ECONOMIC DISPATCH CONSIDERING EMISSIONS USING MOTH FLAME OPTIMIZATION AND BAT HYBRID ALGORITHM

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2018

Economic Dispatch Considering Emissions Using Moth Flame Optimization and Bat Hybrid Algorithm

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EE300-0009/17

A thesis submitted to Pan African University Institute for Basic Sciences, Technology and Innovation in partial fulfilment for the Degree of Master of Sciences in Electrical Engineering

November 2018

DECLARATION

This work in this thesis is my original work and has not been presented for a degree in any other university.

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This thesis has been submitted with our approval as University supervisors.

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DEDICATION

This research is dedicated to my wife Christina Benny, my Mother and my siblings for their continuous support and encouragement.

ACKNOWLEDGEMENT

Thanks and glory is to the Almighty God for being my provider till this stage of my education.

I am really grateful to the African Union for the scholarship to pursue a Master's degree in Electrical Engineering. Also, I extend my appreciation to Japan International Cooperation Agency for their financial assistance.

Special thanks to my supervisors Dr.Michael Saulo and Prof. Nicodemus Abungu for their advice, directive, support, guidance and mentorship.

I also appreciate PAUISTI administration for their continuous guidance without forgetting my classmates for being co-operative and supportive.

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ABC – Artificial Bee Colony

ABC_SA – Artificial Bee Colony and Simulated Annealing Hybrid Algorithm

AFOLU – Agriculture, Forestry and Other Land Use

ALHN – Augmented Lagrange Hopfield Network

ANN – Artificial Neural Network

BA – Bat Algorithm

BBO – Biography Based Optimization

CAAA - Clean Air Act Amendments

CO_X – Carbon Oxides

DE_BBO – Differential Evolution and Biography Based Optimization Hybrid Algorithm

EDCE – Economic Dispatch Considering Emissions

FFA – Firefly Algorithm

GA – Genetic Algorithm

IEEE – Institute of Electrical and Electronics Engineers

MFO – Moth Flame Optimization

MFO_BAT – Moth Flame Optimization and Bat Hybrid Algorithm

NO_X – Nitrogen Oxides

PECOD – Pure Economic Dispatch

PED – Pure Emissions Dispatch

PSO – Particle Swarm Optimization

QPSO – Quantum Particle Swarm Optimization

RDPSO – Random Drift Particle Swarm Optimization

SO_X – Sulphur Oxides

WWOA – Water Wave Optimization Algorithm

ABSTRACT

The cost of generating electrical energy from different sources tend to differ from one power plant to another depending on the energy source used and amount of emissions produced by each individual power plant. As a result of different operation cost, the economic dispatch considering emissions techniques are normally applied in order to optimize the power systems aiming at reducing the operation cost and pollutant emissions.

The generation of electric power keeps increasing day by day due to economic development across the world. The expansion in electrical generation contributes to large extent an increase of greenhouse gases emissions which are causing global warming, ozone layer depletion and air pollution.

Fuels are the major source of electric energy generation, 42% of total global electricity generation is from coal which is the primary fuel globally. As a result of high dependability on fuel for electric generation, the electric energy is too expensive due to high expenses incurred by generation companies on emissions fees and purchase of fuels.

In this study, the mitigation of the discussed situation was done through the implementation of developed Moth Flame Optimization and Bat hybrid algorithm in economic dispatch considering emissions. The results of the developed method were compared to others reported in literature and found to be promising in terms of electric generation cost and emissions reduction.

CHAPTER ONE

INTRODUCTION

1.1 Background

Electrical power system consists of three main components which include generation, transmission and distribution. The generation part deals with the generation of electric power while transmission segment deals with transmission of power from generation plants to distribution system which is the part responsible for distributing the electric energy to consumers [1].

Generation of electric power involves the conversion of different forms of energy into electrical energy by using an acceptable conversion process. This involves the application of linked systems for converting the different form of energy which are potential energy (hydro), thermal energy, nuclear energy, solar energy, kinetic energy (wind) i.e. to electrical energy. In general, the linked systems which normally work in coordination for the purpose of generating electric power are usually termed as power plants. Power plants are normally named depending on the source of energy which is used by the individual power plant for generating electric energy. Due to different source of energy, types of power plants are nuclear, hydro, gas, diesel, coal (steam), solar, geothermal, wind etc. However gas, diesel and coal (steam) power plants in general are termed as thermal power plants [2].

Depending on different sources of energy, the cost of fuel and the amount of emission tend to differ from one plant to another. The cost of fuel is very high in thermal power plant as compared to another kind of power plants. Due to the different cost of fuel, electric energy must be dispatched depending on a fuel cost of each power plant for the purpose of reducing the overall generation cost. Also, the issue of minimizing the amount of emission to the atmosphere is normally taken into consideration while dispatching the electric energy from thermal power plants for the purpose of reducing air pollution. Both factors depend upon the type of fuel used by the concerned power plant and the efficiencies of power plants which are largely are affected by ageing [3].

Coal is the main source of energy for electric generation whereby 42% of total global electricity generation is from coal [4], but it's price is at the elevated level [5]. Generally, the price of fossil fuels which includes coal, natural gas and oil have been fluctuating at the higher price which causes the energy sectors being subjected to high operation cost because of high expenses incurred for purchasing fuel.

In general, thermal power plants produce the pollutant gaseous which includes CO_x, NO_x and SO_x which contributes largely to environmental pollution, ozone layer depletion and global warming [6][7]. Due to an increase of emissions of pollutant gaseous from power plants and manufacturing industries which endanger perpetuation of life on the earth, the Clean Air Act Amendments of 1990 (CAAA) was launched which states that the global emission must be reduced by 12 million ton/year from the level of 1980 [8]. Putting emphasize on the Act, the electrical power plants were subjected to emission charges which are supposed to be paid based on the amount of emissions generated by the individual plant [9]. As a result of the Clean Air Act Amendments of 1990, the cost of power generation consists of cost of fuel, emission charges and fixed costs factors.

Making assessment on the trend of greenhouse gas emissions in which carbon dioxide is the main contributor, the amount of emissions from human activities are increasing year after year even with the introduction of Clean Air Act Amendments of 1990. Figure 1.1 shows the trend of carbon dioxide emissions to the atmosphere starting from the year 1970 up to 2015 showing how the emissions to our earth atmosphere have been increasing exponentially.

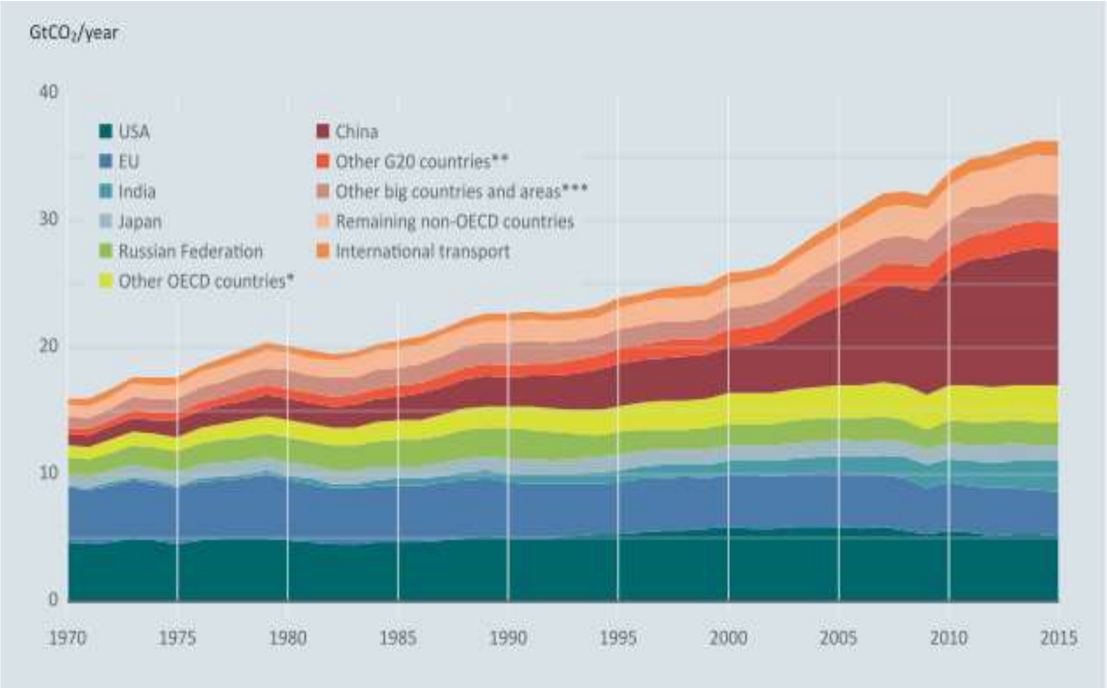


Figure 1.1: Carbon dioxide emission from fossil-fuel uses and industries [10]

The electric generation, AFOLU and manufacturing industries sectors are the main contributors to emissions crisis. Electric generation sector being extensively engaged in fossil fuel uses which are coal, oil and natural gas is the leading sector which produces high emissions as compared to other sectors [11]. The contribution of coal power plants itself is 28% of global carbon dioxide (CO_2) emissions [4].

Currently in order to reduce the cost of power generation, both variables which are the cost of fuel and emission charges are optimized simultaneously so as to reduce the cost of power generation while having the positive effect on emission reduction [9]. Thus gave birth to the studies of economic dispatch considering emissions. The optimization of emissions has two positive impacts which are environmental and cost reduction impacts, while reducing the cost of generation also the environments are preserved through reduction of emission which is the worldwide crucial agenda [12].

1.2 Problem Statement

Across the globe, the electric energy generation sector is facing the challenge of high cost of electric generation due to high fuel cost and emission charges. Emissions charge is normally charged to generation companies based on the amount of emissions generated by the concerned plant, thus the higher the amount of emissions generated the higher the emission charges and vice versa is true [13]. Also, industrial products which are basic needs to human being such as food products, clothes and building materials like cement i.e. are expensive since its' production cost is high due to high price of electricity which is the essential energy for manufacturing industries [14]. Some governments have opted to subsidize the electric generation cost so as to provide some relief to their citizen [15]. As a result of this approach, most of those governments are carrying the huge burden and spending a lot of government funds in subsidization of energy sector instead of being invested into other sectors such as health, water, agriculture i.e. which are still behind especially in developing countries. A number of researches have been done in this area by using different approaches with the aim of reducing the cost of generating electric power and emissions, though the cost of power generation is still high as well as the emissions are still increasing year after year [16], [17]. In this study, Moth Flame Optimization and Bat hybrid algorithm is used to mitigate the high cost of generating electric power facing the energy sector with the consideration of reducing the amount of emissions from thermal power plants.

1.3 Objectives of the Study

1.3.1 General Objective

The general objective of this study is to determine the economic dispatch considering emissions using Moth Flame Optimization and Bat hybrid algorithm.

1.3.2 Specific Objectives

The specific objectives of this study are:

i) To develop Moth Flame Optimization and Bat hybrid algorithm for economic dispatch considering emissions.

ii) To apply Moth Flame Optimization and Bat hybrid algorithm in economic dispatch considering emission.

iii) To evaluate the performance of Moth Flame Optimization and Bat hybrid algorithm in economic dispatch considering emission.

1.4 Justification

This study addressed the vital problems facing the electric power generation sector which are high generation cost of electric power and pollutant emissions from thermal power plants [18]. The application of this study to electric generation stations will result into low generation cost due to reduction of fuel cost and emissions fees. Thus will contribute into elimination of the burdens which are subjected to many governments in form of subsidies to electric sector.

1.5 Scope of the Study

The implementation of this study was based on real power dispatch from thermal power plants. The dispatching of energy considered the valve point effect whereby the types of pollutants gases from thermal power plants accounted for include NO_X, CO_X and SO_X emissions. The study was implemented by using IEEE-30 bus whereby the system demand was changed through increasing the loads evenly at each loading point, other systems which were used are ten units system with valve point effect and six units system. The loss coefficient matrices were assumed constant during the iterative process.

1.6 Thesis Organization

This thesis is organized as follows:

Chapter one presents the background of this study, problem statement and objectives of the study. Also, justification and scope of this study along with publication work from this study are presented in chapter one.

Chapter two describes the theories of Moth Flame Optimization, Bat algorithm and economic dispatch considering emissions.

Chapter three presents the development of Moth Flame Optimization and Bat hybrid algorithm. Also, the problem formulation which includes economic dispatch objective function, emission dispatch objective function and conversion of multi-objective economic dispatch considering emission into a single objective function using price penalty factor.

Chapter four presents the results of this study and a detailed discussion. The evaluation of MFO_BAT in the area of economic dispatch considering emissions is also presented in chapter four through comparing its performance with other methods reported in the literature and furthermore evaluation by cost and emission benefit analysis.

Chapter five presents the conclusion of this study and recommendation for further studies on the subject matter.

1.7 Note on Publication

A paper title “Emission Constrained Economic Dispatch Using Moth Flame Optimization and Bat Hybrid Algorithm” was published from this work. This publication based on solution improvement of economic dispatch considering emissions by using the novel Moth Flame Optimization and Bat hybrid algorithm. The citation of this paper can be done as shown below:

Wilbert Ruta, Michael Saulo and Nicodemus Abungu Odero, “Emission Constrained Economic Dispatch Using Moth Flame Optimization and Bat Hybrid Algorithm”, International Journal of Engineering Research and Technology (IJERT), Volume 11, Number 5, pp.827-843, 2018.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter discusses the theories of economic and emission dispatch together with its implementation approaches. The theoretical review on Moth Flame Optimization and Bat algorithms are described, and the empirical review on previous research work performed for purpose of reviewing the achievements attained by the previous researchers and the current research gap in a concerned area.

2.2 Economic dispatch

Economic dispatch is the way of determining the power output of each generation station in a power system aimed at reducing the fuel cost while satisfying the equality and inequality constraints of the system. This is done so as to meet the system load at a minimum possible cost of fuel with the main intention of reducing the operation cost [3].

Generally, each generating unit has its own characteristic depending on its efficiency and the type of fuel used which determine the relationship between the cost of fuel and power generated. The relationship function which relates fuel cost and generated power is normally termed cost function, depending on the type of the system this function can be a quadratic function or a quadratic function with ripples [19]. Figure 2.1 shows the cost function of the quadratic form which relate the input and output of the power plants depending on the fuel cost and amount of power generated respectively.

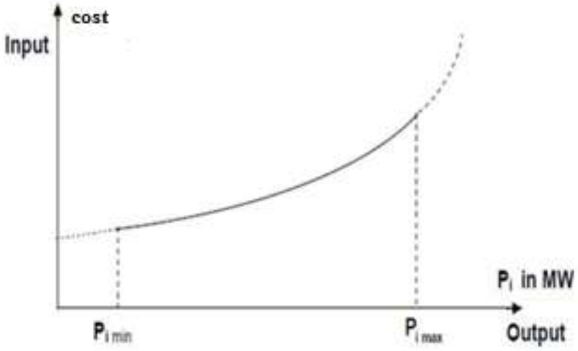


Figure 2.1: Input-output curve of generating unit [19]

Each generator normally has its own cost function depending on its characteristics. Due to different cost functions among generators, the operating cost tends to differ between the generators. As a result of different operating costs between the generators, the economic dispatch techniques are normally applied so as to minimize the overall cost of generation when operating with more than one power plant of the system [20]. Normally the load demand is dispatched in economical approach among the generating units so as to reduce the fuel cost. The main essence of the economic dispatch is based on achieving the same per unit cost that is equal to incremental or marginal cost while maintaining the overall power output which is supposed to be supplied to the system load [3].

In[3], it is stated that;

$$L = F + \lambda\left(P_D - \sum_{i=1}^{N} P_{Gi}\right) \tag{2.1}$$

Where L stands for Lagrage equation and F for cost functions while P_D is the power demand and P_{Gi} represents the generation of ith .unit.

Considering two units in a system, equation (2.1) can be written as;

$$L = F_1(P_1) + F_2(P_2) + \lambda(P_{load} - P_1 - P_2) \tag{2.2}$$

Considering the two generator cost functions gives the following equations:

$$F_1(P_1) = a_1 + b_1 P_1 + c_1 P_1^2 \tag{2.3}$$

$$F_2(P_2) = a_2 + b_2 P_2 + c_2 P_2^2 \tag{2.4}$$

Where a_1, b_1, c_1, a_2, b_2 and c_2 are fuel cost coefficients of two generating units

Then, equation (2.2) can be written as;

$$L = a_1 + b_1 P_1 + c_1 P_1^2 + a_2 + b_2 P_2 + c_2 P_2^2 + \lambda(P_{load} - P_1 - P_2) \tag{2.5}$$

Lagrange differentiation of (2.5) with respect to P_1, P_2 and λ gives;

$$\frac{\partial L}{\partial P_1} = b_1 + 2c_1 P_1 - \lambda \tag{2.6}$$

$$\frac{\partial L}{\partial P_2} = b_2 + 2c_2 P_2 - \lambda \tag{2.7}$$

$$\frac{\partial L}{\partial \lambda} = P_{load} - P_1 - P_2 \tag{2.8}$$

By optimizing the system, derivatives must be equal to zero (0), thus;

$$\frac{\partial L}{\partial P_1} = \frac{\partial L}{\partial P_2} = \frac{\partial L}{\partial \lambda} = 0 \tag{2.9}$$

Therefore;

$$b_1 + 2c_1 - \lambda = 0 \tag{2.10}$$

$$b_2 + 2c_2 - \lambda = 0 \tag{2.11}$$

$$P_{load} - P_1 - P_2 = 0 \tag{2.12}$$

Using equation (2.10), (2.11) and (2.12) the value of P_1, P_2 and λ for a given load demand (P_{load}) can be computed as;

$$P_{load} - \frac{\lambda - b_1}{2c_1} - \frac{\lambda - b_2}{2c_2} = 0 \tag{2.13}$$

$$P_1 = \frac{\lambda - b_1}{2c_1} \tag{2.14}$$

$$P_2 = \frac{\lambda - b_2}{2c_2} \tag{2.15}$$

Whereby P_1 and P_2 are dispatched power at the incremental cost (λ), and is summarized in Figure 2.2.

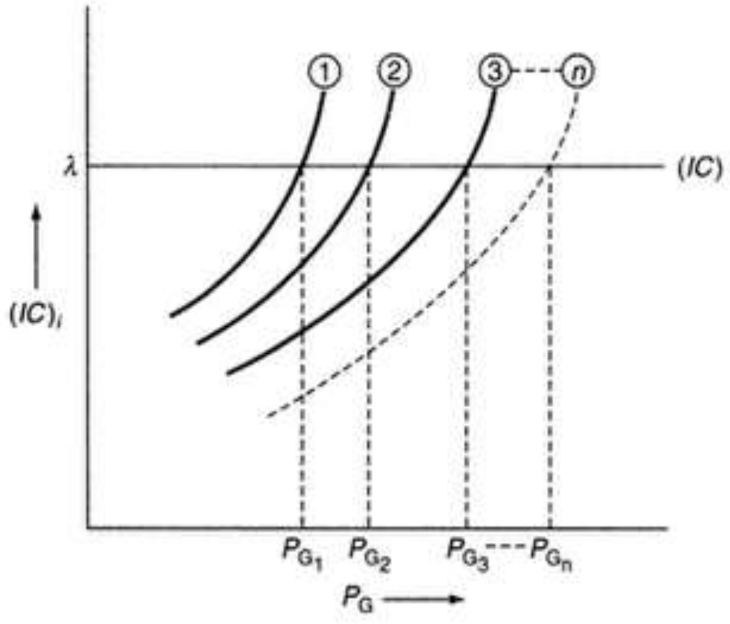


Figure 2.2: Real power economic dispatch [21]

The generation units normally possess the limits of generations which have minimum and maximum limits and result in inequality constraint while the balance between the generation and load with inclusion of line losses results into equality constraint, generally these are boundaries of economic dispatch optimization [3].

The economic load dispatch objective function is the single objective function based on the minimization of fuel cost only while satisfying the system constraints. The fuel cost in ($/hr) is a function of power generated by each individual unit and cost coefficients of generating units in a given power system. This objective function is biased toward fuel cost minimization while neglecting the emissions from the concerned power system.

In [22], the cost function is expressed as;

$$Cost = \sum_{i=1}^{NG} a_i P_i^2 + b_i P_i + c_i \tag{2.16}$$

Where $a_i,\ b_i\ ,c_i$ are fuel cost coefficient of i^{th} unit and P_i is generated power by i^{th} unit.

In [23], the economic load dispatch objective function is given as;

$$Minimize(\mathrm{cost}) = \sum_{i=1}^{NG} a_i P_i^2 + b_i P_i + c_i \tag{2.17}$$

Under the two categories of constraints;

i) Equality constraints;

Power balance

$$P_i = \sum_{i=1}^{NG} P_D + P_L \tag{2.18}$$

Where P_D and P_L are load demand and power transmission losses respectively.

ii) Inequality constraints;

$$P_{i(\min)} \le P_i \le P_{i(\max)} \tag{2.19}$$

The economic dispatch objective function can be used for the bundled system in overall dispatch of power from power stations. For the case of unbundled system, the given objective function can be used for power dispatch of generators from the same power station.

2.3 Economic Dispatch with Valve Point Effect

With the purpose of increasing the efficiency of power plants, the generators' engines are designed with valve point effects. This is the mechanism of controlling the opening of the valves depending on the variation of power demand so as to match the generator input with the demanded power. This process is normally controlled by generator governor which controls the opening of input valves depending on the output demanded. Due to opening and closing of valves, the cost function adapts the ripple shape [24]. Figure 2.3 shows the cost function of economic dispatch with valve-point effect.

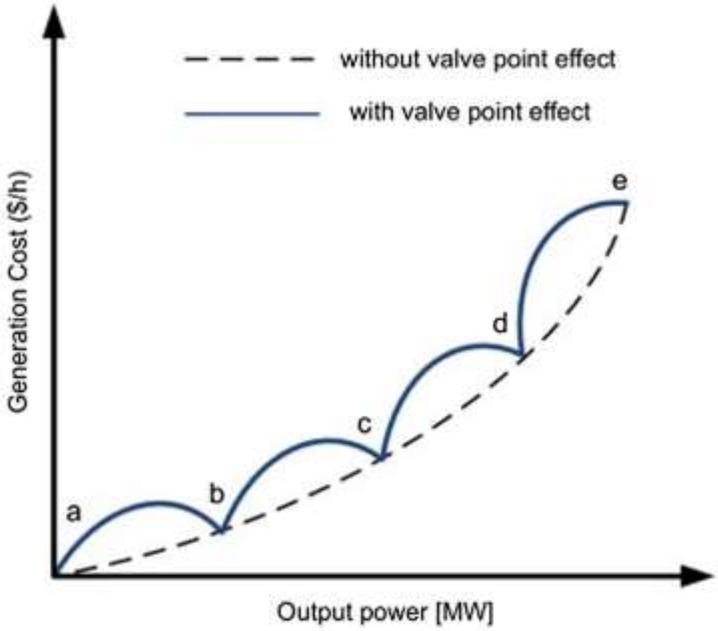


Figure 2.3: Fuel cost function with valve-point effect [25]

In [24] the objective function formulation of the economic dispatch with valve-point loading effect is as follows;

$$Cost = \sum_{i=1}^{NG} (a_i P_i^2 + b_i P_i + c_i + \left| e_i \sin(f_i (P_i^{\min} - P_i)) \right|) \tag{2.20}$$

Objective function;

$$Minimize(Cost) = \sum_{i=1}^{NG} (a_i P_i^2 + b_i P_i + c_i + \left| e_i \sin(f_i (P_i^{\min} - P_i)) \right|) \tag{2.21}$$

Under the constraints;

$$P_i = \sum_{i=1}^{NG} P_D + P_L \tag{2.22}$$

$$P_{i(\min)} \le P_i \le P_{i(\max)} \tag{2.23}$$

Where e_i and f_i are constants of valve-point effect

2.4 Emission Dispatch

With the increase in emissions from the power plants and manufacturing industries in the form of CO_X, SO_X and NO_X, different strategies have been adopted and among them is the thermal power plant emission dispatch. The fundamental of emission dispatch involves generation of required power for serving the system load at the least emissions to the atmosphere [7].

