UNIVERSITY OF NAIROBI

Department of Electrical and Information Engineering

MSc. (ELECTRICAL AND INFORMATION ENGINEERING)

COMBINED ECONOMIC AND EMISSION DISPATCH (CEED) CONSIDERING LOSSES USING ARTIFICIAL BEE COLONY AND PARTICLE SWARM OPTIMIZATION HYBRID WITH CARDINAL PRIORITY RANKING

By

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A research thesis submitted in partial fulfillment of the degree of Master of Science in Electrical and Electronic Engineering of the University of Nairobi.

Date of Submission: 15th July 2013

DECLARATION

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

…………………………………………

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This MSc. research thesis has been submitted to the School of Engineering, Department of Electrical and Information Engineering, The University of Nairobi with my approval as supervisor

……………..

Dr.N.Abungu

Date:………

DEDICATION

This research is dedicated first and foremost to Almighty Yahweh and to all who have made this dream possible.

ACKNOWLEDGEMENT

“Behold, I am with you and will keep you wherever you go, and will bring you back to this land. For I will not leave you until I have done what I have promised you." Gen 28:15

First and foremost, I give all glory to the Lord God who has made this research a success. But for his providence, this would have not been possible. For the good health, strength, guidance, wisdom and encouragement he gave me all along the way, I say Asante sana. Secondly I appreciate the support from Mr. and Mrs. Manteaw, my parents who have been with me all throughout this research journey. I also acknowledge the encouragement from my siblings Philip and Joe. My deepest gratitude also goes to my supervisor Dr. Nicodemus Abungu whose zeal for excellence and hard work pushed me to achieve this feat. I say a big thank you to Association of Commonwealth Universities and University of Nairobi who sponsored me for this MSc. program. Finally my appreciation goes to all the staff of the Electrical Department for their tireless effort in bringing the best out of all the students under their tutelage.

ABSTRACT

The problem of power system optimization has become a deciding factor in current power system engineering practice with emphasis on cost and emission reduction. The economic and emission dispatch problem has been addressed in this thesis using two efficient optimization methods, Artificial Bee Colony (ABC) and Particle Swarm Optimization (PSO). A hybrid produced from these two algorithms is implemented on a 3-generator test system, 30-bus 6 generator IEEE test system and a 10 generator test system. The results are compared with PSO, Genetic Algorithm (GA), with respect to the 3-generator test system, ABC, Fuzzy Controlled Genetic Algorithm (FCGA) and Non Sorting Genetic Algorithm (NSGA-II), with respect to the 6-generator test system and differential evolution, Non sorting genetic algorithm II and Strength Pareto Evolutionary Algorithm, with respect to the 10-generator test system. This proposed optimization method is found to be effective on the combined economic and emission dispatch problem.

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NOMENCLATURE

ABC	Artificial Bee Colony
AGC	Automatic Generation Control
CEED	Combined Economic Emission Dispatch
DE	Differential Evolution
ED	Economic Dispatch
EED	Economic and Emission Dispatch
EPSO	Efficient Particle Swarm Optimization
FCGA	Fuzzy Controlled Genetic Algorithm
GA	Genetic Algorithm
HNN	Hopfield Neural Network
IEEE	Institute of Electrical and Electronic Engineering
NOx	Nitrogen Oxide
NSGA	Non Sorting Genetic Algorithm
PSO	Particle Swarm Optimization
QP	Quadratic Programming
SPEA	Strength Pareto Evolutionary Algorithm
SOx	Sulphur Oxide
SO_2	Sulphur Dioxide

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Chapter 1

INTRODUCTION

Optimal system operation, in general, involves the consideration of economy of operation, system security, emissions at certain fossil-fuel plants, optimal release of water at hydro generation, etc. with the aim of improving the efficiency of the power system. In this research work, consideration will be given to two aspects of the optimal system operation, emissions and economy of operation, also known as economic dispatch [1].

1.1 ECONOMIC DISPATCH

Economic Dispatch (ED) optimization problem is one of the most important issues which must be taken into consideration in power systems. The problem of ED in power systems is to plan the power output for each devoted generator unit in such a way that the operating cost is minimized and simultaneously, matching load demand, power operating limits and maintaining stability. Based on convention, electrical power systems are operated based on minimizing operational cost while maintaining system constraints [2]. The total generator operating cost includes fuel, labor, supplies and maintenance costs. For simplicity we consider fuel cost as the only variable cost since generally the costs of labor, supplies and maintenance are fixed percentages of the fuel cost. The fuel cost is meaningful in the case of thermal and nuclear plants, but nuclear plants are operated at constant output levels and for hydro stations where the energy cost is apparently free, the operating cost is not that meaningful. Hence only thermal plants are considered in this research.

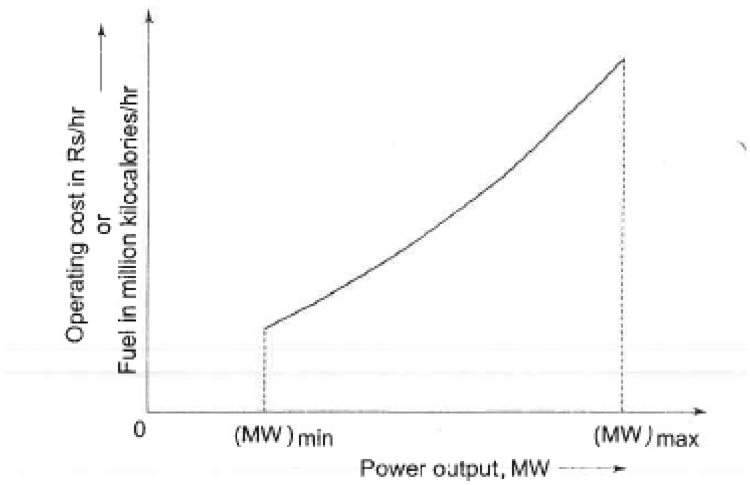


Figure 1.1: Fuel Cost curve [11]

The fuel cost is generally assumed to be a smooth quadratic function. It is depicted in the figure 1.1. This definition however makes many assumptions which are impractical to real systems amongst which are defined below:

1. It assumes a smooth cost function
2. It assumes a static problem
3. It does not take into consideration emissions that occur as a result of the operation of the thermal plant
4. The start up and shut down costs are neglected.

With these assumptions the problem of economic dispatch is solvable using the traditional methods such as the lambda iteration, gradient search method, base point, participation factor method, dynamic programming, linear programming etc [15]. But as earlier said these assumptions are impractical in the real world. These assumptions are impractical due to the reasons explained below:

1.11 NON SMOOTH COST FUNCTIONS

In reality, the objective function of an ED problem has non differentiable points according to valve-point effects and change of fuels; therefore, the objective function should be composed of a set of non-smooth cost functions. Hence non smooth cost functions are accounted for due to two main cases. One is the case with the valve-point loading problem where the objective function is generally described as the superposition of sinusoidal functions and quadratic functions. The other is the case with the multiple -fuel problem where the objective function is expressed as the piecewise quadratic cost functions. In both cases, the problems have multiple minima, therefore, the task of finding the global solution still remains to be tackled [4]-[7].

1) Non-smooth Cost Functions With Valve-Point Effects*:* The generator with multi-valve steam turbines has very different input-output curve compared with the smooth cost function. Typically, the valve point results in, as each steam valve starts to open, the ripples like in figure 2. [6]- [8]. To take account for the valve-point effects, sinusoidal functions are added to the quadratic cost functions.

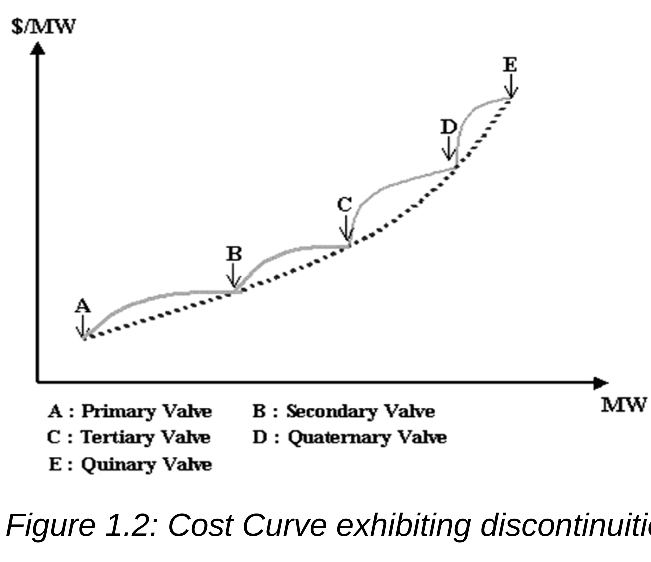


Figure 1.2: Cost Curve exhibiting discontinuities due to valve point effect [6]

2) Multiple fuel mix:

Some generation units especially those units which are supplied with multiple fuel sources (gas and oil) are faced with the problem of determining the most economical fuel to burn. As fossil fuel costs increase, it becomes even more important to have a good model for the production cost of each generator. Therefore a more accurate formulation is obtained for the ED problem by using hybrid cost function and hybrid incremental cost function and expressing these generation cost function as a piecewise quadratic function and linear function respectively [9] as shown in figure 1.3 below.

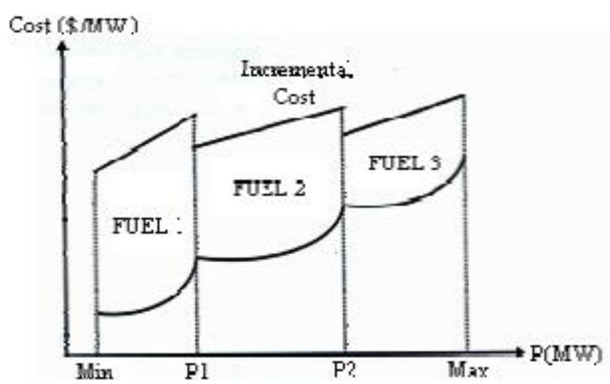


Figure 1.3: Impact of multiple fuels on cost curve [9]

1.12 DYNAMIC DISPATCH

Economic dispatch may sometimes be classified as a static optimization problem in which costs associated with the act of changing the outputs of generators are not considered. On the other hand, a dynamic dispatch is one that considers change related costs [10]. The dynamic ED takes the ramp rate limits and prohibited operating zone of the generating units into consideration.

1.13 EMISSION DISPATCH CONSIDERATIONS

Recently, energy sources to generate mechanical power applied to the rotor shaft of generating units are of fossil fuels. This causes a vast amount of carbon dioxide, sulfur dioxide, nitrogen oxides emissions which cause atmospheric pollution. There has been a keen attention for emission control over environmental pollution caused by fossil-fired generating units and the enforcement of environmental regulations. In addition, the increasing public awareness of the environmental pollution and the passage of the Clean Air Act amendments of 1990 have forced the utilities to modify their design or operational strategies to reduce pollution and atmospheric emissions of the thermal power plants. Thus nowadays, the ED optimization technique should also consider this environmental pollution scenario [2]. Emissions like $SO_2 and\ NO_x$ [11] as well as carbon dioxide are becoming necessary to control. Hence have to be fitted into the objective function using weighting functions with a decision maker or a price penalty function [12], [14].

1.14 START UP COST CONSIDERATIONS

The cost of starting up the plants is also no longer negligible and has to be factored in the economic dispatch problem. Hence the objective becomes

$$F = \ minimize\ \sum_{i=1}^{N} (Cost\ of\ Fuel + Cost\ of\ Start\ up) \qquad (1)$$

With the inclusion of all these considerations, the traditional methods are not able to optimize the economic dispatch efficiently due to the non linear and combinatorial multi-objective problem as well as its non convex nature. Hence recent Meta-heuristic methods are being applied in to the ED problem amongst which are Fuzzy Logic, Artificial Neural Networks, Genetic Algorithm, Evolutionary Programming, Simulated Annealing, Tabu Search, Particle Swarm Optimization, GA-PSO hybrid, Ant Colony, Fire Fly, Artificial Bee Colony etc.

With the advent of these methods the multi faceted economic dispatch problem is being addressed but the challenges being faced by the above are [13]:

1. High computational time
2. Convergence to a local optima
3. Not feasible solutions
4. Malfunctioning of algorithm for large and medium sized systems.

Hence the areas of current research are aimed at improving the quality of solutions. Interestingly, literature proved the improved efficiency in the methods when they are hybridized.

1.2 OBJECTIVE OF RESEARCH

Hence in this research work, exploration of the area of hybridizing PSO and the Artificial Bee Colony method and studies of its behavior in comparison with the other methods addressing the combined emission and economic dispatch problem will be done.

1.3 LITERATURE SURVEY

ECONOMIC DISPATCH PROBLEM

Chowdhury and Rahman, 1990 [10] in their study of recent advances in economic dispatch identified four very important and related areas of economic dispatch in papers published in the general area of economic dispatch. These are classified as (i) Optimal power flow, (ii) economic dispatch in relation to AGC, (iii) dynamic dispatch and (iv) economic dispatch with non-conventional generation sources.

Gerald F. Reid et al, 1972 [16] proposed a quadratic programming problem using the economic dispatch problem and solved it using Wolfe's algorithm for equality and inequality constraints. Although the advantage here was fast convergence, solutions are inaccurate. This method was also not dependent on the selection of gradient step sizes or penalty factors.

Happ, 1977 [17,18] and IEEE Working Group, 1981 [19,20]. Both Happ and the IEEE Working Group present the work of authors from the inception of economy loading to the status existing in 1979. Happ reviews the progress of optimal dispatch going as far back as the early 1920's, when engineers were concerned with the problem of economic allocation of generation or the proper division of the load among the generating units available.

N. Nabona et al, 1973 [21] resolved the non linear difficulty in the economic dispatch problem by the derivation of linear constraints. It takes less computational time but results are not very accurate due to the linearization.

David C. Walters et al, 1993 [22] introduces the use of Genetic algorithm solution to the economic dispatch problem with valve point loading considerations. This method, GA, is effective but has the problem of premature convergence and also time consuming. It also has the problem of failure to locate a global solution.

A.Y. Abdelaziz et al, 2008 [23] proposes a hybrid Hopfield Neural Network (HNN) - Quadratic programming (QP) method for solving dynamic economic dispatch. This method uses an enhanced HNN to solve the static part and the QP to solve the dynamic part of the economic dispatch. It has the advantage of global optimality of the solution due to its look ahead capability.

Rahul Garag et al, 2008 [13] solves the economic dispatch problem in two layers. It uses GA to solve the unit commitment problem and then uses Lagrangian relaxation to perform the economic dispatch. In this method the optimality of solution cannot be guaranteed and also in some instances uses a high computation time, nonetheless it is an advantageous method for large systems

S. H. Ling et al, 2003 [24] proposes an improved Genetic algorithm to solve the economic load dispatch problem. The paper introduces new selection and cross over processes into the GA. In comparison to other previously invented GA's it has better solution in terms of convergence rate, reliability and operation cost.

T. Yalcinoz et al, 2001 [25] also introduces a Genetic algorithm based economic dispatch based on arithmetic cross over. This makes use of real value representation scheme, arithmetic cross over mutation and elitism to generate successive sets of possible operating policies. In comparison with Fuzzy Logic Controlled GA and Advanced Hopfield Neural Network and Advanced Engineering Conditioning GA it shows better results in terms of operation cost for the 20 unit test system. However it is noted that the proposed method does not show any marked improvement in comparison to the other algorithms on the 6 unit test systems.

