

MULTIOBJECTIVE ECONOMIC EMISSION DISPATCH USING JAYA OPTIMIZATION ALGORITHM

A Dissertation submitted in fulfillment of the requirements for the Degree

of

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in

Power Systems

Submitted by

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DECLARATION

I hereby certify that the work which is presented in dissertation entitled, "**Multiobjective Economic Emission Dispatch Using Jaya Optimization Algorithm**", in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Power Systems, submitted to Electrical & Instrumentation Engineering Department of Thapar Institute of Engineering and Technology, Patiala is as authentic record of my own work carried under the supervision of **Ms. Manbir Kaur**. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

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TABLE OF CONTENT

<i>DECLARATION</i>	<i>i</i>
<i>ACKNOWLEDGEMENT</i>	<i>ii</i>
<i>LIST OF FIGURES</i>	<i>v</i>
<i>LIST OF TABLES</i>	<i>vii</i>
<i>List of Abbreviations</i>	<i>viii</i>
<i>List of Notations</i>	<i>ix</i>
<i>ABSTRACT</i>	<i>x</i>
CHAPTER 1 INTRODUCTION	1-10
1.1 OVERVIEW	1
1.2 LITERATURE SURVEY	1
1.3 OBJECTIVE OF WORK	9
1.4 OUTLINE OF THE DESSERTATION	9
CHAPTER 2 COMBINED ECONOMIC EMISSION LOAD DISPATCH	11-15
2.1 INTRODUCTION	11
2.2 ECONOMIC LOAD DISPATCH	11
2.3 EMISSION DISPATCH	14
2.4 CONSTRAINTS	14
2.4.1 Equality Constraints	14
2.4.2 Inequality Constraints	15
2.5 ECONOMIC LOAD DISPATCH USING LAGRANGE MULTIPLIER	15
METHOD	
2.5.1 ELD without losses	15
2.5.2 ELD considering losses	18
CHAPTER 3 OPTIMISATION TECHNIQUES	20
3.1 MULTIOBJECTIVE PARTICLE SWARM OPTIMIZATION	20

3.2 MULTIOBJECTIVE JAYA OPTIMIZATION TECHNIQUE		
CHAPTER 4	PROBLEM FORMULATION	26
4.1	OBJECTIVE FUNCTION	26
4.2	CONSTRAINTS	27
4.3	SOLUTION METHODOLOGY	28
4.3.1	MOPSO Algorithm for Combined EED Problem	28
4.3.1	MO Jaya Algorithm for Combined EED Problem	30
CHAPTER 5	RESULTS AND DISCUSSION	34
5.1	TEST SYSTEM 1	34
5.2	TEST SYSTEM 2	36
5.3	COMPARATIVE ANALYSIS	38
CHAPTER 6	CONCLUSION AND FUTURE SCOPE	42
6.1	CONCLUSION	42
6.2	FUTURE SCOPE	42
REFERENCES		43
APPENDIX		46

LIST OF FIGURES

Figure Number	Caption	Page Number
Figure 2.1	Basic model of fossil plant	12
Figure 2.2	Fuel cost curve of thermal generator	12
Figure 2.3	Cost curve exhibitory discontinuities due to valve point effect	13
Figure 3.1	Flow chart for PSO	23
Figure 3.2	Flow chart of Jaya Algorithm	25
Figure 4.1	Flowchart of MOPSO for CEED problem	29
Figure 4.2	Flowchart of MO Jaya for CEED problem	32
Figure 5.1	Convergence characteristics of economic emission and economic cost for 6 generator system using MOPSO	34
Figure 5.2	Convergence characteristics of economic emission and economic cost for 6 generator system using MO JAYA	34
Figure 5.3	Convergence characteristics of economic emission and economic cost for 10 generator system using MOPSO	36
Figure 5.4	Convergence characteristics of economic emission and economic cost for 10 generator system using MO JAYA	36
Figure 5.5	Comparison of economic cost using MOPSO and MO JAYA for 6 generator system	37
Figure 5.6	Comparison of economic cost using MOPSO and MO JAYA for 6 generator system	38
Figure 5.7	Pareto optimal front for MOPSO and MO JAYA for 6 generators system	38
Figure 5.8	Comparison of economic cost using MOPSO and MO JAYA for 10 generator system	39
Figure 5.9	Comparison of economic emission using MOPSO and MO	39

JAYA for 10 generator system

Figure 5.10

Pareto optimal front for MOPSO and MO JAYA for 10
generators system

40

LIST OF TABLES

Table Number	Title	Page Number
Table 5.1	Comparison of cost and emission using MOPSO and MO Jaya for 6 generators system	33
Table 5.2	Comparison of cost and emission using MOPSO and MO Jaya for 10 generator system	35