In [7], the emission dispatch function is defined as the quadratic function as expressed below;

$$EC = \sum_{i=1}^{N} \alpha_i P_i^2 + \beta_i P_i + \gamma_i \tag{2.24}$$

Where $\alpha_i, \beta i, \gamma_i$ are coefficient of emission of the i^{th} generating unit

The objective function of emissions dispatch is;

$$Minimize(EC) = \sum_{i=1}^{N} \alpha_i P_i^2 + \beta_i P_i + \gamma_i \tag{2.25}$$

Under the two categories of constraints as in (2.22) and (2.23).

2.5 Economic Dispatch Considering Emission

Economic dispatch considering emission as the objective function which harmonizes the conflict of the two objective functions which are economic load dispatch and emissions dispatch [26]. The main focus of the economic dispatch considering emissions is to minimize the cost of fuel while taking into account the emissions being released by the generating stations. In this, the fuel cost optimization is constrained by emission dispatch objective function [27].

In [28], the objective function formulation for economic dispatch considering emission is discussed as follows;

$$Minimize(F_T) = \sum_{i=1}^{N} (A + hB) \tag{2.26}$$

Where *A* is the fuel cost function, *B* is the emissions function and *h* is the penalty factor

In expanded form this objective function is expressed as;

$$Minimize(F_T) = \sum_{i=1}^{N} ((a_i P_i^2 + b_i P_i + c_i) + h_i (\alpha_i P_i^2 + \beta_i P_i + \gamma_i)) \tag{2.27}$$

Under the two categories of constraints as in (2.22) and (2.23).

The price penalty factor "*h"* is given by;

$$h_i = \frac{a_i P_{i(\max)}^2 + b_i P_{i(\max)} + c_i}{\alpha_i P_{i(\max)}^2 + \beta_i P_{i(\max)} + \gamma_i} \tag{2.28}$$

Where P*i*(*max)* is maximum generator limit in MW of i^{th} unit

2.6 Moth Flame Optimization Algorithm

Moth Flame Optimization algorithm is the bio-inspired algorithm which was developed by Seyedali Mirjalili in 2015; it is based on Moths property of flying in the straight line at night while maintaining a particular angle toward the moon. In this method moths are assumed to move at a particular constant angle towards the flame of light, as a results the moths are caught in a spiral path toward the flame. In this algorithm, the flame is taken as the best solution while the position of moth with reference to flame is taken as the solution at a given time. The population of moths represents all possible solutions from which one best optimal solution is found. Moth Flame Optimization is reported to be the best algorithm for searching the search space (exploration) due to individual searching of moth around the flame which in turn avoids local stagnation [29].

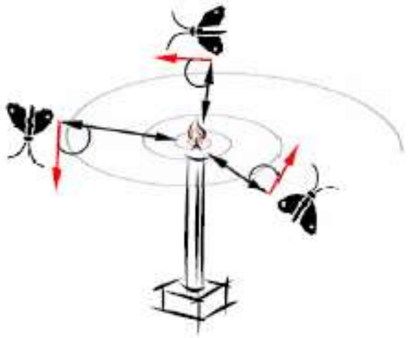


Figure 2.4: Spiral flying path around close light sources [29]

In Moth Flame Optimization, moth carries candidate solutions and the number of decision variable determines the dimension of the solution. The moth's population is normally represented in a matrix form as shown below;

$$M = \begin{bmatrix} m_{1,1} & m_{1,2} & \cdots & \cdots & m_{1,d} \\ m_{2,1} & m_{2,2} & \cdots & \cdots & m_{2,d} \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ m_{n,1} & m_{n,2} & \cdots & \cdots & m_{n,d} \end{bmatrix}$$

Where *n* is the number of moths and *d* is the number of decision variable (dimension)

Moths fitness is also represented in the matrix form as follows:

$$OM = \begin{bmatrix} OM_1 \\ OM_2 \\ . \\ . \\ . \\ OM_n \end{bmatrix}$$

Where *n* is the number of moths

In this technique, it is assumed that each moth moves in the transverse movement around the flame which is the current best solution. In this method flames which correspond to moths are represented in the matrix form as;

$$F = \begin{bmatrix} F_{1,1} & F_{1,2} & \cdots & \cdots & F_{1,d} \\ F_{2,1} & F_{2,2} & \cdots & \cdots & F_{2,d} \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ F_{n,1} & F_{n,2} & \cdots & \cdots & F_{n,d} \end{bmatrix}$$

Where *n* is the number of moths and *d* is the number of decision variable (dimension)

Each flame normally has its own fitness as is shown below;

$$OF = \begin{bmatrix} OF_1 \\ OF_2 \\ . \\ . \\ . \\ OF_n \end{bmatrix}$$

Where n is the number of moths.

For searching the best solution, each moth navigates around its flame. Through this property, MFO avoids local stagnation and becomes useful for searching purpose.

In the MFO algorithm, the logarithmic spiral mechanism is used for position updating [30] as it given in equation (2.29).

$$S\left(M_i, F_j\right) = D_i e^{bt} \cos\left(2\pi t\right) + F_j \tag{2.29}$$

The distance between the flame and moth (D) is calculated using equation (2.30);

$$D_i = \left|F_j - M_i\right| \tag{2.30}$$

Where

b is a constant of defining the shape of a logarithmic spiral

t is a random number in [-1, 1]

F_j is a position of the jth flame

M_i is a position of the ith moth

The number of flames are normally updated in each iteration whereby the flame with the poor solution is removed. The flame updating is done by using equation (2.31).

$$Flame(number) = round\left(N - l \times \frac{N-l}{T}\right) \tag{2.31}$$

Where

l is current number of iterations

N is a maximum number of flames

T is a maximum number of iterations

The MFO algorithm can be successfully tuned between the exploration and exploitation mode through fine-tuning of parameters related to equation (2.29) which are *t* and *b*

2.7 Bat Algorithm

Bat algorithm was developed by Xin-She Yang in 2010; it is the bio-inspired algorithm which is based on echolocation of bat when hunting the prey. The bats normally emit the sound and wait for echo so as to allocate their prey and detects any obstacles along the way. The emissions of sound normally tend to vary depending on the closeness of the prey to the bat which in turn results into rate and frequency variation. In this algorithm, the position of prey is normally treated as the best solution while the population of bats creates numbers of possible optimal solutions with reference to prey location. The Bat algorithm is reported to be very strong in terms of exploiting the solution for finding the quality solution [31].

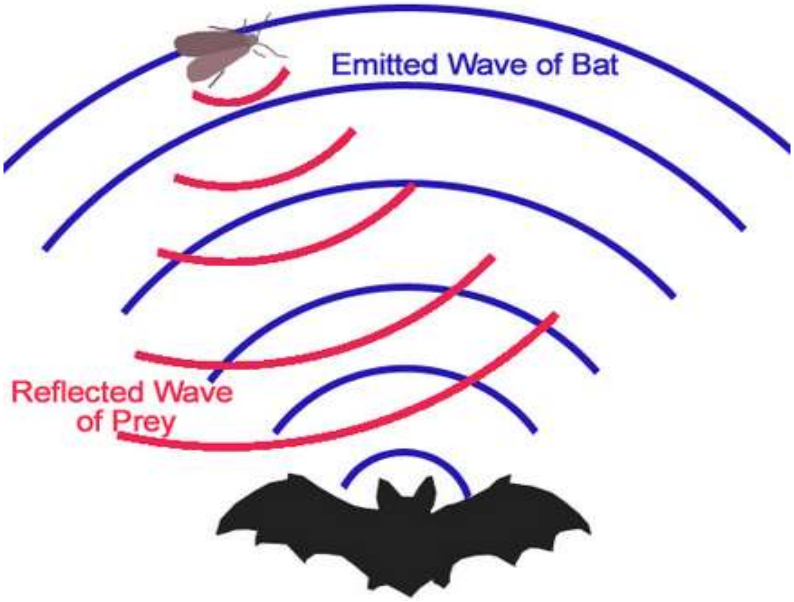


Figure 2.5: Bat echolocation mechanism [32]

The following idealized rules are normally considered in Bat algorithm;

- All bats employs the echolocation for distance determination and are able to differentiate between the prey and barriers.
- All bats fly randomly and can automatically adjust the pulse rate and loudness depending on the proximity of their prey
- The loudness varies in a variety range but tends to decrease from maximum to minimum value as the bat approaches the target/prey.

In this algorithm, each bat's position represents the solution of the optimization problem and the solution tend to improve as the bat approaches its target/prey. The solution is updated by the factor of velocity as the number of iteration increases. Sometimes the obtained solution is poor as compared to the previously obtained solution. In this case, the previous solution is retained for the next iteration [33]. By using frequency and velocity, the solution of bat algorithm (bats positions) can be updated from one iteration to another [34] as is shown in equations (2.32 – 2.34)

$$f_i = f_{\min} + (f_{\max} - f_{\min})\beta \tag{2.32}$$

$$v_i^t = v_i^{t-1} + (x_i^t - x_*) f_i \tag{2.33}$$

$$x_i^t = x_i^{t-1} + v_i^t \tag{2.34}$$

Where f, x, v and β are frequency, position, velocity and random number respectively

The Loudness (A) and pulse rate (r) of bat algorithm are normally iteratively updated by using equation (2.35) and (2.36) respectively.

$$A_i^{t+1} = \alpha A_i^t \tag{2.35}$$

$$r_i^{t+1} = r_i^0[1 - \exp(-\gamma t)] \tag{2.36}$$

Subjected to $0 < \alpha < 1$ and $\gamma > 0$

2.8 Literature Survey

Different approaches have been taken in order to come up with the best optimal solution for economic and emission dispatch aiming at the reduction of generation cost and emissions from thermal power plants. A number of different algorithms have been used for solving the economic and emission dispatch whereby among them are Fire Fly Algorithm, Particle Swarm Optimization, Artificial Bee Colony etc.

In [35] the gradient method which is the modified version of the conventional gradient method possessing the ability to converge to a global minimum regardless of initial point settings. The Lagrange multiplier was not assumed but it was calculated by using the generator limits. With the consideration of losses in the line and lossless system, the economic dispatch was implemented however the study was bounded within a small test system of three generating units which don't give the real scope of the modern power systems.

By using PSO the economic dispatch considering emissions was solved in [36], the IEEE-30 bus test system was used as the benchmark. Random Drift Particle Swarm Optimization (RDPSO) which is the novel algorithm derived from PSO and Conventional Lambda technique was used for proposing the better algorithm. In RDPSO, the searching ability is increased by adjusting the velocity updating equation. The combined multi-objective functions of both economic and emission dispatch was converted into a single objective function by using price penalty factor approach. The results showed that the RDPSO was more effective as compared to PSO and Conventional Lambda technique since the amount of emissions and cost of fuel were low as compared to other two comparative algorithms. However, the study didn't consider the effect of valve point effect.

In [37], the Improved Artificial Bee Colony (ABC) was used for performing the economic dispatch, but the issue of environmental dispatch was not considered. Also, the ABC method has a weakness of convergence speed.

In [38] the Genetic Algorithm was used for performing the economic dispatch while considering of line losses. In this work the concept of economic dispatch was extended by considering the plant's locations, the location of the plants affects the amount of power losses along the line. The cheaper plant being located far from the load centre will results into higher losses, as a result it will not be economical to operate it at a higher power dispatch. The issue of plant location is taken into account by using the allocation vector but in this study mitigation on pollutant emissions from the thermal power plan was not considered.

The suggestion of Quantum behaved Particle Swarm Optimization for solving economic dispatch problems was established in [39]. The performance comparison between PSO, GA and Quantum behaved Particle Swarm Optimization in the optimization of economic dispatch problems was demonstrated. The analysis was done by using three generating units and the dispatch done under four different load demands for comparison. In general, the result of the simulation showed that Quantum behaved Particle Swarm Optimization was superior as compared to PSO and GA. However, PSO was better as compared to GA, but the study didn’t account the system losses.

The Bat Algorithm (BA) was used for performing the economic dispatch including wind power integration in [40] aimed at finding more promising results. In this study, the optimization was done in two different benchmarks, one with six generator sets the another with fifteen. With two types of power plants under consideration (thermal and wind power) two different cost functions related to thermal and wind plants cost functions were considered. With the wind integration in both six and fifteen generating unit, the results of the simulation showed that the Bat Algorithm produced the most promising results as compared to PSO. Thus the generating cost was reduced significantly when using the Bat Algorithm as compared to using the PSO. However in this study, the emissions from the thermal power plants were not considered.

In [41] a novel Moth Flame Optimization(MFO) algorithm was implemented for solving economic dispatch considering emissions with consideration of valve point effect. The constraint which was considered for the case of equality constraints was power balance constraints and the inequality constraint was generator power output limits. In this study, the IEEE-30 bus test system was used as the benchmark for validation of the results, and three conditions of dispatching considered are economic dispatch, emission dispatch and combined economic and emission dispatch. A novel MFO algorithm was compared with PSO so as to establish its optimization ability as compared to other optimization algorithms. The simulation results in both scenarios, demonstrated the high ability of optimization by MFO algorithm as compared to PSO. However in the study, the two objective functions which are economic dispatch and emission dispatch objective function were not combined so as to convert the multi-objective problem into a single objective problem but each objective function was optimized independently. The two objective functions depends on the power output of generators, optimizing them independently resulted into wrong conclusion since the power outputs by which the conclusion was drawn were different.

The concept of hybridization of algorithms was used in [42] whereby PSO and Artificial Neural Network were hybridized for performing the economic dispatch considering emissions. In the developed hybrid algorithm the ANN was used for training the PSO, the hybridized algorithm was implemented in IEEE-30 bus system where developed hybrid was compared with other kinds of algorithms such as classic technique, Quadratic programming, Evolutionary programming and Genetic algorithm. In all cases the developed hybrid results where superior to single algorithm optimization. However, in this study the valve point effect consideration was not accounted.

Also, in [43] the developed hybrid algorithm from PSO and Firefly algorithm was used for performing the economic dispatch considering emissions . The developed algorithm was validated under standard test system of the generating unit. The results showed that the developed hybrid algorithm was superior in optimization as compared to PSO and FFA when working individually. But in this study, only NOx emissions was considered while COx and SOx which are also primary emissions from thermal power plants were neglected. Normally each emission carries the individual objective function when formulating the economic dispatch objective function. So, neglecting some of the emissions affects the objective function and the results of the study.

2.9 Research Gap

As reported in the literature Moth Flame Optimization (MFO) is a very effective algorithm in searching the search space (exploration) as compared to other algorithms, this is due to the mechanism of each individual moth being subjected to the corresponding solution (flame). This mechanism avoids the local stagnation or premature convergence of MFO algorithm [29], but MFO is not very effective in exploiting the global solution for finding the possible quality solutions. On the other hand Bat algorithm is a more effective algorithm in exploiting the global best for finding the possible best solution but it is vulnerable to local stagnation [31]. The review of the past researches shows that none of a researcher has engaged in hybridizing the two strong properties of exploration in Moth Flame Optimization and exploitation in Bat algorithm respectively so has to come up with the stronger hybrid algorithm for improving the optimization problem solutions [44]. This research had contributed to the mitigation of electric generation cost and pollutants emissions from the thermal power plant through addressing the reported gap in this area of optimization. The two strong properties of exploration and exploitation of the concerned algorithms were combined in developing the MFO_BAT algorithm. The developed MFO_BAT was applied to economic dispatch considering emissions and resulted in significant reduction of electrical generation cost and emission from thermal power plants as compared to the findings reported earlier in the literature.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter is describing the methods used for achieving the objectives of this study, these methods include the implementation of Bat algorithm, Moth flame Optimization algorithm and MFO_BAT algorithm in economic dispatch considering emissions. Various objective function involved in the study are formulated and the tools which were used for study implementation highlighted.

3.2 Moth Flame Optimization Algorithm

The detailed coding process of MFO for economic dispatch considering emission is described in this section.

3.2.1 Detailed Pseudocode of the Moth Flame Optimization Algorithm Coding for Economic Dispatch Considering Emissions

Step 1: Define the load demand, maximum and minimum power limits of generators.

Step 2: Define the economic dispatch/emission dispatch/economic dispatch considering emission objective function and equality constraints using power balance violation.

Step 3: Map the moths' positions to the generators' power.

Step 4: Define the dimension of moth position depending on the number of generating units in a system.

Step 5: Initialize the positions of moths based on the maximum and minimum limits of generators

Step 6: Set iteration to 1

Step 7: Update flame number using equation (3.1)

$$Flame(number) = round\left(N - l \times \frac{N - l}{T} \right) \tag{3.1}$$

Step 8: Bring back the moths which are outside the search space with the reference to generator power limits.

Step 9*:* Compute the power losses in the system and then evaluate the economic dispatch/emission dispatch/economic dispatch considering emission objective function fitness using Moths positions with the consideration of the equality constraint.

Step 10: If iteration count is 1, sort moth's fitness and position. Select the best moth based on the fitness sorted and assigned it to the flame (F_j).

Step 11: If iteration count is greater than 1, sort moth's fitness and position based on the previous iteration and current iteration. Select the best moth's fitness and position based on the fitness sorted and assigned it to the flame (F_j).

Step 10: Compute "a" using equation (3.2)

$$a = (\text{-}1 + current\ iteration) \times \left(\frac{\text{-}1}{Maximumi\ iteration} \right) \tag{3.2}$$

Step 11: Compute "t" using equation (3.3)

$$t = (a\ \text{-}1) \times rand + 1 \tag{3.3}$$

Step 12: Calculate the distance of month with respect to the corresponding flame using equation (3.4)

$$D_i = \left| F_j - M_i \right| \tag{3.4}$$

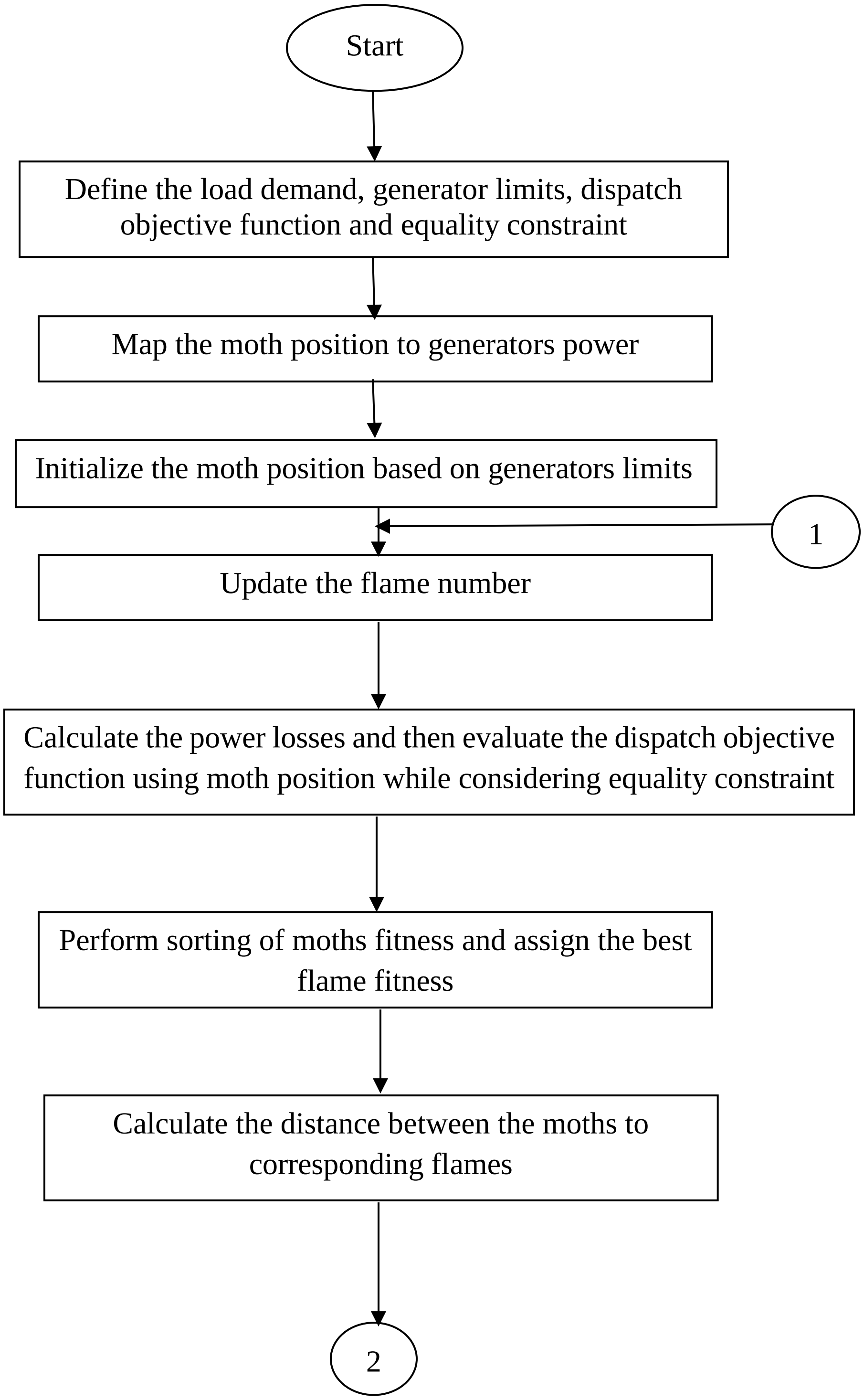
Step 13: Update moths position using equation (3.5)

$$Moth\_Position = D_i e^{bt} \cos\left(2\pi t\right) + F_j \tag{3.5}$$

Step 14: Increase the iteration

Step 15: Repeat step 7-14 until the maximum number of iteration is reached

Step 16: Display the best flame fitness which gives the value of the objective function which is the total cost of generation/fuel cost/emissions and corresponding moth position which gives the amount of power generated in each unit


Start
Define the load demand, generator limits, dispatch objective function and equality constraint
Map the moth position to generators power
Initialize the moth position based on generators limits
1
Update the flame number
Calculate the power losses and then evaluate the dispatch objective function using moth position while considering equality constraint
Perform sorting of moths fitness and assign the best flame fitness
Calculate the distance between the moths to corresponding flames
2