Ahish Ahmad et al, 2011 [26] proposes the use of Particle swarm Optimization in solving of the economic dispatch problem. In the larger systems it has marked superiority in comparison with other heuristic methods. But in smaller systems it's advantage is of no effect.

Saravuth Pothiya et al, 2001 [27] proposes the use of Multiple Tabu search Algorithm in solving the economic dispatch problem. Here the classical Tabu search method is improved upon by the introduction of local updating and global updating of solutions. A reduced computation time is achieved and guarantees a near optimal solution, hence better in comparison with Tabu search and Genetic Algorithm.

M. Vanitha et al, 2011 [28] uses biogeography in solving the economic dispatch problem. Here the geographical behavior of nature in distributing species is employed to solve the Economic dispatch problem. It uses migration and mutation to operate successfully. In comparison with PSO, GA and simulated annealing it has a better convergence, computational efficiency and better quality of solution. It is however complex in comparison with PSO and also its behavior can be very dismal if parameters are not successfully chosen.

Jong – Bae Park et al, 2005 [29] applies a PSO to the economic dispatch problem with non smoothing functions. Primarily the difference between this and the classical PSO is how the equality and inequality constraints are handled in the modification of each individual's search point. Also in a bid to accelerate the convergence speed, a dynamic search space reduction method is devised. Simply put this method is efficient.

D. C. Secui et al, 2010 [30] uses a swarm intelligence approach in solving the economic dispatch problem. It applies the use of time varying acceleration coefficients to improve the global search in the early stages of the optimization process and to accelerate the convergence of particles to the global optimum in the final part of the process. It shows better quality of solutions and lower computation time for larger systems, though in smaller systems it is comparable to traditional methods.

Wang Xiao-Hua et al, 2011 [31] addresses the challenges of the classical PSO which includes the possibility of falling into local optima, reduced search precision and its consideration for job dead zone constraint by the use of chaotic quantum behaved PSO algorithm. It aims at improving the global optimization performance of PSO by using quantum behaved PSO initially, allowing particles to fall into local optima, after which a chaos is applied to the algorithm to make the particles jump out of local optima to find global solutions. In comparison with other methods of PSO it is superior.

G. Baskar et al, 2009 [32] uses a hybrid of the classical PSO and an improved PSO with line constraints to perform the economic dispatch problem. Applying the constriction factor approach and a new velocity update rule it shows better performance for larger system.

S. Muthu Vijaya et al, 2010 [33] uses a hybrid of Evolutionary Programming and Efficient PSO algorithm considering transmission losses to solve the economic dispatch problem with both smooth and non smooth cost functions. In this method of hybridizing, the EP is used to initially get near optimal solutions which are then passed on to EPSO to get better solutions. This method gives better solutions than EPSO, though has slightly higher computational time. However, it is far superior in comparison with Neural Network (NN), Evolutionary programming (EP), NN-EPSO and EP-Simple quadratic programming.

Mimoun Younes et al , 2011 [34] uses a hybrid of GA and PSO to solve the economic dispatch problem. This hybrid converges more stably and gives efficient and high quality solutions. Its main quality is the flexibility in modeling which it gives. Its computational time is good but can be improved.

Y. Labbi et al, 2010 [35] uses a hybrid of GA and Pattern search method to solve the economic dispatch problem. It solves the challenge of having to randomly select a starting point for the Pattern Search method by using GA to get that point.

Lahouaoria Benasla et al, 2008 [36] uses the Hooke-Jeeves method to solve the economic dispatch problem. It focuses on the reduction in the number of variables and the removal of constraints after which the Hooke-Jeeves pattern search method is applied to solve the economic dispatch problem.

COMBINED ECONOMIC AND EMISSION DISPATCH

Gopala Krishnan et al, 2011 [37] outlines a summary of techniques that have been applied so far to the combined economic and emission dispatch problem. The paper highlights new techniques which have been applied the CEED problem from the year 2000 to the year 2010. It also highlights challenges faced by the use of traditional methods due to the non linearity of cost functions. It generally encourages the use of PSO.

Biswajit Purkayasha et al, 2010 [38] aims at non dominated solutions in considering the multi-objective optimization problem of economic and emission dispatch using Non-dominated Sorting GA II. The results demonstrate the effectiveness in solving the multi-objective problem. It considers the cost of fuel, SOx and NOx.

Celal Yasar et al, 2005 [39] uses the first order gradient method in solving the Combined Economic and Emission Dispatch problem. It has the advantage of easy control of constraints. Also all intermediate solutions are feasible for application to the power system. It has the disadvantage of not having a clearly defined method for the choice of $\propto_G$ which happens to be the most important parameter guiding the speed of convergence.

Anurag Gupta et al, 2012 [40] uses PSO on the combined economic and emission dispatch problem. It combines the two objectives into one using the price penalty function. It shows a better advantage in terms of cost, fast convergence, and less computational time than other heuristic methods like GA and dynamic programming. Also PSO gives efficiently high quality solutions with more stable convergence characteristics than the other heuristic methods afore mentioned.

Lakshmi A. Devi et al, 2008 [41] uses the evolutionary programming method on the combined economic and emission dispatch problem. This paper proposes the use of the lambda in the evolutionary algorithm with the reason being that it makes the coding of the chromosomes independent on the number of units. Notably PSO generates a lower fuel cost and emission release but sometimes have a higher computational time than GA.

Harry Rughooputh et al, 2005 [42] applies both deterministic and stochastic methods to the economic environmental problem.

Ahmed Farag, 1995 [43] uses linear programming in addressing the multi-objective problem of the economic dispatch. It uses the constriction factor approach to handle the CEED problem

M. R. Alrashidi et al, 2008 [44] on the impact of loading conditions on the emission and economic dispatch problem uses weighting functions on the double objective of emission and fuel cost. It provide a simple way of addressing the equality constraint. The rule guiding the application of the weights to the objectives is not explicitly shown. Also this method is not applied to the CEED rather it optimizes the objectives independently.

Gaurav Prasad et al, 2011 [45] applies a new technique called Artificial Bee Colony method (ABC) the economic load dispatch problem. In comparison to other heuristic methods it shows highly superior features like quality of solution, stable convergence characteristics and good computational efficiency. It does not consider the environmental or emission dispatch problem.

Y. Sonmez et al, 2011 [46] applies the Artificial Bee Colony method to solve the multi-objective economic and environmental dispatch problem using the penalty factor approach. It is superior in comparison to the other heuristic methods and more efficient.

1.4 SUMMARY OF LITERATURE REVIEW

Generally the heuristic methods like Genetic algorithm, Simulated annealing, Particle Swarm Optimization, Ant Colony and Artificial Bee Colony (ABC) techniques and their various modifications have shown marked improvement in the addressing of the economic dispatch problem as well as the combined economic and emission dispatch problem. From the above literature there shows a need in still improving the quality of solutions for the combined economic and emission dispatch problems, in terms of better convergence, lower losses, faster computation times, reduced fuel costs and reduced emissions. It is worthy of notice that hybrid methods yield superior solutions, either a heuristic and a traditional method or two heuristics. So far the hybrids existing in open literature do not include the hybrid of PSO and ABC even though both methods yield good solutions individually.

1.5 PROBLEM STATEMENT/ MOTIVATION

In the effort to improve the economic dispatch so as to minimize the cost of fuel used in the operation of the power system as well as minimize the emission that a plant produces in the bid to enhance the environmental conditions and reduce the adverse effect of technology on the ozone layer, there is the need for better quality of solutions to power system economic and emission dispatch problems aiming at better convergence, faster computational time, reduced emissions and reduced fuel cost, which culminates into overall reduction in the operational cost of a power system. This will enhance real time operation of the power system and also enable better general operation of the power system and reduction in negative environmental impact as well as improve the economic viability of power system business.

1.6 OBJECTIVES

1 Study the multi-objective problem of the power system in terms of fuel cost and emission. Where here the emission is primarily Nitrogen Oxide. (NOx)
2. To combine the multi-objective problem into one objective using the weighting function method and cardinal priority ranking.
3. Study the Particle Swarm Optimization and Artificial Bee Colony optimization models
4. To formulate an algorithm that hybridizes the advantages of both optimization models and applies it to the multi-objective problem.
5. To test the algorithm on the standard IEEE 30 bus 6-generator test system, 3-generator test system and 10-generator test systems.
6. To compare the hybrid's results with those obtained by other authors using other methods.

1.7 ORGANIZATION OF THESIS

This thesis has six chapters. Chapter 1 is an introduction giving a survey of earlier work, statement of the problem and organization of the thesis. In Chapter 2, a presentation of detailed economic and emission dispatch problem is outlined culminating into the formulation of the multi-objective problem using the weighting functions and the cardinal priority ranking method.

In Chapter 3, the Particle Swarm Optimization and Artificial Bee Colony Algorithms' pseudo-codes are written with application to the multi-objective problem defined resulting in the hybridizing of the two algorithms to form the hybrid ABC_PSO algorithm.

Chapter 4 shows the results of implementing the proposed algorithm on the formulated multi-objective problem.

In Chapter 5, analysis and discussion of the results of the implementation of the hybrid in comparison with results obtained by other methods from other authors is conducted. Areas of further research are also identified for future work.

Chapter 6 concludes the thesis.

Chapter 2

THE WEIGHTING FUNCTION METHOD AND CARDINAL PRIORITY RANKING METHODS FORMULATION

2.1 INTRODUCTION

The fundamental requirement of power system economic load dispatch is to generate, at the lowest possible cost, the adequate quantity of electricity to meet the demand. It is defined as the minimization of the combination of the power generation, which minimizes the total cost while satisfying the power balance relation. To meet the stringent quality requirements, accurate tools based on realistic models with faster solution speed and a high degree of reliability is required. To achieve higher reliability, improved security, and less environmental impact, utilities are implementing tighter control on operation of their facilities [47]. Hence the economic emission dispatch (EED) option is an attractive short term alternative in which the emission in addition to the fuel cost objective is to be minimized. At present, thermal plants account for a good percentage of generating plants. Generally the coal used in the thermal plants is of poor quality and high ash, Sulphur Oxide SO_x and oxides of Nitrogen (NO_x) are the major emissions from these thermal plants due to the combustion of coal which will cause ill effects on human beings as well as plants and animals. The Clean Air Act Amendment 1990 mandates that the electric utility industry reduces its SO_x emissions by 10 million tons/year from the 1980 level [48]. The NO_x emission is required to be reduced by 2 million tons/year from the 1980 level. Minimum emission dispatching may be imposed by government and regulatory agencies of developing countries also in the near future to control and reduce air pollution [49]. These have brought about the necessity of greater sophistication in power system planning, operation and control. The problem of economic dispatch can be formulated as minimization of the cost function subjected to the equality and inequality constraints.

2.2 ECONOMIC DISPATCH

The majority of generators are nuclear, hydro and fossil. The figure below is a simple model of a fossil fuel plant. The power output of the fossil fuel plant is increased sequentially by opening a set of valves at the inlet to its steam turbine. The throttling losses in a valve are as large as just when it is opened and small when it is fully opened.

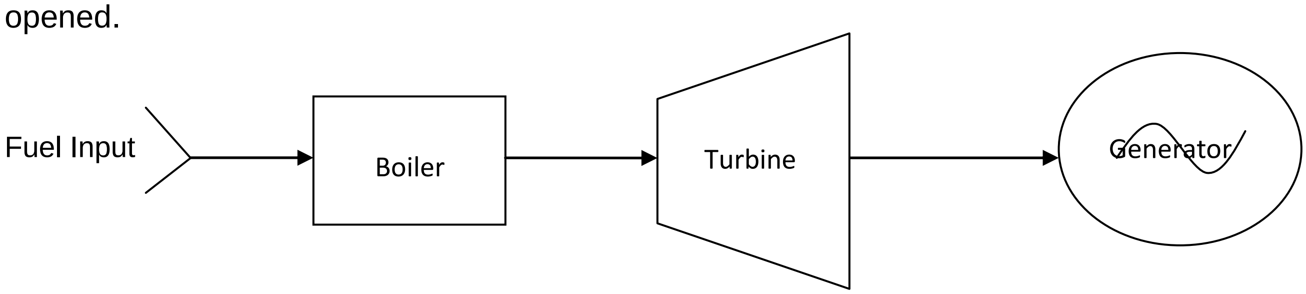


Figure 2.1: Simple model of a fossil fuel [50]

2.21 GENERAL FORMULATION FOR ECONOMIC DISPATCH ON A BUS BAR

The following assumptions are made:

1. Unit Commitment has already been done to know which generators will be committed for supply of power
2. Load demand is known.

Hence the economic dispatch problem will be formulated as:

Minimize the cost function which is approximated as:

$$\sum_{i=1}^{NG} F(P_{gi}) = a_i P_{gi}^2 + b_i P_{gi} + c_i \text{ \$/hr} \tag{2}$$

, where P_{gi} is the real power contributed by the i_{th} generator and a_i , b_i , c_i are cost coefficients, subject to equality constraints of:

$$\sum P_{gi} - P_D - P_l = 0 \tag{3}$$

, where $P_l = \sum_{i=1}^{NG} \sum_{j=1}^{NG} P_{gi} B_{ij} P_{gj}$ (4)

also known as George's formula [50] and inequality constraint of:

$$P_{gi(min)} \leq P_{gi} \leq P_{gi(\max)} \tag{5}$$

.The above constrained problem is converted to an unconstrained problem using the Lagrange multiplier. The Lagrange multiplier, in which a function is minimized (or maximized) with side condition in the form of equality constraints, is used. Using this method, an augmented function is defined as:

$$\mathcal{L}(P_{gi}, \lambda) = F\left(P_{gi}\right) + \lambda(P_D + P_l - \sum_{i=1}^{NG} P_{gi}) \tag{6}$$

, where λ is the Lagrangian multiplier.

A necessary condition for a function $F(P_{gi})$, subject to energy balance constraint having a relative minimum point P_{gi}, is that the partial derivative of the Lagrange function defined by the $\mathcal{L} = \mathcal{L}(P_{gi}, \lambda)$ with respect to each of its arguments must be zero. So the necessary condition for the optimum problem is:

$$\frac{\partial \mathcal{L}(P_{gi},\lambda)}{\partial P_{gi}} = \frac{\partial\ F\ (P_{gi})}{\partial P_{gi}} - \lambda + \lambda \frac{\partial P_l}{\partial P_{gi}} = 0 \tag{7}$$

, which can also be written as:

$$\frac{\partial \mathcal{L}(P_{gi},\lambda)}{\partial P_{gi}} = \frac{\partial\ F\ (P_{gi})}{\partial P_{gi}} - \lambda(1 - \frac{\partial P_l}{\partial P_{gi}}) = 0 \tag{8}$$

. Hence we can write:

$$\frac{\partial\ F\ (P_{gi})}{\partial P_{gi}} = \lambda(1 - \frac{\partial P_l}{\partial P_{gi}}) \tag{9}$$

, which is called the exact coordination equation; where:

$$\frac{\partial\ F\ (P_{gi})}{\partial P_{gi}}$$

, is the incremental operating cost of the generator in $/MWh, and :

$$\frac{\partial P_l}{\partial P_{gi}}$$

, is the incremental transmission losses.

