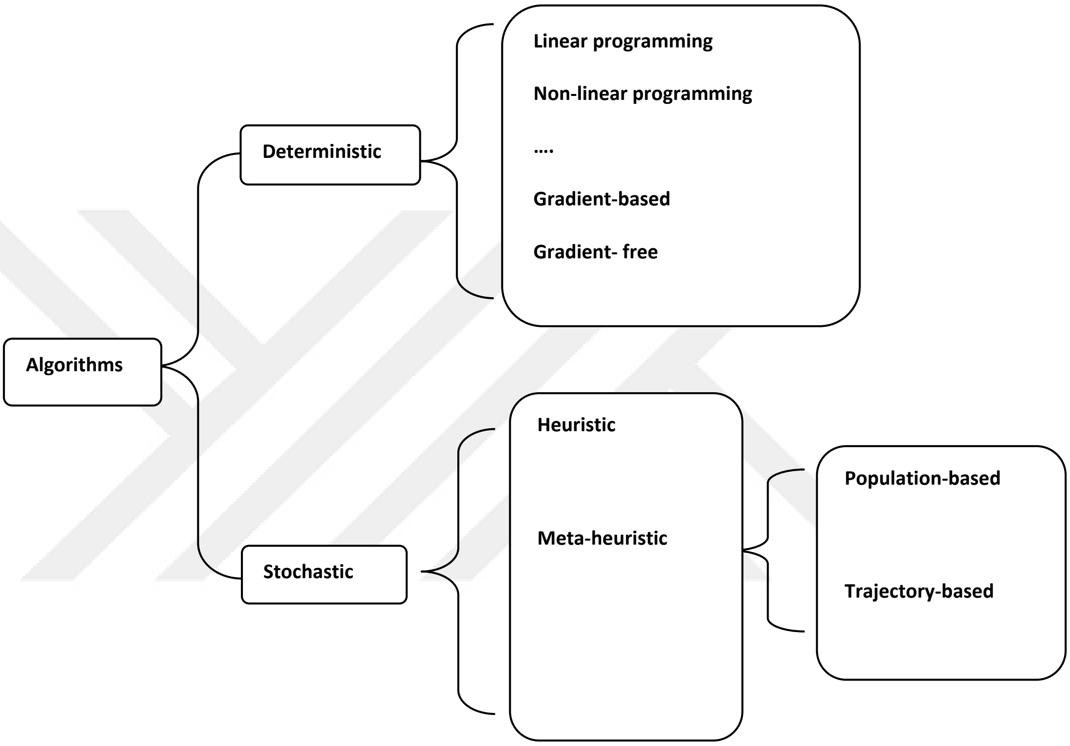

Figure 4.1: Classification of algorithms.

According to our study of the optimization algorithms that are used to solve the problem of EPD, we found that there are many algorithms that have proved their efficiency and reliability in solving the problem and reducing the costs. We have chosen some of these algorithms which are considered the most efficient and reliable among the others.

4.3.1 Novel Bat Algorithm (NBA)

Bat algorithm (BA) is a meta-heuristic optimization algorithm and it has been done by Xin-She Yang in 2010 to be one of the best optimization algorithms [41]. In original BA, the effect of Doppler and the foraging idea of the bat were not considered and each essential bat is expressed by position and velocity and it searches preys during dimensional spaces with achieving trajectory. Actually, this case does not exist only. In the NBA, the Doppler Effect is included and essential bat can recompense adaptively for the Doppler Effect in the phenomenon of echoes [42].

The essential bat is viewed to possess foraging habitats diversely in the NBA. Bat searches for its food solely in one habitat in BA because of the mechanical conduct of virtual bat. In summary, the NBA is obligated for the following idealized basics:

1. The motion of bats can be around in various habitats.
2. Bats can recompense for the effect of Doppler in echo phenomenon.
3. Bats can acclimate and set their compensation averages and they depend on its target proximity.

A. Quantum Behavior:

It is supposed that bats are going to conduct in such a behavior that while one of bats group found its prey in a specific habitat, immediately the rest bats would start to feed from the same prey. This supposition guides mathematically to the following formulation of the bat positions [42].

$$X_{i,j}^{t+1} = \begin{matrix} g_j^t + \theta * \left| mean_j^t - X_{i,j}^t \right| * \ln(\frac{1}{u_{i,j}}), if rand_j(0,1) \langle 0.5 \\ g_j^t - \theta * \left| mean_j^t - X_{i,j}^t \right| * \ln(\frac{1}{u_{i,j}}), if rand_j(0,1) \langle 0.5 \end{matrix} \tag{4.2}$$

B. Mechanical Behavior:

It is supposed that the speed of the virtual bat will not overtake the sound speed which is estimated 340 m/s. The bat will compensate the Doppler Effect and this compensation will be expressed mathematically as CR that it varies among various bats. CR and the inertia weight (w) are in the range of 0 to 1. The value (ξ) represents the smallest constant to avoid the probability of division by 0. CR will be 0, if there is no compensation for the Doppler Effect by the bat, and it will be 1, if there is compensation. This description can be expressed mathematically as follows:

$$f_{i,j} = f_{\min} + (f_{\max} - f_{\min}) * rand(0,1) \tag{4.3}$$

$$f_{i,j} = \frac{c + v_{i,j}^{t}}{c + v_{g,j}^{t}} * f_{i,j} * (1 + CR_i * \frac{g_j^t - X_{i,j}^t}{\left| g_j^t - X_{i,j}^t \right| + \xi}) \tag{4.4}$$

$$V_{i,j}^{t+1} = w * V_{i,j}^{t} + (g_j^t - X_{i,j}^t) * f_{i,j} \tag{4.5}$$

$$X_{i,j}^{t+1} = X_{i,j}^{t} + V_{i,j}^{t} \tag{4.6}$$

C. Local Search:

It is supposed logically that bats will raise the value of the pulse emission rate and reduce loudness when they approach prey. Whatever loudness value bats use, the loudness factor needs to be considered in the around environment. This description means, the equations have been developed and expressed as follows:

If (rand (0, 1) > ri)

$$X_{i,j}^{t+1} = g_j^t * (1 + randn(0, \sigma^2)) \tag{4.7}$$

$$\sigma^2 = \left| A_i^t - A_{mean}^t \right| + \xi \tag{4.8}$$

Where rand n $(0, \sigma^2)$ as Gaussian distribution with mean value 0, and (σ^2) is the standard perversion, and (A_{mean}^t) is the mean loudness.

In our study, we will use the NBA in [4], in order to solve the problem of EPD and check the performance of it based on large and small scale systems. The parameters of the NBA are shown in Table 4.1:

Table 4.1: The Parameters of NBA.