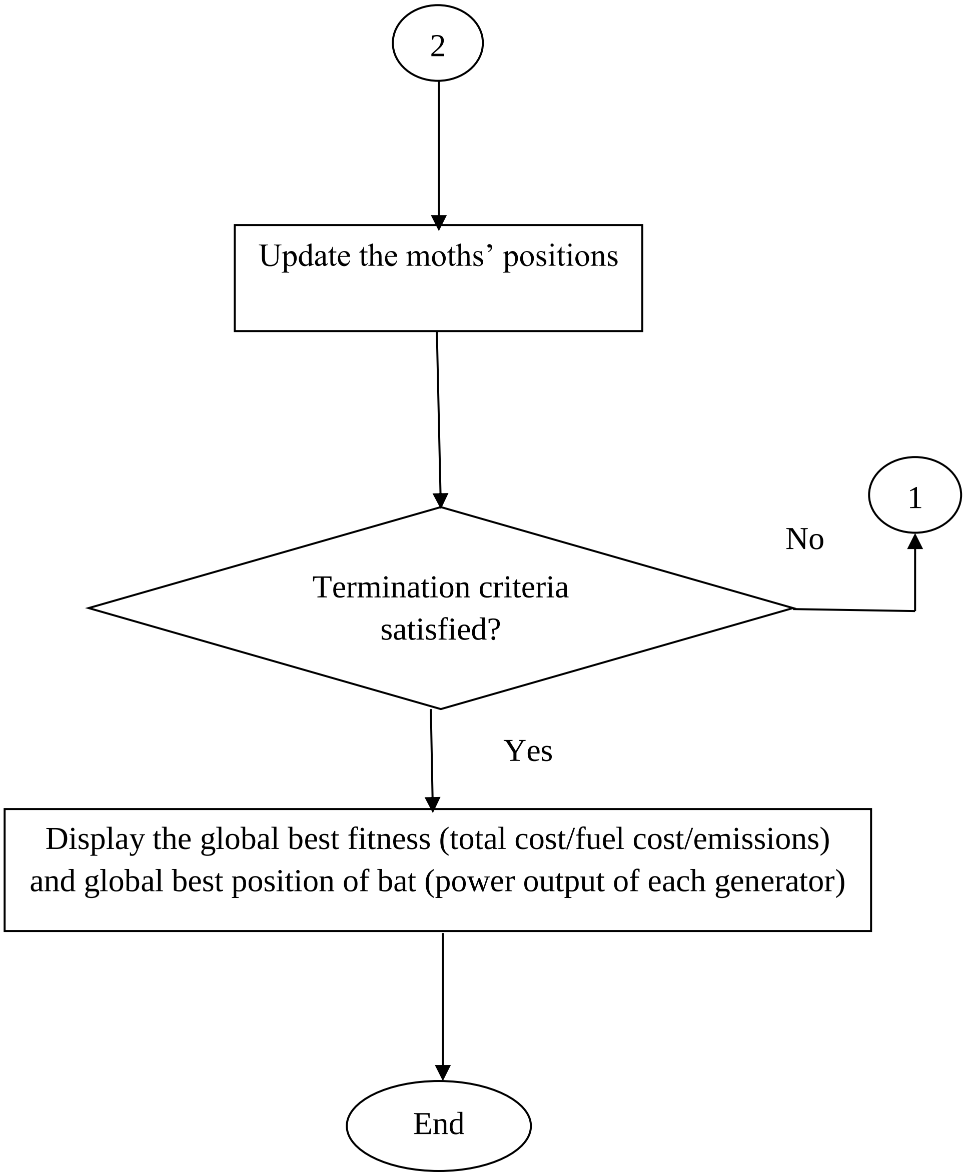


Figure 3.1: Moth Flame Optimization algorithm flow chart

Table 3.1: Moth Flame Optimization implementation in economic dispatch considering emissions

Moth-flame optimization	**Economic/Emission dispatch**
Decision variable(dimensions)	Number of generators in a system
Moths' position	Dispatched power
Fitness	Generation cost/ Emissions
Lower and upper boundaries	Generator Limits

3.2.2 Parameters Setting of Moth Flame Optimization

Population = 40

b=1

3.3 Bat Algorithm

Detailed Pseudocode for Bat algorithm coding for economic dispatch considering emission is discussed under this section.

3.3.1 Detailed Pseudocode of Bat Algorithm Coding for Economic Dispatch Considering Emissions

Step 1: Define the load demand, maximum and minimum power limits of generators

Step 2: Define the economic dispatch/emission dispatch/economic dispatch considering emission objective function and equality constraints using power balance violation

Step 3: Define the maximum and minimum frequency, initialize the value of pulse rate and loudness.

Step 4: Map the bat's positions to the generators' power

Step 5: Define the dimensions of bats positions depending on the number of generating units.

Step 6: Initialize the velocity and frequency of bats.

Step 7: Initialize the positions of bats based on the maximum and minimum limits of generators.

Step 8: Calculate the power losses and then evaluate the fitness of the economic dispatch/emission dispatch/economic dispatch considering emission objective function while satisfying the equality constraints by using bat position in step 7.

Step 9: Select the minimum fitness among all with its corresponding position as the global best values.

Step 10: Set iteration to 1.

Step 11: Compute the new position of bat using equation (3.8) after updating frequency and velocity using equation (3.6) and (3.7) respectively.

$$f_i = f_{\min} + (f_{\max} - f_{\min})\beta \tag{3.6}$$

$$v_i^t = v_i^{t-1} + (x_i^t - x_*) f_i \tag{3.7}$$

$$x_i^t = x_i^{t-1} + v_i^t \tag{3.8}$$

Step 12: If the random number is greater than the pulse rate, generate the best position of bat

Step13: Bring back the bats which are outside the search space with the reference to generator power limits (inequality constraints).

Step 14: Calculate the power losses and then evaluate the new fitness of the economic dispatch/emission dispatch/economic dispatch considering emission objective function while satisfying the equality constraints by using bat position computed in step 11.

Step 15: If the new fitness is less than the previous fitness and random number less than loudness, update the fitness and its corresponding position as the local best values.

Step 16: Update loudness and pulse rate using equation (3.9) and (3.10) respectively

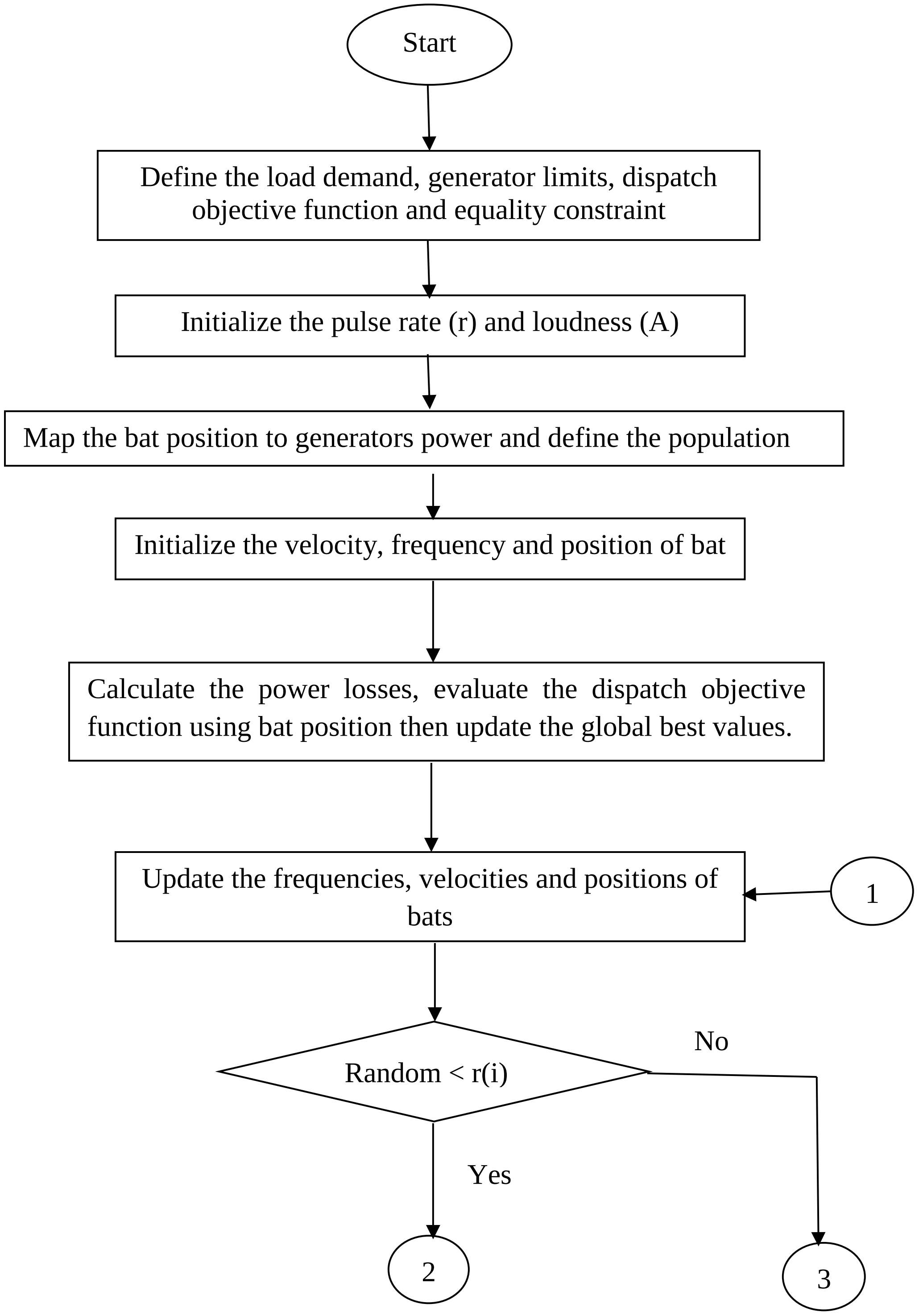
$$A_i^{t+1} = \alpha A_i^t \tag{3.9}$$

$$r_i^{t+1} = r_i^0[1 - \exp(-\gamma t)] \tag{3.10}$$

Step 17: If among the new fitnesses there is the fitness which is less than the previous best fitness, update it as the global best including its position as the global best position.

Step 18: Repeat step 11-17 until the maximum iteration is reached

Step 19: Display the global best fitness which gives the value of the objective function which is the total cost of generation/fuel cost/emissions and corresponding global best position which gives the amount of power generated in each unit


Start
Define the load demand, generator limits, dispatch objective function and equality constraint
Initialize the pulse rate (r) and loudness (A)
Map the bat position to generators power and define the population
Initialize the velocity, frequency and position of bat
Calculate the power losses, evaluate the dispatch objective function using bat position then update the global best values.
Update the frequencies, velocities and positions of bats
1
Random < r(i)
No
Yes
2
3

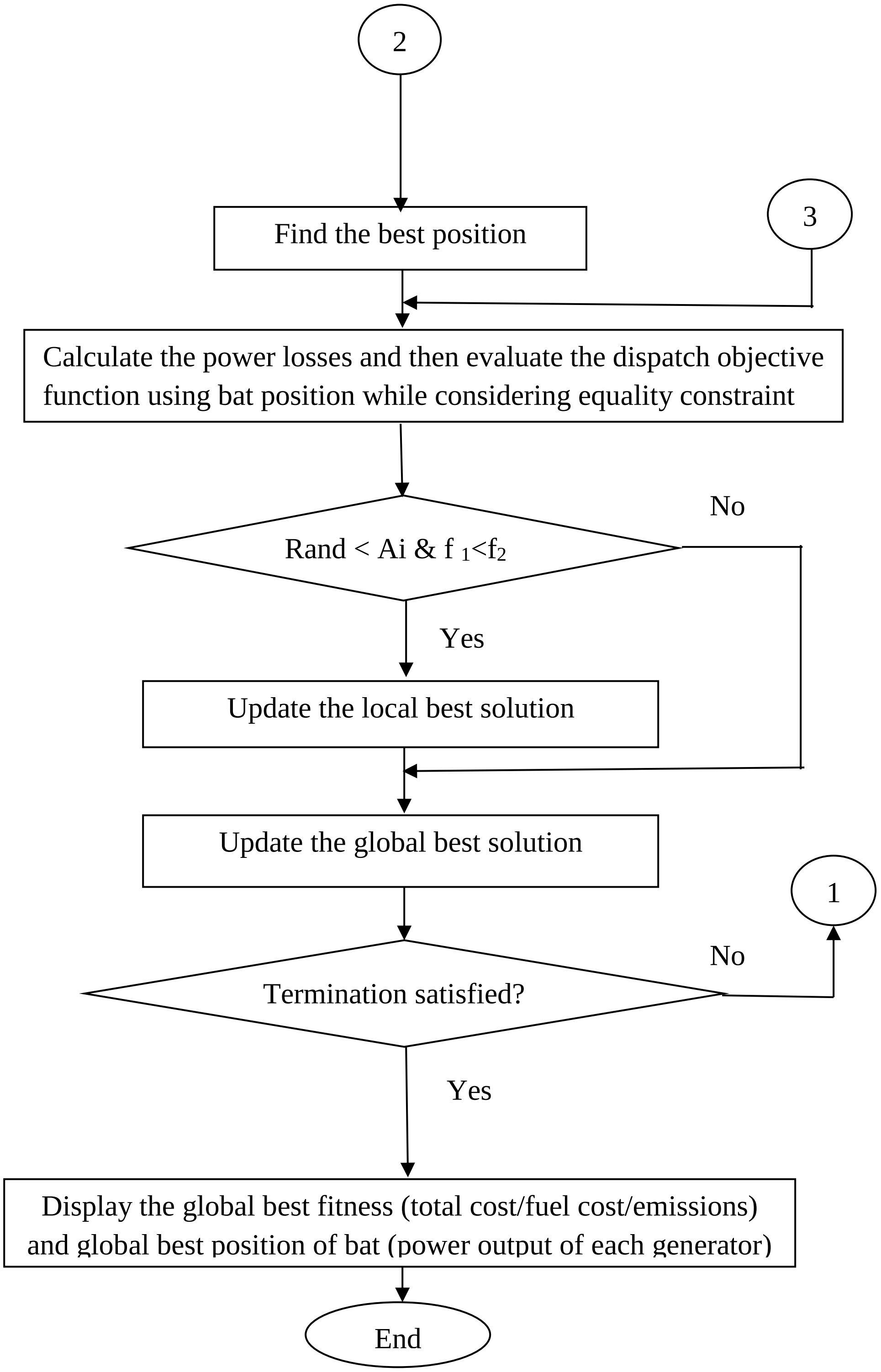


Figure 3.2: Bat algorithm flow chart

Table 3.2: Implementation of Bat algorithm in economic dispatch considering emissions

Bat Algorithm	**Economic/Emission dispatch**
Decision variable(dimensions)	Number of generators in a system
Bat position	Dispatched power
Fitness	Generation cost/Emissions
Lower and upper boundaries	Generator Limits

3.3.2 Parameters Setting of Bat Algorithm

Population = 40

Initial value of A=0.8

Initial value of r =0.2

Maximum frequency = 0.333

Minimum frequency = -0.333

3.4 Hybridization of Moth Flame Optimization and Bat Algorithm

The limitation of bat algorithm is on the searching of the solution in the search space but it is very effective in terms of exploitation of possible best solution [33]. For the case of MFO, the algorithm is more effective for searching the search space and capable of avoiding local minimum [29], this is due to moth navigation in the spiral path subjected to the corresponding solution (flame). The development of MFO_BAT algorithm from two parent algorithms involves combining the strong property of MFO which is exploration with the strong property of Bat which is exploitation. In the MFO_BAT algorithm, MFO was used for exploration and Bat algorithm was used for exploitation. Equation (3.11 – 3.15) are updating equation of MFO_BAT, in order to ensure the successful exploration of the search space MFO was dedicated for searching the search space and Bat algorithm was used for finding the best optimal solution so as to improve the solution quality.

$$Moth\_position = D_i e^{bt} \cos(2\pi t) + F_j \tag{3.11}$$

$$f_i = f_{\min} + (f_{\max} - f_{\min})\beta \tag{3.12}$$

$$v_i^t = v_i^{t-1} + (Moth\_position_i^t - x_*) f_i \tag{3.13}$$

$$x_i^t = Moth\_position_i^{t-1} + v_i^t \tag{3.14}$$

$$x_* = x_{old} + \partial A^t \tag{3.15}$$

The parameter x_{old} is the bat position obtained in the previous iteration and A^t is the amplitude of bat echo of the current iteration updated by using equation (3.9). In the MFO_BAT algorithm, the MFO algorithm was switched into full exploration mode through adjusting the value of "*b*" in equation (3.11) and Bat algorithm was switched into exploitation mode through adjusting the values of loudness and pulse rate.

3.4.1 Moth Flame Optimization and Bat Algorithm Hybridization Steps

Step 1: Define the load demand, maximum and minimum power limits of generators

Step 2: Define the economic dispatch/emission dispatch/economic dispatch considering emission objective function and equality constraints using power balance violation

Step 3: Map the moths' and bats' positions to the generators' power.

Step 4: Define the dimensions of moths and bats position based on the number of generating units

Step 5: Define the population

Step 6: Define the maximum and minimum frequency, pulse rate, loudness of bats

Step 7: Initialize the velocity and frequency of bats

Step 8: Initialize the positions of moths based on the maximum and minimum limits of generators

Step 9: Compute the power losses and evaluate the fitness of the economic dispatch/Emission dispatch/ Economic dispatch considering emissions objective function using Moth position while taking into account the equality constraint.

Step 10: Select the minimum fitness among all with its corresponding position as the global best values

Step 11: Set iteration to 1

Step 12: Update flame number using equation (3.16)

$$Flame(number) = round\left(N - l \times \frac{N-l}{T} \right) \tag{3.16}$$

Step 13: If iteration count is 1, sort moths' positions and assign them as sorted population (F_j).

Step 14: If iteration count is greater than 1, sort moth's positions based on the previous iteration and current iteration and assign them as sorted population (F_j).

Step 15: Compute "a" using equation (3.17)

$$a = (\text{-}1 + current\ iteration) \times \left(\frac{\text{-}1}{Maximum\ iteration} \right) \tag{3.17}$$

Step 16: Compute "t" using equation (3.18)

$$t = (a\,\text{-}1) \times rand + 1 \tag{3.18}$$

Step 17: Calculate the distance of month with respect to the corresponding flame using equation (3.19)

$$D_i = \left| F_j - M_i \right| \tag{3.19}$$

Step 18: Update moths position using equation (3.20)

$$Moth\_position = D_i e^{bt} \cos(2\pi t) + F_j \tag{3.20}$$

Step 19: Bring back the moths which are outside the search space with the reference to generator power limits

Step 20: Updating frequency and velocity using equation (3.21) and (3.22) respectively

$$f_i = f_{\min} + (f_{\max} - f_{\min})\beta \tag{3.21}$$

$$v_i^t = v_i^{t-1} + (Moth\_position_i^t - x_*)\, f_i \tag{3.22}$$

Step 21: Update the new position of bats using the equation (3.23)

$$x_i^t = Moth\_position_i^{t-1} + v_i^t \tag{3.23}$$

Step 22: If the random number is greater than the pulse rate, generate the best position of bat

Step 23: Bring back the bats which are outside the search space with the reference to generator power limits

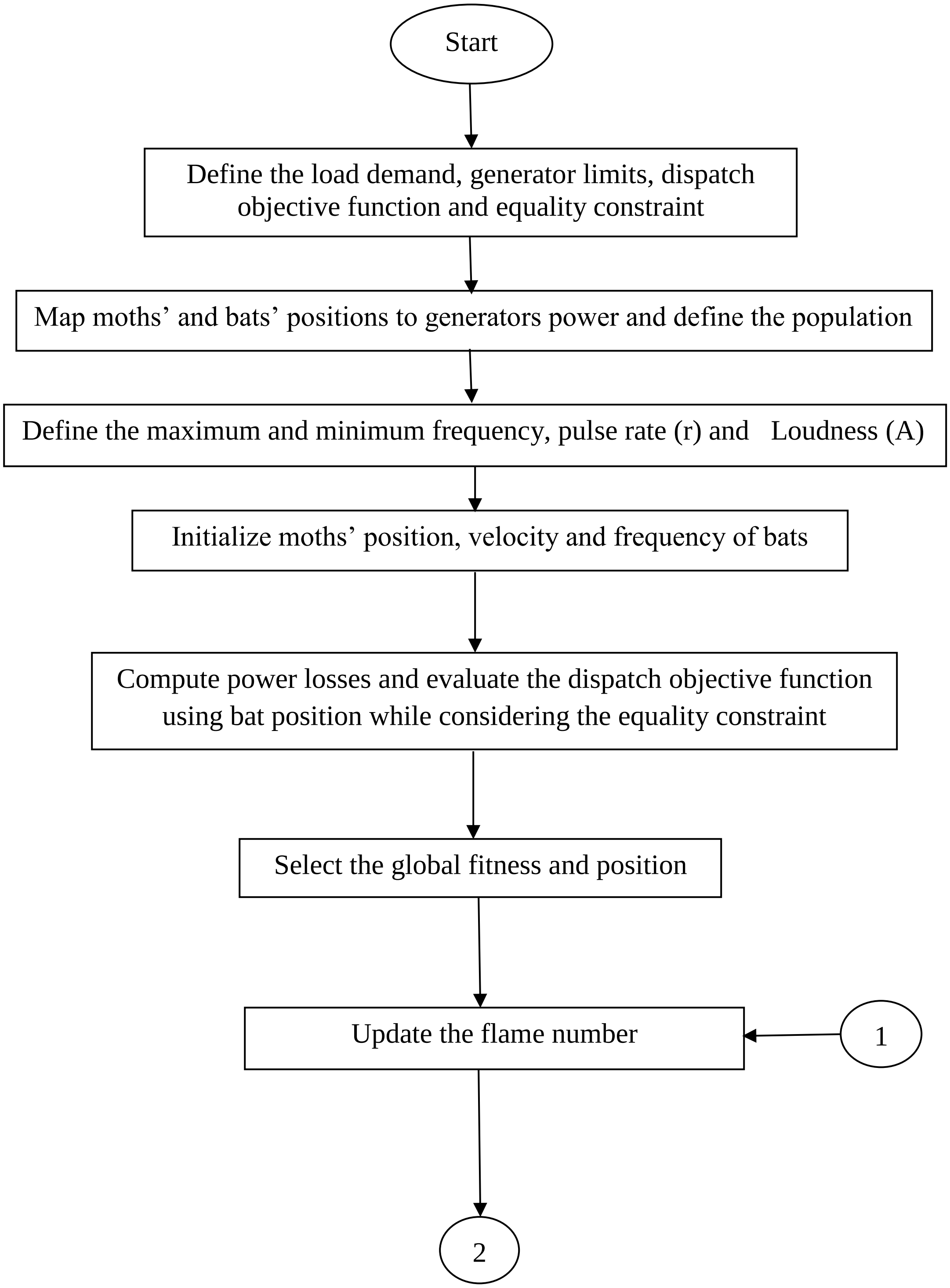
Step 24: Calculate the power losses and then evaluate the new fitness of economic dispatch/emission dispatch/economic dispatch considering emissions objective function by using bat position in step 22 while satisfying the equality constraints using power balance