The exact coordination equation is solved together with the equality constraint already defined in equation (3) to yield the lagrange multiplier and the optimal generation of NG generators.

By differentiating the transmission loss equation with respect to P_{gi}:

$$\frac{\partial P_l}{\partial P_{gi}} = \sum_{j=1}^{NG} 2\, B_{ij}\, P_{gi} \quad (i = 1,2,3 \dots .NG) \tag{10}$$

, and differentiating the cost function with respect to P_{gi}:

$$\frac{\partial\, F\,(P_{gi})}{\partial P_{gi}} = 2a_i P_{gi} + \ b_i \tag{11}$$

, the exact coordination equations can be rewritten as:

$$\frac{\frac{\partial\, F\left(P_{gi}\right)}{\partial P_{gi}}}{1-\frac{\partial P_l}{\partial P_{gi}}} = \ \lambda \tag{12}$$

,or:

$$\left(\frac{\partial\, F\,(P_{gi})}{\partial P_{gi}}\right) L_i = \lambda \tag{13}$$

, where:

$$L_i = \ \frac{1}{1-\frac{\partial P_l}{\partial P_{gi}}} \tag{14}$$

, is called the penalty factor.

Hence the exact coordination equation can be written as:

$$2a_i P_{gi} + \ b_i = \ \lambda\,(1 - \sum_{j=1}^{NG} 2\, B_{ij}\, P_{gi}) \tag{15}$$

. Therefore

$$P_{gi} = \ \frac{\lambda - b_i - \lambda(\sum_{j=1, j\neq i}^{NG} 2\, B_{ij}\, P_{gj})}{2(a_i + \lambda B_{ii})} \tag{16}$$

. If the initial values of $P_{gi}(i = 1,2,3 \dots NG)$ and λ are known the above equation can be solved iteratively until the equality equation is satisfied by modifying λ.This technique is called successive approximation.

2.22 EVOLUTIONARY SEARCH METHOD FOR ECONOMIC DISPATCH.

2.22.1 OBJECTIVE FUNCTION FORMULATION

Let NG be the number of generating units committed to deliver output subject to their respective energy balance constraints and capacity constraints. A dependent unit P_d is selected arbitrarily from the committed units to meet the equality constraints. The power output of the dependent unit is computed by rewriting the energy balance equation as follows:

using George's formula [3],[50]

$$P_l = \sum_{i=1}^{NG} \sum_{j=1}^{NG} P_{gi} B_{ij} P_{gj} \qquad (4)$$

, the equality constraint can be rewritten as

$$P_d + \sum_{\substack{i=1, \\ i\neq d}}^{NG} P_i = [\sum_{\substack{i=1 \\ i\neq d}}^{NG} \sum_{\substack{j=1 \\ j\neq d}}^{NG} P_{gi} B_{ij} P_{gj} + \sum_{\substack{j=1 \\ j\neq d}}^{NG} P_j \big(B_{jd} + B_{dj}\big) P_d + B_{dd} P_d^2] + P_D. \qquad (17)$$

The above formula can be rewritten as:

$$XP_d^2 + YP_d + Z = 0 \qquad (18)$$

, where

$$X = B_{dd},$$

$$Y = \sum_{\substack{j=1 \\ j \neq d}}^{NG} P_j \left(B_{jd} + B_{dj} \right) - 1 \,,$$

$$Z = \sum_{\substack{i=1 \\ i \neq d}}^{NG} \sum_{\substack{j=1 \\ j \neq d}}^{NG} P_{gi} B_{ij} P_{gj} + P_D - \sum_{\substack{i=1 \\ i \neq d}}^{NG} P_i \,, \tag{19}$$

The positive roots of the equation are obtained as:

$$P_d = \frac{-Y \pm \sqrt{(Y^2 - 4XZ)}}{2X} \tag{20}$$

, where $Y^2 - 4XZ \geq 0$.

Only positive values of roots which lie within operating limits are considered. Then the fuel cost is computed. In case transmission loss is neglected:

$$\mathrm{X} = 0, \mathrm{Y} = -1, \mathrm{Z} = \mathrm{P_D} - \sum_{\substack{\mathrm{i}=1 \\ \mathrm{i} \neq \mathrm{d}}}^{\mathrm{NG}} \mathrm{P_i}. \tag{21}$$

2.23 FUEL COST FUNCTION MODIFIED BY VALVE POINT EFFECT

The generating units with multiple valve steam turbines exhibit a greater variation in the fuel cost function. This cost function or the heat rate curves can be modified by the presence of ripples arising from valve point effects to become:

$$F(P_{gi}) = a_i P_i^2 + b_i P_{gi} + c_i + e_i * \sin(f_i * (P_{imin} - P_i)) \ \text{\$/hr} \tag{22}$$

, where e_i, f_i are the fuel cost coefficients of the unit with valve point effects. Hence the problem is to minimize the above objective subject to equality and inequality constraints.

2.3 EMISSION DISPATCH

The primary objective of this problem is to determine the most economic loadings of the generators such that the load demands of the generation can be met and the operation constraints of the generators are satisfied. In addition, the total emissions need to satisfy the allowable emission limit. The generation of electricity from fossil fuel releases several contaminants, such as Sulfur Oxides, Nitrogen Oxides and Carbon Dioxide, into the atmosphere [51]. The two primary power plant emissions from a dispatching perspective are sulfur oxides (SO_x) and nitrogen oxides (NO_x). In the power plant, the sulfur enters the boiler as a part of the fuel. During the combustion process, some of the sulfur unites with oxygen from the fuel and combustion air to form SO_x. The remaining sulfur becomes a part of the bottom ash in the boiler. If stack gas clean up equipment is present, most of the SO_x is removed. The remaining SO_x exits the stack as an emission. Fuel blending, fuel switching and scrubbers are the primary methods for reducing the amount of SO_x emitted. NO_x emissions are more complex. There are two sources of nitrogen that combine with oxygen from the fuel and the combustion air to produce NO_x.The first source is nitrogen in the air that produces an emission called thermal NO_x.The second source is nitrogen in the fuel that produces an emission called fuel NO_x. The total NO_x produced during combustion is the sum of the thermal NO_x and fuel NO_x. In coal, there is no apparent correlation between the amount of fuel-bound nitrogen and the fuel NO_x produced [52].

The emission dispatch formula can be formulated as

$$E(P_{gi}) = \alpha_i P_i^2 + \beta_i P_{gi} + \gamma_i + \eta_i * \exp(\delta_i * P_{gi}) \quad \text{kg/hr} \tag{23}$$

2.4 MULTI OBJECTIVE DISPATCH PROBLEM

Here the main objective of the CEED problem is to minimize the two objectives given as fuel cost $F(P_{gi})$ and emission cost $E(P_{gi})$ simultaneously to ensure optimal output of generated power whilst satisfying the equality and inequality constraints.

Economy objectives

$$F(P_{gi}) = a_i P_i^2 + b_i P_{gi} + c_i + e_i * \sin(f_i * (P_{imin} - P_i)) \quad \text{\$/hr} \tag{22}$$

Environmental Objectives

$$E(P_{gi}) = \alpha_i P_i^2 + \beta_i P_{gi} + \gamma_i + \eta_i * \exp(\delta_i * P_{gi}) \quad \text{kg/hr} \tag{23}$$

Subject to equality and inequality constraints

Equality constraint

$$\sum P_{gi} - P_D - P_l = 0 \tag{3}$$

Where P_{gi} is generated real power, P_D is total demanded load and P_l is losses

Inequality constraints

$$P_{gi(min)} \leq P_{gi} \leq P_{gi(\max)} \tag{5}$$

The multi-objective economic and emission dispatch problem can be defined as

$$\text{Min } \{G = [F(P_{gi}) , E(P_{gi})] \} \tag{24}$$

2.5 FORMULATION BY THE WEIGHTING FUNCTION METHOD AND CARDINAL PRIORITY RANKING METHOD

The weighting function method is applied in this research. The weighting function converts the multi-objective problem into a scalar optimization. This approach yields meaningful results when solved many times with different values of w_i [50]. Hence by the usage of the weighting function the objective function can be reformulated as:

$$G = w_1 F(P_{gi}) + w_2 E(P_{gi}) \tag{25}$$

, where: $\sum_{i=1}^{n} w_i = 1$; n = number of objectives.

The weights given by w_1 , w_2 will be increased in steps of 0.1 from w_1 =1, $w_2 = 0$ which is a purely economic dispatch problem through to $w_1 = 0$, $w_2 = 1$ which will be a purely emission dispatch problem. The best combined objective will be determined by the usage of the cardinal priority ranking method. The purpose of the cardinal priority ranking will be to generate non- inferior solutions through the normalized weights. The formulated EED problem is solved using the weighting method to generate non inferior solutions which allows explicit trade-offs between objective levels for each non inferiors solution. Exploiting the fuzzy decision making theory, membership functions relating to objectives are defined. These membership functions play a key role in the finding of the best alternative among the non-inferior solutions [50].

2.51CARDINAL PRIORITY RANKING

The fuzzy sets are defined by equations called membership functions, which represent the goals of each objective function. The membership function represents the degree of achievement of the original objective function as a value between 0 and 1 with $\mu(F_i\ )$ =1 as completely satisfactory and $\mu(F_i\ )$= 0 as unsatisfactory. Such a linear membership function represents the decision maker's fuzzy goal of achievement, and at the same time scales the original objective functions with different physical units into measure of 0-1. By taking account of the minimum and maximum values of each objective function together with the rate of increase of membership satisfaction, the decision maker must determine the membership function $\mu(F_i\ )$ in a subjective manner given by:

$$\{1\ ;\ F_i \leq\ F_{imin}\}$$

$$\mu(F_i\ ) = \quad \left\{\frac{(F_{imax}-F_i)}{(F_{imax}-F_{min})};\ F_{imin} \leq F_i \leq\ F_{imax}\right\} \tag{26}$$

$$\{0\ ;\ F_{imax} \leq\ F_i\}$$

, where F_{imin} and $F_{imax}$are minimum and maximum values of i_{th} objective function in which the solution is expected. The value of the membership function indicates how much (in the scale from 0 to 1) a non–inferior solution has satisfied the i_{th} objective. The sum of the membership function values $\mu(F_i\ )$, i= 1, 2, … l , where l is the number of objectives, for all the objectives can be computed in order to measure the 'accomplishment' of each solution in satisfying the objectives. The 'accomplishment' of each non-dominated solution can be rated with respect to all the M non-dominated solutions by normalizing its 'accomplishment' over the sum of the 'accomplishment' of the M non-dominated solutions as follows:

$$\mu_D^k = \frac{\sum_{i=1}^{L} \mu(F_i)^k}{\sum_{k=1}^{M} \sum_{i=1}^{L} \mu(F_i)^k} \tag{27}$$

. Hence from the accomplishments given by μ_D^k , a set of non dominated solutions will be arrived at, from which the maximum value will be chosen as the best suited result.

Chapter 3

HYBRIDIZATION OF ARTIFICIAL BEE COLONY (ABC) AND PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHMS

3.1 BASIC PSO ALGORITHM FOR COMBINED ECONOMIC AND EMISSION DISPATCH PROBLEM

1. Define all the information needed for implementation;

   Cost coefficients, emission coefficients, B or loss coefficients, $P_{D,}P_{max,}P_{min,}V_{max,}$ and V_{min}
2. A population of NP x NG agents is created randomly.

   Where NP is the number of individuals and NG is the number of generators being evaluated
3. Randomly generate initial velocities for all particles also ensuring that the limits have not been exceeded.
4. Evaluate each particle's position according to the objective function. In this case it is the total operational cost given by G for each particle and evaluate their fitness (i.e minimization of the objective function)
5. Choose the best or minimum cost as the global best
6. Set the $P_{ij'}$ resulted so far as the local best for each individual and the cost arising from them as the local best cost
7. Save the global best and its real power generations
8. Set Iteration =0

   DO

9. Increment IT=IT+1
10. Compute

$$w = w_{max} - \frac{w_{max} - w_{min}}{IT} * IT_{max} \tag{28}$$

11. Update the velocity of the particles according to the formula

$$V_i(t) = wV_i(t-1) + c_i r_i\big(Pbest(t-1) - x_i(t-1)\big) + c_2 r_2\big(gbest(t-1) - x_i(t-1)\big) \tag{29}$$

The first term represents the particles inertia, the second being personal influence, the third being social influence.

w = inertia weight

c = acceleration factor.

r = a function that generates uniform random numbers of the range [0, 1]. Some authors call it random vectors; others call it random real numbers.

12. Evaluate the velocity to ascertain if it is the range of

$$v_{min} \leq v_i \leq v_{max} \tag{30}$$

13. Move particles to their new position

$$x_i(t) = x_i(t-1) + V_i(t) \tag{31}$$

14. Evaluate to ensure that limits have not been exceeded.
15. Evaluate the fitness of the new positions according to the evolutionary dispatch method
16. Compare each particle's fitness evaluation with its previous pbest. If the current value is better than the previous pbest, then set the pbest value equal to the

current value and the pbest location equal to the current location in the N dimensional search space.