Parameter	Description	Value
M	Maximum generations (iterations)	1000
Pop	Population size	30
Dim	Dimension	(:,1)
$r0_{max}$	Maximum pulse rate	1
$r0_{min}$	Minimum pulse rate	0
A_{max}	Maximum loudness	2
A_{min}	Minimum loudness	1
Freq D_{max}	Maximum frequency	1.5
Freq D_{min}	Minimum frequency	0

Table 4.1 (Continued): The parameters of NBA.

Parameter	Description	Value
G	The frequency of updating the loudness and pulse emission rate	10
$Prop_{max}$	Maximum probability of habitat selection	0.90
$Prop_{min}$	Minimum probability of habitat selection	0.7
$Theta_{max}$	Maximum contraction-expansion coefficient	1
$Theta_{min}$	Minimum Contraction-expansion coefficient	0.5
C_{max}	Maximum compensation rate for Doppler effect in echoes	0.8
C_{min}	Minimum compensation rate for Doppler effect in echoes	0.1
w_{max}	Maximum inertia weight	0.80
w_{min}	Minimum inertia weight	0.50

The main steps of the NBA can be expressed as a pseudo code as follows:

```
Input: N: the number of individuals (bats) contained by the population.
Step 1: Define the parameters.
If (rand (0, 1) < P)
Step 2: Generate new solutions using equation (4.2).
Else
Step 3: using equations (4.3)-(4.6). Generate new solutions.
End if.
If (rand (0, 1) > ri)
Step 4: using equations (4.7) and (4.8), Generate a local solution around the selected best solution.
End if
Step 5: Evaluate the value of the objective function for each individual.
Step 6: using equations of original BA, Update the solutions, the pulse emission rate and the loudness.
Step 7: Rank the solutions and find the current best (gt).
If (gt) does not improve in G time step,
Step 8: Re-initialize the loudness (Ai), and set temporary pulse rates (ri), which is a uniform random number between [0.85- 0.9].
End if
t = t + 1;
```

End while

Outputs: the output represents the individual with the values of the fuel cost function in the population.

The flow chart of NBA is shown in Figure 4.2.

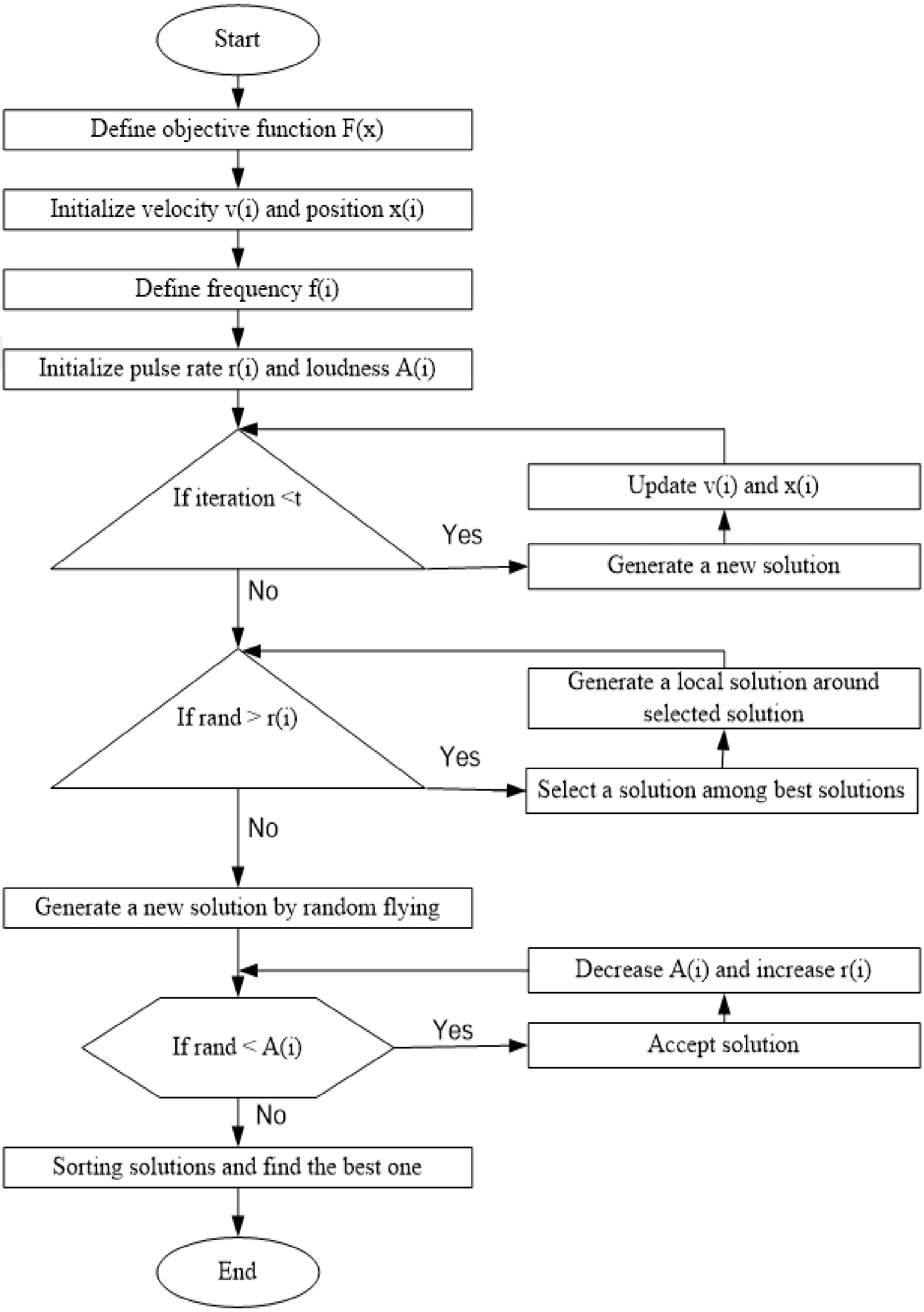

Figure 4.2: Flowchart of NBA.

4.3.2 Genetic Algorithm (GA)

The GA is a one of the best optimization methods that used in order to solve the constrained and unconstrained optimization problems. The GA depends on the natural selection. The GA has been done by John Holland [5], and it is used widely to solve the optimization problem. The basic idea of this algorithm is taken from the biological processes and genetics, which states that survival of the fittest. This algorithm is classified as a heuristic search approach, and it has used in order to solve the EPD problem and gave good results in minimizing the fuel cost. The Figure 4.3 shows the flowchart of GA.