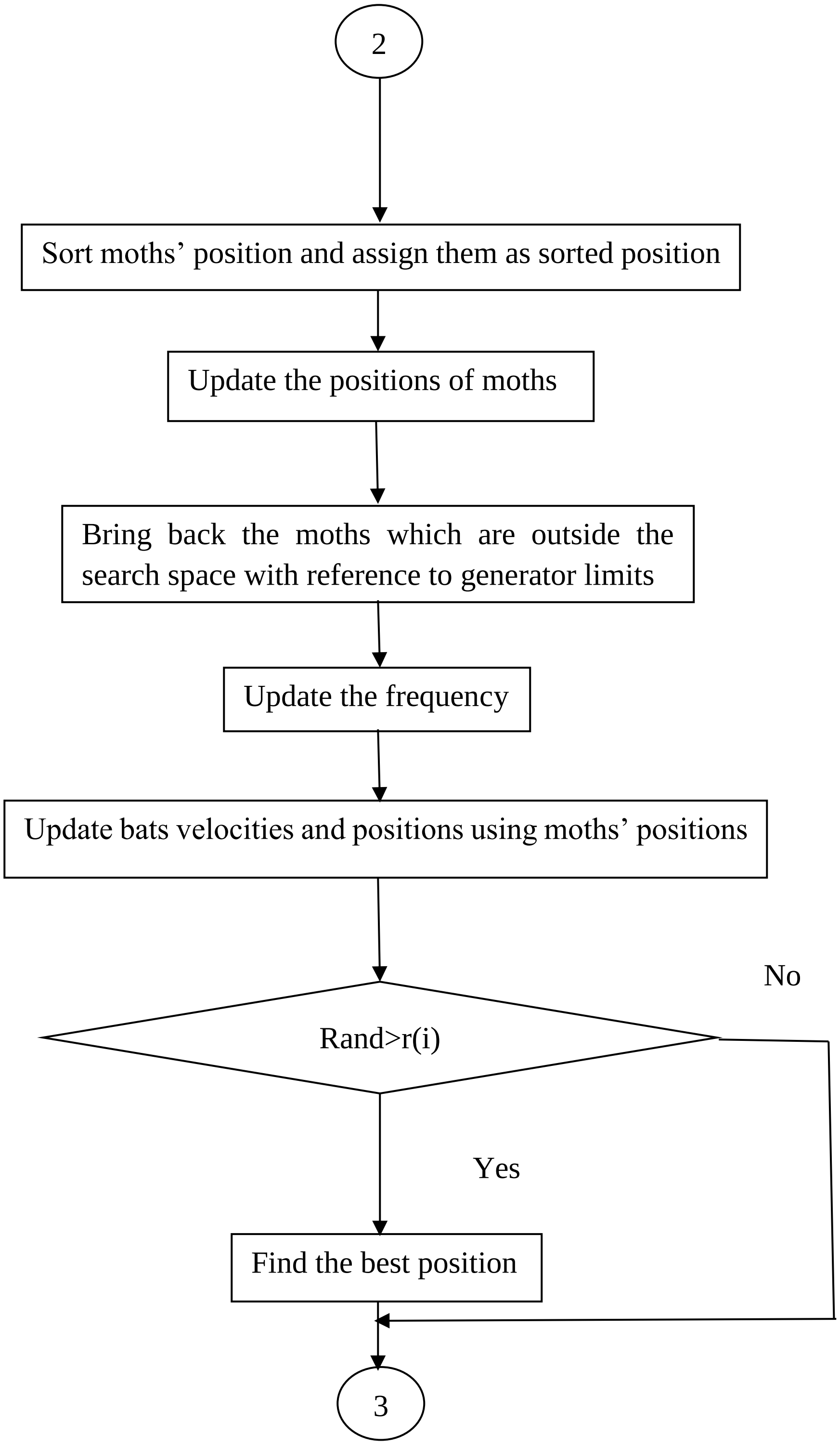
Step 25: If the new fitness is less than the previous fitness and random number less than loudness, update the fitness and its corresponding position as the local best values

Step 26: If among the new fitnesses computed there is one which is less than the previous best fitness, update it as the global best including its position as the global best position

Step 27: Repeat step 12-26 until the maximum iteration is reached

Step 28: Display the global best fitness which gives the value of the objective function which is the total cost of generation/fuel cost/ emissions and corresponding global best position which gives the amount of power generated in each unit.


Start
Define the load demand, generator limits, dispatch objective function and equality constraint
Map moths' and bats' positions to generators power and define the population
Define the maximum and minimum frequency, pulse rate (r) and Loudness (A)
Initialize moths' position, velocity and frequency of bats
Compute power losses and evaluate the dispatch objective function using bat position while considering the equality constraint
Select the global fitness and position
Update the flame number
1
2


2
Sort moths' position and assign them as sorted position
Update the positions of moths
Bring back the moths which are outside the search space with reference to generator limits
Update the frequency
Update bats velocities and positions using moths' positions
No
Rand>r(i)
Yes
Find the best position
3

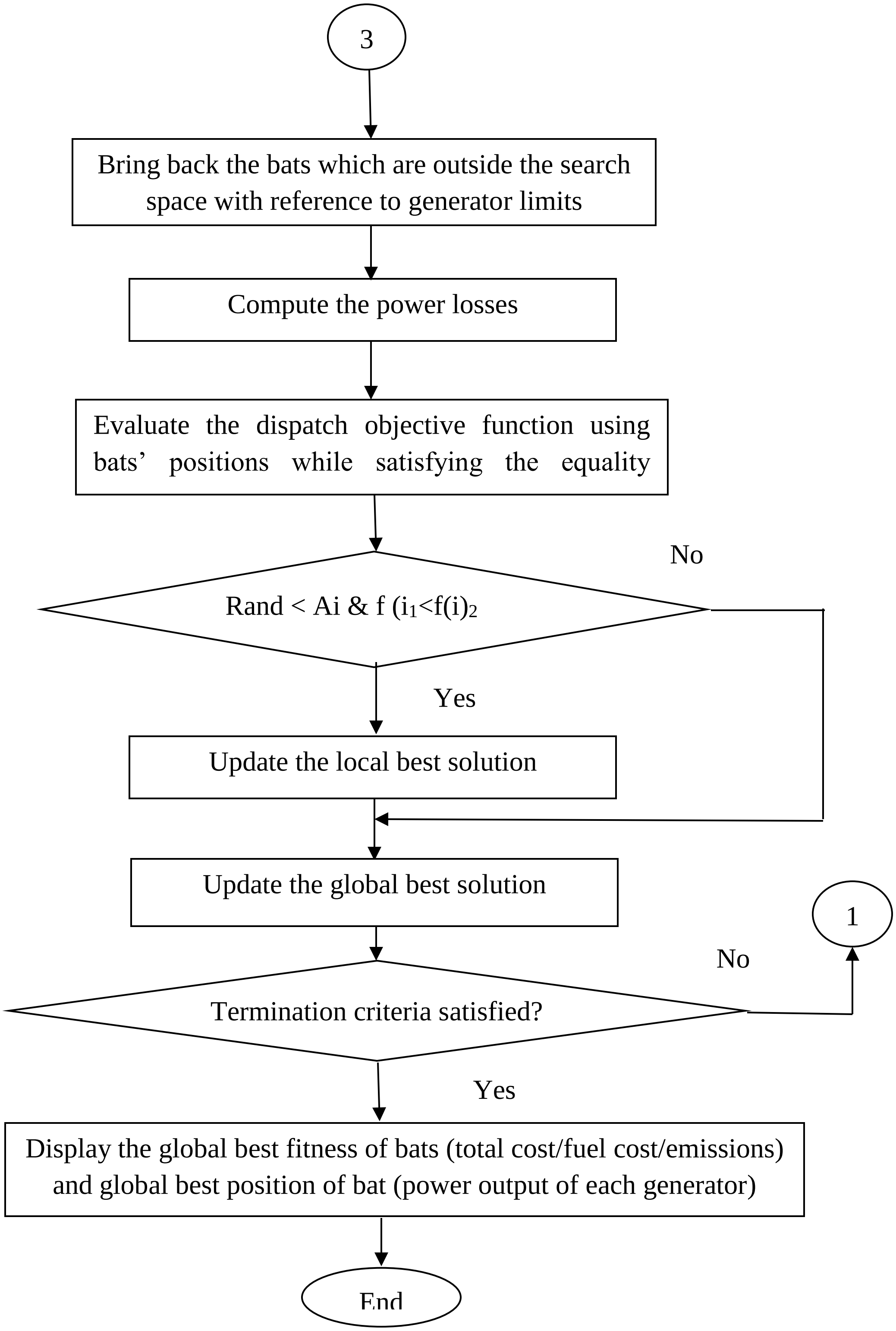


Figure 3.3: Moth Flame Optimization and Bat hybrid algorithm flow chart

Table 3.3: MFO_BAT implementation in economic dispatch considering

MFO_BAT	**Economic/Emission dispatch**
Decision variable(dimensions)	Number of generators in a system
Bats' position	Dispatched power
Fitness computed by BAT algorithm	Generation cost/ Emissions
Lower and upper boundaries	Generator Limits

The position of Moth Flame Optimization was used for updating the position of Bat algorithms as shown in equation (3.23).

3.4.2 Parameters Setting of MFO_BAT Algorithm

Population = 40

b=5

A=0.9

r =0.001

Maximum frequency = 0.333

Minimum frequency = -0.333

3.5 Objective Functions Formulation

Under this section, different objective functions which were optimized in this study are presented. This includes objective functions for economic dispatch, emission dispatch, economic dispatch considering emissions and economic dispatch considering emissions with valve point.

3.5.1 Economic Dispatch Objective Function

Economic dispatch considering emissions objective factor were formulated by converting the economic dispatch and emissions dispatch objective functions into a single objective function optimization process by means of price penalty factor. This can be referred in equations (2.27) and (2.28)

The steps by step of determining the load price penalty factor according to [45] are;

i) Determine the maximum fuel cost of each generator

$$F_i(p_{i(\max)}) = a_i P_{i(\max)}^2 + b_i P_{i(\max)} + c_i \tag{3.24}$$

ii) Determine the maximum emission of each individual plant

$$E_i(p_{i(\max)}) = \alpha_i P_i^2{}_{(\max)} + \beta_i P_{i(\max)} + \gamma_i \ \ (Kg/hr) \tag{3.25}$$

iii) Divide each maximum fuel cost to its corresponding maximum emission to obtain the individual price penalty function.

$$h_i = \frac{F_i(p_{i(\max)})}{E_i(p_{i(\max)})} \tag{3.26}$$

iv) Arrange the price penalty factor in ascending order such that

$$h = [h_1 < h_2 < h_3 ....., h_n]$$

v) Arrange the individual maximum demand according to price penalty factor order.

vi) Add the individual maximum demand one by one till the following condition is attain

$$\sum_{i=1}^{N} p_{i(\max)} \geq P_D \tag{3.27}$$

Where

P_D is the total load demand

N is the unit which satisfies the inequality condition

The corresponding *hi* to the last value of the maximum demand of unit *"N"* is the price penalty factor of the system load.

3.5.2 Economic Dispatch considering Emissions with Valve-Point Effect

The consideration of both economic and emission dispatch with valve-point effect was formulated in the equation (3.28) below;

$$Minimize(Total\ cost) = \sum_{i=1}^{NG} A + hB \qquad (\$/hr) \tag{3.28}$$

Whereby *A*, *B* and *h* are fuel cost function, emissions function and price penalty factor respectively given by equation (3.29 - 3.31) and *NG* is the total number of generating units.

$$A = a_i P_i^2 + b_i P_i + c_i + \left| e_i \sin(f_i (P_i^{\min} - P_i)) \right| \qquad (\$/hr) \qquad (3.29)$$

$$B = \alpha_i P_i^2 + \beta_i P_i + \gamma_i + \eta_i \exp(d_i \times P_i) \qquad (Kg/hr) \qquad (3.30)$$

$$h_i = \frac{a_i P_{i(\max)}^2 + b_i P_{i(\max)} + c_i + \left| e_i \sin(f_i (P_{i(\min)} - P_{i(\max)})) \right|}{\alpha_i P_{i(\max)}^2 + \beta_i P_{i(\max)} + \gamma_i + \eta_i \exp(d_i \times P_{i(\max)})} \qquad (\$/Kg) \qquad (3.31)$$

Where e and f are fuel cost constants while d and η are the emission constants of valve point effect.

3.5.3 Economic Dispatch Considering both CO_X, NO_X and SO_X Emissions

The main focus of this objective function was to minimize the cost of fuel while taking into account the three primary categories of the emissions from thermal power plants which include CO_X, NO_X and SO_X. In this case, four objectives functions which are fuel cost objective function and three emissions objective functions were optimized at a time. According to [46]the multi-objective optimization was converted into a single objective optimization by using the price penalty factors of each individual emission as shown in equation (3.32) below.

$$minimize(Total\ \cos t) = \sum_{i=1}^{NG} F_f + h_N E_N + h_S E_S + h_C E_C \qquad (\$/hr) \qquad (3.32)$$

Whereby F_f, E_N, E_S and E_C are fuel cost, NO_X emissions, SO_X emissions and CO_X emissions objective functions respectively given by equation (3.33 – 3.36) while h_N, h_S and h_C are price penalty factor of NO_X emissions, SO_X emissions and CO_X emissions respectively given by equation (3.33 – 3.36)

$$F_f = a_i P_i^2 + b_i P_i + c_i \qquad (\$/hr) \qquad (3.33)$$

$$E_N = \alpha_{i(N)} P_i^2 + \beta_{i(N)} P_i + \gamma_{i(N)} \qquad (Kg/hr) \qquad (3.34)$$

$$E_S = \alpha_{i(S)} P_i^2 + \beta_{i(S)} P_i + \gamma_{i(S)} \qquad (Kg/hr) \qquad (3.35)$$

$$E_C = \alpha_{i(C)} P_i^2 + \beta_{i(C)} P_i + \gamma_{i(C)} \qquad (Kg/hr) \qquad (3.36)$$

Where

$\alpha_{i(N)}$, $\beta_{i(N)}$ and $\gamma_{i(N)}$ are coefficients of NO_X emission of the *i*th generating unit

$\alpha_{i(S)}$, $\beta_{i(S)}$ and $\gamma_{i(S)}$ are coefficients of SO_X emission of the *i*th generating unit

$\alpha_{i(C)}$, $\beta_{i(C)}$ and $\gamma_{i(C)}$ are coefficients of CO_X emission of the *i*th generating unit

$$h_{i(N)} = \frac{a_i P_{i(\max)}^2 + b_i P_{i(\max)} + c_i}{\alpha_{i(N)} P_{i(\max)}^2 + \beta_{i(N)} P_{i(\max)} + \gamma_{i(N)}} \qquad (\$/Kg) \qquad (3.37)$$

$$h_{i(S)} = \frac{a_i P_{i(\max)}^2 + b_i P_{i(\max)} + c_i}{\alpha_{i(S)} P_{i(\max)}^2 + \beta_{i(S)} P_{i(\max)} + \gamma_{i(S)}} \qquad (\$/Kg) \qquad (3.38)$$

$$h_{i(C)} = \frac{a_i P_{i(\max)}^2 + b_i P_{i(\max)} + c_i}{\alpha_{i(C)} P_{i(\max)}^2 + \beta_{i(C)} P_{i(\max)} + \gamma_{i(C)}} \qquad (\$/Kg) \qquad (3.39)$$

3.5.4 System Constraints

The limits of any optimization problem are normally termed as the system constraints. The optimization problems in this study were subjected to both equality and inequality constraints which both of them limits the parameter of optimization in this study which is power. The power balance of the system dedicates the equality constraint whereby the total generated power was equal to power demand (P_D) with the addition of system losses as it given in equation (2.22) and (2.23).

3.6 Test systems

Depending on the availability of data, various systems were used in the implementation of this study. These test systems involve IEEE 30 bus test system, ten units test system with valve-point effect and six units system with CO_X, NO_X and SO_X emissions coefficients.

3.7 IEEE-30 Bus Test System

The IEEE-30 bus test system was used for implementation of this study due to its suitability in relation to the study. Since IEEE-30 bus test system possess both generation and transmission data, it is suitable for this study. The necessary data for the study which are cost and emission coefficients of each generating unit, generators limits and *B*-loss coefficient matrix are also provided.

3.7.1 IEEE-30 Bus Test System Data

Table 3.4: Fuel cost coefficients and generator limits of IEEE-30 bus test system [47]

Unit	a_i (\$/MW^{2}hr)	b_i (\$/MWhr)	c_i (\$/hr)	Pmax (MW)	Pmin (MW)
1	0.15247	38.53973	756.79886	125	10
2	0.10587	46.15916	451.32513	150	10
3	0.02803	40.39655	1049.32513	250	40
4	0.03546	38.30553	1243.5311	210	35
5	0.02111	36.32782	1658.5696	325	130
6	0.01799	38.27041	1356.27041	315	125

Table 3.5: NO_X emissions coefficients of IEEE-30 bus system [47]

Unit	α_i (Kg/MW^{2}hr)	β_i (Kg/MWhr)	γ_i (Kg/hr)
1	0.00419	0.32767	13.85932
2	0.00419	0.32767	13.85932
3	0.00683	-0.54551	40.2669
4	0.00683	-0.54551	40.2669
5	0.00461	-0.51116	42.89553
6	0.00461	-0.51116	42.89553

Referring to [48] the transmission loss coefficient matrices were determined as follows,

i) The load flow of IEEE-30 bus test was determined at each individual load.

ii) Then copper losses was extracted from the results of the load flow.

iii) The B coefficients were calculated using (3.40)

$$Bij = \frac{P_L}{P_i P_j} \tag{3.40}$$

Whereby;

Bij = Loss coefficient between bus i and j

P_L = Copper losses.

P_i =Power generated at bus i

P_j =Power generated at bus j

The load flow simulation results of IEEE-30 bus which were used to compute the coefficients can be referred in appendix B.

The obtained B-loss coefficients matrices were;

For 500MW;

$$B = \begin{bmatrix} 0.000084 & 0.002513 & -0.000132 & -0.000163 & 0.007314 & -0.001748 \\ 0.002513 & 0.000262 & -0.001376 & -0.000017 & 0.003879 & 0.000321 \\ -0.000132 & -0.001376 & 0.002039 & 0.000743 & -0.000131 & 0.000141 \\ -0.000163 & -0.000017 & 0.000743 & 0.002561 & -0.000151 & 0.003618 \\ 0.007314 & 0.003879 & -0.000131 & -0.000151 & 0.014521 & -0.00131 \\ -0.001748 & 0.000321 & 0.000141 & 0.003618 & -0.000131 & 0.000004 \end{bmatrix}$$

For 700MW;

$$B = \begin{bmatrix} 0.002022 & -0.000286 & -0.000534 & -0.000565 & -0.000454 & -0.000103 \\ -0.000286 & 0.003243 & 0.000016 & -0.000307 & -0.000422 & -0.000147 \\ -0.000534 & 0.000016 & 0.002085 & 0.000831 & 0.000023 & -0.000270 \\ -0.000565 & -0.000307 & 0.000831 & 0.001129 & 0.000113 & -0.000295 \\ -0.000454 & -0.000422 & 0.000023 & 0.000113 & 0.000460 & -0.000153 \\ -0.000103 & -0.000147 & -0.000270 & -0.000295 & -0.000153 & 0.000898 \end{bmatrix}$$

For 900M MW;

$$B = \begin{bmatrix} 0.000231 & 0.004741 & -0.000033 & 0.001274 & 0.003134 & 0.000012 \\ 0.004741 & 0.001232 & 0.000014 & 0.000712 & 0.003139 & 0.002178 \\ -0.000033 & 0.000014 & 0.000241 & -0.000163 & -0.000136 & 0.000013 \\ 0.001274 & 0.000712 & -0.000163 & 0.000341 & 0.000168 & 0.001457 \\ 0.003134 & 0.003139 & -0.000136 & 0.000168 & 0.003175 & -0.000147 \\ 0.000012 & 0.002178 & 0.000324 & 0.001457 & -0.000147 & 0.000132 \end{bmatrix}$$

3.7.2 Determination of Load Price Penalty Factor (h) of IEEE-30 Bus

From;

$$h_i = \frac{a_i P_{i(\max)}^2 + b_i P_{i(\max)} + c_i}{\alpha_i P_{i(\max)}^2 + \beta_i P_{i(\max)} + \gamma_i} \qquad (\$/Kg)$$

The price penalty factors computed of IEEE-30 bus system are as shown in Table 3.6

Table 3.6: Computed price penalty factors of IEEE-30 bus test system

h_1	h_2	h_3	h_4	h_5	h_6
66.1470	62.0357	39.0016	47.8222	43.1533	44.7863

Using

$$\sum_{i=1}^{N} p_{i(\max)} \geq P_D$$

In Table 3.7. The price penalty factors were arranged in the ascending order so as to determine the system load price penalty factor. The maximum demand of the individual price penalty factor were added one by one whereby the price penalty factor which corresponded to the cumulative maximum demand which is equal or greater to the system load qualified as a system load price penalty factor.

Table 3.7: Price penalty factor extraction of IEEE-30 bus system

Price penalty factor in ascending order	39.0016	43. 1533	44.7863	47.8222	62.0357	66.1470
Corresponding maximum demand	250	325	315	210	150	125
Cumulative maximum demand	250	575	890	1100	1250	1375

Table 3.8: Price penalty factor at each load demand of IEEE-30 bus system

Load demand	Price penalty factor(h)
500MW	43.1533
700MW	44.7863
900MW	47.8222

3.8 Ten Units Test System

The ten units test system was used for making the study more realistic since it possesses the valve point effect coefficients. The system has ten generating units whereby the necessary data such as coefficients of economic and emission dispatch are provided. Also, the generator limits are present with the inclusion of valve point effect coefficients and B-loss matrix coefficients.