IF ($G_i^{new} < G_i^{best}$) THEN set $G_i^{best} = G_i^{new}$ else $G_i^{best} = G_i^{best}$

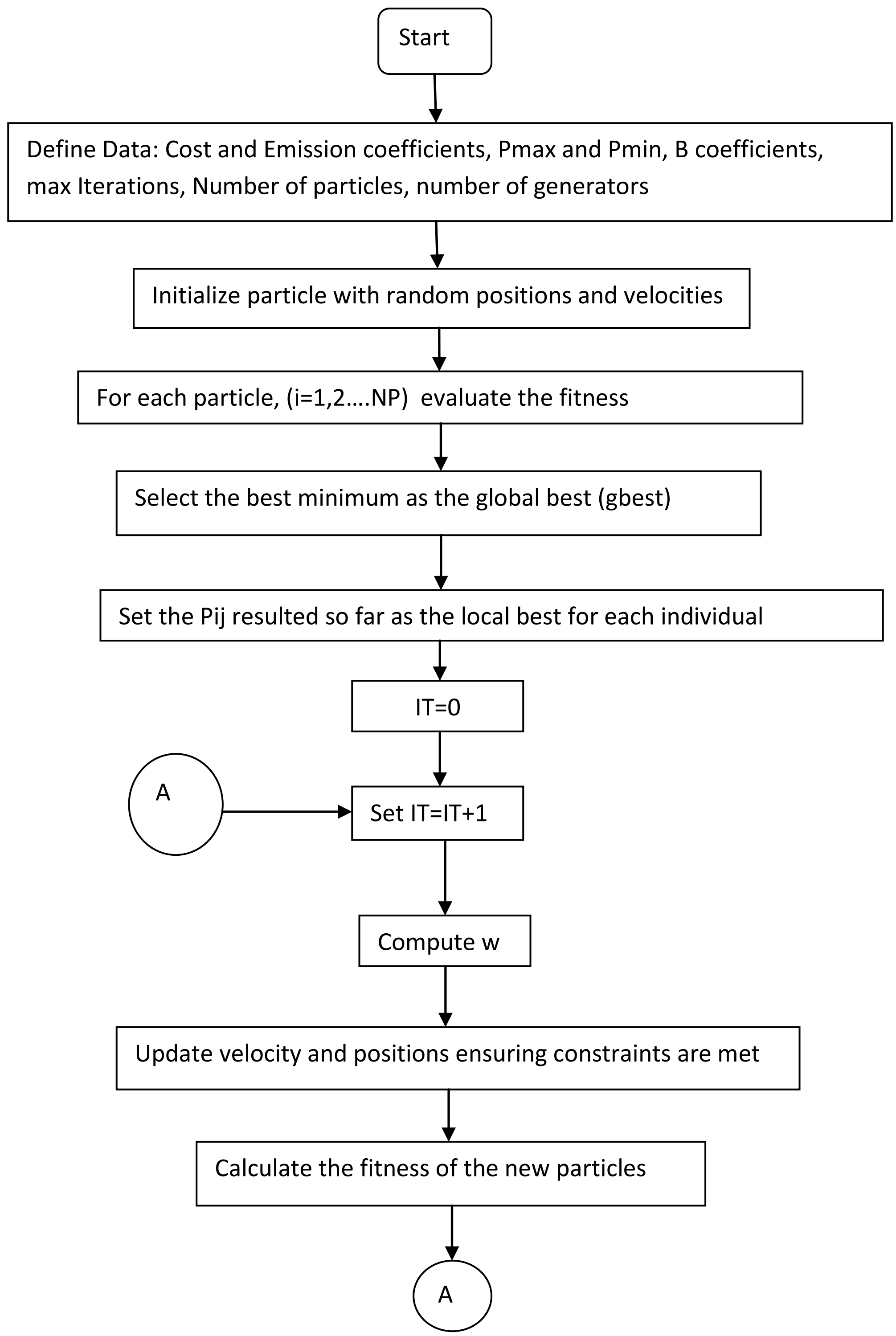
17. Compare the best current fitness evaluation with the population gbest. If the current value is better than the population gbest, then reset the gbest to the current best position and the fitness value to current fitness value.

    IF($gbest > G_i^{best}$) THEN set $gbest = G_i^{best}$

    WHILE ($IT < IT_{max}$)

18. Repeat for equal changes in step size of 0.1 from $w_1 = 1 \; and \; w_2 = 0$ to $w_1 = 0 \; and \; w_2 = 1$
19. STOP
20. Now from the results tabulated select $F_1^{max}, F_1^{min}, F_2^{max} \; and \; F_2^{min}$
21. Compute the membership functions and accomplishment function respectively
22. Choose the highest accomplishment function as the best combined objective

The flow chart below is repeated for w1 and w2 as they change from 1 and 0 respectively to 0 and 1 respectively in varying steps of 0.1. The membership functions and accomplishment functions are then computed for the best combination.


Start
Define Data: Cost and Emission coefficients, Pmax and Pmin, B coefficients, max Iterations, Number of particles, number of generators
Initialize particle with random positions and velocities
For each particle, (i=1,2….NP) evaluate the fitness
Select the best minimum as the global best (gbest)
Set the Pij resulted so far as the local best for each individual
IT=0
A
Set IT=IT+1
Compute w
Update velocity and positions ensuring constraints are met
Calculate the fitness of the new particles
A

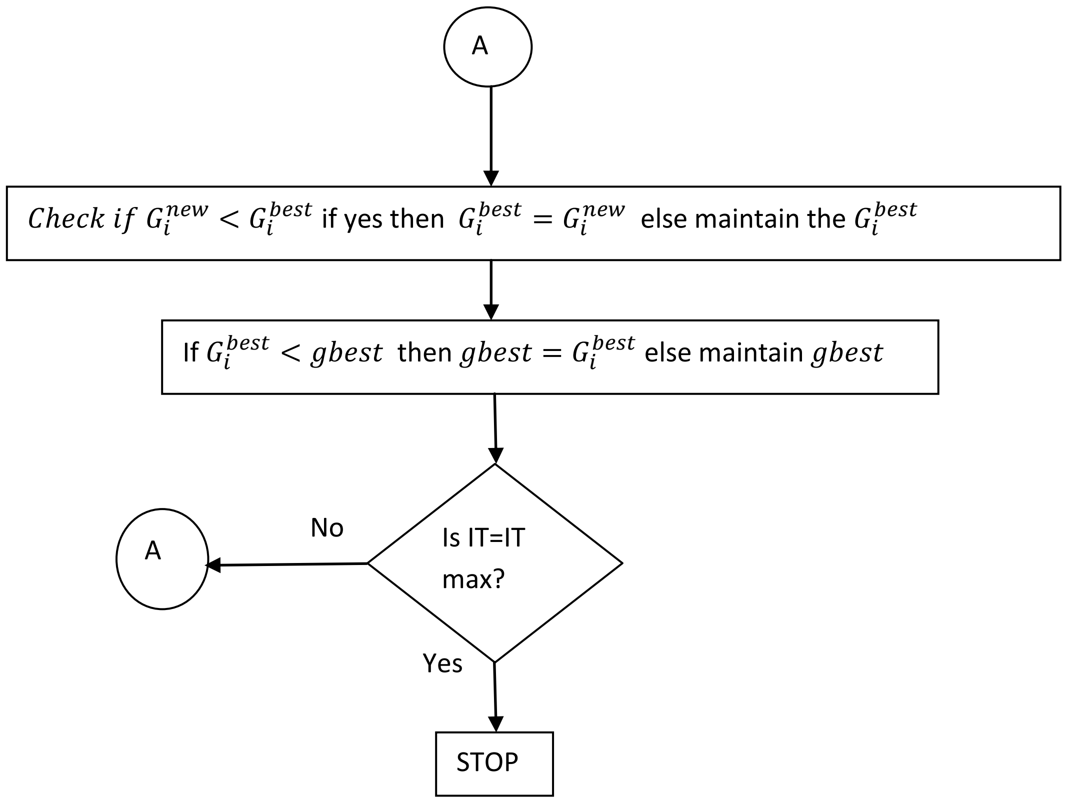


Figure 3.1: Flow chart showing particle swarm optimization

3.2 ARTIFICIAL BEE COLONY ALGORITHM FOR COMBINED ECONOMIC AND EMISSION DISPATCH PROBLEM

1. Define all the information needed for implementation;

   Cost coefficients, Emission coefficients, B coefficients, $P_{D,}P_{max,}P_{min,}$

2. Initialize all control parameters

   Colony Size, Limit, (which means number of trials after which a food source will be abandoned) , and Food Number.

3. Randomly generate initial population and check if constraints have been met
4. Evaluate the population using the objective function

Cycle =1

Repeat

5. Produce new solutions for the employed bees using

$v_{ij} = x_{ij} + \emptyset_{ij}(x_{ij} - x_{kj})$ (32)

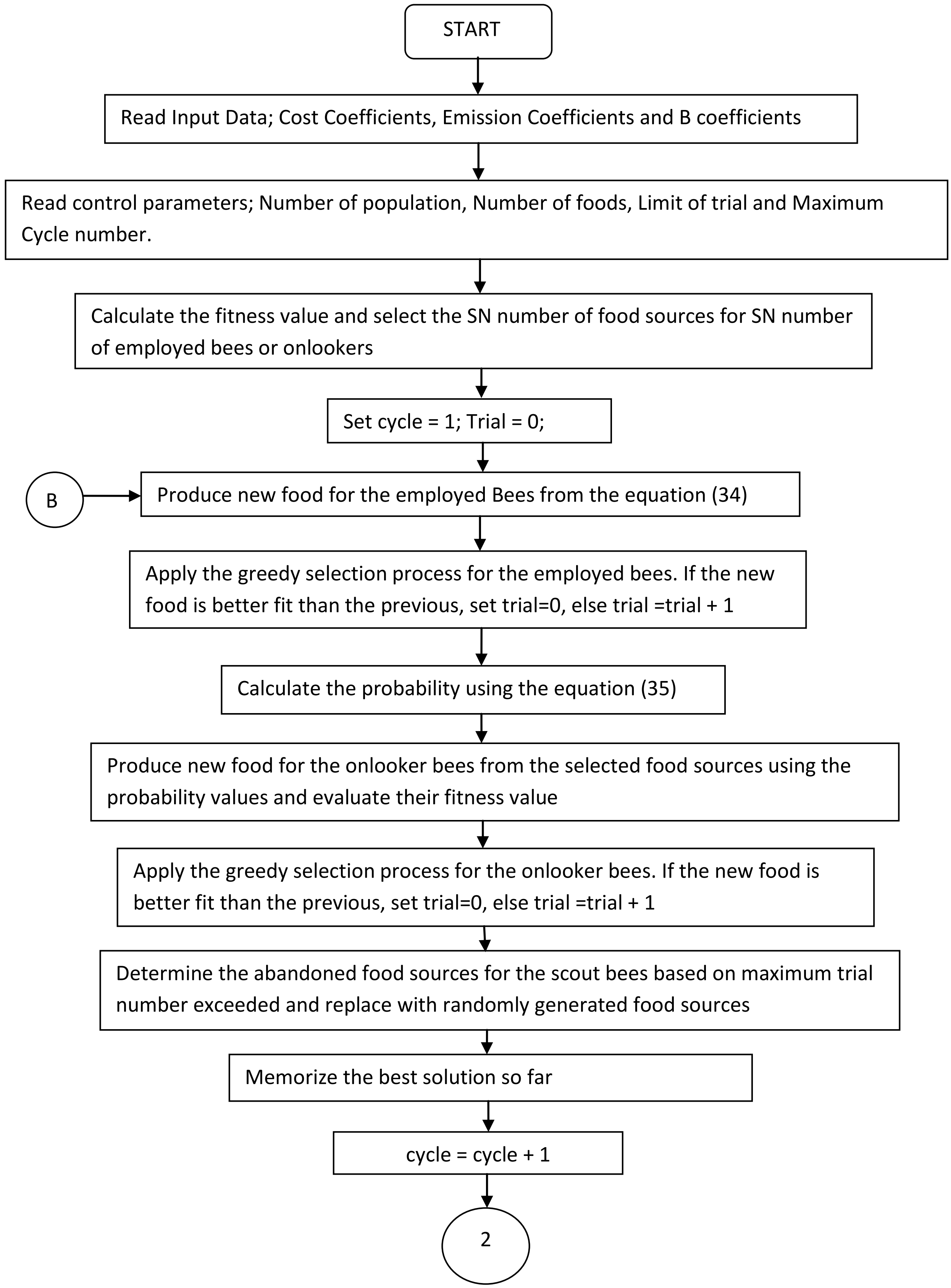
6. Apply the greedy selection process where the best solution is chosen
7. Calculate the probabilities of the solutions using the formula given by Dervis Karaboga [54]

$P_i = \frac{0.9*Fitness}{maxFitness} + 0.1$ (33)

8. Produce new solutions v_i for the onlookers from the solution of x_i selected depending on the P_i and evaluating them according to the objective function
9. Apply the selection process to them
10. Determine the abandoned food sources or solution (this happens when the trial number has been reached for a particular food source in failing to better its fitness) for a scout. If this exist then the food source is replaced with

$x_{ij} = x_j^{min} + \left(x_j^{max} - x_j^{min}\right) * rand \;\; j \in \{1,2 \ldots . D\}$ (34)

11. The best solution so far is memorized
12. Cycle = cycle +1
13. Until the maximum cycle number is achieved.
14. Repeat for equal changes in step size of 0.1 from $w_1 = 1 \; and \; w_2 = 0$ to $w_1 = 0 \; and \; w_2 = 1$
15. STOP
16. Now from the results tabulated select $F_1^{max}, F_1^{min}, F_2^{max} \; and \; F_2^{min}$
17. Compute the membership functions and accomplishment function respectively
18. Choose the highest accomplishment function as the best combined objective


START
Read Input Data; Cost Coefficients, Emission Coefficients and B coefficients
Read control parameters; Number of population, Number of foods, Limit of trial and Maximum Cycle number.
Calculate the fitness value and select the SN number of food sources for SN number of employed bees or onlookers
Set cycle = 1; Trial = 0;
B
Produce new food for the employed Bees from the equation (34)
Apply the greedy selection process for the employed bees. If the new food is better fit than the previous, set trial=0, else trial =trial + 1
Calculate the probability using the equation (35)
Produce new food for the onlooker bees from the selected food sources using the probability values and evaluate their fitness value
Apply the greedy selection process for the onlooker bees. If the new food is better fit than the previous, set trial=0, else trial =trial + 1
Determine the abandoned food sources for the scout bees based on maximum trial number exceeded and replace with randomly generated food sources
Memorize the best solution so far
cycle = cycle + 1
2

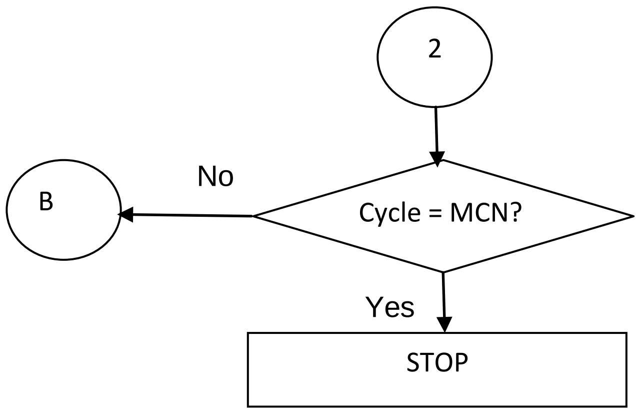


Figure 3.2: Flow chart for artificial bee colony

3.3 ABC_PSO HYBRID ALGORITHM FOR COMBINED ECONOMIC AND EMISSION DISPATCH PROBLEM

In this method of hybridization, ABC runs till its stopping criterion, which in this case is the maximum number of iterations, is met. Then the minimum values of individuals generated by the ABC are given to the PSO as its starting point. Ordinarily the PSO randomly generates its first individual sets, but in this case of hybridization that is taken care of by providing the starting point for the Particle Swarm Optimization who are the final values for individuals generated by the Artificial Bee Colony.