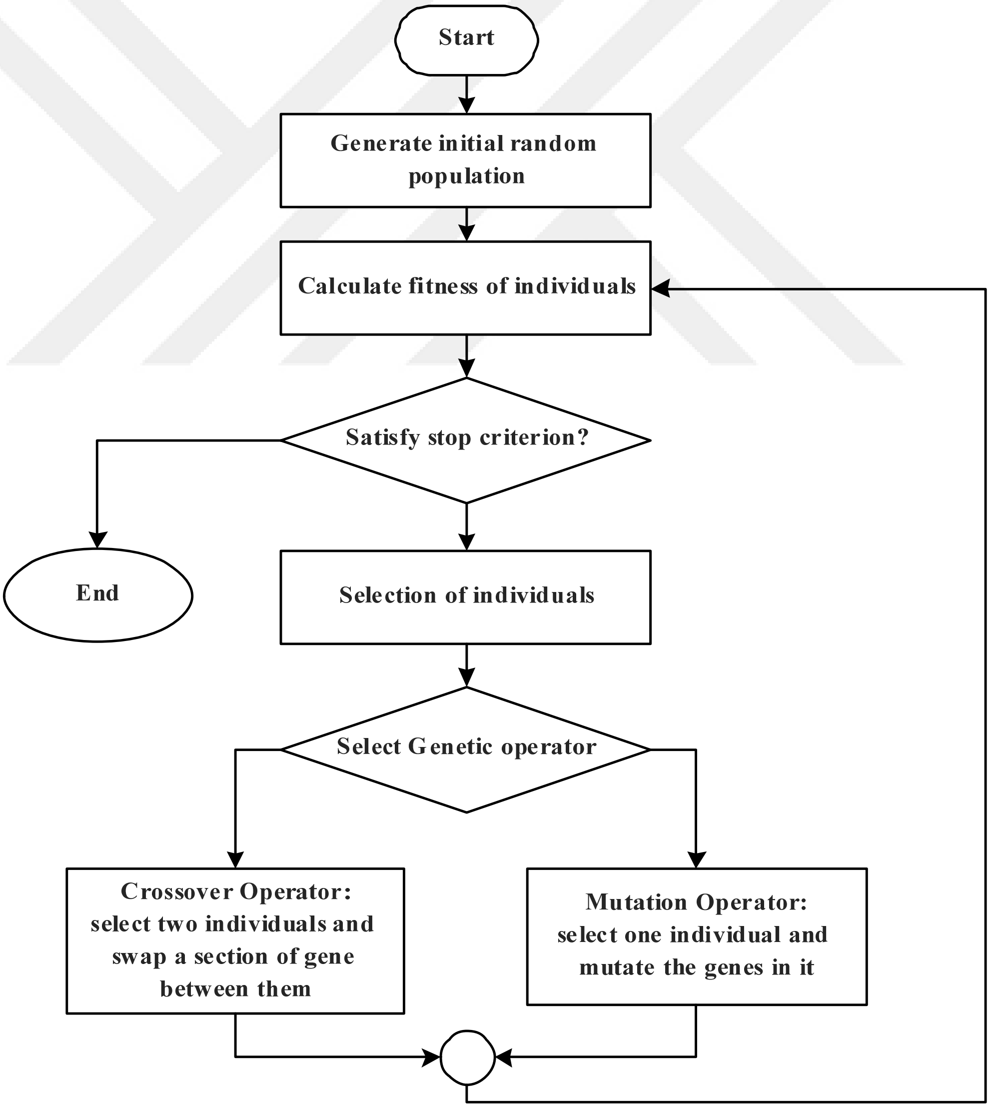

Figure 4.3: GA flowchart.

We can explain the terms of GA as follows:

1. Population (Pop): it means the set of initial random solution.
2. Chromosome: it shows the solution of the problem and it presents each individual among the population.
3. Generations: the chromosome evaluates during the iteration using fitness measurements and the chromosome evolution during the iterations is called the generation.
4. Offspring: a new chromosome is formed by a modulation process using a mutation, or merging process using a crossover, and the purpose of these processes is to create the next generation. This generation is formed by choosing parents and their offspring and refusing the others, in order to control a fixed population to take into consideration the fitness measurements.
5. Crossover: it is a necessary and important factor in the operation of the GA, and it is a merging process for two chromosomes to create the next generation. In the Crossover process, two chromosomes are usually exchanged sequentially.
6. Mutation: it is also an important part of GA's work, and it is a modulation process for chromosomes in order to create the next generation. Mutation usually occurs after the crossover process, and the purpose of this process is to change the genes of the chromosome randomly.
7. Selector: it is responsible for the process of selecting the new offspring from the old population, according to the principle of fitness for the population. The roulette wheel method is considered in the selection process.

The GA is considered one of the most important algorithms which are used widely in order to solve the problem and give optimal solutions. The pseudo code of GA is as follows [43]:

```
Step 1: choosing the initial population randomly for the individual.
Step 2: making evaluation of the individual fitness.
Repeat
Step 3: selecting the best individual in order to be used by the GA operators.
Step 4: generate the new individual by using GA operators (crossover and mutation).
```

Step 5: evaluate the individuals’ fitness.

Step 6: replacing the worst individual by the new one (best new individual) for population.

Step 7: until some stop criteria.

4.3.3 Particle Swarm Optimization (PSO)

PSO is one of the recent algorithms of meta-heuristic Optimization, and it was discovered by Kennedy and Eberhart in 1995 [44]. The main idea of PSO has been inspired from the behaviors of fish schools and bird flocks. PSO is considered one of the best algorithms used to solve problems and especially the EPD problems. This algorithm has been used to solve the EPD problem and it has given excellent results in reducing the operational costs and making the power systems work economically. The PSO is discovered by making a simulation for the bird flock and it represented the flock in a two dimensional space. The PSO algorithm mainly depends on the vectors of position and velocity.

PSO starts with a set of random particles, and then it starts looking for the optima by making updating for the iteration. In each iteration (generation), the particles are updated by using two best values (pbest and gbest). The first value (pbest) represents the fitness (best solution), and it has obtained so far, and this value (fitness) is stored. The second value (gbest) is the global best and this value is tracked by the optimizer of particle swarm, and it is the best value achieved so far for each particle. When the particles take parts of the population as their topological neighbors, the local best (lbest) is the best value. After finding the best values (pbest and gbest), the particles start to modify their positions and velocities. The velocity and position updates can be expressed by the following equations [45]:

$$V_i^t = wV_i^{t-1} + C_1R_1(X_{lbesti}^{t-1} - X_i^{t-1}) + C_2R_2(X_{gbesti}^{t-1} - X_i^{t-1}) \qquad (4.9)$$

$$X_i^t = X_i^{t-1} + V_i^t \qquad (4.10)$$

Where (V_i^t) is the agent (i) velocity in iteration (t), and (w) presents the weight function. C1 and C2 are the acceleration constants. R1 and R2 are random values and they are between 0 and 1.the value (X_i^t) is the agent position for iteration (t).