3.8.1 Ten Units Test System Data

Table 3.9: Fuel cost coefficients, valve-point effects coefficients and generator limits of ten units system [49]

Unit	a_i (\$/MW^{2}hr)	b_i (\$/MWhr)	c_i (\$/hr)	e_i (\$/hr)	f_i (rad/MW)	Pmax (MW)	Pmi (MW)
1	0.12951	40.5407	1000.403	33	0.0174	55	10
2	0.10908	39.5804	950.606	25	0.0178	80	20
3	0.12511	36.5104	900.705	32	0.0162	120	47
4	0.12111	39.5104	800.705	30	0.0168	130	20
5	0.15247	38.539	756.799	30	0.0148	160	50
6	0.10587	46.1592	451.325	20	0.0163	240	70
7	0.03546	38.3055	1243.531	20	0.0152	300	60
8	0.02803	40.3965	1049.998	30	0.0128	340	70
9	0.02111	36.3278	1658.569	60	0.0136	470	135
10	0.01799	38.2704	1356.659	40	0.0141	470	150

Table 3.10: NO_X emissions and valve point effect coefficients of ten units system [49]

Unit	α_i (Kg/MW^{2}hr)	β_i (Kg/MWhr)	γ_i (Kg/hr)	η_i (kg/hr)	δ_i (1/MW)
1	0.04702	-3.9864	360.0012	0.25475	0.01234
2	0.04652	-3.9524	350.0056	0.25475	0.01234
3	0.04652	-3.9023	330.0056	0.25163	0.01215
4	0.04652	-3.9023	330.0056	0.25163	0.01215
5	0.0042	0.3277	13.8593	0.2497	0.012
6	0.0042	0.3277	13.8593	0.2497	0.012
7	0.0068	-0.5455	40.2669	0.248	0.0129
8	0.0068	-0.5455	40.2669	0.2499	0.01203
9	0.0046	-0.5112	42.8955	0.2547	0.01234
10	0.0046	-0.5112	42.8955	0.2547	0.01234

Transmission loss coefficients matrices [49]

$$B = 10^{-4} \times \begin{bmatrix} 0.49 & 0.14 & 0.15 & 0.15 & 0.16 & 0.17 & 0.17 & 0.18 & 0.19 & 0.20 \\ 0.14 & 0.45 & 0.16 & 0.16 & 0.17 & 0.15 & 0.15 & 0.16 & 0.18 & 0.18 \\ 0.15 & 0.16 & 0.39 & 0.1 & 0.12 & 0.14 & 0.14 & 0.16 & 0.16 & 0.16 \\ 0.15 & 0.16 & 0.1 & 0.4 & 0.14 & 0.1 & 0.11 & 0.12 & 0.14 & 0.15 \\ 0.16 & 0.17 & 0.12 & 0.14 & 0.35 & 0.11 & 0.13 & 0.13 & 0.15 & 0.16 \\ 0.17 & 0.15 & 0.12 & 0.1 & 0.11 & 0.36 & 0.12 & 0.12 & 0.14 & 0.15 \\ 0.17 & 0.15 & 0.14 & 0.11 & 0.13 & 0.12 & 0.38 & 0.16 & 0.16 & 0.18 \\ 0.18 & 0.16 & 0.14 & 0.12 & 0.13 & 0.12 & 0.16 & 0.4 & 0.15 & 0.16 \\ 0.19 & 0.18 & 0.16 & 0.14 & 0.15 & 0.14 & 0.16 & 0.15 & 0.42 & 0.19 \\ 0.20 & 0.18 & 0.16 & 0.15 & 0.16 & 0.15 & 0.18 & 0.16 & 0.19 & 0.44 \end{bmatrix}$$

$B_{oi} = 0$

$B_{oo} = 0$

3.8.2 Price Penalty Factor (h) Determination of Ten Units Test System

From;

$$h_i = \frac{a_i P_{i(\max)}^2 + b_i P_{i(\max)} + c_i + \left| e_i \sin(f_i (P_{i(\min)} - P_{i(\max)})) \right|}{\alpha_i P_{i(\max)}^2 + \beta_i P_{i(\max)} + \gamma_i + \eta_i \exp(d_i \times P_{i(\max)})} \qquad (\$ / Kg)$$

The price penalty factors computed are as shown in Table 3.11

Table 3.11: Computed price penalty factors of ten units test system

h1	12.8584
h2	14.5596
h3	13.3531
h4	13.1330
h5	61.8537
h6	52.0394
h7	31.8403
h8	27.4994
h9	25.9780
h10	25.8693

Using

$$\sum_{i=1}^{N} p_{i(\max)} \geq P_D$$

The price penalty factors at different loading were determined by arranging the price penalty factors in ascending order with the corresponding maximum demand as shown in Table 3.12.

Table 3.12: Price penalty factor extraction for ten units test system

Price penalty factor in ascending order	Corresponding maximum demand	Cumulative maximum demand
12.8584	55	55
13.1330	130	185
13.3531	120	305
14.5596	80	385
25.8693	470	855
25.9780	470	1,325
27.4994	340	1,665
31.8403	300	1,965
52.0394	240	2,205
61.8537	160	2,365

Table 3.13: Price penalty factor at each load demand for ten units tests system

Load demand	Price penalty factor(h)
2,000MW	52.0394

3.9 Six Units Test System with both CO_X, NO_X and SO_X Emissions.

Six unit test system with CO_X, NO_X and SO_X Emissions Coefficients was used for further making the study realistic through consideration of all primary emissions from thermal power plants which are CO_X, NO_X and SO_X Emissions.

3.9.1 Six Units Test System Data

Table 3.14: Fuel cost coefficients and generator limits of six units test system with both CO_X, NO_X and SO_X emissions [50]

Unit	a_i (\$/MW^{2}hr)	b_i (\$/MWhr)	c_i (\$/hr)	Pmax (MW)	Pmi (MW)
1	0.002035	8.43205	85.6348	400	150
2	0.003866	6.41031	303.7780	400	200
3	0.002182	7.42890	847.1484	600	350
4	0.001345	8.30154	274.2241	400	5
5	0.002182	7.42890	847.1484	500	270
6	0.005963	6.91559	202.0258	300	170

Table 3.15: NO_X emission coefficients of six units test system [50]

Unit	$\alpha_{i(N)}$ (Kg/MW^{2}hr)	$\beta_{i(N)}$ (Kg/MWhr)	$\gamma_{i(N)}$ (Kg/hr)
1	0.006323	-0.38128	80.9019
2	0.006483	-0.79027	28.8249
3	0.003174	-1.36061	324.1775
4	0.006732	-2.39928	610.2535
5	0.003174	-1.36061	324.1775
6	0.006181	-0.39077	50.3808

Table 3.16: SO_X Emission coefficients [50]

Unit	$\alpha_{i(S)}$ (Kg/MW^{2}hr)	$\beta_{i(S)}$ (Kg/MWhr)	$\gamma_{i(S)}$ (Kg/hr)
1	0.001206	5.05928	51.3778
2	0.002320	3.84624	182.2605
3	0.001284	4.45647	508.5207
4	0.110813	4.97641	165.3433
5	0.001284	4.45647	508.5207
6	0.003578	4.14938	121.2133

Table 3.17: CO_X emission coefficients [50]

Unit	$\alpha_{i(C)}$ (Kg/MW^{2}hr)	$\beta_{i(C)}$ (Kg/MWhr)	$\gamma_{i(C)}$ (Kg/hr)
1	0.001206	5.05928	51.3778
2	0.002320	3.84624	182.2605
3	0.001284	4.45647	508.5207
4	0.110813	4.97641	165.3433
5	0.001284	4.45647	508.5207
6	0.003578	4.14938	121.2133

Transmission loss coefficients matrices [50]

$$B = 10^{-4} \times \begin{bmatrix} 1.102 & 0.1 & 0.15 & 0.05 & 0 & -0.3 \\ 0.1 & 3.0 & -0.2 & 0.01 & 0.12 & 0.1 \\ 0.15 & -0.2 & 1.0 & -0.1 & 0.1 & 0.08 \\ 0.05 & 0.01 & -0.1 & 1.5 & 0.06 & 0.5 \\ 0 & 0.12 & 0.1 & 0.06 & 2.5 & 0.2 \\ -0.3 & 0.1 & 0.08 & 0.5 & 0.2 & 2.1 \end{bmatrix}$$

$$B_{oi} = 0$$

$$B_{oo} = 0$$

3.9.2 Determination of Load Price Penalty Factor (h) of Six Units Test System with CO_X, NO_X and SO_X Emissions

Using (3.37), (3.38) and (3.39) the price penalty factors computed are as shown in Table 3.18, 3.19 and 3.20.

Table 3.18: Computed NO_X emissions price penalty factors of six units test system

$h_{1(N)}$	$h_{2(N)}$	$h_{3(N)}$	$h_{4(N)}$	$h_{5(N)}$	$h_{6(N)}$
4.0253	4.6486	9.3627	5.2360	11.6768	5.7481

Table 3.19: Computed SO_X emissions price penalty factors

$h_{1(S)}$	$h_{2(S)}$	$h_{3(S)}$	$h_{4(S)}$	$h_{5(S)}$	$h_{6(S)}$
1.6684	1.6666	1.6709	0.1916	1.6702	1.6666

Table 3.20: Computed CO_X emissions price penalty factors

$h_{1(C)}$	$h_{2(C)}$	$h_{3(C)}$	$h_{4(C)}$	$h_{5(C)}$	$h_{6(C)}$
0.1639	0.2446	0.1805	0.2771	0.2216	0.2542

Using

$$\sum_{i=1}^{N} p_{i(\max)} \geq P_D$$

The price penalty factors of individual NO_X, SO_X and CO_X emissions at a load of 1,800MW were determined by arranging the price penalty factors in ascending order with the corresponding maximum demand as shown in Table 3.21, 3.22 and 3.23.

Table 3.21: NO_X Price penalty factor extraction of six units test system

Price penalty factor in ascending order	4.0253	4.6486	5.2360	5.7481	9.3627	11.6768
Corresponding maximum demand	400	400	400	300	600	500
Cumulative maximum demand	400	800	1200	1500	2100	2600

Table 3.22: SO_X Price penalty factor extraction of six units test system

Price penalty factor in ascending order	0.1916	1.6666	1.6666	1.6684	1.6702	1.6709
Corresponding maximum demand	400	400	300	400	500	600
Cumulative maximum demand	400	800	1100	1500	2000	2600

Table 3.23: CO_X Price penalty factor extraction of six units test system

Price penalty factor in ascending order	0.1639	0.1805	0.2216	0.2446	0.2542	0.2771
Corresponding maximum demand	400	600	500	400	300	400
Cumulative maximum demand	400	1000	1500	1900	2200	2600

Table 3.24: Price penalty factor of NO_X, SO_X and CO_X emissions at a load of 1,800MW

Emission	Price penalty factor(h)
NO_2	9.3627
SO_2	1.6702
CO_2	0.2446

3.10 Tool

Coding of the optimization problem was implemented by using MATLAB 2016 software and can be referred in appendix A.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses the results of this research which are based on analyzing economic dispatch while considering emission using Moth Flame Optimization algorithm, Bat algorithm and Moth Flame Optimization and Bat hybrid algorithm. Also, the relation between the pure economic dispatch, pure emission dispatch and economic dispatch considering emission (emission constrained economic dispatch) is discussed in details by using the obtained results. To demonstrate the strength of the methods above, economic dispatch considering emission with valve-point effect, economic dispatch considering both NO_X, CO_X and SO_X emissions are also presented. The evaluation of the performance of the novel MFO_BAT algorithm was done by comparing its results with other results reported in the literature.

4.2 IEEE 30 Bus Test System

Using IEE-30 bus test system for the implementation of this study, the algorithms were tested under different load conditions which are 500MW, 700MW and 900MW for the purpose of checking their performance at different loading point. The different load conditions was achieved through evenly increase of load for all buses of the system. It is clear that when the algorithm is subjected to a load of total upper limits or lower limits of the generators, the task of allocating the power to each generating unit becomes a simple dispatch of power by taking the upper limits or lower limits of each generator. Thus, to determine which algorithm is better as compared to another in terms of dispatching power in this condition is not possible since all algorithms seem to perform better. The same case applies to the load near to the margin of the total lower or upper limits of system generators. In order to ensure the successfully checking of the performance of the algorithms, the load was changed step by step between the lower and upper margin of total generators limits in which the load of 500MW, 700MW and 900MW was used.

At a load of 500MW, the study was extended further by involving the pure economic dispatch alone, pure emission dispatch alone and economic dispatch considering emission. This was done with the purpose of checking the effects of three approaches on fuel cost and emissions from thermal power plants.

Figure 4.1 shows the convergence curve of pure economic dispatch at the load of 500MW. In this case, the optimization problem focused on minimizing the fuel cost while neglecting the minimization of emissions from the concerned thermal power plants. The blue, red and green show the convergence of MFO, BAT and MFO_BAT respectively as shown in the legend of the convergence curve. It is clear that the MFO_BAT performed better than MFO and BAT in terms of minimizing the fuel cost objective function as shown in Figure 4.1. The numerical results of pure economic dispatch at a load of 500MW are presented in Table 4.1 where the fuel cost, emissions from power plants, losses and total generation are shown. From Table 4.1 it is clear from the highlighted row of the section of pure economic dispatch that the MFO_BAT algorithm performed better in terms of minimizing the cost of fuel which is the main focus of pure economic dispatch as compared to MFO and BAT algorithms.

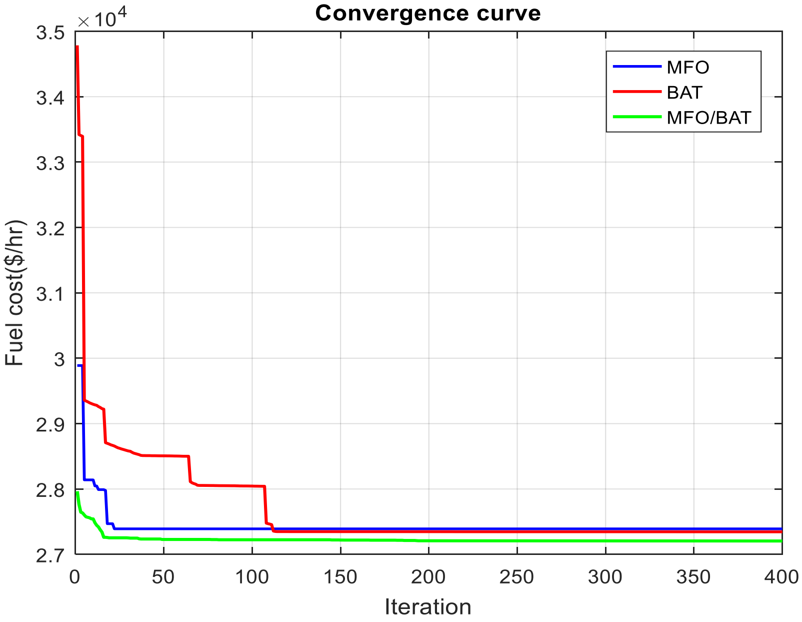


Figure 4.1: Convergence curve of pure economic dispatch at the load demand of 500MW

The highlighted row at the section of pure emission dispatch in Table 4.1 shows the emissions which were obtained during the pure emission dispatch at a load of 500MW by using each algorithm. The economic dispatch considering emission is presented in Table 4.1 in the last section whereby the highlighted row shows the total cost minimization which is the main focus of this objective function but with the consideration of minimizing emission from the power plants, generally this total cost is due to the cost of fuel and cost of emission charges. Figure 4.2 shows the convergence curve of economic dispatch considering emissions at a load of 500MW. In both cases, the performance of MFO_BAT was better compared to either MFO or BAT algorithms.

Table 4.1: Pure economic dispatch, pure emission dispatch, Economic dispatch considering emissions at a load of 500MW

Pure economic dispatch			
Generating unit	MFO	BAT	MFO_BAT
P1(MW)	10.0000	10.0000	10.0001
P2(MW)	10.0000	10.0000	10.1967
P3(MW)	40.0000	118.7535	75.6958
P4(MW)	35.0000	35.4552	80.1496
P5(MW)	281.3616	204.1481	179.5489
P6(MW)	125.0000	125.0035	148.6636
Total generation (MW)	501.3616	503.3603	504.2546
Losses (MW)	1.3616	3.3603	4.2546
Fuel cost ($/hr)	27390.7936	27344.9613	27204.7387
Emission(kg/hr)	409.0795	318.1322	282.2435
Pure emission dispatch			
Generating unit	MFO	BAT	MFO_BAT
P1(MW)	10.0000	34.5508	19.3243
P2(MW)	31.3314	12.5644	28.5947
P3(MW)	92.9326	94.5100	93.4465
P4(MW)	97.5005	92.1474	95.3728
P5(MW)	141.2307	131.9195	139.4883
P6(MW)	137.5182	150.4877	136.2347
Total generation (MW)	510.5134	516.1798	512.4613
Losses (MW)	10.5134	16.1798	12.4613
Fuel cost ($/hr)	27690	27852	27745
Emission(kg/hr)	268.7981	272.5946	267.819
Economic dispatch considering emissions			
Generating unit	MFO	BAT	MFO_BAT
P1(MW)	10.0000	10.7745	13.8352
P2(MW)	10.0000	10.0000	10.0000
P3(MW)	102.8599	120.7070	95.8799
P4(MW)	104.2275	85.5681	96.6216
P5(MW)	130.0000	151.9478	152.2672
P6(MW)	149.2626	126.3182	137.2685
Total generation (MW)	506.3500	505.3156	505.8726
Losses (MW)	6.35	5.3156	5.8726

Fuel cost ($/hr)	27411	27371	27327
Emission(kg/hr)	272.7948	276.5102	270.3638
Total cost ($/hr)	40456.2663	40594.8113	40256

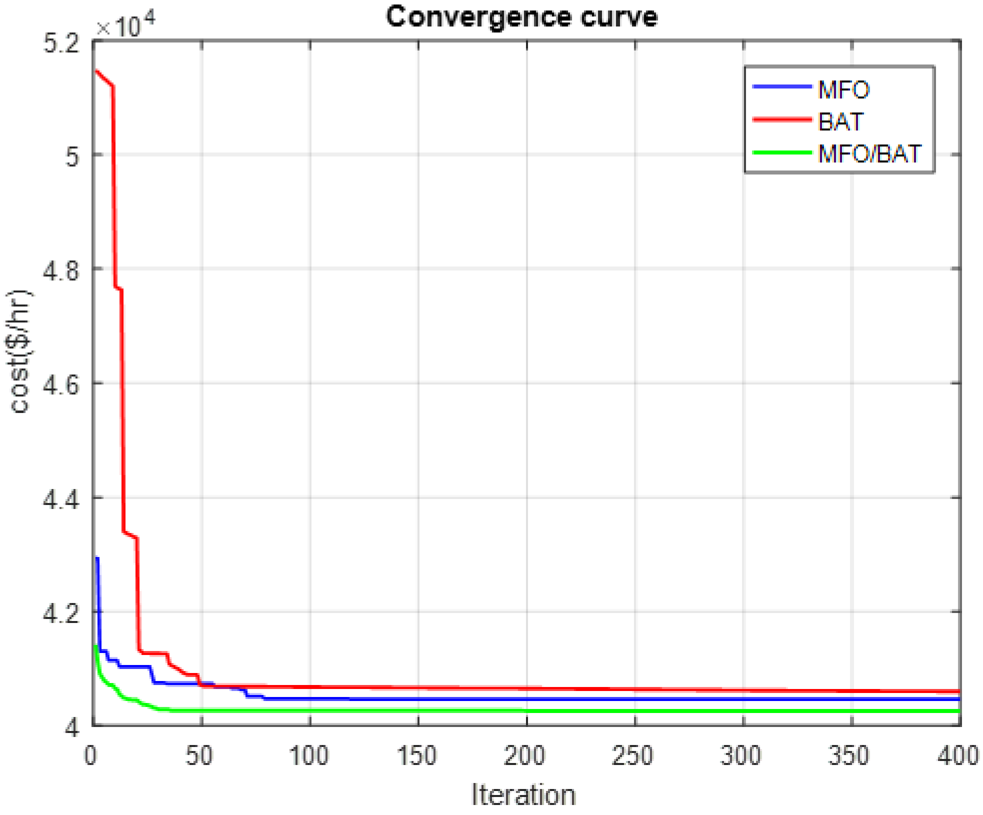


Figure 4.2: Convergence curve of Economic dispatch considering emissions at a load of 500MW

In order to find the amount of emissions for the case of pure economic dispatch, the dispatched power from each unit was subjected to emission dispatch objective function direct and the emissions were computed by using dispatched power from pure economic dispatch. The same approach was used in the case of pure emission dispatch and economic dispatch considering emissions. Figure 4.3 shows the analytical representation of the relationship between the pure economic dispatch (PECOD), pure emission dispatch alone and economic dispatch considering emission.

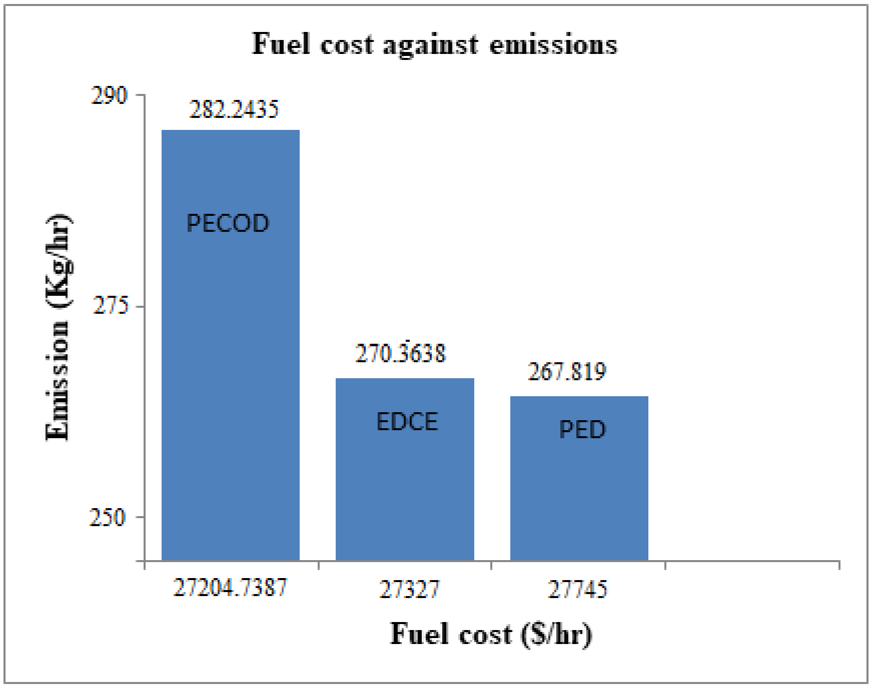


Figure 4.3: Relationship between Economic dispatch considering emission, pure economic dispatch and pure emission dispatch

The analysis done in Figure 4.3 was based at a load demand of 500MW. For the case of pure economic dispatch (PECOD), the fuel cost was found to be 27204.7387 $/hr while the amount of emissions under this condition was 282.2435 Kg/hr as it shown in Table 4.1. But for the case of pure emission dispatch, the amount of emissions was found to be 267.819 Kg/hr while the cost fuel at this condition was 27745 $/hr. Generally, as it can be seen from Figure 4.3 the economic dispatch is a biased optimization which focuses only on minimizing the cost of fuel without limiting the amount of emissions produced. The same case applies to the case of pure emission dispatch while the objective function reduces the amount of emissions without limiting the fuel cost. So, the pure economic dispatch and pure emission dispatch are two conflicting optimization approaches.

In order to harmonize pure economic dispatch and pure emission dispatch as the two conflicting optimization option, the economic dispatch considering emission was adopted so as to minimizing both fuel cost and the amount of emissions. Thus, emissions act as a constraint to economic dispatch since they limit the minimization of fuel cost while maintaining reasonable amount of emissions from the generation plants. Generally, the economic dispatch considering emission objective function is expressed in terms of total cost since the emissions are in terms of emission charges fees which is also an objective function. So, inconclusive this objective function focus on minimizing the total cost subjected to power plants while minimizing the amount of emissions. In Figure 4.3 the economic dispatch considering emissions can also be termed as emissions constrained economic dispatch produced emission of 270.3638 Kg/hr while maintaining the fuel cost of 27327 $/hr which is the harmonized dispatch.