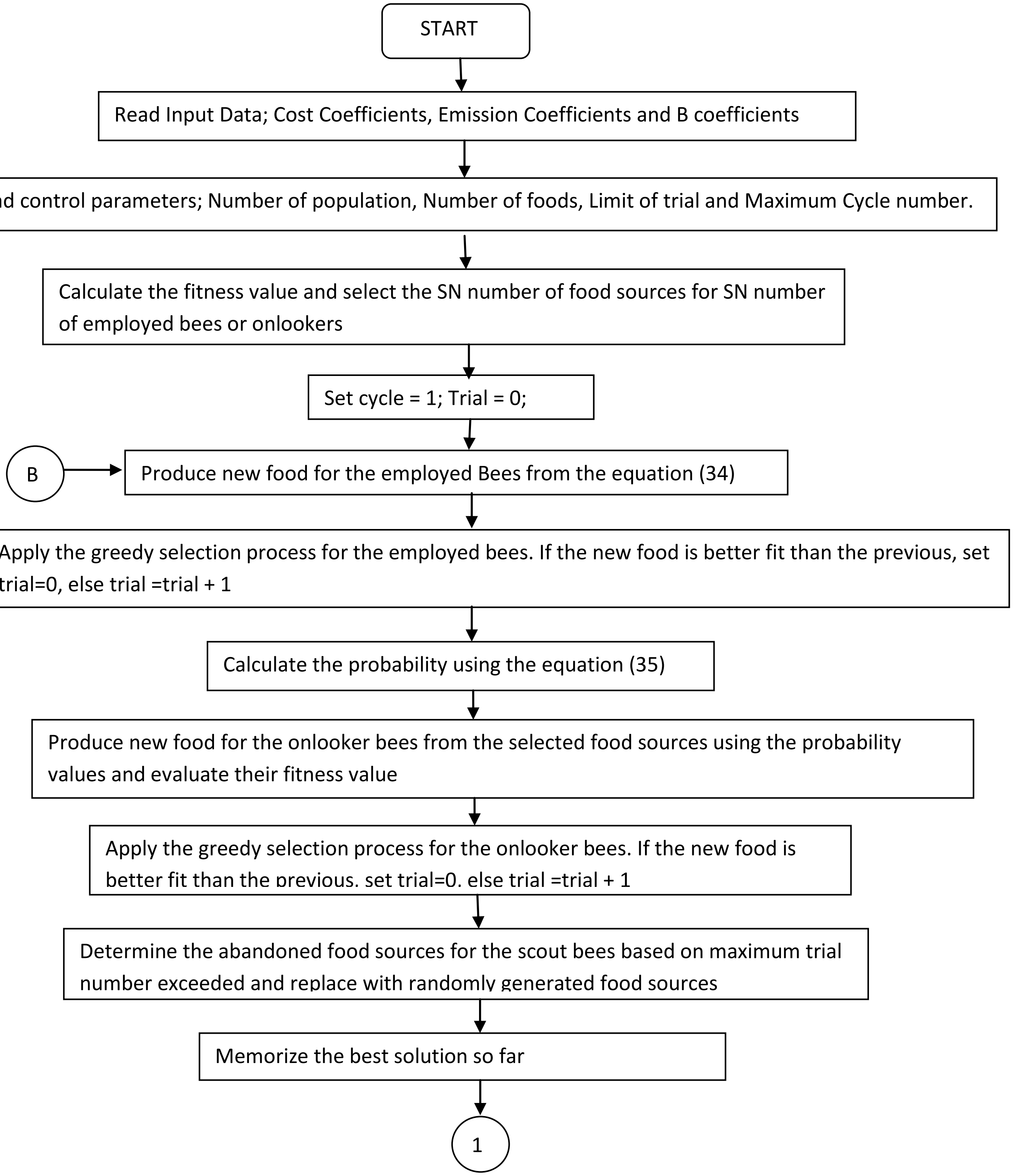
PSEUDO-CODE

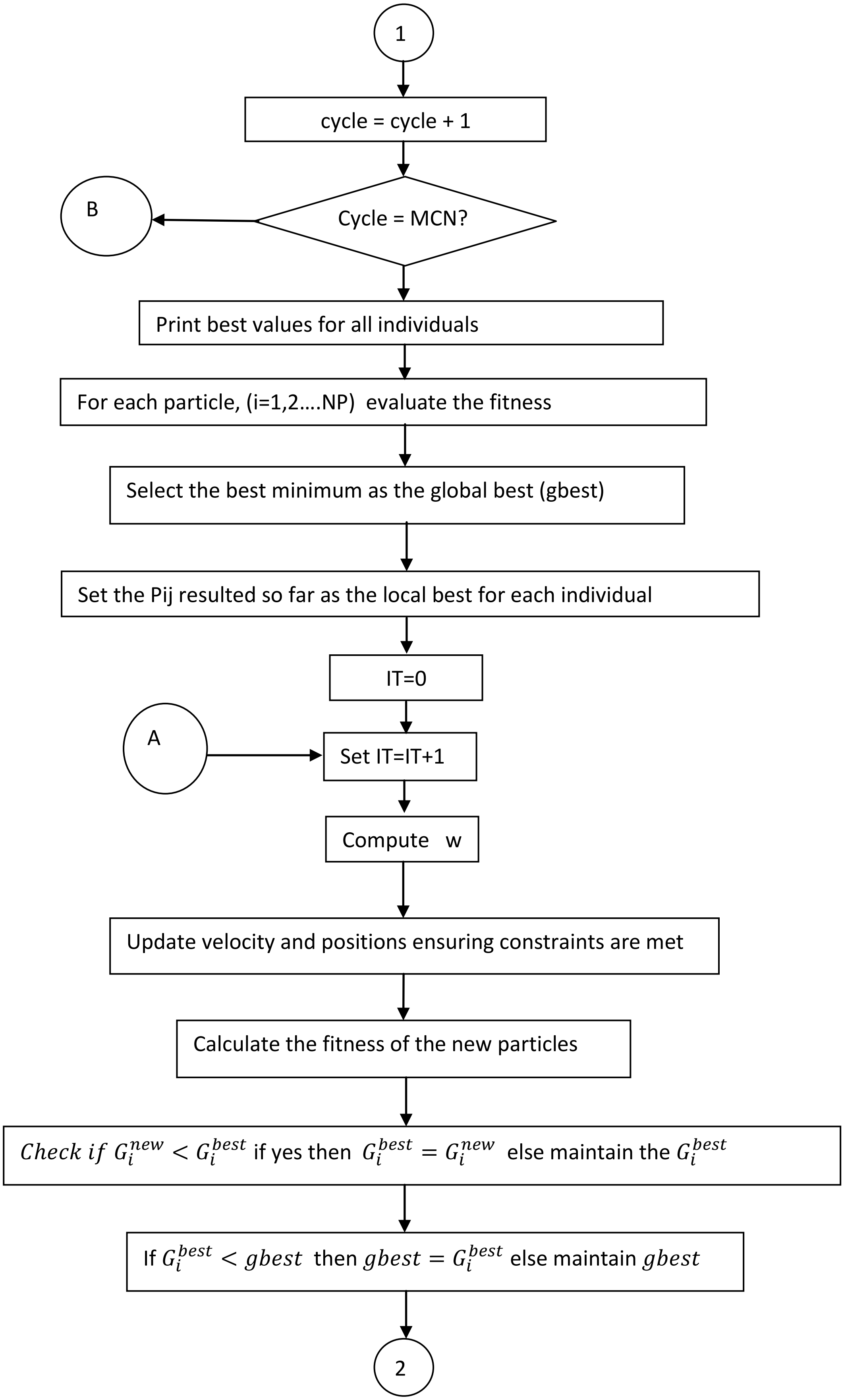
Run ABC

Generate minimum values for all individuals

Pass these individuals to the PSO as starting points

Run till stopping criteria is met


START
Read Input Data; Cost Coefficients, Emission Coefficients and B coefficients
Read control parameters; Number of population, Number of foods, Limit of trial and Maximum Cycle number.
Calculate the fitness value and select the SN number of food sources for SN number of employed bees or onlookers
Set cycle = 1; Trial = 0;
B
Produce new food for the employed Bees from the equation (34)
Apply the greedy selection process for the employed bees. If the new food is better fit than the previous, set trial=0, else trial =trial + 1
Calculate the probability using the equation (35)
Produce new food for the onlooker bees from the selected food sources using the probability values and evaluate their fitness value
Apply the greedy selection process for the onlooker bees. If the new food is better fit than the previous, set trial=0, else trial =trial + 1
Determine the abandoned food sources for the scout bees based on maximum trial number exceeded and replace with randomly generated food sources
Memorize the best solution so far
1


1
cycle = cycle + 1
B
Cycle = MCN?
Print best values for all individuals
For each particle, (i=1,2….NP) evaluate the fitness
Select the best minimum as the global best (gbest)
Set the Pij resulted so far as the local best for each individual
IT=0
A
Set IT=IT+1
Compute w
Update velocity and positions ensuring constraints are met
Calculate the fitness of the new particles
$Check\ if\ G_i^{new} < G_i^{best}$ if yes then $G_i^{best} = G_i^{new}$ else maintain the G_i^{best}
If $G_i^{best} < gbest$ then $gbest = G_i^{best}$ else maintain $gbest$
2

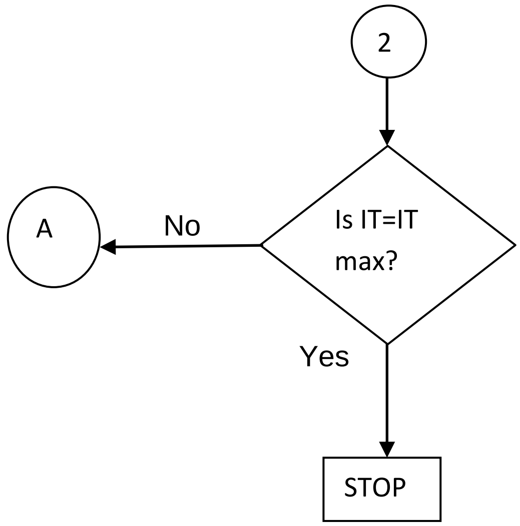


Figure 3.3: flow chat show the ABC_PSO hybrid algorithm

Chapter 4

RESULTS WITH LIMITED INTERPRETATION

The test cases systems that will be employed in validating the new algorithm are:

1. 3 generator test system [41]
2. 6 generator IEEE test system, Lee and Darwish 2008 [46]
3. 10 generator test system [52]

The test cases were subjected to ABC_PSO hybrid algorithm with varied load demands and compared with other results obtained by other authors who used different methods. The program was implemented on Matlab 2009. The control settings used for the PSO and the ABC algorithms are listed in the tables 4.1 and 4.2 respectively below.

Table 4.1: PSO settings

Particle Swarm Optimization control settings
Cognitive learning factor: c_1 ,= 2
Social learning factor: c_2 = 2
r_1, r_2 : randomly generated values between 0 and 1
Maximum number of iterations = 1000
Population number = 15 individuals

Table 4.2: ABC settings

Artificial Bee Colony control settings
Colony size = 30
Food Number = 15
Limit of trials = 90
Maximum cycle Number = 500

4.1 Test Case Study 1: 3 Generator test system

Data for test system showing cost coefficients (a to c), emission coefficients (α to γ), P_{min} in MW and P_{max} in MW. Data was taken from Lakshmi Devi et al [41]

Table 4.3: Coefficients of fuel cost, emission and capacities of the 3 generating units.

Unit	a Rs/MW²h	b Rs/MWh	c Rs/h	α kg/MW²h	β kg/MWh	γ kg/h	$Pmin$ MW	$Pmax$ MW
1	0.03546	38.30553	1243.5311	0.00683	-0.54551	40.2669	70	200
2	0.02111	36.32782	1658.5696	0.00461	-0.5116	42.89553	100	300
3	0.01799	38.27041	1356.6592	0.00461	-0.5116	42.89553	120	300

Table 4.4: Loss coefficient matrix of 3 generating units

0.000071	0.00003	0.000025
0.00003	0.000069	0.000032
0.000025	0.000032	0.00008

Using the above data in tables 4.3 and 4.4 above, the following results were obtained for the various demand levels:

Table 4.5: Showing results for 3 generators with 350MW load demand.

Weighting functions		Fuel Cost (Rs/hr)	Emission (kg/hr)	Membership functions		Accomplishment function
w1	w2	F	E	μ_1	μ_2	μ_D^k
1	0	18564.5	164.95	1	0	0.074968
0.9	0.1	18564	164.7041	0.9839	0.0414	0.076864
0.8	0.2	18565	164.4164	0.9823	0.0898	0.080373
0.7	0.3	18565	164.0776	0.9786	0.1469	0.084376
0.6	0.4	18565	163.6733	0.9715	0.2149	0.088942
0.5	0.5	18565	163.184	0.9584	0.2973	0.094137
0.4	0.6	18566	162.5829	0.9344	0.3985	0.099924
0.3	0.7	18567	161.835	0.8887	0.5244	0.105937
0.2	0.8	18570	160.9033	0.796	0.6813	0.11075
0.1	0.9	18577	159.8046	0.5846	0.8662	0.108763
0	1	18595	159.01	0	1	0.074968

Using a load demand of 350MW with the implementation of the weighting function along with the cardinal priority ranking method, the table 4.5 above generated shows that at $w_1 = 1$, and $w_2 = 0$, the multi-objective problem has been reduced to a complete economic dispatch problem hence the minimum fuel cost which in this case generated is 18564.5 Rs/hr whilst its corresponding emission at that level is given by 164.95kg/hr. At $w_1 = 0, w_2 = 1$, the multi-objective problem has been reduced to a complete emission dispatch problem which gives the minimum emission as 159.01kg/hr and its corresponding fuel cost as 18595 Rs/hr. By varying the weighting functions from their maximum of 1 to 0, we can see the conflicting nature of the two objectives. The fuel cost is at a minimum when $w_1 = 1$, and maximum at $w_1 = 0$. The emission reduces from its maximum value when fuel cost is at its minimum value to its minimum value when the fuel cost is at its maximum value. This is depicted in Figure 4.1 below. Hence the conflicting nature of these two objectives is explicitly depicted in the weighting function method. In determining the best combination of the two objectives to give us a non-dominated solution the cardinal priority ranking method is employed. The $F_i max$ and $F_i min$, $(i = 1,2)$ are taken from the highest and lowest values of each objective function. The highest accomplishment function is taken to be the best result which meets the multi-objective problem.

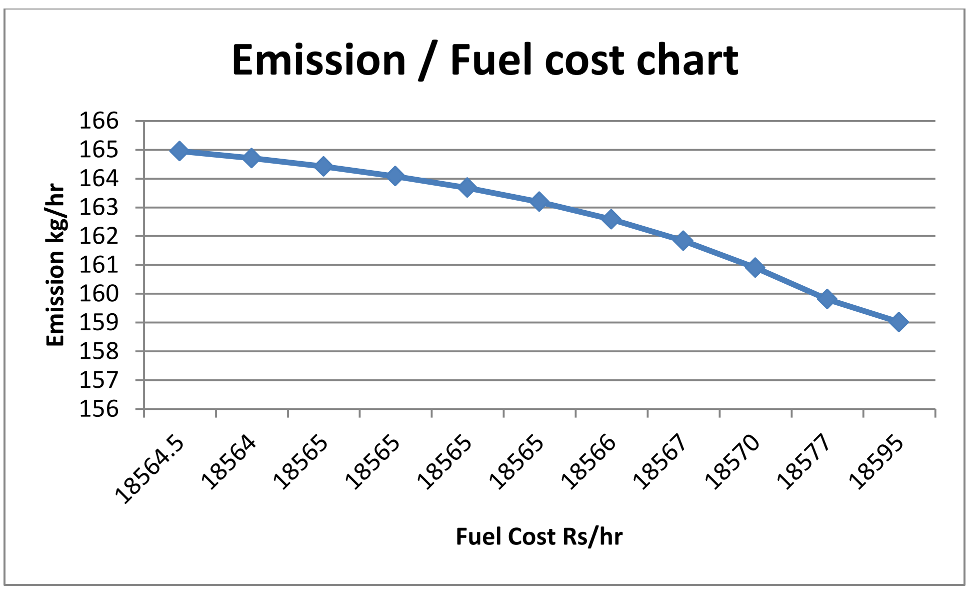


Figure 4.1: Chart showing the conflicting nature of fuel cost and emission objectives

The Table 4.6 below shows the real power ratings for the 3 generators and losses that resulted in the pure economic dispatch scenario at $w_1 = 1$, $w_2 = 0$. It also shows the real power ratings for the 3 generators and losses for the pure emission dispatch scenario at $w_1 = 0$, $w_2 = 1$ and the real power ratings for the 3 generators and losses for the best combination of the two objectives as chosen by the cardinal priority ranking.