The parameters of PSO are shown in the Table 4.2, and the flowchart of it is shown in Figure 4.3 which it shows how the algorithm operates.

Table 4.2: The parameters of PSO.

Parameter	Value
Maximum iteration (generation)	2000
Population size	24
Acceleration constant 1	2
Acceleration constant 2	2
Initial inertia weight	0.9
Final inertia weight	0.4

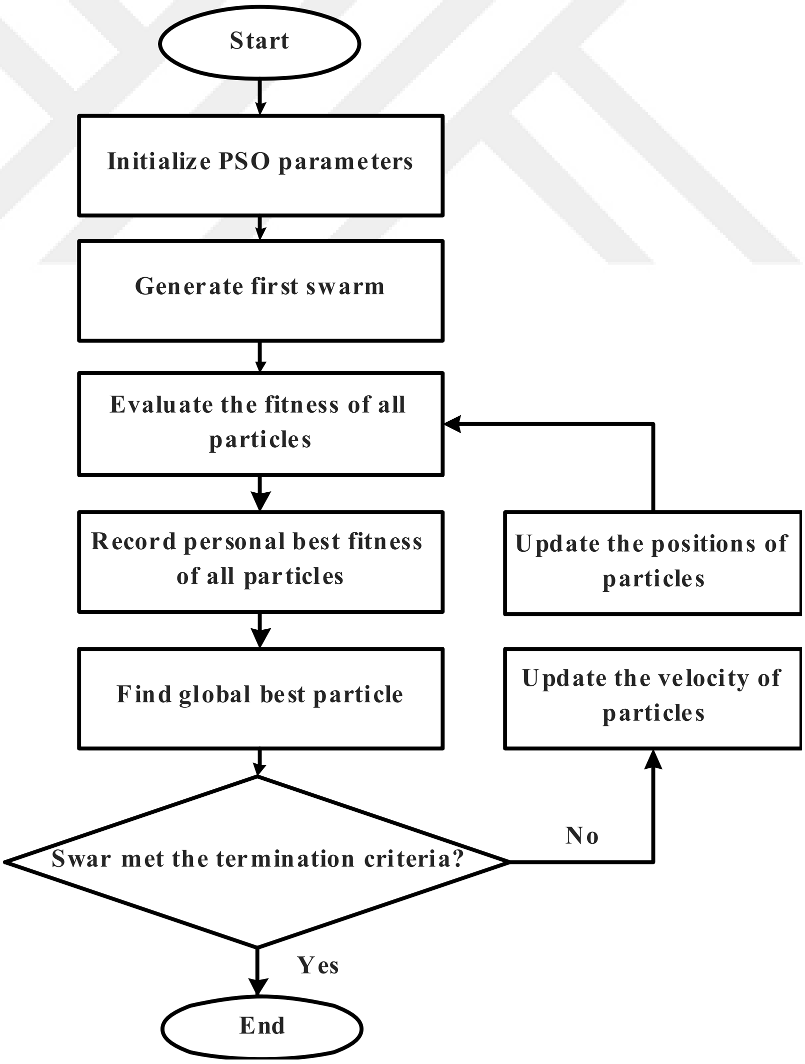

Figure 4.4: PSO flowchart.

PSO is considered one of the most well-known algorithms and it uses widely to solve the problem, PSO has many features compared with the other optimization algorithms and these features are as follows:

1. It demands a fitness function in order to measure the quality of the obtained results instead of complicated mathematical equations, and this feature reduces the complexity of the algorithm.
2. It is considered less sensitive than the other algorithms with the initial solution due to it depends on the population method.
3. It is so easy to make hybridization with other algorithms.
4. It has the capability of escape from the local minimum due to it follows probabilistic movement basics.

We can introduce the pseudo code of the PSO as follows:

```
Step 1: define the PSO parameters.
Step 2: for every particle in PSO, Initialize the particle.
Step 3: calculate the fitness for each particle.
Step 4: if the value of fitness is better than (pbest), set the current value as a new (pbest).
End
Step 5: for each particle:
1. Find the particle according to the best fitness.
2. Calculate the velocity according to equation (4.9).
3. Update the position of particle according to equation (4.10).
End
```

If the particle meets the termination of criteria, the results will be the generator's output.

4.3.4 Quadratic Programming (QP)

Quadratic Programming (QP) is an optimization method. The aim of this algorithm is to get the optimal solution for the problems. This optimization method employs for the quadratic functions and linear constraints. Also, we can employ this algorithm for the non-quadratic functions and with nonlinear constraints, but we must approximate the objective to the quadratic function and the non-linear constraints as a linear [46]. This algorithm has been employed to solve the problem of EPD and it could achieve good results compared with other well-known algorithms [47]. The procedures of this algorithm to solve the EPD problem with transmission loss are as follows [48]:

1. Evaluate the transmission loss (P_L) and incremental loss coefficients (a_i,b_i and c_i) and update the load demand (P_D), in order to initialize lower limit of each generating plant. Also, we must find the vector (x) which will minimize the cost function.

$$P_i = P_i^{\min} \tag{4.11}$$

$$x_i = 1 - \sum_{j=1}^{n} B_{ij} P_i \tag{4.12}$$

$$P_D^{new} = P_D + P_L^{old} \tag{4.13}$$

2. Determine the incremental cost (λ) by substituting the cost coefficients and solve the linear equations.

$$\lambda = \frac{\sum_{i}^{n} 0.5 * \frac{bi}{ai}}{P_D^{new} + \sum_{i}^{n} 0.5 * \frac{bi}{ai}} \tag{4.14}$$

3. Determine the power output for each generating plant.

$$P_i^{new} = \frac{\lambda - \left(\frac{bi}{ai}\right)}{2 * \left(\frac{ai}{xi}\right)} \tag{4.15}$$

4. Check the convergence.

$$\left| \sum_{i}^{n} P_i - P_D^{new} - P_L \right| \le \varepsilon \tag{4.16}$$

Where (ε) is the tolerance limit of the power balance infringement.

5. Execute the procedures (2-4) using the next iteration till convergence is obtained.

4.4 Summary

In this chapter, We have touched explanation of the optimization algorithms which will employ in our study, which are considered the best algorithms currently in use. We have explained the structures and the work procedures of these algorithms. These algorithms were including the NBA, PSO, GA and QP.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Introduction

In this chapter, the optimization algorithms of EPD problem that are shown previously will be employed to solve the problems of EPD in order to minimize the total fuel cost of the systems. Four cases will be taken, and they are as follows:

Case Study-1: Solving the EPD for 3-thermal unit system.

Case Study-1: Solving the EPD for 6-thermal unit system.

Case Study-1: Solving the EPD for 31-thermal unit system.