Table 4.2 shows the numerical results of the economic dispatch considering emission at a load of 700MW and 900MW. The three algorithms which are MFO, Bat and MFO_BAT were compared at each loading as highlighted in Table 4.2. The comparison was based on the total cost and emission reduction which is the main objective of economic dispatch considering emission. The convergence curve of economic dispatch considering emission at a load of 900MW is shown in Figure 4.4 whereby the novel MFO_BAT outperformed both MFO and BAT algorithm.

Table 4.2: Economic dispatch considering emissions at a loads of 700MW and 900MW

Load of 700MW			
Generating unit	MFO	BAT	MFO-BAT
P1(MW)	90.7887	72.1289	94.0534
P2(MW)	63.8034	76.3761	65.6911
P3(MW)	83.6857	87.5312	82.2747
P4(MW)	108.2828	87.6265	109.4433
P5(MW)	207.0946	206.3405	203.0048
P6(MW)	181.3405	211.5895	179.8069
Total generation (MW)	734.9956	741.5927	734.2742
Losses (MW)	34.9956	41.5927	34.2742
Fuel cost ($/hr)	38748	38909	38816
Emission(kg/hr)	470.2457	487.2056	468.3389
Total cost ($/hr)	59808.9441	60729.3434	59791.6083
Load of 900MW			
Generating unit	MFO	BAT	MFO-BAT
P1(MW)	109.0661	101.2087	121.6072
P2(MW)	118.9609	131.0999	124.0219
P3(MW)	115.9007	116.6836	122.0751
P4(MW)	210.0000	161.3076	177.4886
P5(MW)	211.6964	221.9754	214.2792
P6(MW)	194.5566	240.5776	205.1379
Total generation (MW)	960.1808	972.8529	964.6098
Losses (MW)	60.1808	72.8529	54.6241
Fuel cost ($/hr)	50952	51398	5.1437
Emission(kg/hr)	766.5041	761.6848	745.7455
Total cost ($/hr)	87607.8942	87823.8286	87099.9792

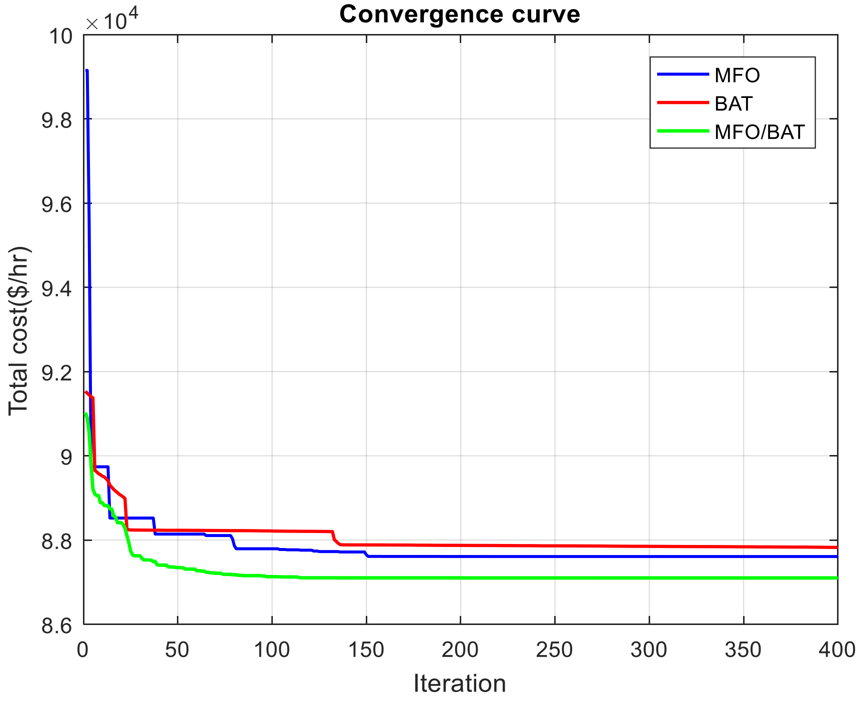


Figure 4.4: Convergence curve of economic dispatch considering emissions at a load of 900MW

4.3 Ten Units Test System with Valve-Point Effect

Table 4.3 presents the results of economic dispatch considering emission with valve-point effect at a load of 2000MW. The highlighted rows are presenting total cost and emissions optimized during the process. The MFO_BAT managed to reduce the total cost and emission much better as compared to MFO and Bat algorithms. Figure 4.5 shows the convergence curve of economic dispatch considering emission with valve-point effect of ten units system at a load of 2000MW whereby the total cost is optimized and the results were transformed in terms of economic dispatch and emission dispatch as shown in Table 4.3.

Table 4.3: Economic dispatch considering emissions with valve-point effect at a load of 2000MW

Generator	MFO	BAT	MFO_BAT
P1(MW)	55.0000	54.1105	55.0000
P2(MW)	79.8402	77.0934	79.2991
P3(MW)	83.9132	111.2782	80.7951
P4(MW)	82.8854	51.3847	82.5905
P5(MW)	159.4891	153.7636	160.0000
P6(MW)	239.8765	210.1091	239.9998
P7(MW)	288.2326	241.3386	288.6319
P8(MW)	302.9969	305.4816	300.4299
P9(MW)	393.5197	426.8086	399.7160
P10(MW)	395.8419	452.5424	395.2387
Emission NOx (Kg/hr)	3,934.9	4,128.6	3,933.2
Fuel cost ($/hr)	116,390	115,150	116,400
Losses (MW)	81.6	83.9	81.7
generation	2,081.6	2,083.9	2,081.7
Total cost ($/hr)	321160.6533	330000.7742	321079.5708

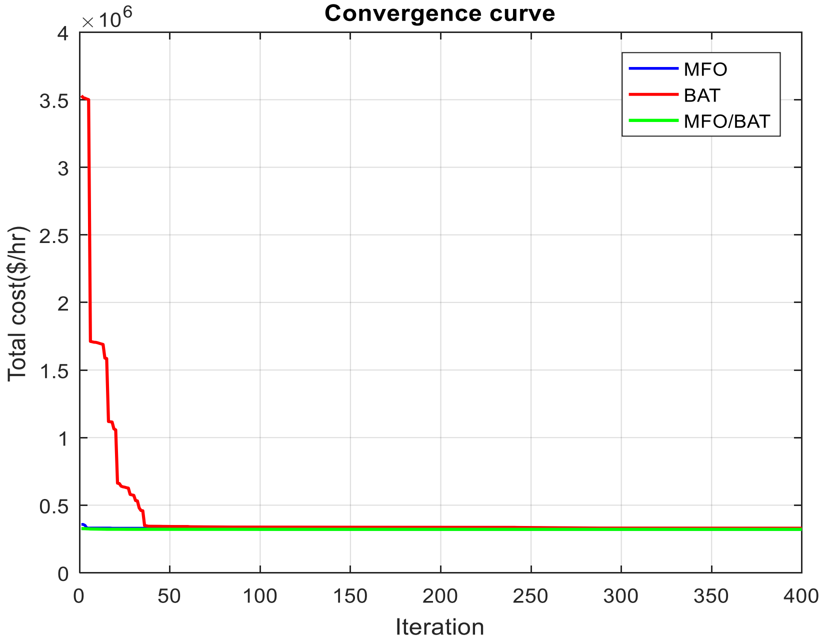


Figure 4.5: Convergence curve of Economic dispatch considering emission at a load of 2000MW

4.4 Economic Dispatch Considering CO_X, NO_X and SO_X Emissions

The developed MFO_BAT was subjected to a more complex system which consists of all the primary three emissions of thermal power plants which are CO_X, NO_X and SO_X Emissions. The system results of pure economic dispatch (best fuel cost), CO_X emissions dispatch, NO_X emissions dispatch and SO_X emissions dispatch at a load of 1800MW are presented under this subsection.

4.4.1 Best Fuel Cost Dispatch

The best fuel cost dispatch were obtained by optimizing the fuel cost objective function without limiting the emissions. Table 4.4 presents the results of the best fuel cost while the highlighted row shows the comparison between the MFO_BAT, MFO and Bat algorithms results during its application to the concerned objective function.

Table 4.4: Best fuel cost of economic dispatch considering CO_X, NO_X and SO_X Emissions at a load of 1800MW

Generator	MFO	BAT	MFO_BAT
P1(MW)	295.3884	282.8479	307.7454
P2(MW)	293.3423	253.5562	297.0914
P3(MW)	478.4156	483.1699	479.1967
P4(MW)	400.0000	371.4759	345.3214
P5(MW)	270.0000	315.3158	297.0159
P6(MW)	182.6413	214.7716	194.1445
Fuel cost ($/hr)	18657.5276	18669.6349	18647.7055
Losses (MW)	119.8	121.1	120.5
Total generation (MW)	1,919.8	1921.1	1,920.5

By using the numerical results in Table 4.4 and the convergence curve shown in Figure 4.6 it is clear that the novel MFO_BAT performed better during minimization of fuel cost at a load of 1800MW as compared to MFO and Bat algorithms.

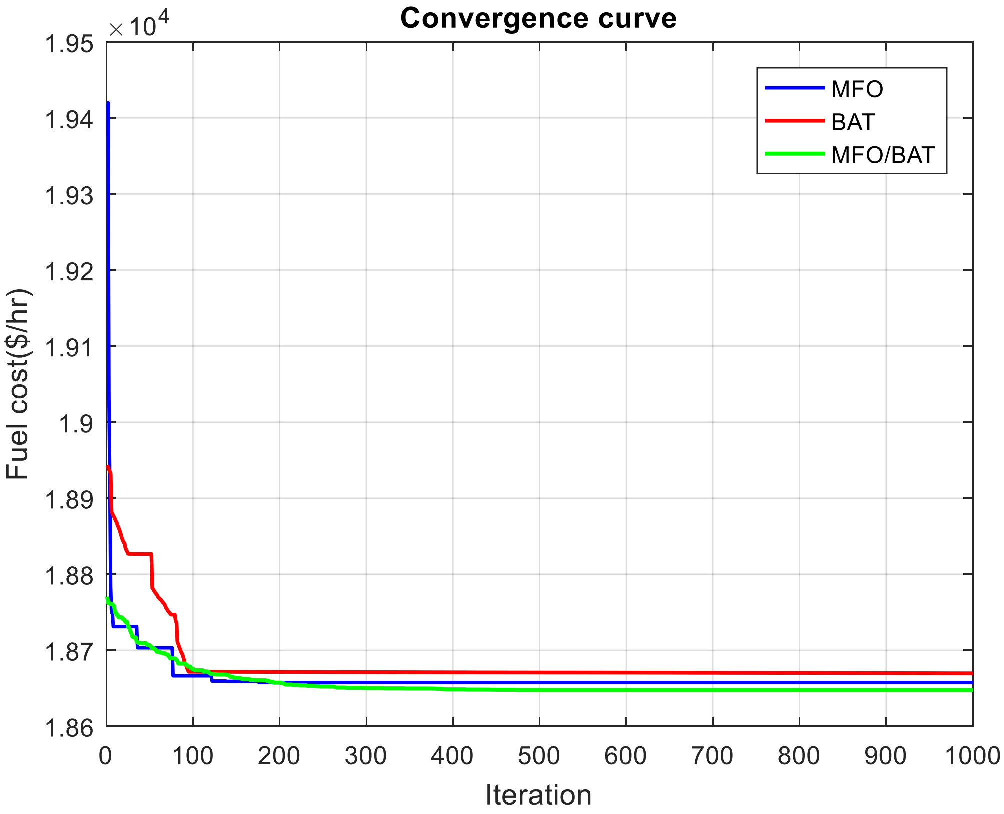


Figure 4.6: Convergence curve of best fuel cost dispatch

4.4.2 Best SO_X Emissions

The optimization of SO_X emissions was achieved through optimizing the SO_X emissions objective function without considering other objective function under this subsection. The results of MFO_BAT are compared to MFO and Bat algorithms results through numerical comparison as it shown in the highlighted row of Table 4.5 and the extracted convergence curves in Figure 4.7.

Table 4.5: Best SO_X emissions at a load of 1800MW

Generator	MFO	BAT	MFO-BAT
P1(MW)	400.0000	399.8542	400.0000
P2(MW)	313.5778	310.0339	338.9214
P3(MW)	600.0000	589.7342	571.8958
P4(MW)	5.0000	6.0567	7.8027
P5(MW)	318.7908	340.2570	365.8485
P6(MW)	300.0000	292.7241	258.7201
Emission SOx (Kg/hr)	11469.9116	11463.6047	11453.4133
Losses (MW)	137.4	138.7	143.2
Total generation(MW)	1,937.4	1,938.7	1,943.2

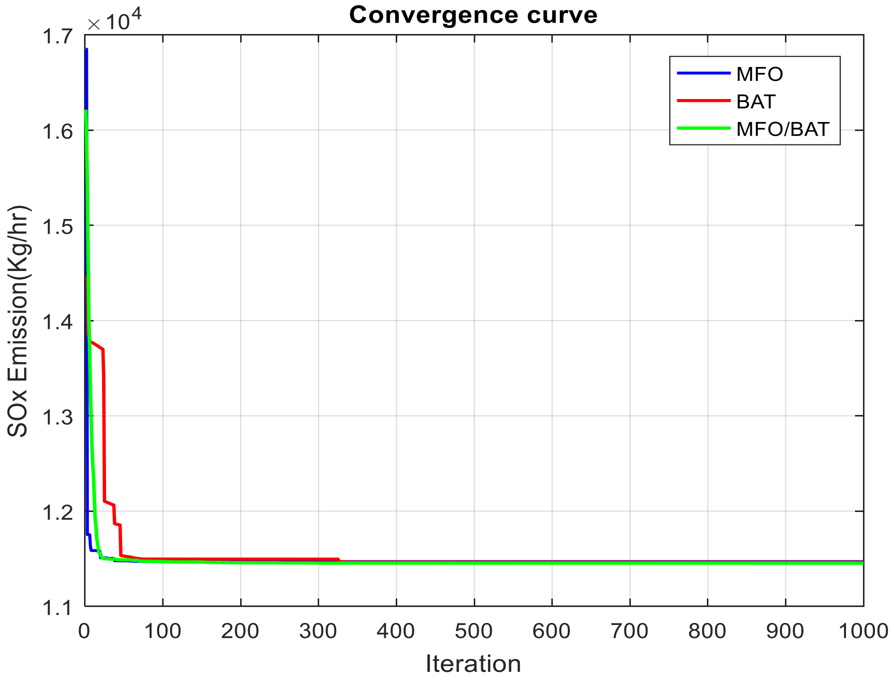


Figure 4.7: Convergence curve of SOX emissions at a load of 1800MW

4.4.3 Best CO_X Emissions

Table 4.6 shows the results of pure CO_X emissions dispatch at a load of 1800MW, the CO_X emissions emitted when MFO_BAT hybrid algorithm was employed was found to be lower as compared to when parents algorithms which are MFO and Bat was employed to perform the same optimization problem.

Table 4.6: Best CO_X emissions at a load of 1800MW

Generator	MFO	BAT	MFO-BAT
P1(MW)	258.8307	253.1283	254.7067
P2(MW)	328.7420	332.3967	331.2674
P3(MW)	395.1099	371.0849	389.6599
P4(MW)	384.2657	396.0251	381.3586
P5(MW)	328.9386	352.1989	342.1442
P6(MW)	236.5545	231.7963	235.1296
Emission CO_X (Kg/hr)	57651.1803	57698.3857	57613.8019
Losses (MW)	134.3	136.6	134.3
Total generation (MW)	1,934.3	1,936.6	1,934.3

The numerical results are compared as shown in the highlighted row in Table 4.6 with the help of the convergence curves in Figure 4.8.

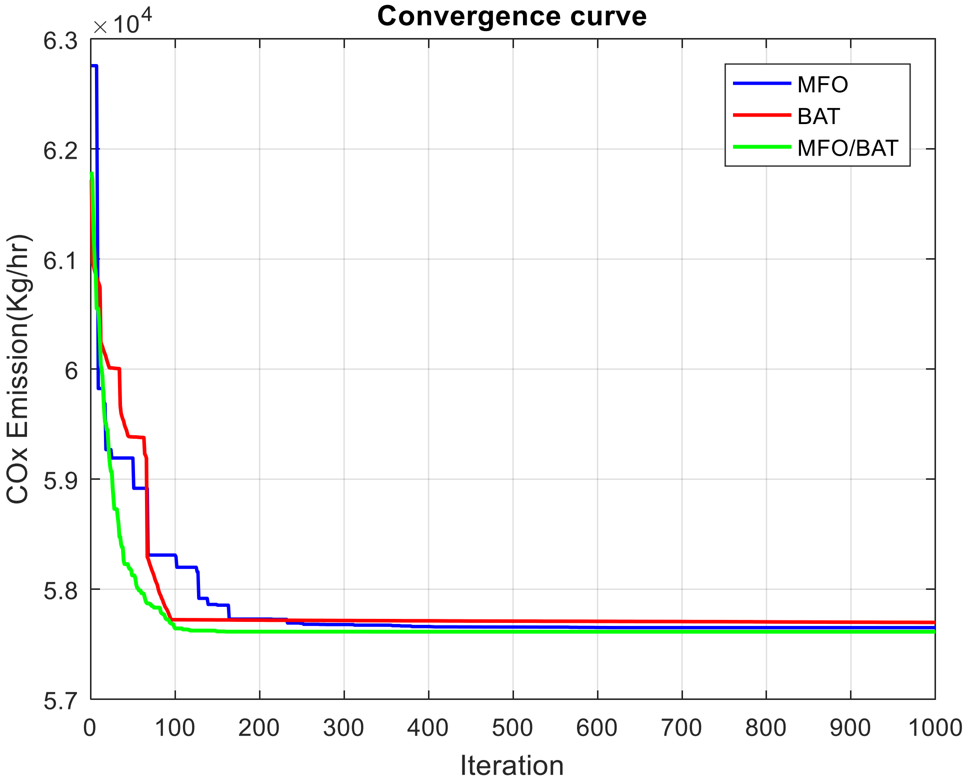


Figure 4.8: Convergence curve of COX emissions at a load of 1800MW

4.4.4 Best NO_X Emissions

As is shown in Table 4.7 and in the convergence curve in Figure 4.9, the results of NO_X emissions dispatch was better when using MFO_BAT as compared to the parent algorithms. This is because the MFO_BAT produced the lower NO_X emissions expressed in Kg/hr than the NO_X emissions which was produced by MFO and Bat algorithms.

Table 4.7: Best NO_X emissions at a load of 1800MW

Generator	MFO	BAT	MFO-BAT
P1(MW)	150.0000	196.4946	199.0379
P2(MW)	200.0000	236.5561	214.0103
P3(MW)	551.9263	514.5112	534.8926
P4(MW)	338.0887	306.6367	328.8702
P5(MW)	500.0000	497.0690	476.5445
P6(MW)	211.7148	196.9023	190.1732
Emission NOx (Kg/hr)	2086.8135	2071.8244	2062.1371
Losses (MW)	151.7	148.2	143.5
Total generation	1,951.7	1,948.2	1,943.5

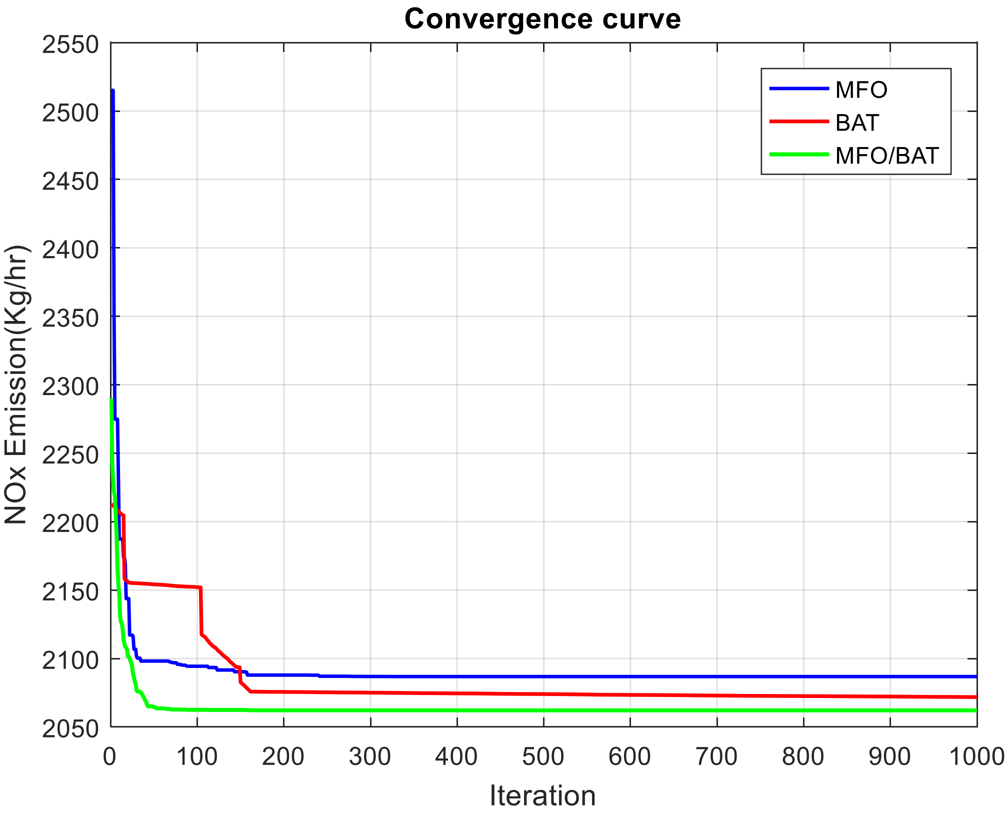


Figure 4.9: Convergence curve of NOX emissions at a load of 1800MW

4.4.5 Best Compromise Solution of Economic Dispatch Considering CO_X, NO_X and SO_X Emissions at a Load of 1800MW

The best compromise solution was obtained by optimizing the multi-objective function which was converted into a single objective function by using the price penalty factor. The objective function expressed in total cost ($/hr) involves fuel cost objective function and emissions charges of CO_X, NO_X and SO_X emissions. The MFO_BAT performed far better in terms of reduction of total cost of generation as compared to MFO and Bat algorithms as it shown in Table 4.8 and Figure 4.10.