Table 4.6: showing results for power ratings for economic dispatch, emission dispatch and CEED at load demand of 350MW for the 3 generator test system

Load demand of 350MW			
	Economic	Emission	EED
P1 (MW)	70.3012	91.8158	79.5131
P2 (MW)	156.2673	131.9884	145.5157
P3 (MW)	129.2084	131.8327	130.678
Losses (MW)	**5.77**	**5.6369**	**5.7**
Fuel Cost Rs/hr	**18564.5**	**18595**	**18570**
Emission kg/hr	**164.95**	**159.01**	**160.9033**

Using a load demand of 500MW with the implementation of the weighting function along with the cardinal priority ranking method, the table 4.7 below generated shows that at $w_1 = 1$, and $w_2 = 0$, the multi-objective problem has been reduced to a pure economic dispatch problem hence the minimum fuel cost which in this case generated is 25465.5 Rs/hr whilst its corresponding emission at that level is given by 318.0212 kg/hr. At $w_1 = 0, w_2 = 1$, the multi-objective problem has been reduced to a pure emission dispatch problem which gives the minimum emission as 311.0785 kg/hr and its corresponding fuel cost as 25502 Rs/hr. Between the varying of the weighting functions from their maximum of 1 to 0, we can see the conflicting nature of the two objectives. The fuel cost at a minimum when $w_1 = 1$, and maximum at $w_1 = 0$. The emission reduces from its maximum value when fuel cost is at its minimum value to its minimum value when the fuel cost is at its maximum value.

Table 4.7: Showing results for 3 generators with 500MW load demand.

Weighting functions		Fuel Cost (Rs/hr)	Emission (kg/hr)	Membership functions		Accomplishment function
w1	w2	F	E	μ_1	μ_2	μ_D^k
1	0	25465.5	318.0212	1	0	0.074243
0.9	0.1	25465	317.7368	1	0.041	0.077287
0.8	0.2	25466	317.4053	0.9988	0.0887	0.08074
0.7	0.3	25466	317.0413	0.9952	0.145	0.084652
0.6	0.4	25466	316.5469	0.9882	0.2124	0.089137
0.5	0.5	25466	315.98	0.9753	0.294	0.094237
0.4	0.6	24567	315.2818	0.9516	0.3946	0.099947
0.3	0.7	25469	314.4099	0.9064	0.5202	0.105916
0.2	0.8	25472	313.3189	0.8142	0.6773	0.110734
0.1	0.9	25480	312.0235	0.6024	0.8639	0.108863
0	1	25502	311.0785	0	1	0.074243

The table 4.8 below shows the real power ratings for the 3 generators and losses that were resulted in the pure economic dispatch scenario at $w_1 = 1, w_2 = 0$. It also shows the real power ratings for the 3 generators and losses for the pure emission dispatch scenario at $w_1 = 0, w_2 = 1$ and the real power ratings for the 3 generators and losses for the best combination of the two objectives as chosen by the cardinal priority ranking.

Table 4.8: showing results for power ratings for economic dispatch, emission dispatch and CEED at load demand of 500MW for the 3 generator test system.

Load demand of 500MW			
	Economic	Emission	EED
P1(MW)	105.8799	131.5442	116.909
P2 (MW)	212.728	190.2644	202.9017
P3 (MW)	193.3065	189.8642	191.9877
Losses (MW)	**11.9144**	**11.6727**	**11.7984**
Fuel Cost Rs/hr	**25465.5**	**25502**	**25472**
Emission kg/hr	**318.0212**	**311.0785**	**313.3189**

Table 4.9: Showing results for 3 generators with 700MW load demand.

Weighting functions		Fuel Cost (Rs/hr)	Emission (kg/hr)	Membership functions		Accomplishment function
w1	w2	F	E	μ_1	μ_2	μ_D^k
1	0	35424.4	660.7442	1	0	0.074367
0.9	0.1	35424	660.3664	0.9987	0.0408	0.077305
0.8	0.2	35425	659.9258	0.9971	0.0884	0.080726
0.7	0.3	35425	659.406	0.9935	0.1445	0.08463
0.6	0.4	35425	658.7844	0.9865	0.2117	0.089107
0.5	0.5	35426	658.0301	0.9736	0.2932	0.094208
0.4	0.6	35427	657.1004	0.9499	0.3936	0.099912
0.3	0.7	35429	655.9385	0.9047	0.5191	0.105884
0.2	0.8	35434	654.4827	0.8123	0.6763	0.110703
0.1	0.9	35444	652.7516	0.5996	0.8633	0.108792
0	1	35473	651.4859	0	1	0.074367

The table 4.9 above shows the results of varying the weighting functions between the two objectives and using the cardinal priority ranking to choose the best non dominated solution at a load demand level of 700MW.

The table 4.10 below shows the real power ratings for the committed generators and the losses at the pure economic dispatch, emission dispatch and the best combined economic and emission dispatch scenarios.

Table 4.10: showing results for power ratings for economic dispatch, emission dispatch and CEED at load demand of 700MW for the 3 generator test system.

Load demand of 700 MW			
	Economic	Emission	EED
P1 (MW)	154.5139	185.7012	167.9602
P2 (MW)	289.3597	269.9692	280.7421
P3 (MW)	279.8944	268.3589	274.8587
Losses (MW)	**23.76**	**23.3293**	**23.5611**
Fuel cost Rs/hr	**35424.4**	**35473**	**35434**
Emission kg/hr	**660.7442**	**651.3589**	**654.4827**

4.2 Test Case Study 2 : IEEE 30 bus 6 generator test system

Data for test system showing cost coefficients (a to c), emission coefficients (α to γ), P_{min} in MW and P_{max} in MW. Data was taken from Y. Sonmez [46]. For diagram please refer to appendix 4.

Table 4.11: Coefficients of fuel cost, emission and capacities of the 6 generating units.

Unit	a $/MW²h	b $/MWh	c $/h	α kg/MW²h	β kg/MWh	γ kg/h	$Pmin$ MW	$Pmax$ MW
1	0.15247	38.53973	756.79886	0.00419	0.32767	13.85932	10	125
2	0.10587	46.15916	451.32513	0.00419	0.32767	13.85932	10	150
3	0.02803	40.3965	1049.9977	0.00683	-0.54551	40.2669	40	250
4	0.03546	38.30553	1243.5311	0.00683	-0.54551	40.2669	35	210
5	0.02111	36.32782	1658.569	0.00461	-0.51116	42.89553	130	325
6	0.01799	38.27041	1356.27041	0.00461	-0.51116	42.89553	125	315

Table 4.12: loss coefficient matrix of the 6 generating units.

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	0.0000016	0.002085	0.000831	0.000024	-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

Using the above data in tables 4.11 and 4.12 above, the following results were obtained for the various demand levels:

The table 4.13 below shows the results of varying the weighting functions between the two objectives and using the cardinal priority ranking to choose the best non dominated solution at load demand of 500MW.

Table 4.13: Showing results for 6 generators with 500MW load demand.

Weighting functions		Fuel Cost ($/hr)	Emission (kg/hr)	Membership functions		Accomplishment function
w1	w2	F	E	μ_1	μ_2	μ_D^k
1	0	28086	306.28	0.9997	0	0.081535
0.9	0.1	28086	305.8834	0.9997	0.0123	0.082538
0.8	0.2	28086	305.405	0.9995	0.0272	0.083737
0.7	0.3	28086	304.818	0.9992	0.0455	0.085205
0.6	0.4	28087	304.0807	0.9984	0.0685	0.087016
0.5	0.5	28088	303.1275	0.997	0.0982	0.089324
0.4	0.6	28089	301.8484	0.994	0.138	0.092325
0.3	0.7	28093	300.0447	0.9876	0.1941	0.096379
0.2	0.8	28103	296.7224	0.9677	0.2976	0.103197
0.1	0.9	28157	288.0057	0.8678	0.569	0.117185
0	1	28625	274.1632	0	1	0.081559

The table 4.14 below shows the real power ratings for the committed generators and the losses at the pure economic dispatch, emission dispatch and the best combined economic and emission dispatch scenarios.

Table 4.14: showing results for power ratings for economic dispatch, emission dispatch and CEED at load demand of 500MW for the 6 generator test system

	Economic	Emission	EED
P1 (MW)	52.0811	58.0262	54.6001
P2 (MW)	29.0774	43.7521	32.484
P3 (MW)	40	75.7412	48.5483
P4 (MW)	68.0743	83.939	77.5172
P5 (MW)	191.4619	133.4165	167.2813
P6 (MW)	136.4027	128.7872	137.2868
Loss MW	**17.0974**	**23.6771**	**17.7177**
Fuel cost $/hr	**28086**	**28625**	**28157**
Emission kg/hr	**306.28**	**274.1632**	**288.0057**

The table 4.15 below shows the results of varying the weighting functions between the two objectives and using the cardinal priority ranking to choose the best non dominated solution at load demand of 700MW. The highest accomplishment function is chosen as the best combined economic and emission dispatch results, thus highlighted.

Table 4.15: Showing results for 6 generators with 700MW load demand

Weighting functions		Fuel Cost ($/hr)	Emission (kg/hr)	Membership functions		Accomplishment function
w1	w2	F	E	μ_1	μ_2	μ_D^k
1	0	38206	536.4332	1	0	0.079832
0.9	0.1	38206	535.279	1	0.0156	0.081078
0.8	0.2	38206	533.8785	0.9998	0.00346	0.080093
0.7	0.3	38207	532.1434	0.9994	0.058	0.084415
0.6	0.4	38208	529.938	0.9984	0.0879	0.086722
0.5	0.5	38210	527.0414	0.9964	0.1271	0.089692
0.4	0.6	38215	523.07	0.9924	0.1808	0.093659
0.3	0.7	38226	517.2949	0.9834	0.2589	0.099176
0.2	0.8	38255	508.1512	0.96	0.3827	0.107191
0.1	0.9	38357	491.6887	0.8766	0.6054	0.118311
0	1	39429	462.5234	0	1	0.079832

The table 4.16 below shows the real power ratings for the committed generators and the losses at the pure economic dispatch, emission dispatch and the best combined economic and emission dispatch scenarios.

Table 4.16: showing results for power ratings for economic dispatch, emission dispatch and CEED at load demand of 700MW for the 6 generator test system

	Economic	Emission	EED
P1 (MW)	76.061	105.2728	83.7406
P2 (MW)	49.0868	76.4622	55.3728
P3 (MW)	45.4208	92.967	65.3057
P4 (MW)	102.7329	109.7931	107.0548
P5 (MW)	266.3032	183.126	232.1865
P6 (MW)	191.3383	169.9964	187.8794
Loss MW	**30.9432**	**37.6172**	**31.5399**
Fuel Cost $/hr	**38206**	**39429**	**38357**
Emission kg/hr	**536.4332**	**462.5234**	**491.6887**

Table 4.17: Showing results for 6 generators with 900MW load demand

Weighting functions		Fuel Cost ($/hr)	Emission (kg/hr)	Membership functions		Accomplishment function
w1	w2	F	E	μ_1	μ_2	μ_D^k
1	0	49294	849.2321	0.9998	0	0.083394
0.9	0.1	49294	848.4993	0.9998	0.0073	0.084003
0.8	0.2	49295	847.6082	0.9997	0.0162	0.084737
0.7	0.3	49295	846.501	0.9995	0.0273	0.085646
0.6	0.4	49296	845.0886	0.999	0.0414	0.08678
0.5	0.5	49297	843.2248	0.9981	0.06	0.088257
0.4	0.6	49300	840.6527	0.9963	0.0857	0.09025
0.3	0.7	49308	836.8761	0.9921	0.1234	0.093044
0.2	0.8	49353	822.5053	0.9656	0.2668	0.102795
0.1	0.9	49528	794.4351	0.8642	0.5471	0.117717
0	1	51014	749.0736	0	0.9996	0.083377

The table 4.17 above shows the results of varying the weighting functions between the two objectives and using the cardinal priority ranking to choose the best non dominated solution at load demand of 900MW. The highest accomplishment function is chosen as the best combined economic and emission dispatch results, thus highlighted.

The table 4.18 below shows the real power ratings for the committed generators and the losses at the pure economic dispatch, emission dispatch and the best combined economic and emission dispatch scenarios.

Table 4.18: showing results for power ratings for economic dispatch, emission dispatch and CEED at load demand of 900MW for the 6 generator test system

	Economic	Emission	EED
P1 (MW)	103.447	125	114.5873
P2 (MW)	70.1428	111.7156	78.3952
P3 (MW)	60.8915	109.5309	80.6928
P4 (MW)	139.3762	143.3235	137.1267
P5 (MW)	325	248.6299	300.203
P6 (MW)	251.7056	224.5396	238.5537
Loss MW	**50.5631**	**62.7404**	**49.5588**
Fuel cost $/hr	**49294**	**51014**	**49528**
Emission kg/hr	**849.2321**	**749.0736**	**794.4351**

4.3 Test Case Study 3: 10 Generator test system

Data was taken from M. Basu [52]

Table 4.19: Coefficients of fuel cost and capacities of the 10 generating units

Unit	a $/MW²h	b $/MWh	c $/h	d $/h	e rad/MW	$Pmin$ (MW)	$Pmax$ (MW)
1	0.12951	40.5407	1000.403	33	0.0174	10	55
2	0.10908	39.5804	950.606	25	0.0178	20	80
3	0.12511	36.5104	900.705	32	0.0162	47	120
4	0.12111	39.5104	800.705	30	0.0168	20	130
5	0.15247	38.539	756.799	30	0.0148	50	160
6	0.10587	46.1592	451.325	20	0.0163	70	240
7	0.03546	38.3055	1243.531	20	0.0152	60	300
8	0.02803	40.3965	1049.998	30	0.0128	70	340
9	0.02111	36.3278	1658.569	60	0.0136	135	470
10	0.01799	38.2704	1356.659	40	0.0141	150	470

Table 4.20: Emission coefficients of the 10 generating units

Unit	α lb/MW²h	β lb/MWh	γ lb/h	η lb/h	δ 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	40.2699	0.248	0.0129
8	0.0068	-0.5455	40.2699	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

Table 4.21: loss coefficient matrix of the 10 generating units

B- coefficients									
0.000049	0.000014	0.000015	0.000015	0.000016	0.000017	0.000017	0.000018	0.000019	0.00002
0.000014	0.000045	0.000016	0.000016	0.000017	0.000015	0.000015	0.000016	0.000018	0.000018
0.000015	0.000016	0.000039	0.00001	0.000012	0.000012	0.000014	0.000014	0.000016	0.000016
0.000015	0.000016	0.00001	0.00004	0.000014	0.00001	0.000011	0.000012	0.000014	0.000015
0.000016	0.000017	0.000012	0.000014	0.000035	0.000011	0.000013	0.000013	0.000015	0.000016
0.000017	0.000015	0.000012	0.00001	0.000011	0.000036	0.000012	0.000012	0.000014	0.000015
0.000017	0.000015	0.000014	0.000011	0.000013	0.000012	0.000038	0.000016	0.000016	0.000018
0.000018	0.000016	0.000014	0.000012	0.000013	0.000012	0.000016	0.00004	0.000015	0.000016
0.000019	0.000018	0.000016	0.000014	0.000015	0.000014	0.000016	0.000015	0.000042	0.000019
0.00002	0.000018	0.000016	0.000015	0.000016	0.000015	0.000018	0.000016	0.000019	0.000044

Using the above data in tables 4.19, 4.20, and 4.21 the following results were obtained for a load demand of 2000 MW:

Table 4.22: Showing results for 10 generators with 2000MW load demand

Weighting functions		Fuel Cost (\$/hr)	Emission (lb/hr)	Membership functions		Accomplishment function
w1	w2	F	E	μ_1	μ_2	μ_D^k
1	0	111500	4571.2	1	0.093	0.088334
0.9	0.1	111500	4562	1	0.1077	0.089522
0.8	0.2	111530	4638.2	0.9949	0.0302	0.082846
0.7	0.3	111530	4610.6	0.9946	0.0622	0.085408
0.6	0.4	111540	4626.4	0.9915	0.0167	0.081481
0.5	0.5	111550	4566.9	0.9944	0.0167	0.081715
0.4	0.6	111560	4478.9	0.9885	0.2247	0.098048
0.3	0.7	111640	4437.6	0.9776	0.2648	0.100408
0.2	0.8	111760	4405.4	0.9562	0.3131	0.102582
0.1	0.9	113410	4125.1	0.6096	0.7343	0.108611
0	1	116420	3932.3	0.0028	1	0.081044

The table 4.22 above shows the results of varying the weighting functions between the two objectives and using the cardinal priority ranking to choose the best non dominated solution at load demand of 2000MW. The highest accomplishment function is chosen as the best combined economic and emission dispatch results, thus highlighted.