Case Study-1: Solving the EPD for IEEE 40-thermal unit system.

In these cases, the transmission line loss is considered for all, and it is a virtual data. The transmission loss is calculated by the B-coefficient method. All the results of the algorithms will be achieved by using MATLAB 2015 a.

5.2 Case Studies

5.2.1 Case Study-1: Solving the EPD For Three-Thermal Units System

In this case, three thermal units are utilized and the network data has taken from [4]. The cost coefficients and generator power limits are shown in Table 5.1. The virtual system has been solved by the NBA and the achieved results of NBA were compared with other optimization methods which they are GA, PSO and QP. The obtained results are shown in Table 5.2.

Table 5.1: Generators limits and cost coefficients for 3-unit system.

Unit	a_i	b_i	c_i	P_{min}	P_{max}
1	0.03546	38.30553	1243.5311	35	210
2	0.02111	36.32782	1658.5696	130	325
3	0.01799	38.27041	1356.6592	125	315

From Table 5.2, the assumed load demand was 500 MW, and transmission losses were considered for this system and they have been calculated by the B-coefficient method. According the obtained results, the NBA is the best in solving the EPD problem and it gave higher quality performance compared with the other algorithms.

Table 5.2: Test results for 3-unit system with load demand 500 MW.

Algorithm	P1(MW)	P2(MW)	P3(MW)	Ploss (MW)	Cost ($-hr.)
NBA	107.3479	200.2140	219.5278	27.0897	**26167.3565**
GA	102.8798	189.7938	234.1524	26.8260	26177.6196
PSO	107.3453	200.2042	219.5406	27.0901	26167.3925
QP	107.4327	200.5192	219.1217	27.0736	28674.0000

5.2.2 Case Study-2: Solving the EPD For Six-Thermal Units System

This case has been done for six thermal units and the network data has taken from [3]. The cost coefficient and power limits of the units are expressed in the Table 5.3. The achieved results have been solved by NBA, then there was a comparison with other optimization methods which they are GA, PSO and QP. The transmission loss is considered and it is a virtual data.

Table 5.3: Generators limits and cost coefficients for 6-unit system.

Unit	a_i	b_i	c_i	P_{min}	P_{max}
1	0.0070	7	240	100	500
2	0.0095	10	200	50	200
3	0.0090	8.5	220	80	300
4	0.0090	11	200	50	150
5	0.0080	10.5	220	50	200
6	0.0075	12	190	50	120

From Table 5.4, the suggested load demand was 700 MW for this case, and the performance of NBA was effective in getting optimal results for generators output.

Table 5.4: Test results for 6-unit system with load demand 700 MW.

Pi (MW)	NBA	GA	PSO	QP
P1	312.7083	286.6210	312.7083	312.7083
P2	72.5257	58.5750	72.5256	72.5252
P3	159.8879	171.0042	159.8878	159.8879
P4	50.0000	67.1123	50.0000	50.0000
P5	54.8817	62.3938	54.8816	54.8817
P6	50.0000	54.2969	50.0000	50.0000
Ploss (MW)	0.0036	0.0032	0.0033	0.0036
Cost ($-hr.)	**8299.4**	8325.2	8299.418	8299.41

5.2.3 Case Study-3: Solving the EPD For Iraqi-Thermal Units System

In Iraqi power system, the thermal units represent a large part of the Iraqi power system. These units are 31-units, and they are distributed in a different area of Iraq. The dataset of our work is composed of the information of the cost coefficients (ai, bi, ci) for 31-thermal unit and the power limits of the units (Pmin, Pmax). Also we have the information about the power output for 19-generators only, because the rest units are shutdown for the maintenance or because of the military operation in Iraq. All the information has been taken by Iraqi ministry of electricity [49]. The dataset is shown in Table 5.5 and 5.6 respectively.

Table 5.5: Cost coefficients and power limits for 31-units.

Unit	a_n	b_n	c_n	P_{min}	P_{max}
1	0.001932	12.11	313	10	55
2	0.001932	12.11	313	10	55
3	0.001932	12.11	313	10	55
4	0.0005601	13.8705	405.75	25	160
5	0.0005601	13.8705	405.75	25	160
6	0.0005601	13.8705	405.75	25	160
7	0.0005601	13.8705	405.75	25	160
8	0.00357	12.2323	396.71	40	300
9	0.00357	12.2323	396.71	40	300

Table 5.5 (Continued): Cost coefficients and power limits for 31-units.

Unit	a_n	b_n	c_n	P_{min}	P_{max}
10	0.00357	12.2323	396.71	40	300
11	0.00357	12.2323	396.71	40	300
12	0.001599	12.9215	561	30	220
13	0.001599	12.9215	561	30	220
14	0.001599	12.9215	561	30	220
15	0.001599	12.9215	561	30	220
16	0.001408	11.012	435	30	220
17	0.001408	11.012	435	30	220
18	0.000371	13.1	225	20	100
19	0.000371	13.1	225	20	100
20	0.00964	15.94	156	35	200
21	0.00964	15.94	156	35	200
22	0.008	10.5	220	35	210
23	0.008	10.5	220	35	210
24	0.008	10.5	220	40	210
25	0.008	10.5	220	40	210
26	0.001292	12.703	529	80	610
27	0.001292	12.703	529	80	610
28	0.000467	17.81	604.97	57	330
29	0.000467	17.81	604.97	57	330
30	0.0003902	11.81	604.97	57	330
31	0.0003902	11.81	604.97	57	330

Table 5.6: The generators' output for 19-unit.

Unit*	(Pi) Unit Output in (MW)	Unit	(Pi) Unit Output in (MW)
1	25.2	19	67.55
2	25.2	20	117.25
4	112.15	21	117.25
5	112.15	22	142.8
6	112.15	23	142.8
8	205.225	26	390.4
9	205.225	27	390.4
10	205.225	28	224.4
11	205.225	29	224.4
18	67.55	PT	3092.55

*The sequence of numbers in Table (5.6) is related to Table (5.5).

A. In this case, the optimization algorithms, including the NBA, GA, PSO and QP have been employed to the 31-unit system with suggested load demand 4500 MW. The transmission line losses are considered for this test and they are virtual values. The aim of this test is to solve the EPD for this system and find the best algorithm in minimizing the system cost.

Table 5.7: The achieved results of 31-unit system.