Table 4.8: Best compromise solution of economic dispatch considering CO_X, NO_X and SO_X emissions at a load of 1800MW

Generator	MFO	BAT	MFO-BAT
P1 (MW)	249.7788	279.6535	270.3457
P2 (MW)	293.0410	307.2588	300.0209
P3 (MW)	600.0000	546.4570	539.3338
P4 (MW)	133.7144	144.5592	140.1550
P5 (MW)	439.3485	444.3207	451.0824
P6 (MW)	228.6593	221.4659	244.3550
Total cost ($/hr)	81312.0483	81062.7071	**80923.6289**
Emission NOx (Kg/hr)	2417.6	2412.6	2415.3
Emission SOx (Kg/hr)	13327	13629	13506
Emission COx (Kg/hr)	71378	68700	68767
Fuel cost($/hr)	18959	18907	18932
Losses (MW)	144.5	143.7	145.3
Total generation(MW)	1944.5	1943.7	1945.3

It was also found that the MFO_BAT was better in terms of CO_X emissions reduction but it produced NOx emissions higher than Bat algorithm and SOx emission higher than MFO

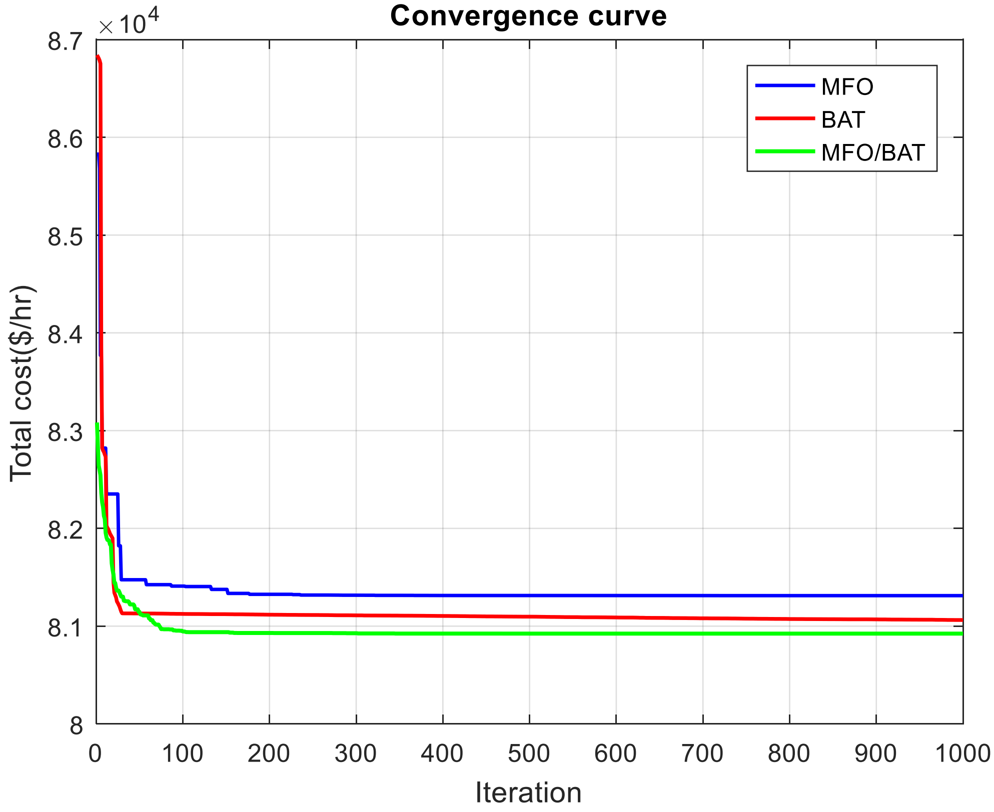


Figure 4.10: Convergence curve of best compromise solution of economic dispatch considering COX, NOX and SOX emissions at a load of 1800MW

4.5 Performance Evaluation of MFO_BAT Algorithm in Economic Dispatch Considering Emissions

Performance evaluation of the developed Moth Flame Optimization and BAT hybrid algorithm was done by comparing its results with other algorithms results reported in the literature which were applied to the same study and systems. The algorithms which were used for comparison were Biogeography-Based Optimization, hybrid Artificial Bee

Colony and Simulated Annealing Algorithm, Genetic Algorithm, Water Wave Optimization Algorithm, Differential Evolution and Biogeography-Based Optimization hybrid algorithm and Augmented Lagrange Hopfield Network.

4.5.1 Results Validation of IEEE-30 Bus Test System

Table 4.9: Results validation of best compromising solution at a load of 500MW

Generating unit	BB0 [50]	GA [45]	ALHN [51]	MFO_BAT
P1(MW)	55.9211	55.3071	-	13.8352
P2(MW)	38.1085	40.1529	-	10.0000
P3(MW)	65.3674	66.5698	-	95.8799
P4(MW)	82.1178	80.2377	-	96.6216
P5(MW)	147.8045	147.4310	-	152.2672
P6(MW)	133.2502	132.9505	-	137.2685
Total generation(MW)	522.5695	522.6490	-	505.8726
Fuel cost ($/hr)	28,456.294513	28475	28423.7037	27327
Emission(kg/hr)	277.728491	277.4178	280.3083	270.3638
Total cost ($/hr)	40,648.100843	-	41,206.8448	40256

Table 4.9 shows the evaluation of MFO_BAT algorithm at a load of 500MW, the total cost of MFO_BAT was 392.10084$/hr and 950.8448$/hr lower than BBO and ALH total cost respectively while fuel cost of MFO_BAT was 1,129.29$/hr, 1,148$/hr and 1,096.7037$/hr lower that BBO, GA and ALH respectively. MFO_BAT emissions were 7.364691 Kg/hr, 7.054 Kg/hr and 9.9445 Kg/hr lower than BBO, GA and ALH respectively.

The evaluation of MFO_BAT at a load of 700MW is presented at table 4.10. The MFO_BAT hybrid total cost was 378.41687$/hr and 1105.9685$/hr lower than BBO and ALH respectively which is very promising. The cost of fuel for MFO_BAT was 184.15002$/hr, 0.1969$/hr, 96$/hr lower than BBO, ALH and WWOA respectively. Better performance was demonstrated by hybrid MFO_BAT in terms of emissions having emissions of 4.329651Kg/hr, 11.5486Kg/hr and 7.2864Kg/hr lower than BBO, ALH and WWOA respectively. The MFO_BAT losses were 4.155483MW and 3.8883MW lower than BBO and WWOA respectively.

Table 4.10: Results validation of best compromising solution at a load of 700MW

Generating unit	BB0 [50]	ALHN [51]	WWOA [47]	MFO_BAT
P1(MW)	93.069693	-	91.2235	94.0534
P2(MW)	66.729002	-	64.7522	65.6911
P3(MW)	83.337800	-	84.5232	82.2747
P4(MW)	110.702668	-	103.2023	109.4433
P5(MW)	205.799186	-	211.4939	203.0048
P6(MW)	178.791334	-	182.9675	179.8069
Total generation (MW)	738.429683	-	738.1625	734.2742
Losses (MW)	38.429683	-	38.1625	34.2742
Fuel cost ($/hr)	39,000.150029	38816.1969	38912	38816
Emission (kg/hr)	472.668551	479.8875	475.6253	468.3389
Total cost ($/hr)	60,170.025173	60,897.5768	-	59791.6083

Table 4.11: Results validation of best compromising solution at a load of 900MW

Generating unit	DE _BBO [46]	BB0 [50]	ALHN [51]	MFO_BAT
P1(MW)	125.00000	124.9838	-	121.6072
P2(MW)	96.032034	95.4689	-	124.0219
P3(MW)	100.422108	99.8332	-	122.0751
P4(MW)	141.523563	141.3275	-	177.4886
P5(MW)	270.654667	271.4903	-	214.2792
P6(MW)	227.701173	227.9015	-	205.1379
Total output (MW)	961.333546	961.0052	-	964.6098
Losses (MW)	61.333546	61.0052	-	54.6241
Fuel cost ($/hr)	50,622.181947	50,596.185723	50340.0820	51437
Emission(kg/hr)	766.249785	766.814796	776.2410	745.7455
Total cost ($/hr)	87,265.96307067	87,266.986933	87,461.63	87099.9792

Table 4.11 shows the results validation at a load of 900MW. Compared to other algorithms, the total cost produced by MFO_BAT was 165.9838$/hr, 167.007$/hr, and 361.65/hr lower than DE_BBO, BBO and ALH respectively. Emitted emissions when using MFO_BAT were 20.504 Kg/hr, 21.069 Kg/hr and 30.4955Kg/hr lower than DE_BBO, BBO and ALH respectively while the recorded losses of MFO_BAT were 6.709446MW, 6.3811MW lower than DE_BBO and BBO respectively.

4.5.2 Validation of Results of Ten Units Test System with Valve-Point Effect

As it shown in Table 4.12 with consideration of the valve point effect using the ten units test system, the total cost found when using MFO_BAT was 9,130.4292 $/hr lower than ABC_SA while the fuel cost of MFO_BAT was 2,890 $/hr higher than ABC_SA. The emission produced by the system when MFO_BAT was used it was 235.8 Kg/hr lower than that found when using ABC_SA. For the case of system losses, the losses accounted by MFO_BAT were 2.75MW lower than that of ABC_SA.

Table 4.12: Results validation of Ten Units Test System with valve Point Effect at a load demand of 2000MW

Generating unit	ABC_SA [49]	MFO_BAT
P1(MW)	55.00	55.0000
P2(MW)	70.32	79.2991
P3(MW)	81.18	80.7951
P4(MW)	96.47	82.5905
P5(MW)	159.72	160.0000
P6(MW)	155.92	239.9998
P7(MW)	229.31	288.6319
P8(MW)	337.57	300.4299
P9(MW)	431.34	399.7160
P10(MW)	467.57	395.2387
Total generation (MW)	2,084.45	2,081.7
Losses (MW)	84.45	81.7
Fuel cost ($/hr)	113510	116,400
Emission(kg/hr)	4169	3,933.2
Total cost ($/hr)	330210	321079.5708

4.5.3 Validation of Results of Economic Dispatch considering CO_X, NO_X and SO_X Emissions

Table 4.13: Results validation of economic dispatch considering CO_X, NO_X and SO_X emissions at a load demand of 1800MW

Generator	BBO [50]	MFO_BAT
P1 (MW)	270.398419	270.3457
P2(MW)	299.351832	300.0209
P3(MW)	538.382133	539.3338
P4(MW)	139.632475	140.1550
P5(MW)	452.562062	451.0824
P6(MW)	245.197113	244.3550
Total cost ($/hr)	80,924.967912	80923.6289
Emission NOx (Kg/hr)	2416.130219	2415.3
Emission SOx (Kg/hr)	13,491.924811	13506
Emission COx (Kg/hr)	68,817.333954	68,767
Fuel cost($/hr)	18,934.704952	18932
Losses (MW)	145.524034	145.3
Total generation (MW)	1945.524034	1945.3

Table 4.13 shows the evaluation of the performance of MFO_BAT when it was subjected to a system which consists of all primary emissions from the thermal power plants which are CO_X, NO_X and SO_X emissions. In terms of the total cost, the MFO_BAT cost was 1.33 $/hr lower than that of BBO and the fuel cost of MFO_BAT was 2.7 $/hr lower than BBO fuel cost. MFO_BAT emissions were 0.83 Kg/hr of NO_X and 50.33 Kg/hr of CO_X lower than emission produced by BBO but it was 14.07 Kg/hr of SO_X higher than that produced by BBO. For the case of losses, the losses of the system when using MFO_BAT were 0.224034MW lower than that recorded from BBO.

4.6 Cost and Emission Analysis

The cost and benefit analysis was done so as show how much cost will be saved in one day (24 hours) when using the MFO_BAT algorithm with reference to other algorithms. The same way for the case of emissions emitted by power plants, it shows the amount of emissions reduced in one day (24 hours) when using MFO_BAT as compared to other methods (algorithms).

The cost saved was calculated by using equation (4.1)

$$\textit{Cost Reduction per 24 hours} = \left(A - B\right)\times 24 \tag{4.1}$$

Where

A = Respetive cost of another algorithm

B=Cost from MFO_BAT algorithm

The emission reduction was computed by using equation (4.2)

$$\textit{Emissions reduction per 24 hours} = \left(C - D\right)\times 24 \tag{4.2}$$

Where

C=Respetive emissions of another algorithm

D=Emissions from MFO_BAT algorithm

Table 4.14 shows the cost and emission benefit analysis whereby the algorithms which were used in this analysis are Differential Evolution and Biogeography-Based Optimization hybrid algorithm (DE_BBO) and Augmented Lagrange Hopfield Network (ALHN).

Table 4.14: Cost and emission benefit analysis

Algorithm	Total cost saving ($)		Emission reduction (Kg)	
	Per hour	Per day	Per hour	Per day
DE_BBO (Load of 900MW) IEEE-30 Bus	165.9838	3,983.6	20.504	492.096
ALHN (Load of 900MW) IEEE-30 Bus	361.65	8,679.6	30.4955	731.892

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this research a new method for solving economic dispatch considering emissions termed Moth Flame Optimization and Bat hybrid algorithm was developed from two algorithms which are Moth Flame Optimization and Bat algorithms. The development of Moth Flame optimization and Bat hybrid algorithm was achieved through combining a strong character of Moth Flame Optimization which is exploration and a strong character of Bat algorithm which is exploitation.

The developed algorithm was used to optimize three categories of objective functions which include pure economic dispatch, pure emission dispatch and economic dispatch considering emissions objective functions. The multi-objective economic dispatch considering emission was converted into a single objective by using the price penalty factor which was determined at each specific load. The IEEE-30 bus test system was employed for implementing the study, for making the study more realistic the ten units test system with valve-point effect and six unit system with all three primary emissions from thermal power plant of CO_X, NO_X and SO_X were used.

Using IEEE-30 bus test system MFO_BAT was implemented at loads of 500MW, 700MW and 900MW. The results of this method were compared to other results reported in the literature which were obtained using the same test system.

At a load of 500MW, the MFO_BAT results were compared with the results of BBO, GA and ALHN algorithms and found to be better.

At a load of 700MW, the results of MFO_BAT were compared with the results of BBO, ALH and WWOA while at the load of 900MW the MFO_BAT results were compared with DE_BBO, BBO and ALHN. In all cases, the MFO_BAT demonstrated the highest capability of optimizing the generation cost and emissions.

For the case of ten units test system the results of MFO_BAT were compared with the results of ABC_SA at a load of 2000MW and for the case of six units system with CO_X, NO_X and SO_X emissions the results of MFO_BAT were compared with BBO at a load of 1800MW. It was found that MFO_BAT results were better as compare to ABC_SA and BBO.

In general, the developed method was tested at different loading and system condition such as valve point effect and CO_X, NO_X and SO_X emissions considerations. The MFO_BAT was more efficient and its performance was better as compared to other results reported in the literature.

5.2 Contributions

This study has contributed to the development of the novel Moth Flame Optimization and Bat hybrid algorithm method for solving economic dispatch considering emissions. Furthermore, using different test systems the developed method was applied for solving the economic dispatch considering emissions aiming at reduction of generation cost and thermal power plants pollutants emissions. With the comparison to other results reported in the literature, there was a significant reduction of generation cost and emissions when the Moth Flame Optimization and Bat hybrid algorithm was applied for solving the optimization problem of this study.

5.3 Recommendations

Though the development of Moth Flame Optimization and Bat hybrid algorithm was achieved in this study as well as its implementation in economic dispatch considering emissions, further investigation can be also conducted as follow:

- Application of MFO_BAT algorithm for solving multi-objective optimization problem having a larger number of different kind of objective functions is one of the potential future work.
- The MFO_BAT hybrid algorithm can be applied in more complex larger systems having different types of power plants (Thermal, hydro, wind, solar i.e.) for checking its effectiveness.
- The developed MFO_BAT algorithm can be applied to a real power system for realizing its benefit and contribution to quality life.