List of Abbreviations

ELD	Economic Load Dispatch
CEED	Combined Economic Emission Dispatch
MOEED	Multiobjective Economic Emission Dispatch
GA	Genetic Algorithm
PSO	Particle Swarm Optimization
MOPSO	Multiobjective Particle Swarm Optimization
DE	Differential Evolution
ABC	Artificial Bee Colony
ACO	Ant Colony Optimization
MPSO	Modified Particle Swarm Optimization
EEPD	Environmental and Economic Power Dispatch
GSA	Gravitational Search Algorithm
JOA	Jaya Optimization Algorithm
MO Jaya	Multiobjective Jaya

List of Notations

P_L	Losses in transmission lines
B_{kl}	Loss coefficients
a_k, b_k, c_k	Cost coefficients of thermal plant
P_{gk}^{min} and P_{gk}^{max}	Minimum and Maximum power limit of k^{th} unit
N	Total power units
F	Fuel cost function
P_{gk}	Power generation of k^{th} unit
w	Inertia weight factor
NG	Number of members in a particle
NP	Number of particles in a group
C_1 and C_2	Acceleration Constants
v_{ij}^{new}	New Velocity of j^{th} member of i^{th} particle
m	No. of Particle
n	Population Size
P_D	Load Demand
IT ^{max}	Maximum number of iteration
$P_{i,worst}^k$	Worst value of Power of $(k)^{th}$ candidate at i^{th} iteration
$P_{i,best}^k$	Best value of Power of $(k)^{th}$ candidate at i^{th} iteration
$P_{i,j}^{k+1}$	Power of j^{th} unit $(k + 1)^{th}$ candidate at i^{th} iteration

ABSTRACT

Economic Emission Dispatch is used for optimization of cost of generation with respect to emission dispatch of different generating units while satisfying load demand along with other equality and inequality constraints. In this work, a multiobjective JAYA algorithm (MO Jaya) for economic emission dispatch problem is proposed in this work considering competing objectives based on cost and emission. The comparative analysis with respect to multiobjective Particle Swarm Optimization (MOPSO) has been carried out. The results obtained are more significant for MO Jaya algorithm. Six and ten generators system has been considered as test system.

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

With the gradual increase in power demand, the scheduling of power generating units is of great significance. Nowadays, due to the present status of industrial and commercial load, the power industries are focusing on to determine the operating strategies and various policies to fulfill the load demand. At the time of power system designing, the main focus is on achieving the best overall economy of the system, i.e. minimizing the power generation cost [1].

Thus, aiming at the cost minimization, Economic Load Dispatch (ELD) is one of the most essential operational function of recent day energy management system. The aim of ELD is to minimize the total cost of power generated from the thermal plants subjected to various constraints [2]. Allocating the total load demand and distributing the present losses between various interconnected units, the objective of ELD is to minimize the total power generation cost fulfilling various equality and inequality constraints. Therefore, in the practical system the generators with the minimum power generation cost are operated for the maximum time interval whereas systems with high power generation cost are operated for the minimum time interval; thus, aiming at minimizing the overall system cost [3].

With the available conventional power generation plants like thermal plants, using fossil fuel like coal, oil, gas, etc. are consumed to produce electric power. These resources emit the different type of unsafe gases in the air like coal produces carbon dioxide, sulphur oxides and nitrogen oxides in the climate. As a result of which the emission control for such units has turned into another essential operational objective.

Moreover, the growing public awareness towards the ecological security has constrained the utilities to alter their operational system, decreasing the contamination and environmental outflows [4]. Therefore, it is important to add the emission constraints into the economic dispatch problem. Thus, aiming at the public interest for clean air, the economic dispatch problem has to be changed to emission dispatch problem. Similar to the economic load dispatch problem, the aim of the EED problem is to minimize the emission of the system

1.2 LITERATURE REVIEW

There are various types of optimization techniques that are highly utilized for the minimization of various problems related to the economic load dispatch such as classical methods, stochastic search techniques and hybrid techniques. Except for these techniques, there were several other approaches [5-30] that can also be considered for the formulation purpose and also for giving solution related to the ELD problems. Several other techniques such as Evolutionary algorithms [5,14,16], hybrid

methodologies [27,28,31,32], PSO technique [15-18] and at last evolutionary algorithm including genetic algorithms [11-13] also included in the literature review.

There were various classical approaches that can also be considered for the minimization of ELD problems likewise lambda-iteration method, sometimes Dynamic programming technique [4] can also be used and the Newton Raphson method [4]. These methods also had some limitations such as it was very difficult to find desired solution from these techniques, objective function derivative was highly required and in case of a complex problem, the computational time was very large. The requirement of piecewise linear cost approximation was quite high in case of linear programming whereas the problem related to the number of inequality constraints was considered for the Newton Raphson method [4]. Recently different heuristic search techniques such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Differential Evolution (DE), Ant Colony Search Method, Evolutionary Programming, and Artificial Bee Colony (ABC) method have been used to solve the complex non linear optimization problem.