Unit	**NBA results (MW)**	**GA results (MW)**	**PSO results (MW)**	**QP results (MW)**
1	55	25.393	55	55
2	55	55	55	55
3	55	55	55	55
4	160	143.4952	25	25
5	25.0132	160	25	25
6	28.2558	30.2801	25	25
7	160	160	25	25
8	40.0006	84.9572	174.8358	174.8358
9	42.846	196.0898	175.5834	175.5834
10	211.0742	115.4627	174.3473	174.3473
11	207.1892	300	175.8544	175.8544
12	199.107	220	174.8368	174.8368
13	220	126.4775	176.5058	176.5058
14	220	220	173.746	173.746
15	36.6743	220	177.1108	177.1108
16	220	220	220	220
17	220	220	220	220
18	100	100	100	100
19	100	45.2676	100	100
20	35.0015	200	35	35
21	35.004	45.3487	35	35
22	210	210	186.0712	186.0712
23	210	70.6375	186.7437	186.7437
24	210	52.6688	186.2892	186.2892
25	210	210	186.6228	186.6228
26	375.4339	223.7363	299.5896	299.5896
27	357.5224	211.4871	303.754	303.754
28	57.0836	74.8099	57	57
29	57.158	284.659	57	57
30	58.5847	106.7048	330	330
31	330	112.8318	330	330
P_L	1.109349	1.323515	0.891412	0.89141
FC	69739.1521	71386.7769	**69568.9325**	69591.8454

From the obtained results in the Table 5.7, the optimization algorithms, including NBA, PSO, QP and GA have been employed to the 31-unit system in order to solve this system. From the obtained results, we concluded that:

First: the PSO results were the best in getting the optimal solution in minimizing the fuel cost compared with the other algorithms.

Second: we noticed that the NBA performance started to decrease compared with the other algorithms, such as the PSO, and it was not the best in minimizing the fuel cost for this large scale system. The figures below show the execution curves of the GA and PSO.

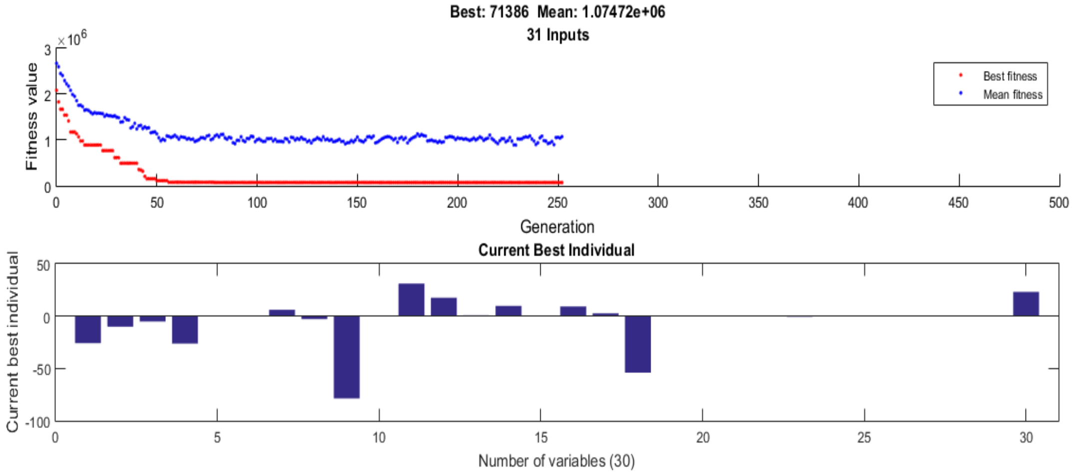

Figure 5.1: The iteration curve for GA.

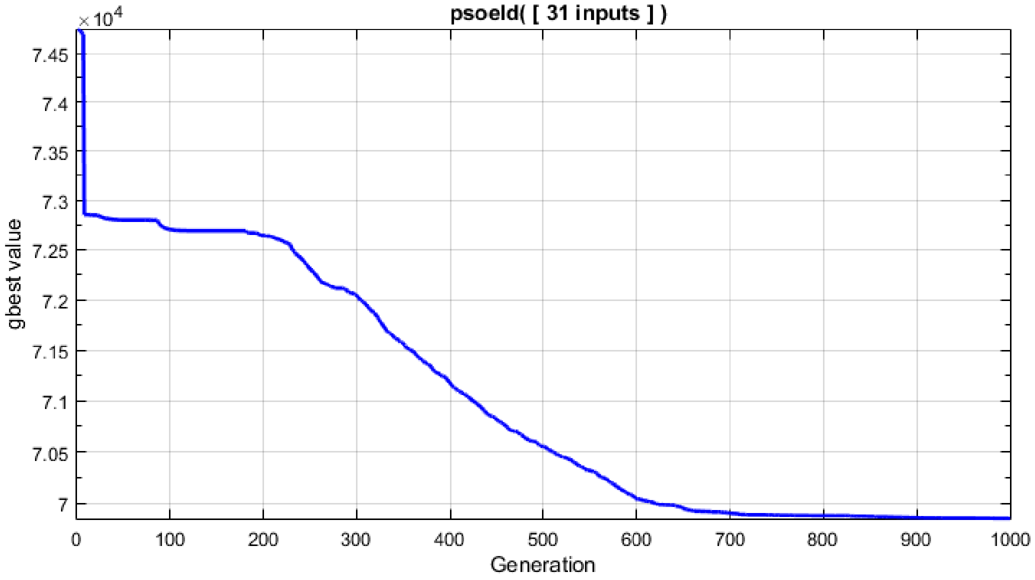

Figure 5.2: The iteration and gbest curve for PSO.

B. From Table 5.6, we have got the power output of 19-units of Iraqi network for March 2017. These values have been taken from the department of the National Control Center in Iraqi ministry of electricity. From the achieved results in Table 5.7, the PSO has given the best results in minimizing the total fuel cost for the system compared with the other algorithms. So that, the PSO was employed for the 19-unit system to solve it, then the total cost has been compared with the total cost of the system without optimization, in order to find how much money we can save by using the optimization. The table (5.8) shows the achieved results of 19 units without optimization.

Table 5.8: The obtained results for 19-units without optimization.

Unit *	**Fuel Cost ($-hr)**	**Unit ***	**Fuel Cost ($-hr)**
1	619.3988	19	1111.5978
2	619.3988	20	2157.4915
4	1968.3937	21	2157.4915
5	1968.3937	22	1882.53472
6	1968.3937	23	1882.53472
8	3057.4425	26	5685.1677
9	3057.4425	27	5685.1677
10	3057.4425	28	4625.0499
11	3057.4425	29	4625.0499
18	1111.5978	**Total Cost**	**50297.43232**

*The sequence of numbers in Table (5.8) is related to Table (5.5).

The fuel cost of the 19-unit system in Table 5.8 has been calculated without optimization method, and the transmission loss is neglected. The total cost of the system was calculated by offsetting the values of (Pi) from Table 5.6 in the cost equation (equation 3.1) for each generating unit. The total fuel cost of this system is 50297.43232 $-hr, and the total load demand for this system was 3092.55 MW.