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APPENDICES

Appendix A: MATLAB Program Codes for Economic Dispatch Considering Emissions

```
% Done by WILBERT RUTA

% Department of Electrical Engineering (Power Systems Option)

%  Pan African University Institute for Basic Sciences, Technology and
Innovation

% IEEE-30 BUS OBJECTIVE FUNCTIONS

function O=Objective (P)

Pd=900 ;%('Enter the value of load demand in MW = ');

a=  [0.15247  0.10587  0.02803  0.03546  0.02111  0.01799]; %Fuel  cost
coefficients

b= [38.53973 46.15916 40.39655 38.30553 36.32782 38.27041]; %Fuel cost
coefficients

c= [756.79886 451.32513 1049.32513 1243.5311 1658.5696 1356.27041]; %Fuel
cost coefficients

g= [0.00419 0.00419 0.00683 0.00683 0.00461 0.00461]; %% Nitrogen oxides
coefficients

h=  [0.32767  0.32767  -0.54551  -0.54551  -0.51116  -0.51116];  %%  Nitrogen
oxides coefficients

l = [13.85932 13.85932 40.2669 40.2669 42.89553 42.89553]; %% Nitrogen

oxides coefficients

% B-losses coefficient matrix for IEEE-30 bus system at a load of 700MW

   Bi= [0.002022 -0.000286 -0.000534 -0.000565 -0.000454 -0.000103

       -0.000286 0.003243 0.000016 -0.000307 -0.000422 -0.000147

       -0.000534 0.000016 0.002085 0.000831 0.000023 -0.000270

       -0.000565 -0.000307 0.000831 0.001129 0.000113 -0.000295
```

```
       -0.000454 -0.000422 0.000023 0.000113 0.000460 -0.000153

       -0.000103 -0.000147 -0.000270 -0.000295 -0.000153 0.000898];

v= [P(1) P(2) P(3) P(4) P(5) P(6)];

 P_loss=v* Bi*v’; % Power losses computation

for i=1:6

%z=(z+P(i)^2*a(i)+P(i)*b(i)+c(i));%%Fuel cost objective function

%z=(z+(P(i)^2*g(i)+P(i)*h(i)+l(i)));%%   Nitrogen   oxides   emissions
objective function

z=z+ (P(i)^2*a(i)+P(i)*b(i)+c(i))+47.8222*(P(i)^2*g(i)+P(i)*h(i)+l(i));
%% Total cost objective function

end

PowerBalanceViolation=max(1-((P(1)+P(2)+P(3)+P(4)+P(5)+P(6)...

P_loss))/Pd,0);%% Check the equality constraints

    q=100;

    O=z*(1+q*PowerBalanceViolation);

end

%%TEN UNIT SYSTEM WITH VALVE POINT OBJECTIVE FUNCTIONS

function O=Objective (P)

Pd=2000 ;%('Enter the value of load demand in MW = ');

a= [0.12951 0.10908 0.12511 0.12111 0.15247 0.10587 0.03546 0.02803...

    0.02111 0.01799]; %% Fuel cost coefficients

b= [40.5407 39.5804 36.5104 39.5104 38.539 46.1592 38.3055 40.3965...

    36.3278 38.2704]; %% Fuel cost coefficients

c= [1000.403 950.606 900.705 800.705 756.799 451.325 1243.531 1049.998...

    1658.569 1356.659]; %% Fuel cost coefficients

e=[33  25  32   30  30  20  20  30  60  40 ];%% Fuel cost valve point
effect coefficients

f= [0.0174 0.0178 0.0162 0.0168 0.0148 0.0163 0.0152 0.0128...
```

```
    0.0136 0.0141]; %% Fuel cost valve point effect coefficients
A= [0.04702 0.04652 0.04652 0.04652 0.0042 0.0042 0.0068 0.0068 ...
    0.0046 0.0046]; %%Nitrogen oxides coefficients
B= [-3.9864 -3.9524 -3.9023 -3.9023 0.3277 0.3277 -0.5455 -0.5455 ...
    -0.5112 -0.5112]; %% Nitrogen oxides coefficients
C= [360.0012 350.0056 330.0056 330.0056 13.8593 13.8593 40.2669...
    40.2669 42.8955 42.8955]; %% Nitrogen oxides coefficients
E= [0.25475 0.25475 0.25163 0.25163 0.2497 0.2497 0.248 0.2499 ...
    0.2547 0.2547]; %% Nitrogen oxides valve point coefficients
F= [0.01234 0.01234 0.01215 0.01215 0.012 0.012 0.0129 0.01203...
    0.01234 0.01234]; %% Nitrogen oxides valve point coefficients
% B-losses coefficient matrix for ten unit system with valve point effect
   Bi= 10^-4*[0.49 0.14 0.15 0.15 0.16 0.17 0.17 0.18 0.19 0.20
        0.14 0.45 0.16 0.16 0.17 0.15 0.15 0.16 0.18 0.18
        0.15 0.16 0.39 0.1 0.12 0.14 0.14 0.16 0.16 0.16
        0.15 0.16 0.1 0.4 0.14 0.1 0.11 0.12 0.14 0.15
        0.16 0.17 0.12 0.14 0.35 0.11 0.13 0.13 0.15 0.16
        0.17 0.15 0.12 0.1 0.11 0.36 0.12 0.12 0.14 0.15
        0.17 0.15 0.14 0.11 0.13 0.12 0.38 0.16 0.16 0.18
        0.18 0.16 0.14 0.12 0.13 0.12 0.16 0.4 0.15 0.16
        0.19 0.18 0.16 0.14 0.15 0.14 0.16 0.15 0.42 0.19
        0.20 0.18 0.16 0.15 0.16 0.15 0.18 0.16 0.19 0.44];
v=[P(1) P(2) P(3) P(4) P(5) P(6) P(7) P(8) P(9) P(10) ];
 Pmin = [10 20 47 20 50 70 60 70 135 150];
 P_loss= v* Bi*v';
```

```
for i=1:10
%z=(z+P(i)^2*a(i)+P(i)*b(i)+c(i)+abs(e(i)*sin(f(i)*(Pmin(i)P(i)))));%%
 Fuel cost objective function
%z=(z+P(i)^2*A(i)+P(i)*B(i)+C(i)+E(i)*exp(F(i)*P(i)));%%Nitrogen
oxides emissions objective function
z=z+(P(i)^2*a(i)+P(i)*b(i)+c(i)+abs(e(i)*sin(f(i)*(Pmin(i)-P(i)))))...
+52.0394*(P(i)^2*A(i)+P(i)*B(i)+C(i)+E(i)*exp(F(i)*P(i))); %% Total
cost objective function
end
PowerBalanceViolation=max(1-((P(1)+P(2)+P(3)+P(4)+P(5)+P(6)+P(7)...
    +P(8)+P(9)+P(10)-P_loss))/Pd,0); %% Check the equality constraints
    q=100;
    O=z*(1+q*PowerBalanceViolation);
end
% SIX UNIT SYSTEM WITH NOx,COx AND SOx EMISSIONS OBJECTIVE FUNCTIONS
function O=Objective (P)
Pd=1800 ;%('Enter the value of load demand in MW = ')
a= [0.002035 0.003866 0.002182 0.001345 0.002182 0.005963]; %% Fuel cost
coefficients
b=  [8.43205  6.41031  7.42890  8.30154  7.42890  6.91559];  %%Fuel  cost
coefficients
c= [85.6348 303.7780 847.1484 274.2241 847.1484 202.0258]; %% Fuel cost
coefficients
g= [0.006323 0.006483 0.003174 0.006732 0.003174 0.006181]; %% Nitrogen
oxides coefficients
h= [-0.38128 -0.79027 -1.36061 -2.39928 -1.36061 -0.39077]; %% Nitrogen
oxides coefficients
```

```
l = [80.9019 28.8249 324.1775 610.2535 324.1775 50.3808]; %% Nitrogen oxides coefficients

A= [0.001206 0.002320 0.001284 0.110813 0.001284 0.003578]; %% Sulphur oxides coefficients

B= [5.05928 3.84624 4.45647 4.97641 4.45647 4.14938]; %% Sulphur oxides coefficients

C= [51.3778 182.2605 508.5207 165.3433 508.5207 121.2133]; %% Sulphur oxides coefficients

G= [0.265110 0.140053 0.105929 0.106409 0.105929 0.403144]; %% Carbon oxides coefficients

H= [-61.01945 -29.95221 -9.552794 -12.73642 -9.552794 -121.9812]; %% Carbon oxides coefficients

L = [5080.148 3824.770 1342.851 1819.625 1342.851 11381.070]; %% Carbon oxides coefficients

% B-losses coefficient matrix for six unit system

   Bi=10^-4*[1.102 0.1 0.15 0.05 0 -0.3

       0.1    3.0 -0.2 0.01 0.12   0.1

       0.15   -0.2 1.0 -0.1   0.1   0.08

       0.05   0.01 -0.1 1.5   0.06 0.5

       0      0.12   0.1 0.06 2.5   0.2

       -0.3    0.1   0.08 0.5 0.2   2.1];

v= [P(1) P(2) P(3) P(4) P(5) P(6)];

 P_loss = v* Bi*v’;

for i=1:6

%z=(z+P(i)^2*a(i)+P(i)*b(i)+c(i));%% Fuel cost objective function

%z=(z+P(i)^2*A(i)+P(i)*B(i)+C(i));%% Sulphur oxides emissions objective function

%z=(z+(P(i)^2*g(i)+P(i)*h(i)+l(i)));%%Nitrogen oxides emissions objective function

%z=(z+(P(i)^2*G(i)+P(i)*H(i)+L(i)));%%Carbon oxides emissions objective function
```

```
 z=z+(P(i)^2*a(i)+P(i)*b(i)+c(i))+9.3627*(P(i)^2*g(i)+P(i)*h(i) ...

+l(i))+1.6702*(P(i)^2*A(i)+P(i)*B(i)+C(i))+0.2446*(P(i)^2*G(i)+ ...

P(i)*H(i)+L(i)); %% Total cost objective function

end

PowerBalanceViolation=max(1-((P(1)+P(2)+P(3)+P(4)+P(5)+P(6)-
P_loss))/Pd,0); %% Check the equality constraints

    q=100;

    O=z*(1+q*PowerBalanceViolation);

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;

clear;

close all;

%% MAIN CODE FOR IEEE-30 BUS TEST SYSTEM

CostFunction=@(P) Objective(P); % Objective function

j=6; %Number of generating units( for ten units system j=10)

VarMin=[ 10 10 40 35 130 125 ];% Generators upper limits

VarMax =[ 125 150 250 210 325 315];% Generators lower limits

% For ten units system

%VarMin=[ 10 20 47 20 50 70 60 70 135 150 ];

%VarMax =[ 55 80 120 130 160 240 300 340 470 470];

% For six unit system with NOx,COx and SOx emissions

%VarMin=[ 150 200 350 5 270 170 ];

%VarMax =[ 400 400 600 400 500 300];

% B-losses coefficient matrix for IEEE-30 bus system at 700MW

 Bi=[0.002022 -0.000286 -0.000534 -0.000565 -0.000454 -0.000103
```

```
        -0.000286 0.003243 0.000016 -0.000307 -0.000422 -0.000147

        -0.000534 0.000016 0.002085 0.000831 0.000023 -0.000270

        -0.000565 -0.000307 0.000831 0.001129 0.000113 -0.000295

        -0.000454 -0.000422 0.000023 0.000113 0.000460 -0.000153

        -0.000103 -0.000147 -0.000270 -0.000295 -0.000153 0.000898];

% OPTIMIZING BY USING MOTH FLAME OPTIMIZATION ALGORITHM

%% Parameter of Moth Flame Optimization

MaxIt= 400; % Maximum iteration

N=40; % Maximum number of flames

%% Initialization of Moth positions

   for i=1:Searching_Agent

   Moth_Position(i,:)=rand*ones(1,j).*(VarMax-VarMin)+VarMin;

   end

 BestCosts=zeros(MaxIt,1);

 It=1;

 %% Main Loop of Moth Flame Optimization Algorithm

 while It<MaxIt+1

    % Flame number updating

     Flame_no= round(N-It*((N-1)/(MaxIt)));

    for i=1:size(Moth_Position,1)

    % Check the inequality constraints

      Flag4VarMax=Moth_Position(i,:)>VarMax;

      Flag4VarMin=Moth_Position(i,:)<VarMin;

  Moth_Position(i,:)=(Moth_Position(i,:).*...

(~(Flag4VarMax+Flag4VarMin)))+VarMax.*Flag4VarMax+VarMin.*Flag4VarMin;

     % Calculate the objective function fitness
```

```
    A(i,:)= CostFunction(Moth_Position(i,:));

    Moth_fitness=sum(A,2);

end

 if It==1

   % sorting of first population of Moth

   [fitness_sorted I]=sort( Moth_fitness);

   sorted_population=Moth_Position(I,:);

   %update the flames

   best_flames=sorted_population;

   best_flame_fitness=fitness_sorted;

 else

     double_population= [previous_population;best_flames];

     double_fitness=[previous_fitness; best_flame_fitness];

     [double_fitness_sorted I]=sort(double_fitness);

     double_sorted_population= double_population(I,:);

     fitness_sorted=double_fitness_sorted(1:N);

     sorted_population=double_sorted_population(1:N,:);

     % Update the flames

     best_flames=sorted_population;

     best_flame_fitness=fitness_sorted;

 end

 % Update the position best flame obtained sor far

 Best_flame_score=fitness_sorted(1);

 Best_flame_position=sorted_population(1,:);

 previous_population=Moth_Position;

 previous_fitness=Moth_fitness;
```

```
% compute a
a=(-1+It)*((-1)/MaxIt);
for i=1:size(Moth_Position,1)
    for j=1:size(Moth_Position,2)
 if i<=Flame_no
% Update the position of moth with respect to its corresponding flame
    distance_to_flame= abs(sorted_population(i,j)-Moth_Position(i,j));
    b=1;
    t=(a-1)*rand+1;
    Moth_Position(i,j)=distance_to_flame*exp(b.*t).*cos(t.*2*pi)...
+sorted_population(i,j);
 end
if i>Flame_no
% Update the position of the moth with respect to one flame
     distance_to_flame=abs(sorted_population(i,j)-Moth_Position(i,j));
      b=1;
      t=(a-1)*rand+1;
Moth_Position(i,j)=distance_to_flame*exp(b.*t).*cos(t.*2*pi)...
+sorted_population(Flame_no,j);
        end
    end
end
BestCosts(It)=Best_flame_score;
display(['Iteration=',num2str(It),'BestCost=',num2str(Best_flame_score.
..)]);%% Display the results
It=It+1;
```

```
P_loss=( Best_flame_position* Bi*(Best_flame_position)');% compute the
losses

 end

 Total_generation=sum(Best_flame_position)

 % Check the equality constraint satisfaction

 constraint_check4= Total_generation-P_loss

 %Displya the power output of each generation unit

 Generator_output4= Best_flame_position

% plot the results of MFO

figure;

plot(BestCosts,'-b','LineWidth',1.3 );

title('Convergence curve')

xlabel('Iteration');

ylabel('Fuel cost($/hr)');

grid on

hold on


%%BAT ALGORITH OPTIMIZATION

%%%% Definition of the problem

CostFunction= @(P) Objective(P);% Objective function

d=6; % Number of generating units( d=10 for ten unit system)

Ub =[ 125 150 250 210 325 315];% Upper limits of generating units

% For ten units system

%Lb=[ 10 20 47 20 50 70 60 70 135 150 ];

%Ub =[ 55 80 120 130 160 240 300 340 470 470];

% For six unit system with NOx,COx and SOx emissions
```

```
%Lb=[ 150 200 350 5 270 170];

%Ub =[ 400 400 600 400 500 300];

% B-losses coefficient matrix for IEEE-30 bus system AT 700mMW

 Bi=[0.002022 -0.000286 -0.000534 -0.000565 -0.000454 -0.000103

      -0.000286 0.003243 0.000016 -0.000307 -0.000422 -0.000147

      -0.000534 0.000016 0.002085 0.000831 0.000023 -0.000270

      -0.000565 -0.000307 0.000831 0.001129 0.000113 -0.000295

      -0.000454 -0.000422 0.000023 0.000113 0.000460 -0.000153

      -0.000103 -0.000147 -0.000270 -0.000295 -0.000153 0.000898];

%% Parameter of Bat Algorithm

n=40;       % Population size

MaxIt=400;  % Maximum number of iteration

A=0.8;      % Loudness

% Frequency range

Qmin=-0.333;         % Frequency minimum

Qmax=0.333;         % Frequency maximum

%% Initializing of frequency and velocity

Q=zeros(n,1);   % Frequency

v=zeros(n,d);   % Velocities

% Initialize the positions and computation of fitness

for i=1:n,

  Sol(i,:)=Lb+(Ub-Lb).*rand(1,d);

  Fitness(i)=CostFunction(Sol(i,:));

end

% Initial best solution

[fmin,I]=min(Fitness);
```

```
best=Sol(I,:);

BestCosts=zeros(MaxIt,1);

%% Main Loop

for It=1:MaxIt,

        for i=1:n,

          % Frequency updating

          Q(i)=Qmin+(Qmax-Qmin)*rand;

          % Velocity updating

          v(i,:)=v(i,:)+(Sol(i,:)-best)*Q(i);

          % Position updating

          S(i,:)=Sol(i,:)+v(i,:);

           % Generation of the best position of bats

          if rand>r

              S(i,:)=best+0.01*randn(1,d);

          end

           % Check for the inequality constraints satisfaction

             S(i,:) = max( S(i,:),Lb);

             S(i,:) = min( S(i,:),Ub);

    % Evaluation of the economic /emissiom dispatch objective function

           Fnew=CostFunction(S(i,:));

      % Updating the local best solution

           if (Fnew<=Fitness(i)) &&(rand<A)

                Sol(i,:)=S(i,:);

                Fitness(i)=Fnew;

        % Updating the loudness and pulse rate

         A=0.5*A;
```

```
          r= 0.2*( 1-exp(-0.99*It));
            end
           % Global best updation
           if Fnew<=fmin,
                 fmin=Fnew;
                 best=S(i,:);
           end
         end
         P_loss2=( best* Bi*(best)') ;%Compute the power losses
         BestCosts(It)=fmin;
% Display the results(fitness)
disp(['Number of Iteration =',num2str(It), 'Fitness=',num2str(fmin)]);
end
% Display the total generation
Total_generation2=sum(best)
% Checking the equality constraint
constraint_check2= Total_generation2-P_loss2
% Display of generators outputs
Generator_output2= best
%Plot of Bat algorithm results
plot(BestCosts,'-r','LineWidth',1.4)
hold on

%OPTIMIZING BY USING MOTH FLAME OPTIMIZATION AND BAT HYBRID ALGORITHM
%% Definition of the problem
CostFunction= @(P) Objective(P);%%  Objective function
```

```
d=6;% Number of generators( d=10 for ten units system)
Lb=[ 10 10 40 35 130 125 ];% Lower limits of generators
Ub =[ 125 150 250 210 325 315];% Upper limits of generators
% For ten units system
%Lb=[ 10 20 47 20 50 70 60 70 135 150 ];
%Ub=[ 55 80 120 130 160 240 300 340 470 470];
% For six unit system with NOx,COx and SOx emissions
%Lb=[ 150 200 350 5 270 170 ];
%Ub=[ 400 400 600 400 500 300];
MaxIt=400;  % Maximum number of iteration
% B-losses coefficient matrix for IEEE-30 bus system
 Bi=[0.002022 -0.000286 -0.000534 -0.000565 -0.000454 -0.000103
       -0.000286 0.003243 0.000016 -0.000307 -0.000422 -0.000147
       -0.000534 0.000016 0.002085 0.000831 0.000023 -0.000270
       -0.000565 -0.000307 0.000831 0.001129 0.000113 -0.000295
       -0.000454 -0.000422 0.000023 0.000113 0.000460 -0.000153
       -0.000103 -0.000147 -0.000270 -0.000295 -0.000153 0.000898];
%% Parameter and Initialization of Bat Algorithm
A1=0.9;      % Loudness
r1=0.001;      % Pulse rate
% Frequency range
Qmin1=-0.333;      % Frequency minimum
Qmax1=0.333;       % Frequency maximum
% Initializing arrays
v1=zeros(n1,d);   % Velocities
%% Parameter of Moth Flame Optimization and Initialization
```

```
N1=n1; % Maximum number of flames

% Initialization of Moth positions

   for i=1:n1

   Moth_Position1(i,:)=rand*ones(1,d).*(Ub-Lb)+Lb;

   Fitness(i)=CostFunction(Moth_Position1(i,:));%   Objective   function
evaluation

   end

 [fmin,I]=min(Fitness);

  best1=Moth_Position1(I,:);

 BestCosts=zeros(MaxIt,1);

 It=1;

 %% Main Loop

 for It=1:MaxIt

     % Flame number updating

     Flame_no= round(N1-It*((N1-1)/(MaxIt)));

    if It==1

       sorted_population1=sort(Moth_Position1);

       %update the flames

       best_flames1=sorted_population1;

     else

         double_population1=[previous_population1;best_flames1];

         double_sorted_population1= double_population1;

         sorted_population1=double_sorted_population1(1:N1,:);

         % Update the flames

         best_flames1=sorted_population1;

    end

     previous_population1=Moth_Position1;
```

```
for i=1:size(Moth_Position1,1)
    for j=1:size(Moth_Position1,2)
   % Update the position of moth with respect to its corresponding flame
 if i<=Flame_no
  distance_to_flame1=abs(sorted_population1(i,j)-Moth_Position1(i,j));
    b=5;
    t=(a-1)*rand+1;
Moth_Position1(i,j)=distance_to_flame1*exp(b.*t).*cos(t.*2*pi)...
+sorted_population1(i,j);
 end
 % Update the position of the moth with respect to one flame
        if i>Flame_no
distance_to_flame1=abs(sorted_population1(i,j)-Moth_Position1(i,j));
      b=5;
      t=(a-1)*rand+1;
Moth_Position1(i,j)=distance_to_flame1*exp(b.*t).*cos(t.*2*pi)...
+sorted_population1(Flame_no,j);
        end
    end
end
    for i=1:size(Moth_Position1,1)
    % Check for generator limits
      Flag4VarMax=Moth_Position1(i,:)>Ub;
      Flag4VarMin=Moth_Position1(i,:)<Lb;
      Moth_Position1(i,:)=(Moth_Position1(i,:).* ...
(~(Flag4VarMax+Flag4VarMin)))+Ub.*Flag4VarMax+Lb.*Flag4VarMin;
    end
```

```
   for i=1:n1
   % Update the frequency
     Q1(i)=Qmin1+(Qmax1-Qmin1)*rand;
   %Update the velocity
     v1(i,:)=v1(i,:)+(Moth_Position1(i,:)-best1)*Q1(i);
   % Update the bats positions
     S(i,:)=Moth_Position1(i,:)+v1(i,:);
     if It<200;
      h=1.5;
    else
         h=0.001;
     end
   % Generation of the best position of bats
     if rand>r1
         S(i,:)=best1+h*randn(1,d);
     end
        % Check the generators inequality constraints
         S(i,:) = max( S(i,:),Lb);
          S(i,:) = min( S(i,:),Ub);
% Evaluate the Economic/Emissions objective function
      Fnew=CostFunction(S(i,:));
% Update the local solutions
      if (Fnew<=Fitness(i)) &&(rand<A1)
          Fitness(i)=Fnew;
      end
  % Update the global solutions
```

```
           if Fnew<=fmin,
                 fmin=Fnew;
                 best1=S(i,:);
           end
         end
        P_loss1=( best1* Bi*(best1)');% compute the power losses
         BestCosts1(It)=fmin;
% Display the results(fitness)
 disp(['Number of Iteration =',num2str(It), 'Fitness=',num2str(fmin)]);
 end
 % Display the total generation
 Total_generation1=sum(best1)
% Check for inequality constraints satisfaction
constraint_check= Total_generation1-P_loss1
% Displays the genarators outputs
Generator_output= best1
% Plot the MFO/BAT results
plot(BestCosts1,'-g','LineWidth',1.5);
legend('MFO','BAT','MFO/BAT');
```

Appendix B: Load Flow Report of IEEE 30 Bus Test System

POWER FLOW REPORT
P S A T 2.1.9
File: C:\Users\Ruta\d_ieee_30_bus.mdl
NETWORK STATISTICS

Buses:	30
Lines:	37
Transformers:	4
Generators:	6
Loads:	21

SOLUTION STATISTICS

Maximum P mismatch [MW]	6.72E-13
Maximum Q mismatch [MVar]	9.28E-13

POWER FLOW RESULTS

Bus	V [kV]	phase [rad]	P gen [MW]	Q gen [MVar]	P load [MW]	Q load [MVar]
Bus1	106	0	124.105	11.42964	0	0
Bus10	99.38492	-0.20034	3.77E-13	9.28E-13	7.716689711	2.700841
Bus11	108.2	-0.16707	3.54E-14	32.34276	0	0
Bus12	100.8911	-0.20405	1.33E-13	6.77E-13	7.952353703	5.964265
Bus13	107.1	-0.20405	-2.8E-14	47.49814	0	0
Bus14	98.51753	-0.21904	4.44E-14	2.22E-14	7.582580569	5.686935
Bus15	98.47805	-0.22179	2.22E-14	2.22E-14	7.576505097	5.682379
Bus16	99.79758	-0.21024	5.55E-14	-1.1E-14	7.780903503	5.835678
Bus17	98.9911	-0.20691	4.44E-14	1.55E-13	7.655653902	5.74174
Bus18	95.92662	-0.22953	-1.2E-13	-1.6E-13	7.188997369	5.391748
Bus19	95.62154	-0.22783	2E-13	3.89E-13	7.143343479	5.357508
Bus2	104.5	-0.03773	143.7	24.60027	8.531445313	6.398584
Bus20	96.09691	-0.22362	-2.8E-13	-2.9E-13	7.214544461	5.410908
Bus21	98.42445	-0.20609	2.89E-13	-4.6E-13	7.568259576	5.676195
Bus22	98.34056	-0.20671	-6E-14	7.26E-13	0	0
Bus23	96.38321	-0.22603	8.88E-14	3.33E-14	7.257596094	5.443197
Bus24	96.1984	-0.21765	-1E-13	-6.1E-14	7.229791126	2.530427
Bus25	94.50448	-0.20923	8.72E-15	4.11E-14	0	0
Bus26	90.67392	-0.22341	0	2.22E-14	6.423250293	4.817438

Bus27	95.3414	-0.19523	-7.7E-14	-1.1E-13	0	0
Bus28	100.24	-0.11381	2.15E-13	6.03E-13	0	0
Bus29	91.06415	-0.2162	4.44E-14	3.33E-14	6.478655728	4.858992
Bus3	102.0308	-0.08055	-6.7E-14	-3E-13	8.133037104	6.099778
Bus30	90.54426	-0.21882	-1.1E-14	-2.2E-14	100.24431	4.80367
Bus4	101.3465	-0.09494	7.77E-14	-8.9E-14	80.216812	6.018235
Bus5	101	-0.07743	10.61239	-11.636	7.96953125	5.977148
Bus6	100.9746	-0.10513	117.6374	7.92E-13	56.78351	8.543942
Bus7	100.6058	-0.09688	1.55E-13	7.22E-13	7.90744588	5.930584
Bus8	101	-0.11002	1.55E-13	10.0016	7.96953125	5.977148
Bus9	101.9825	-0.16707	-1.7E-13	-7.1E-13	0	0

LINE FLOWS

From Bus	Bus	Line	P Flow [MW]	Q Flow [MVar]	P Loss [MW]	Q Loss [MVar]
Bus1	Bus3	1	50.01699	10.11205	1.2937722	-0.03875
Bus16	Bus23	2	74.088	1.317588	44.83	-3.03086
Bus10	Bus9	3	-30.6492	-22.9595	-7.10543E-15	1.633195
Bus11	Bus9	4	3.54E-14	32.34276	6.93889E-16	1.858502
Bus2	Bus6	5	42.97783	6.049952	5.426342696	-0.86099
Bus13	Bus12	6	-2.8E-14	47.49814	0	2.753609
Bus14	Bus12	7	-8.2809	-5.11072	0.120101295	0.249666
Bus12	Bus16	8	7.264774	10.32541	0.015658796	0.156588
Bus1	Bus2	9	-0.53179	4.333147	44.83	0.036799
Bus17	Bus10	10	-8.19747	-1.44539	0.022909136	0.059748
Bus2	Bus5	11	24.24597	10.81042	5.915476718	-3.03556
Bus14	Bus15	12	0.69832	-0.57622	0.001866421	0.001687
Bus15	Bus23	13	5.659534	7.415129	0.089724815	0.181244
Bus23	Bus24	14	-1.68779	1.790688	0.011667507	0.017599
Bus24	Bus25	15	0.386701	4.738322	0.046037089	0.0804
Bus1	Bus3	16	6.622722	5.115391	0.1332	0.297954
Bus25	Bus27	17	-6.28206	-0.45747	0.048553013	0.092708
Bus27	Bus29	18	7.502824	5.894436	0.220131055	0.415926
Bus5	Bus6	19	0.804037	0.619519	1.635422297	0.005632
Bus27	Bus30	20	5.795049	4.549695	0.19121263	0.359912
Bus20	Bus10	21	-14.4528	-8.5216	0.285324246	0.637102

Bus3	Bus6	22	15.94825	-3.76716	0.134901655	-1.77522
Bus15	Bus18	23	7.248685	7.952582	0.128109289	0.260875
Bus18	Bus19	24	-0.06842	2.299959	0.003676606	0.007434
Bus19	Bus20	25	-7.21544	-3.06498	0.02285266	0.045705
Bus4	Bus6	26	-3.41775	-1.8148	16.47996117	0.003654
Bus22	Bus24	27	9.461328	5.721949	0.145381023	0.226289
Bus10	Bus22	28	6.082508	3.987426	0.038933198	0.080276
Bus3	Bus4	29	11.05136	7.631423	0.484737868	0.136775
Bus2	Bus4	30	37.39166	5.689765	0.1959616	-1.58102
Bus12	Bus15	31	19.87688	22.51411	0.0886113	0.886113
Bus4	Bus5	32	-40.6019	-4.30581	0.128545102	-0.25479
Bus1	Bus6	33	25.7135	1.379989	12.3183614	-0.65314
Bus6	Bus20	34	16.8446	7.032391	0.056846051	-1.11437
Bus28	Bus8	35	-2.84073	-5.05257	0.010439375	-4.30047
Bus1	Bus5	36	10.83611	-4.13627	9.632912165	-0.86392
Bus6	Bus7	37	-7.89304	6.286812	0.029715034	-1.63572
Bus3	Bus5	38	30.6492	-3.94343	0.011306735	1.948085
Bus6	Bus10	39	17.1599	3.70458	-3.55271E-15	1.680596
Bus1	Bus4	40	43.49501	4.178367	2.02785145	4.758724
Bus28	Bus27	41	19.62848	13.19933	0	2.205023