Sinha *et al.* [5] discussed the evolutionary programming which was considered as the best possible optimization tool for the for the problems related to the nonlinear programming. The previously discussed methods were modified to achieve the desired speed as well as the performance was presented here and these techniques were imposed on the same mathematical problem to get the best possible solution. The utilization of evolutionary programming for the minimization of economic dispatch problems were also analyzed and presented in this paper. The results verify its effectiveness in comparison to other in terms of superior convergence rate and the chances of getting best solution was maximum.

Guerrero *et al.* [6] presented a highly effective DE based algorithm for the elimination of various issues related to economic dispatch by the utilization of nonsmooth cost function. The technique used in the proposed work was highly effective for the optimization of various issues such as non-convex as well as irregular arrangement etc. The proposed strategy was discussed for the effective analysis as well as the technique was further tested on the various test system to satisfy its feasibility in the practical environment. The results were improving the reliability and the performance of the system by solving the issues related to the objective function consider in the system.

Pancholi *et al.* [7] presented a novel approach for the various issues related to the economic load dispatch with security constraints. For the effective elimination of several economic load dispatch related problems, the introduction of particle swarm optimization was done to improve the efficiency as well as the performance of the complete system. To verify the effectiveness of the proposed technique, it was initially imposed on the various standard framework such as IEEE 14 bus system, IEEE 30 bus system and at last IEEE 57 bus system separately. The effectiveness of the proposed technique was also discussed in this paper as well as the obtained results were compared with the conventional techniques such as linear programming approach, genetic algorithm technique and at last the quadratic programming approach.

Park *et al.* [8] presented an advance particle swarm optimization technique for the reduction of various issues related to the Economic dispatch with the equality as well as inequality constraints. The formulation of methodology was also done to minimize the several issues related to ED whereas the dynamic response of the proposed algorithm was also protected. The results also verify the effectiveness of the proposed technique over the conventional numerical based strategies as well as over the Hopfield neural network but its results were quite comparable to the conventional Hopfield neural systems.

Dixit *et al.* [9] presented a novel approach by providing a solution of issues related to economic load dispatch by the implementation of artificial bee colony algorithm. The main objective of the technique is to reduce the overall cost function of the thermal generating units within the boundary conditions. this technique was further applied to the three different cases to verify the effectiveness of the proposed algorithm such as case I it consists of 18 thermal units as well as the utilization of quadratic cost function whereas in case II it consists of standard 30 bus system as well as 6 generator unit framework and case III it consists of standard fifteen unit framework as well as constraints too. Results prove that ABC optimization is the highly effective way of solving severe problems within the system.

Noman *et al.* [10] projected a novel approach of Differential evolution algorithm for the solution of economic load dispatch problems. This technique was highly considered for its ability to provide

solution of numerous real world related ELD problem. The problems related to ELD was quite complex as well as nonlinear in nature with equality as well as inequality constraints. The implementation of this technique was quite comparable with the MHNN whereas quite similar to MPSO. The results show its superiority over the other alternatives and the comparative study of the various factors related to the ELD issues was also discussed in this research paper.

Mahor *et al.* [11] discussed the implementation of particle swarm optimization strategy for the issues related to economic dispatch such as shortage of various energy related assets, problems related to the uncontrollable growth in the power generation cost, environment related issues as well as issues related to the overgrowing demand of electricity. The objective function of several issues related to the economic dispatch is nonlinear and having extreme equality as well as the inequality constraints. The previously accepted techniques were not able to solve such issues due to which introduction of PSO was achieved as reviewed in the research paper.

Abido *et al.* [12] presented a multi objective evolutionary algorithm considering Environmental and Economic Power Dispatch (EPPD) problem. The aforementioned problem has been developed as a nonlinear multiobjective optimization problem. A standard test system has been taken considering fuel cost along with objectives based on environmental impacts. An SPEA (Strength Pareto Evolutionary algorithm) has been proposed to solve the problem. A technique based on hierarchical clustering has been implemented which offer Pareto optimal set to the system operator. From the results, it has been observed that the proposed technique could efficiently solve the considered problem.

Mohan *et al.* [13] projected hybrid Genetic Algorithm (GA) for solving Combined Economic and Emission Dispatch problem. Minimising of Nitrogen Oxide (NO_x) which is a pollutant has been emphasized. Different types of constraints including power balance equality constraints; generator capacity inequality constraints as well as prohibited zone constraints have been considered. The results obtained has been compared with Fuzzy controlled genetic algorithms (FCGA). It has been observed that the proposed method is more efficient as the amount of loses as well as emission is low compared to the FCGA method. The utilization of participation factor (PF) method together with GA make the method faster.