The PSO has been utilized for the same system (19 units) to calculate the total cost of the system during the optimization. The Table 5.9 showed the achieved results.

Table 5.9: The achieved results of PSO.

Unit *	Unit Output in (MW)	Unit *	Unit Output in (MW)
1	54.9999	14	99.9999
2	54.9999	15	35
4	79.4628	16	35
5	79.4628	17	209.9999
6	79.4628	20	209.9999
8	241.9067	22	486.2671
9	241.9067	23	486.2671
10	241.9067	24	57
11	241.9067	25	57
18	99.9999	Total Cost	**48113.8697**

*The sequence of numbers in Table (5.9) is related to Table (5.5).

The PSO has been employed to the 19-unit system in order to calculate the total cost of the system. The total load demand for the system is 3092.55 MW. The obtained results of the PSO are shown in Table 5.9, and the total cost with PSO was 48113.8697 $-hr. The Figure 5.3 shows the execution of the algorithm and the iteration curve.

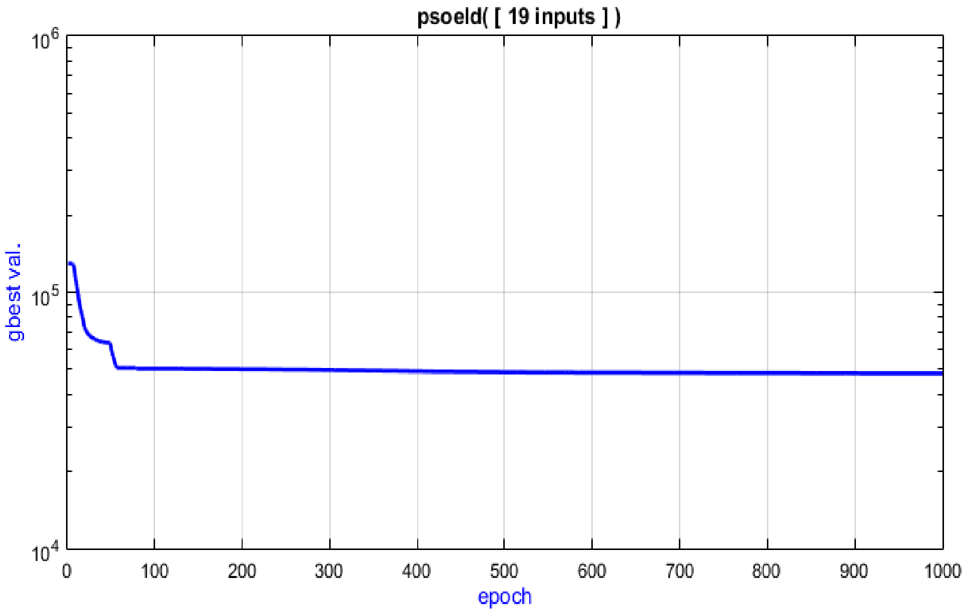

Figure 5.3: The iteration with gbest curve for PSO based on 19-units.

By comparing the results in Table 5.8 and 5.9, the PSO has given the best result and it minimized the fuel cost. We could save money estimated by 2183.56262 \$-hr or 19128008.55 \$-year. This amount is considered a huge and it is wasted because, the Iraqi power system is not working according to the economic dispatching.

5.2.4 Case Study-4: Solving the EPD for IEEE 40-Thermal Unit System

In this case, IEEE 40-unit system has been utilized as a large-scale power system. The details of this system - including the cost coefficient and the power limits of generators - are shown in Table 5.10.

Table 5.10: The details of IEEE 40-thermal units.

Unit	a_i	b_i	c_i	P_{min}	P_{max}
1	0.0307300	8.3360	170.440	40.0	80.0
2	0.0202800	7.07060	309.540	60.0	120.0
3	0.0094200	8.18170	369.030	80.0	190.0
4	0.0848200	6.94670	135.480	24.0	42.0
5	0.0969300	6.55950	135.190	26.0	42.0
6	0.0114200	8.05430	222.230	68.0	140.0
7	0.0035700	8.03230	287.710	110.0	300.0
8	0.0049200	6.9990	391.980	135.0	300.0
9	0.0057300	6.6020	455.760	135.0	300.0
10	0.0060500	12.9080	722.820	130.0	300.0
11	0.0051500	12.9860	635.20	94.0	375.0
12	0.0056900	12.7960	654.690	94.0	375.0
13	0.0042100	12.5010	913.40	195.0	500.0
14	0.0075200	8.84120	1760.40	195.0	500.0
15	0.0070800	9.15750	1728.30	195.0	500.0
16	0.0070800	9.15750	1728.30	195.0	500.0
17	0.0070800	9.15750	1728.30	195.0	500.0
18	0.0031300	7.96910	647.850	220.0	500.0
19	0.0031300	7.9550	649.690	220.0	500.0
20	0.0031300	7.96910	647.830	242.0	550.0
21	0.0031300	7.96910	647.810	242.0	550.0
22	0.0029800	6.63130	785.960	254.0	550.0
23	0.0029800	6.63130	785.960	254.0	550.0
24	0.0028400	6.66110	794.530	254.0	550.0

Table 5.10 (Continued): The details of IEEE 40-thermal units.

Unit	a_i	b_i	c_i	P_{min}	P_{max}
25	0.0028400	6.66110	794.530	254.0	550.0
26	0.0027700	7.10320	801.320	254.0	550.0
27	0.0027700	7.10320	801.320	254.0	550.0
28	0.5212400	3.33530	1055.10	10.0	150.0
29	0.5212400	3.33530	1055.10	10.0	150.0
30	0.5212400	3.33530	1055.10	10.0	150.0
31	0.2509800	13.0520	1207.80	20.0	70.0
32	0.1676600	21.8870	810.790	20.0	70.0
33	0.263500	10.2440	1247.70	20.0	70.0
34	0.3057500	8.37070	1219.20	20.0	70.0
35	0.1836200	26.2580	641.430	18.0	60.0
36	0.3256300	9.69560	1112.80	18.0	60.0
37	0.3372200	7.16330	1044.40	20.0	60.0
38	0.2391500	16.3390	832.240	25.0	60.0
39	0.2391500	16.3390	834.240	25.0	60.0
40	0.2391500	16.3390	1035.20	25.0	60.0

From Table 5.11, the assumed load demand for this case was 6500 MW with considered transmission losses. The achieved results showed that the NBA was not the best in getting an optimal solution. The PSO and QP were better than the NBA in minimizing the fuel cost and getting optimal results.

Table 5.11: The obtained results for IEEE 40-units.