The table 4.23 below shows the real power ratings for the committed generators and the losses at the pure economic dispatch, pure emission dispatch and the best combined economic and emission dispatch scenarios:

Table 4.23: showing results for power ratings for economic dispatch, emission dispatch and CEED at load demand of 2000MW for the 10 generator test system

	Economic	Emission	EED
P1 (MW)	55	55	55
P2 (MW)	80	80	80
P3 (MW)	106.93	81.9604	81.14
P4 (MW)	100.5668	78.8216	84.216
P5 (MW)	81.49	160	138.3377
P6 (MW)	83.011	240	167.5086
P7 (MW)	300	300	296.8338
P8 (MW)	340	292.78	311.5824
P9 (MW)	470	401.8478	420.3363
P10 (MW)	470	391.2096	449.1598
Losses MW	**87.0344**	**81.5879**	**84.1736**
Fuel cost $/hr	**111500**	**116420**	**113420**
Emission lb/hr	**4571.2**	**3932.3**	**4120.1**

Chapter 5

ANALYSIS AND DISCUSSIONS

5.1 FORMULATION

This formulation was done using the existing quadratic functions that define fuel cost functions and emission along with valve point loading effects which were responsible for discontinuities in the cost curves as well its non convex nature.

With the use of the weighting functions which were varied from 1 to 0 for both objectives contradictorily, the best results that satisfied the multi-objective problem was decided on by the use of the decision maker. In this case the decision maker employed was the cardinal priority ranking method. Here the membership functions were used to arrive at the accomplishment function, amongst which the best result was chosen without bias.

5.2 COMPUTER PROGRAM

The program was implemented using Matlab 2009. The optimum results generated by the Artificial Bee Colony were passed on to the Particle Swarm Optimization as initial values to generate the final results. For each given load demand the program was run once. However it may be run a number of times to assess its accuracy.

5.3 NUMERICAL RESULTS

5.3.1 3- Generator test system

5.3.1.1 Economic Dispatch comparison

Table 5.3.1: Economic dispatch comparison for 3 generator test system at 350MW demand

Load demand = 350 MW			
	ABC_PSO [this method]	PSO [41]	GA [41]
P1 (MW)	70.301		
P2 (MW)	156.27		
P3 (MW)	129.21		
Losses MW	**5.77**		
Fuel Cost Rs/hr	**18565**	**18464.6**	**18566**
Emission kg/hr	**164.95**	**164.359**	**164.4**

When the results of the hybrid are compared with that of PSO and GA at demand of 350MW in table 5.3.1 above, considering economic dispatch only, it is observed that the hybrid produces lower fuel cost of 0.1Rs/hr lower than PSO and 1.Rs/hr lower than GA. However its emission is slightly higher than the PSO and GA by 0.591kg/hr.

Table 5.3.2: Economic dispatch comparison for 3 generator test system at 500MW demand

Load demand = 500 MW.			
	ABC_PSO [this method]	PSO [41]	GA [41]
P1 (MW)	105.8799		
P2 (MW)	212.728		
P3 (MW)	193.3065		
Losses MW	**11.9144**		
Fuel Cost Rs/hr	**25465.5**	**25465.6**	**25469**
Emission kg/hr	**318.0212**	**317.233**	**317.36**

Comparing results at 500MW load demand in table 5.3.2 above, again the hybrid produces lower fuel cost of 0.1 Rs/hr in comparison with PSO and 3.8 Rs/hr in comparison with GA. However its emission is higher by 0.7882kg/hr in comparison with PSO and 0.6592kg/hr in comparison with GA.

Table 5.3.3: Economic dispatch comparison for 3 generator test system at 700MW demand

Load demand = 700 MW			
	ABC_PSO [this method]	PSO [41]	GA[41]
P1 (MW)	154.51		
P2 (MW)	289.36		
P3 (MW)	279.89		
Losses MW	**23.76**		
Fuel Cost Rs/hr	**35424**	**35424.7**	**35426.8**
Emission kg/hr	**660.74**	**659.467**	**659.623**

Considering results at the 700MW demand level in table 5.3.3 above, the hybrid produces a lower fuel cost of 0.3 Rs/hr in comparison with PSO and 2.4 Rs/hr in comparison with GA. However its emission is higher by 1.2772kg/hr with respect to PSO and 1.12kg/hr in comparison with GA.

5.3.1.2 Emission Dispatch comparison

Table 5.3.4: Emission dispatch comparison for 3 generator test system at 350MW demand

Load demand = 350MW			
	ABC_PSO [this method]	PSO [41]	GA [41]
P1 (MW)	91.816		
P2 (MW)	131.99		
P3 (MW)	131.83		
Losses MW	**5.6369**		
Fuel Cost Rs/hr	**18595**	**18595**	**18596**
Emission kg/hr	**159.01**	**159.01**	**159.03**

Considering emission dispatch only in table 5.3.4 above, at a load demand of 350MW the hybrid and the PSO fuel costs are equal and lower by 1.3 Rs/hr than that of the GA. Its emission at the same demand level is also comparable with PSO and lower than GA by 0.016kg/hr.

At 500MW load demand in table 5.3.5 below, the hybrid produces a lower fuel cost of 0.02 Rs/hr than PSO and 3.1 Rs/hr lower that GA. It emission is comparable with that of PSO and lower by 0.0805kg/hr than that of the GA.

Table 5.3.5: Emission dispatch comparison for 3 generator test system at 500MW demand

Load demand = 500MW			
	ABC_PSO [this method]	PSO [41]	GA [41]
P1 (MW)	131.54		
P2 (MW)	190.26		
P3 (MW)	189.86		
Losses MW	**11.673**		
Fuel Cost Rs/hr	**25502**	**25502**	**25505**
Emission kg/hr	**311.08**	**311.08**	**311.16**

Table 5.3.6 : Emission dispatch comparison for 3 generator test system at 700MW demand

Load demand = 700 MW			
	ABC_PSO [this method]	PSO [41]	GA [41]
P1 (MW)	185.7		
P2 (MW)	269.97		
P3 (MW)	268.36		
Losses MW	**23.329**		
Fuel Cost Rs/hr	**35473**	**35474**	**35476**
Emission kg/hr	**651.36**	**651.49**	**651.57**

At 700MW load demand in table 5.3.6 above, the hybrid yields better solutions that PSO in terms of lower fuel cost and emission of 1 Rs/hr and 0.1281kg/hr respectively. It also yields better fuel cost and emission of 3 Rs/hr and 0.2141kg/hr lower than that of GA.

5.3.1.3 Combined Economic and Emission Dispatch comparison

Table 5.3.7: CEED comparison for 3 generator test system at 350MW demand

Load demand =350 MW			
	ABC_PSO [this method]	PSO [41]	GA [41]
P1 (MW)	79.513	89.557	89.568
P2 (MW)	145.52	134.53	134.55
P3 (MW)	130.68	131.56	131.59
Losses MW	**5.7**	**5.6476**	**5.6496**
Fuel Cost Rs/hr	**18570**	**18589**	**18592**
Emission kg/hr	**160.9**	**159.08**	**159.12**

At the combined economic and emission dispatch problem level in table 5.3.7 above, the hybrid generally yields better overall solution than PSO and GA.

At 350MW demand ABC_PSO yields a lower fuel cost of 19.2 Rs/hr than PSO and 21.8 Rs/hr than GA. Its emission is slightly higher by 1.8kg/hr with respect to PSO and 1.78kg/hr with respect to GA.

Table 5.3.8: CEED comparison for 3 generator test system at 500MW demand

Load demand =500 MW			
	ABC_PSO [this method]	PSO [41]	GA [41]
P1 (MW)	116.91	128.98	129
P2 (MW)	202.9	192.65	192.68
P3 (MW)	191.99	190.06	190.11
Losses MW	**11.798**	**11.692**	**11.696**
Fuel Cost Rs/hr	**25472**	**25495**	**25499**
Emission kg/hr	**313.32**	**311.15**	**311.27**

At 500MW demand in table 5.3.8 above, ABC_PSO produces a lower fuel cost of 23 Rs/hr than PSO and 27.4 Rs/h than GA whilst its emission is greater than PSO by 2.1689kg/hr and GA by 2.0459kg/hr.

Table 5.3.9: CEED comparison for 3 generator test system at 700MW demand

Load demand =700 MW			
	ABC_PSO [this method]	PSO [41]	GA [41]
P1 (MW)	167.96	182.81	182.78
P2 (MW)	280.74	271.48	271.48
P3 (MW)	274.86	269.09	269.13
Losses MW	**23.561**	**23.363**	**23.365**
Fuel Cost Rs/hr	**35434**	**35465**	**35466**
Emission kg/hr	**654.48**	**651.57**	**651.63**

At 700MW demand in table 5.3.9 above, ABC_PSO yields a lower fuel cost of 30.6 Rs/hr that PSO and 32 Rs/hr than GA. Its emission is higher than PSO by 2.913kg/hr and GA by 2.85kg/hr.

However generally considering the overall results the ABC_PSO yields a better Combined Economic and Emission dispatch that both GA and

5.3.2 6-Generator test system

5.3.2.1 Economic Dispatch comparison

Comparing results yielded by ABC_PSO hybrid with ABC, FCGA and NSGA-II at demand levels of 500, 700 and 900 MW considering economic dispatch only.

At demand level of 500MW in table 5.3.10 below, with only economic dispatch the hybrid produces a fuel cost of 8$/hr higher than ABC, 64$/hr lower than FCGA and NSGA-II. Also its emission is lower by 2.822kg/hr than ABC, 8.25kg/hr than FCGA and

2.76kg/hr than NSGA-II. Its losses are higher by 0.30634 than ABC but better than FCGA and NSGA-II

Table 5.3.10: Economic dispatch comparison for 6 generator test system at 500MW demand

Load demand of 500 MW				
	ABC_PSO [this method]	ABC [46]	FCGA [53]	NSGA-II [53]
P1 (MW)	52.081	52.532	49.47	50.836
P2 (MW)	29.077	29.4	29.4	31.806
P3 (MW)	40	35	35.31	35.12
P4 (MW)	68.074	70.871	70.42	73.44
P5 (MW)	191.46	191.63	199.03	191.99
P6 (MW)	136.4	137.02	135.22	135.02
Loss MW	**17.097**	**16.734**	**18.86**	**18.208**
Fuel cost $/hr	**28086**	**28078**	**28150**	**28150**
Emission kg/hr	**306.28**	**309.1**	**314.53**	**309.04**

At demand level of 700MW in table 5.3.11 below, the hybrid produces a fuel cost of 2.21$/hr lower that ABC, 178$/hr lower that FCGA and 164.75$/hr lower than NSGA-II. Its emission is greater by 0.6462kg/hr than ABC, but lower than FCGA by 7.0468kg/hr and lower than NSGA-II by 7.4908. Its losses are higher by 0.1342MW than ABC but lower than FCGA and NSGA-II.

Table 5.3.11: Economic dispatch comparison for 6 generator test system at 700MW demand

Load demand of 700MW				
	ABC_PSO [this method]	ABC [46]	FCGA [53]	NSGA-II [53]
P1 (MW)	76.061	77.017	72.14	76.179
P2 (MW)	49.087	48.542	50.02	51.81
P3 (MW)	45.421	44.568	46.47	49.82
P4 (MW)	102.73	103.89	99.33	103.41
P5 (MW)	266.3	264.64	264.6	267.98
P6 (MW)	191.34	192.15	203.58	184.73
Loss MW	**30.943**	**30.809**	**36.15**	**33.934**
Fuel cost $/hr	**38206**	**38208**	**38384**	**38371**
Emission kg/hr	**536.43**	**535.79**	**543.48**	**534.92**

Table 5.3.12: Economic dispatch comparison for 6 generator test system at 900MW demand

Load demand of 900 MW				
	ABC_PSO [this method]	ABC [46]	FCGA [53]	NSGA-II [53]
P1 (MW)	103.45	103.35	101.11	102.96
P2 (MW)	70.143	72.426	67.64	74.235
P3 (MW)	60.892	61.426	50.39	66.003
P4 (MW)	139.38	138.85	158.8	140.32
P5 (MW)	325	325	324.08	324.89
P6 (MW)	251.71	249.15	256.56	248.42
Loss MW	**50.563**	**50.101**	**58.58**	**56.822**
Fuel cost $/hr	**49294**	**49300**	**49655**	**49620**
Emission kg/hr	**849.23**	**846.16**	**877.61**	**849.33**

At demand level of 900MW in table 5.3.12 above, the hybrid produces a lower fuel cost of 6$/hr than ABC, 361.4$/hr lower than FCGA and 316$/hr lower that NSGA-II. Its emission is slightly higher that ABC by 3kg/hr and lower than FCGA and NSGA-II by 28.3779kg/hr and 0.0939kg/hr respectively. Its losses are 0.46MW higher that ABC but lower than the other methods.

5.3.2.2 Emission Dispatch comparison

Comparing results for the emission dispatch at various demand levels amongst the various methods.