Venkatesh *et al.* [14] proposed a new Multi-Objective Evolutionary Programming (MOEP) method to solve the CEED problems. It is a dual objective optimization problem which includes fuel cost and NO_x emission as objective. By using the weighted sum method both the objectives have been combined to form a single objective optimization problem. Fuel cost, NO_x and SO₂ emissions have been considered as objectives. GA, MGA and EP methods have been applied for solving ELD problem. These methods are compared among them as well as with the conventional methods. The developed algorithm has been implemented on IEEE 14,30 and 118 systems.

Chaturvedi *et al.* [15] employed modified PSO for non-convex economic dispatch in which time varying acceleration coefficient has been considered. It has been considered for controlling the local and global search along with evading the premature convergence problem faced in conventional PSO method.

Basu *et al.* [17] proposed the Multiobjective Differential Evolution algorithm for EED problem. The results have been obtained using the proposed algorithm. It has been further compared with Pareto DE and NSGA-II methods.

Dixit *et al.* [18] in his work proposed the Artificial Bee Colony (ABC) based algorithm. The algorithm focuses to solve the issues related with combined economic and emission dispatch (CEED) with different number of generating plants. Validating the proposed ABC algorithm, the results have been compared with the various conventional techniques. The resulting analysis shows the algorithm to be better than the GA based conventional technique in terms of solving the more complicated problem.

Gopalakrishnan *et al.* [19] modifying the algorithm proposed in [18], presented the modified ABC approach considering the same problem. With several benefits over the conventional technique like an effective drop in fuel cost, reduced number of iterations and time along with less complex system characteristics, modified ABC overcomes most of the conventional techniques.

Bhongade *et al.* [20] similar to [18] [19], to solve the problem of CEED presented the ABC algorithm considering another constraint of transmission loss. Being less complex, robust and flexible, the approach has been validated by considering two different test systems. The analysis of the proposed algorithm with added constraints shows the results to be satisfactory.

Gopalakrishnan *et al.* [21] presented a modified Ant Colony based optimization algorithm (MACO) to solve the similar CEED problem. Compared with the basic genetic algorithm and other technique, the proposed approach utilizes a lesser number of iterations and gives better optimized results considering fuel cost and emissions.

Čepin *et al.* [22] also highlighted the nonlinear CEED problem with multiple constraints. Using the modified dynamic normalization method, the problem has been solved whereas, a different penalization technique for calculating the constraints violation has been used. To validate the system, three different test systems with different thermal and hydrothermal units have been considered.

Güvenç *et al.* [23] proposed the Gravitational Search Algorithm (GSA) to solve the similar CEED problem. Converting the multiobjective optimization problem into a single objective optimization problem with price penalty factor as an added constraint, the work is validated by implementing it on four test systems. The resulting analysis shows the algorithm to be fit for solving the CEED problem.

Banerjee *et al.* [24] proposed a recently developed Teaching learning based optimization algorithm (TLBO) for solving the basic ELD problem considering a thermal unit without any transmission losses. TLBO is based on the two fundamental concepts of the regular education system, i.e. teaching and learning. Validating the proposed algorithm, three different test systems with various equality and inequality constraints have been simulated resulting in impressive optimized results. Also, comparing the results; particle swarm optimization (PSO) based technique has also been highlighted.

Radosavljeviae et al. [25] motivated by [23], presented the hybrid optimization approach, i.e. PSO with gravitational search algorithm (GSA). The work focuses on to solve the CEED problem with numerous test cases ranging from three to forty with several constraints and conditions. From results, utilizing the benefits of both PSO and GSA, the proposed technique converges the optimization problem in less time and number of iterations.

Singh et al. [26] provided a novel approach for the minimization of various objective function such as cost as well as fuel consumption. However, it can be achieved by the implementation of weighting method that converts issues related to MOELD into the scaler optimization. Basically, the weighting method assigned different weights to the individual objective function on the basis of their priority order. This method was used to solve the issues related to MOELD for the various generator combinations such as six, ten and the forty generator combination. The obtained results were compared with the previous approaches was also discussed in the paper and the obtained results verify its ability to tackle various objectives

Bhaskar et al. [27] discussed a new approach for the economic load dispatch problems related to the security constraints within the thermal unit, which were competent in getting economic scheduling for utility framework. In case of improved particle swarm optimization technique strategy which was quite reasonable for a large scale framework and the summary of constriction factor approach (CFA) were too discussed in the given research. Results show that the proposed technique takes less time as well as having higher reliability in comparison to other PSO based techniques.

Santra et al. [28] proposed a new hybrid technique which is basically a combination of particle swarm optimization as well as ant colony optimization for the minimization of issues related to economic load dispatch. The simulated results discuss the uniform distribution of load over the 6 generator framework. Also, the simulated results confirm the effectiveness of the proposed technique in comparison to classical PSO as well as the proposed combination of PSO and ACO improve the overall efficiency of the system.