Pi (MW)	NBA results	GA results	PSO results	QP results
1	40	47.7988	40	40
2	60.3730	120	61.8501	61.8501
3	80.1652	81.4008	80	80
4	24.0472	42	24	24
5	28.3045	42	26	26
6	73.3975	140	68	68
7	111.4304	300	217.1984	217.1984
8	300	146.4729	258.7956	258.7956
9	135.0618	146.4857	260.0330	260.0330
10	130.0025	131.4314	130	130
11	94.3453	137.8951	94	94
12	94.0382	106.6941	94	94
13	195.3256	239.5136	195	195

Table 5.11 (Continued): The obtained results for IEEE 40-units.

Pi (MW)	**NBA results**	**GA results**	**PSO results**	**QP results**
14	196.0112	213.5743	195	195
15	195.2119	275.6720	195	195
16	195.0475	197.9386	195	195
17	195.1048	213.9538	195	195
18	220.0003	229.1696	257.2110	257.2110
19	388.8812	242.5194	260.0793	260.0793
20	550	469.9283	251.8288	251.8288
21	243.2754	284.6752	257.6483	257.6483
22	550	292.3266	494.6209	494.6209
23	254.1536	394.0592	495.2679	495.2679
24	550	274.9325	507.8255	507.8255
25	550	294.7605	514.2391	514.2391
26	550	550	446.9388	446.9388
27	254.0040	335.6258	447.6347	447.6347
28	10.2862	150	10	10
29	11.4445	15.1741	10	10
30	10.1169	14.3578	10	10
31	20.7115	70	20	20
32	20.0393	70	20	20
33	20.0050	22.6434	20	20
34	20.3573	23.4375	20	20
35	18.2462	20.5085	18	18
36	18.0036	18.1234	18	18
37	20.0263	31.0269	20	20
38	25.0251	25.3631	25	25
39	25.2612	31.4245	25	25
40	25.7147	60	25	25
Ploss	3.4205	2.9108	3.1719	3.1719
Cost ($-hr.)	94865.7363	110845.0015	**94020.3830**	94081.3704

5.3 Summary

In this chapter, many optimization techniques have employed in order to solve the EPD problem and minimize the fuel cost for the power system. These algorithms are considered the best in solving the EPD problem as we mentioned in the previous chapters. We could reduce the cost by using these algorithms, especially in the case of Iraqi thermal units, where we were able to reduce the operating cost of the system by using the PSO and we were able to save money estimated by 19.128 million dollar per year, and the Figure 5.3 shows the total cost achieved to the 19-units system during the optimization and without optimization. We conclude that the best way to minimize the cost of power dispatching is by using these optimization techniques.

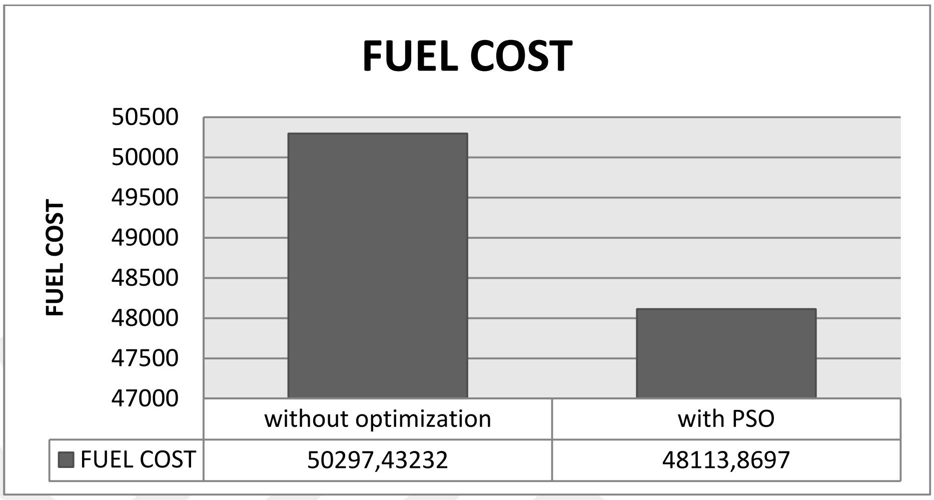

Figure 5.4: The cost of 19-units with and without optimization.

Table 5.12 indicates to the summary of fuel costs obtained in the forth cases, and these summarized results showed the performance of NBA compared with the obtained results of the other algorithms. The NBA has given a higher quality performance in case 1 and 2 (small-scale systems), and it recorded the best solution for EPD problem. But when NBA applied to case 3 and 4 (large-scale systems), it has recorded lower performance and accuracy compared with the other algorithms, and PSO has given the best solution for EPD problem.

Table 5.12: The summary of obtained results.

System	NBA	GA	PSO	QP
3-units	**26167.3565**	26177.6196	26167.3925	28674
6-units	**8299.4**	8325.2	8299.418	8299.4
31-units	70335	72778	**69568.93**	69591.84
40-units	94865.7363	110845.0015	**94020.3830**	94081.3704

CHAPTER SIX

CONCLUSION AND FUTURE WORK

6.1 Conclusion

Solving the problem of Economic Power Dispatch (EPD) considers an integral part of the economic operations of the power system. The major aim of using the EPD is for achieving reliable and efficient operations out of the power system. These operations should be achieved by minimizing the generator fuel cost. The EPD problem was solved by the classical method, such as the Lagrange Multiplier method and Lamda Iteration method. These days, the constraints of power system increase and the problem of EPD became more difficult. The classical methods have become less efficient in giving an optimal solution with these new constraints. Getting optimal solutions to EPD problem requires efficient optimization algorithms. So that, the researchers go toward the optimization algorithms in order to deal with this problem.

In this thesis, many optimization algorithms have been utilized in order to solve the EPD problem for the Iraqi system. This power system consists of 31 units, and these units represent all thermal units in the Iraqi power system. The details of these units have been taken from the Iraqi ministry of electricity. Many optimization algorithms have employed in this system, including NBA, PSO, GA and QP. All these algorithms have proven their efficiency and reliability previously. We could get optimal results in reducing the fuel cost of the Iraqi system by using these optimization methods.

Also, we proposed the NBA as an optimization method in order to solve the EPD problem. The aim of this part was to watch the performance of NBA with the large-scale power system. Four tests were used, including 3-units, 6-units, 31-units and IEEE 40-units respectively. The high quality performance of NBA has been already proved in small-scale power system such as 3 and 6 units. When NBA has been applied for large-scale power system, including 31 and 40 units, the performance of it started to decrease gradually compared to other well-known optimization methods, including Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Quadratic Programming (QP). According to the achieved results, we concluded that NBA performance with small-scale power system is better than large ones.

6.2 Future Work

Other operational constraints can be considered for this study. These constraints make the problem more difficult. We can solve these systems with the additional constraints, such as ramp rate limit constraint, prohibited operating zones and the valve point effect.

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