Table 5.3.13: Emission dispatch comparison for 6 generator test system at 500MW demand

Load demand of 500 MW				
	ABC_PSO [this method]	ABC [46]	FCGA [53]	NSGA-II [53]
P1 (MW)	58.026	54.088	81.08	56.931
P2 (MW)	43.752	37.518	13.93	41.542
P3 (MW)	75.741	72.925	66.37	73.896
P4 (MW)	83.939	83.53	85.59	84.931
P5 (MW)	133.42	139.69	141.7	136.5
P6 (MW)	128.79	136.02	135.93	131.33
Loss MW	**23.677**	**23.777**	**24.61**	**25.129**
Fuel cost $/hr	**28625**	**28496**	**28757**	**28641**
Emission kg/hr	**274.16**	**275.17**	**286.59**	**275.54**

At 500MW demand level in table 5.3.13 above, the hybrid yields a higher fuel cost of 129$/hr than ABC, lower cost of 131$/hr than FCGA and 16$/hr than NSGA-II. Its emission levels are better than ABC by 1.008kg/hr, 12.4268kg/hr than FCGA and 1.3808kg/hr than NSGA-II. Its losses are better than ABC by 0.1MW and better than the other algorithms by 0.9329MW and 1.4519MW for FCGA and NSGA-II respectively.

Table 5.3.14: Emission dispatch comparison for 6 generator test system at 700MW demand

Load demand of 700 MW				
	ABC_PSO [this method]	ABC [46]	FCGA [53]	NSGA-II [53]
P1 (MW)	105.27	101.02	120.16	103.08
P2 (MW)	76.462	73.163	21.36	73.505
P3 (MW)	92.967	92.687	62.09	91.556
P4 (MW)	109.79	110.25	128.05	110.79
P5 (MW)	183.13	185.94	209.65	187.87
P6 (MW)	170	174.77	201.12	174.29
Loss MW	**37.617**	**37.83**	**42.44**	**41.083**
Fuel cost $/hr	**39429**	**39271**	**39455**	**39473**
Emission kg/hr	**462.52**	**463.11**	**516.55**	**467.39**

At demand level of 700MW in table 5.3.14 above, the hybrid yields a higher fuel cost of 158$/hr than ABC, 26$/hr less than FCGA and 44.42$ less than NSGA-II. Its emission levels are better than ABC by 0.939kg/hr, 54kg/hr than FCGA and 4.8646kg/hr than NSGA-II. Its losses are better than ABC by 1.2128MW, by 4.8228MW than FCGA and 3.4658MW than NSGA-II.

At demand level of 900MW in table 5.3.15 below, the hybrid yields a higher fuel cost of 71$/hr than the ABC, 2,285.6$/hr than FCGA and 240.2 $/hr than NSGA-II. Its emission is lower than ABC by 0.4554kg/hr, 36.5664kg/hr than FCGA and 10.978 than NSGA-II. Its losses are slightly higher that ABC by 0.5MW and lower than FCGA and NSGA-II by 2.2MW and 6.1296MW respectively.

Table 5.3.15: Emission dispatch comparison for 6 generator test system at 900MW demand

Load demand of 900 MW.				
	ABC_PSO [this method]	ABC [46]	FCGA [53]	NSGA-II [53]
P1 (MW)	125	124.99	133.31	124.99
P2 (MW)	111.72	109.86	110	109.86
P3 (MW)	109.53	109.88	100.38	109.88
P4 (MW)	143.32	141.71	119.27	141.71
P5 (MW)	248.63	250.73	250.79	250.73
P6 (MW)	224.54	225.07	251.25	226.58
Loss MW	**62.74**	**62.24**	**65**	**68.87**
Fuel cost $/hr	**51014**	**50943**	**53300**	**51254**
Emission kg/hr	**749.07**	**749.53**	**785.64**	**760.05**

5.3.2.3 Combined Economic and Emission Dispatch comparison

Table 5.3.16: CEED comparison for 6 generator test system at 500MW demand

Load demand of 500 MW				
	ABC_PSO [this method]	ABC [46]	FCGA [53]	NSGA-II [53]
P1 (MW)	54.6	54.262	65.23	54.048
P2 (MW)	32.484	35.98	24.29	34.25
P3 (MW)	48.548	51.408	40.44	54.497
P4 (MW)	77.517	76.527	74.22	80.413
P5 (MW)	167.28	162.62	187.75	161.87
P6 (MW)	137.29	137.09	125.48	135.43
Loss MW	**17.718**	**17.88**	**17.41**	**20.508**
Fuel cost $/hr	**28157**	**28194**	**28231**	**28291**
Emission kg/hr	**288.01**	**284.98**	**304.9**	**284.36**

The strength of the hybrid is evidenced in the combined economic and emission dispatch phase.

At 500MW demand level the hybrid in table 5.3.16 above, produces a lower fuel cost of 37$/hr than ABC, 74.06$/hr than FCGA and 134$/hr than NSGA-II. Its emission is higher that ABC by 3kg/hr, lower by 16.8943kg/hr than FCGA and 3.6437kg/hr than NSGA-II. It also has lower losses than ABC by 0.16MW, 0.307MW lower than FCGA and 2.79MW lower than NSGA-II.

Table 5.3.17: CEED comparison for 6 generator test system at 700MW demand

Load demand of 700 MW				
	ABC_PSO [this method]	ABC [46]	FCGA [53]	NSGA-II [53]
P1 (MW)	83.741	87.128	80.16	86.286
P2 (MW)	55.373	59.978	53.71	60.288
P3 (MW)	65.306	74.184	40.93	73.064
P4 (MW)	107.05	110.86	116.23	109.04
P5 (MW)	232.19	211.44	251.2	223.45
P6 (MW)	187.88	190.2	190.62	184.11
Loss MW	**31.54**	**33.792**	**32.85**	**36.324**
Fuel cost $/hr	**38357**	**38570**	**38409**	**38672**
Emission kg/hr	**491.69**	**477.29**	**527.46**	**484.93**

At 700MW demand level in table 5.3.17 above, the hybrid produces a far lower fuel cost of 213$/hr than ABC, 51.82$/hr than FCGA and 314.81$/hr than NSGA-II. Its emission is higher than ABC by 14.4kg/hr and lower by 35.77kg/hr and 6.7577kg/hr than FCGA and NSGA-II respectively. It possesses a lower loss than ABC by 2.251MW, 1.3101MW lower than FCGA and 4.7841MW lower than NSGA-II.

Table 5.3.18: CEED comparison for 6 generator test system at 900MW demand

Load demand of 900 MW				
	ABC_PSO [this method]	ABC [46]	FCGA [53]	NSGA-II [53]
P1 (MW)	114.59	119.95	111.4	120.06
P2 (MW)	78.395	82.309	69.33	85.202
P3 (MW)	80.693	87.103	59.43	89.565
P4 (MW)	137.13	136.52	143.26	140.28
P5 (MW)	300.2	290.06	319.4	288.61
P6 (MW)	238.55	233.95	252.11	233.69
Loss MW	**49.559**	**49.873**	**54.92**	**57.405**
Fuel cost $/hr	**49528**	**49722**	**49674**	**50126**
Emission kg/hr	**794.44**	**778.42**	**850.29**	**784.7**

At 900MW demand level in table 5.3.18 above, the hybrid produces a lower fuel cost of 194$/hr than ABC, 146.28$/hr lower than FCGA and 598$/hr than NSGA-II. Its emission is higher than ABC by 16kg/hr, lower by 55.8549kg/hr than FCGA and higher by 9.7391kg/hr than NSGA-II. It has better losses than ABC by 0.1342MW, than FCGA by 5.3612MW and NSGA-II by 7.8462MW.

Generally the hybrid produces better results in the combined economic and emission dispatch problem solution.

5.3.3 10- Generator test system

5.3.3.1 Economic Dispatch comparison

Table 5.3.19: Economic dispatch comparison for 10 generator test system at 2000MW demand

Load demand of 2000 MW		
	ABC_PSO [this method]	DE [52]
P1 (MW)	55	55
P2 (MW)	80	79.89
P3 (MW)	106.93	106.8253
P4 (MW)	100.5668	102.8307
P5 (MW)	81.49	82.2418
P6 (MW)	83.011	80.4352
P7 (MW)	300	300
P8 (MW)	340	340
P9 (MW)	470	470
P10(MW)	470	469.8975
Losses MW	**87.0344**	
Fuel cost $/hr	**111500**	**111500**
Emission lb/hr	**4571.2**	**4581**

In comparison of the hybrid's result with the DE at the economic dispatch level in table 5.3.19 above, at the demand of 2000MW their fuel costs are comparable and equal but the hybrid yields a lower emission by 9.8lb/hr than the DE.

5.3.3.2 Emission Dispatch comparison

In the emission dispatch phase as compared in table 5.3.20 below, the hybrid yields greater fuel cost and emission than DE of 20$/hr and 8.9lb/hr respectively.

Table 5.3.20: Emission dispatch comparison for 10 generator test system at 2000MW demand

Load demand of 2000 MW		
	ABC_PSO [this method]	DE [52]
P1 (MW)	55	55
P2 (MW)	80	80
P3 (MW)	81.9604	80.5924
P4 (MW)	78.8216	81.0233
P5 (MW)	160	160
P6 (MW)	240	240
P7 (MW)	300	292.7434
P8 (MW)	292.78	299.1214
P9 (MW)	401.8478	394.5147
P10(MW)	391.2096	398.6383
Losses MW	**81.5879**	
Fuel cost $/hr	**116420**	**116400**
Emission lb/hr	**3932.3**	**3923.4**

5.3.3.3Combined Economic and Emission Dispatch comparison

Again the strength of the algorithm in the combined economic and emission dispatch problems is highlighted in table 5.3.21 below. It yields a lower fuel cost of 60$/hr than DE, 120$/hr than NSGA and 100$/hr than SPEA-2. Its emission is also lower than DE by 4.8lb/hr, lower than NSGA by 10.1lb/hr but higher than SPEA-2 by 11lb/hr.

Table 5.3.21: CEED comparison for 10 generator test system at 2000MW demand

Load demand of 2000 MW				
	ABC_PSO [this method]	DE [52]	NSGA-II [52]	SPEA-2 [52]
P1 (MW)	55	54.9487	51.9515	52.9761
P2 (MW)	80	74.5821	67.2584	72.813
P3 (MW)	81.14	79.4294	73.6879	78.1128
P4 (MW)	84.216	80.6875	91.3554	83.6088
P5 (MW)	138.3377	136.8551	134.0522	137.2432
P6 (MW)	167.5086	172.6393	174.9504	172.9188
P7 (MW)	296.8338	283.8233	289.435	287.2023
P8 (MW)	311.5824	316.3407	314.0556	326.4023
P9 (MW)	420.3363	448.5923	455.6978	448.8814
P10(MW)	449.1598	436.4287	431.8054	423.9025
Losses MW	**84.1736**			
Fuel cost $/hr	**113420**	**113480**	**113540**	**113520**
Emission lb/hr	**4120.1**	**4124.9**	**4130.2**	**4109.1**

Generally the hybrid performs well under the combined economic and emission dispatch problem than other optimization methods. It yields overall lower generation cost for optimum emission and fuel costs. It is evident that the proposed hybrid yield better overall combined economic and emission dispatch results in all instances tested. With the aim of this research work being the development of a better algorithm to solve the combined economic and emission dispatch problem, the hybrid developed satisfies the intended objective resulting in better efficiency of the power system in general.

The method was subjected to different loading conditions and different test systems to ascertain its strength in the CEED problem. In all cases it can be said to be comparable in terms of results obtained and better in the multi-objective optimization problem than all other methods compared with.

The hybrid which comprised of PSO and ABC gave better results due to the individual strengths of the comprising algorithms. ABC has the following strengths:

- Better ability to reach near global optimal solutions
- Fewer control parameters
- Quality solutions
- Stable convergence characteristics
- Computational efficiency.

The weakness that ABC exhibits is found in its high computational time which it takes to arrive at the global solution.

PSO on the other hand also possesses the following strengths:

- Modeling flexibility
- Sure and fast convergence
- Less computational time
- Fewer control parameters.

The weakness of PSO is the probability to be locked in the local optima.

The hybrid so proposed makes use of the faster computational time of the PSO coupled with its convergence strength to implement the results yielded by the ABC in getting better near global solution. Hence the hybrid shows the following strengths:

- Better ability to reach near global optimal solution
- Quality solution
- Stable convergence characteristics
- Modeling flexibility.

It however shows the following weakness:

- High computational time.

These traits account for the better results exhibited by the hybrid algorithm in the test cases.

CHAPTER 6

6.1 CONCLUSION

In this research a new approach to solving the multi-objective problem of economic and emission dispatch problem has been proposed using a hybrid formed from Particle Swarm Optimization and Artificial Bee Colony methods. Validating this new optimization method using a 3-generator test system, IEEE 6-generator test system and a 10-generator test system and comparing the results obtained from other optimization methods shows the efficiency of this new proposed method in addressing the multi-objective problem.

The 3-generator was subjected to 350MW, 500MW and 700MW levels of power demand. With the aid of the cardinal priority ranking method and the classical weighted sum, the Economic dispatch, Emission dispatch and the Combined Economic and Emission dispatch was deduced for the various loading levels. The ABC_PSO hybrid performed very well in the Emission dispatch stage and had comparable results at the Economic dispatch and CEED stage when evaluated against PSO and GA

The 6-generator test system was also subjected to 500MW, 700MW and 900MW levels of power demand. Using the classical weighted sum and cardinal priority ranking method the Economic dispatch, Emission dispatch and CEED was deduced for the various loading levels, The ABC_PSO hybrid performed well in the Emission dispatch and CEED stage in comparison with ABC, FCGA and NSGA-II. It had comparable results at the Economic dispatch stage.

The 10-generator test system was subjected to 2000MW power demand. The ABC_PSO hybrid performed well in the Economic dispatch and the CEED stage when compared with DE, NSGA-II and SPEA-2 algorithms. It had comparable results in the Emission dispatch stage.

The variation of levels of power demand and different types of test systems was done to show that the proposed optimization method has a stable behavior independent of the size of the system, does not converge to local optima and also has feasible solutions.

This method however shows some weakness in terms of high computational time hence areas of further research have been proposed as well.

The research and the results that have been arrived at in this thesis will be very valuable for generating companies who aim at cost reduction and at the same time have regard for the environment. The method of optimization proposed in this thesis will also open up a new area of optimization that will be very helpful for many more fields other than the electrical power generation field alone.

6.2 FUTURE WORK

The following areas are recommended for further research:

- Improving the computational speed of the hybrid by the use of other mutation operators from other algorithms, like cross-over operators from GA.

- Application to larger test systems, like 60 - generator, 100 - generator test to examine how the algorithm reacts in those scenarios.
- Application to real systems such as actual power systems and power pools so as to realize its full benefit to society.

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1. Emmanuel Dartey Manteaw, Dr. Abungu N. O., "Multi-objective environmental/ economic dispatch solution using ABC_PSO hybrid algorithm", IJSRP (International Journal of Scientific and Research Publications), Volume 2, Issue 12, December 2012, pp. 8-14.

2. Emmanuel Dartey Manteaw, Dr. Abungu N. O., "Combined Economic and Emission Dispatch problem using ABC_PSO hybrid algorithm with valve point loading effect", IJSRP (International Journal of Scientific and Research Publications), Volume 2, Issue 12, December 2012, pp. 609-615.

APPENDIX 1: Single line diagram of IEEE 30-bus 6 generator test system.