Chopra et al. [29] projected approach of hybrid optimization method MPSOSM which was basically a combination of random approach which was considered for the base level searching whereas, for the local level searching process, the deterministic approach was considered. The effectiveness of the proposed research was checked for the problems related to the multi objective economic load dispatch including transmission losses. Further, the proposed method results were compared with the results of the previous technique and it shows that the proposed technique was better than other technique in several ways such as performance etc. At last, to check the strength of the proposed work in comparison to the classical PSO, its quality examination, as well as comparative study of its convergence characteristics has been achieved.

Suganya et al. [30] discussed the solution of several issues related to the multi objective economic power dispatch optimization by the EP method. The proposed work considers a single emission related to the nitrogen oxide for the effective analysis was also discussed in this paper. Here, the implementation of economic load dispatch was done for the two cases such as in the primary one, the transmission losses were completely eliminated whereas in the secondary one, the transmission losses were considered for the framework for the analysis, a standard 30 bus IEEE system was considered with six generator framework and the simulation of the proposed work was done for the efficient analysis of the complete system.

Fang Yao et al. [31] discussed about the utilization of multi objective economic load dispatch (ELD) for the minimization of emission cost function that arise due to various gases such as CO_2 and NO_2 . This paper considered the emission cost as the objective function and also works towards the solution of economic load dispatch related problem with the help of differential evolution approach. To verify the feasibility of the proposed technique, the proposed model was implemented on the standard test system including 6 thermal units and the results showed the effectiveness of the proposed technique in comparison to other alternatives for solving the ELD related problems.

Jagadeesh Gunda et al. [32] discussed about the solution technique for the minimization of economic load dispatch related problems for the effective operation and the efficient planning of the complete system. With the incremental awareness related to environment leads the generating

units towards the optimization of emission as well as cost function. It also discussed about the CEED problem related to ELD by the utilization of Hybrid differential evolution algorithm (HDEA). For evaluating the efficiency of the proposed technique, it was tested on the standard IEEE-30 bus system including 6 generating units for the effective solution of CEED problem as well as the results proved its effectiveness in comparison to the previously proposed techniques for the optimization of cost function etc.

M. A. Abido *et al.* [33] proposed MOPSO technique for finding the solution of economic dispatch problem. The problem has been developed based on fuel cost as well as environmental influence. Management of set size of pareto optimal has been done by using a clustering technique. The best settlement solution has been perceived by employing fuzzy based mechanism. IEEE 30 bus system has been considered for the comparative analysis for different optimisation technique. From the results, the efficiency of MOPSO has been observed.

1.3 OBJECTIVE OF WORK

The aim of the dissertation work is to optimize the multiobjective dispatch problem. The objectives are given below -

- To optimize the fuel cost and emission of multiobjective economic emission dispatch problem.
- Implement multiobjective Particle Swarm Optimization (MOPSO) and Jaya Optimization algorithm to find the optimal solution.
- Comparative analysis of proposed algorithms for multiobjective problem.

1.4 OUTLINE OF THE DISSERTATION

Chapter 1 includes an overview of the dissertation, brief literature review, objective of the work and organization of the dissertation.

Chapter 2 describes the economic load and emission dispatch.

Chapter 3 gives an introduction to multiobjective Particle Swarm Optimization (PSO) and the various steps involved in its implementation. In addition, multiobjective Jaya algorithm has also been discussed in detail.

Chapter 4 discusses the multiobjective problem formulation considering Multiobjective PSO and multiobjective Jaya algorithm and further its implementation at common economic emission dispatch problem.

Chapter 5 describes the comparison of two different techniques for two different cases.

Chapter 6 presents the conclusion drawn with future scope.

CHAPTER 2

COMBINED ECONOMIC EMISSION LOAD DISPATCH

2.1 INTRODUCTION

In thermal power plants, the combustion of fossil fuels like coal produces various harmful gases like NO_x, SO_x and CO₂ which are emitted in the open atmosphere. These emissions affect the atmosphere as well as is related with the ecological concerns. Also, according to the Clean air act [34] these emissions influences the various utilities to modify their usual procedure, meeting the ecological emission standards. Thus, considering the emission as an important parameter in dispatch problem, it becomes important to add the emission constraint into the system. Hence, considering the emission constraint as well as the economic constraints; the new problem can be formulated as the multiobjective problem. Discussing the economic dispatch and its applications, the approach focuses on to find the optimal power outputs of generating units along with minimizing the total operating cost subjected to system constraints. As per [2], considering the multiobjective problem (economic and emission function) both the functions inverse nature, i.e. with the variation in the economic functions the emission function varies inversely and therefore must be examined at the same time to find out optimal dispatch.

Solving the multiobjective problem in dispatch, the other most important parameter is the optimization of the optimal solution. Discussing the optimization process; the objective function, design variables and constraints are three basic components of the system. Focusing on its working, the optimization method either minimize or maximizes the objective function by evaluating the values of various variables subjected to constraints. To get the optimal solution of objective function, numerous combination of variable values must be explored.

2.2 ECONOMIC LOAD DISPATCH

Discussing the economic load dispatch algorithm, the objective of economic load dispatch is to minimize the operating cost while considering equality and inequality constraints of an electric power system having complex and nonlinear characteristics [1].

Below the Figure 2.1 shows the basic model of fossil fuel based plant, where G represents generator, T represent the turbine and B represents boiler. The various type of generators available

in the electrical power system are; nuclear based power plant, hydro source based power plant and fossil fuel based (coal) power plant.

Out of all the above plants, the economic dispatch problem in case of hydro plants is not available, i.e. the system does not possess any variable operating cost and similarly for nuclear plants the output is maintained at a constant level. Therefore, focusing on the fossil fuel based plants the economic dispatch algorithm for optimizing the operating cost can be applied.

Considering the transmission, distribution, maintenance and the labour cost as nearly constant percentage of fuel cost, the other major components of the overall plant cost includes the fuel cost.

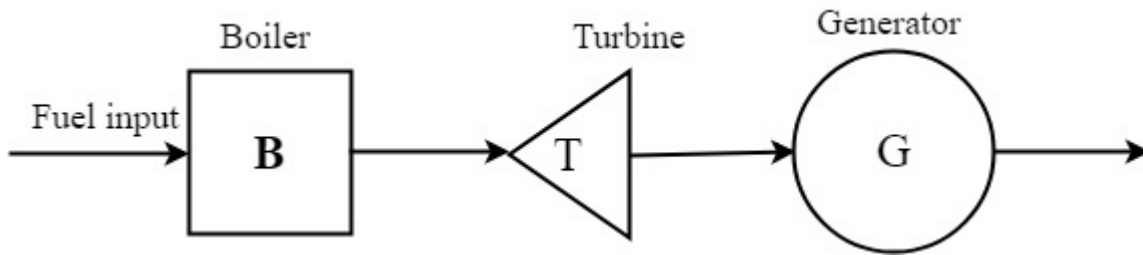


Figure 2.1 Basic model of fossil plant.

A basic model of fossil plant showed in figure 2.1. The output of fossil plant is varied by opening and closing of the inlet valve to its steam turbine [2].

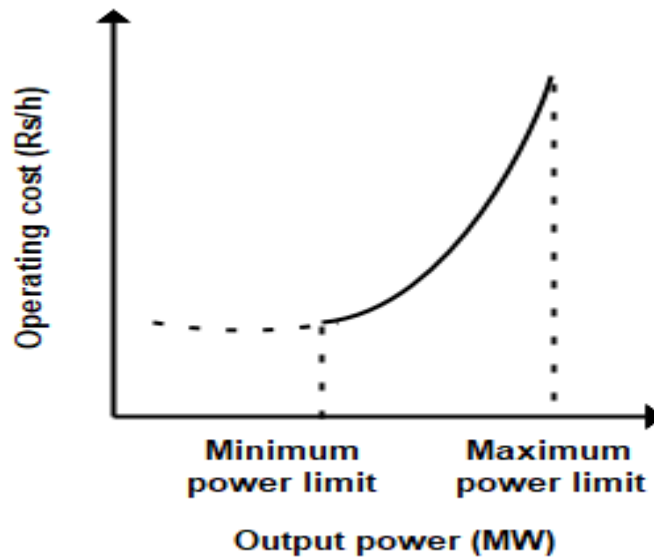


Figure 2.2 Fuel cost curve of thermal generator.

Figure 2.2 shows operating cost curve of the plant which estimated as quadratic by one or more quadratic sections. So, the fuel cost curve is represented as a quadratic expression-

$$F(P_{gk}) = \sum_{k=1}^N (a_k P_{gk}^2 + b_k P_{gk} + c_k) \quad (2.1)$$

Where, a_k, b_k, c_k – cost coefficients of thermal plant

P_{gk} – power generation of k^{th} unit

F -fuel cost function

N -represents total power units

When valve point loading effect is considered, the input output cost curve shows the higher order of nonlinearities and discontinuities. The effect of valve point loading has been represented as a rectified sinusoidal function, shows in figure 2.4 which is added to the quadratic fuel cost curve [5].

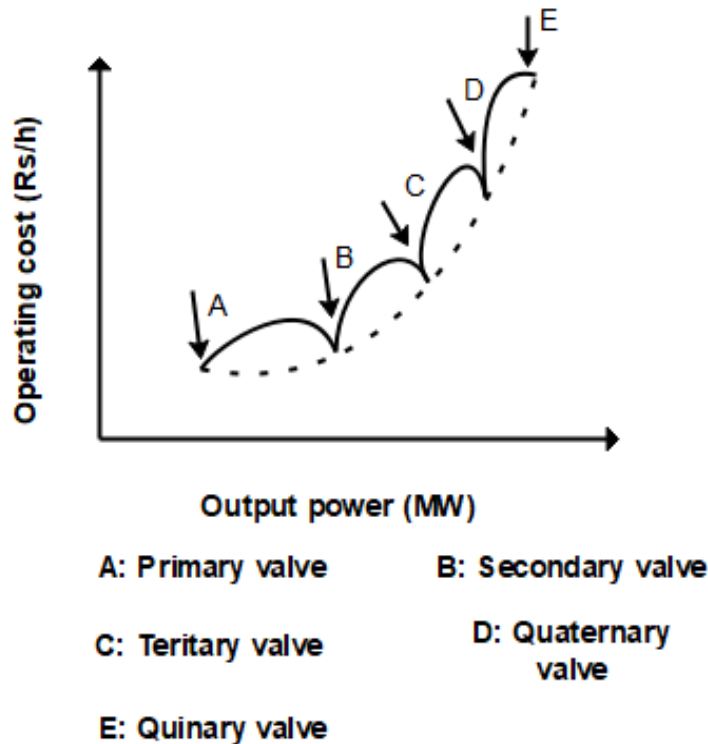


Figure 2.3 Cost curve exhibiting discontinuities due to valve point effect

Mathematically, the fuel cost curve after adding valve point loading effect is represented as-

$$F(P_{gk}) = \sum_{k=1}^N (a_k P_{gk}^2 + b_k P_{gk} + c_k) + |d_k * \sin[e_k(P_{gk}^{min} - P_{gk})]| ($) \quad (2.2)$$

where e_k , and d_k are fuel cost coefficients of unit k with valve-point effect.

P_{gk}^{min} - least power limit of k^{th} unit

2.3 EMISSION DISPATCH

Concerning the ecological emission as an essential issue in operation of fuel based power plants the operating cost of the system is no more the concerned parameter for optimal operation. The environmental issues related with the fuel based plants should also be taken into consideration for efficient power dispatch as the use of fossil fuel for generation of electricity releases harmful contaminants such as NO_x, SO_x and CO₂ which causes an adverse impact on the environment. Thus, the emission constraint must be added to the optimal dispatch problem.

Discussing the emission related problem formulation, equation 2.3 shows the relation between the emission dispatch coefficient and the number of generators for fuel based power plants.

$$E(P_{gk}) = \sum_{k=1}^N (\alpha_k P_{gk}^2 + \beta_k P_{gk} + \gamma_k + \eta_k * \exp(\delta_k * P_{gk})) (\text{lb}) \quad (2.3)$$

where $\alpha_k, \beta_k, \gamma_k, \eta_k$ and δ_k are the emission coefficients and N represents number of generators.

2.4 CONSTRAINTS

For economic and emission dispatch problem, there are basically two types of constraints-

1. Equality constraint
2. Inequality constraint

2.4.1 Equality constraints

- 1) **Power balance constraint:** Total power generation must meet the load demand and losses in transmission lines.

$$\sum_{k=1}^N P_{gk} = P_D + P_L \quad (2.4)$$

Where, P_D - load demand

P_L - losses in transmission lines

P_{gk} – power generation of k^{th} unit

2.4.2 Inequality constraints

- 1) **Generator limits:** The power generation of thermal plants has to be within its maximum and minimum generation limit.

$$P_{gk}^{min} \leq P_{gk} \leq P_{gk}^{max} \quad (2.5)$$

P_{gk}^{min} and P_{gk}^{max} are the least and extreme limit of power generation of thermal power unit respectively.

2.5 ECONOMIC LOAD DISPATCH USING LAGRANGE MULTIPLIER METHOD

In this section, the ELD problem is formulated using the Lagrange Multiplier method with and without considering losses.

2.5.1 ELD without losses

Suppose there are N generating units to supply the load demand and the cost function is represented as a quadratic equation,

$$F(P_{gk}) = \sum_{k=1}^N (a_k P_{gk}^2 + b_k P_{gk} + c_k) \quad (2.6)$$

Subjected to equality and inequality constraints given in equation (2.4) & (2.5) ($P_L=0$).

Above constrained problem is modified to unconstrained problem by using Lagrange multiplier method and the augmented function is represented as,

$$L(P_{gk}, \lambda) = F(P_{gk}) + \lambda (P_D - \sum_{k=1}^N P_{gk}) \quad (2.7)$$

The minimum value of the function is calculated by finding the partial derivative of the function and equating it to zero, i.e.,

$$\frac{\partial L}{\partial P_{gk}} = 0 \quad (2.8)$$

$$\frac{\partial L}{\partial \lambda} = 0 \quad (2.9)$$

From equation (2.8),

$$\frac{\partial F(P_{gk})}{\partial P_{gk}} = \lambda \quad (2.10)$$

Where

$$\frac{\partial F(P_{gk})}{\partial P_{gk}} = \sum_{k=1}^N 2a_k P_{gk} + b_k \quad (2.11)$$

From equation (2.10) & (2.11),

$$\sum_{k=1}^N 2a_k P_{gk} + b_k = \lambda \quad (2.12)$$

Solving equation (2.12),

$$\sum_{k=1}^N P_{gk} = \frac{\lambda - \sum_{k=1}^N b_k}{\sum_{k=1}^N 2a_k} \quad (2.13)$$

From equation (2.9),

$$\sum_{k=1}^N P_{gk} = P_D \quad (2.14)$$

When losses are not considered, equation (2.14) represented equality constraints which are to be subjected.

From equation (2.13) & (2.14),

$$P_D = \frac{\lambda - \sum_{k=1}^N b_k}{\sum_{k=1}^N 2a_k} \quad (2.15)$$

$$\lambda = \frac{P_D + \sum_{k=1}^N \frac{b_k}{2a_k}}{\sum_{k=1}^N \frac{1}{2a_k}} \quad (2.16)$$

The value of λ is computed using equation (2.16) and further power generated (P_{gk}) is calculated using equation (2.13) subjected to constraints.

2.5.2 ELD considering losses

In a huge interconnected network, transmission losses affect the optimal dispatch of generation. therefore, it is important to consider the losses while performing economic dispatch. The transmission losses are represented as,

$$P_L = \sum_{l=1}^N \sum_{k=1}^N P_k B_{kl} P_l \quad (2.17)$$

Where B_{kl} represents loss coefficients.

The ELD problem after considering losses is now formulated by using the Lagrange multiplier method as-

$$L(P_{gk}, \lambda) = F(P_{gk}) + \lambda (P_D + P_L - \sum_{k=1}^N P_{gk}) \quad (2.18)$$

For minimizing the function,

$$\frac{\partial L}{\partial P_{gk}} = 0 \quad (2.19)$$

$$\frac{\partial L}{\partial \lambda} = 0 \quad (2.20)$$

From equation (2.19),

$$\frac{\partial F(P_{gk})}{\partial P_{gk}} = \lambda \left(1 - \frac{\partial P_L}{\partial P_{gk}}\right) \quad (2.21)$$

$$\frac{1}{\left(1 - \frac{\partial P_L}{\partial P_{gk}}\right)} \frac{\partial F(P_{gk})}{\partial P_{gk}} = \lambda \quad (2.22)$$

$$L_k \frac{\partial F(P_{gk})}{\partial P_{gk}} = \lambda \quad (2.23)$$

Where $k=1,2,\dots,N$.

Where L_k represents the Penalty Factor. $\frac{\partial F(P_{gk})}{\partial P_{gk}}$ and $\frac{\partial P_L}{\partial P_{gk}}$ represent the incremental fuel cost and incremental transmission losses.

The loss coefficient equation (2.17) can be simplified as-

$$\frac{\partial P_L}{\partial P_{gk}} = \sum_{l=1}^N 2 B_{kl} P_l \quad (2.24)$$

$$\frac{\partial F(P_{gk})}{\partial P_{gk}} = \sum_{k=1}^N 2a_k P_{gk} + b_k \quad (2.25)$$

By substituting the values of $\frac{\partial P_L}{\partial P_{gk}}$ and $\frac{\partial F(P_{gk})}{\partial P_{gk}}$ in equation (2.21),

$$2a_k P_{gk} + b_k + \lambda \left(\sum_{l=1}^N 2 B_{kl} P_l \right) = \lambda \quad (2.26)$$

P_{gk} can be calculated as

$$P_{gk} = \frac{1 - \frac{b_k}{\lambda} - \sum_{\substack{l=1 \\ l \neq k}}^N 2 B_{kl} P_l}{\frac{2a_k}{\lambda} + 2B_{kk}} \quad (2.27)$$

Assuming initial values of λ and P_{gk} the above equation can be solved iteratively and stopped when equality constraints are satisfied by modifying λ .

CHAPTER-3

OPTIMISATION TECHNIQUES

3.1 MULTIOBJECTIVE PARTICLE SWARM OPTIMIZATION

3.1.1 Introduction

PSO was first introduced by Kennedy and Eberhart which was inspired by social performance of animal such as bird flocking. It is an optimization tool which utilizes a population based search process. The individuals taken into consideration are called particles whose positions or state varies with time. Search space is of multidimensional in which the particles modify their positions according to their own observation along with the observed value of the adjacent particles. The observations made or compared to reach the best position. The observations made or compared to reach the best position. The direction of moment described set of neighboring particles together with the past experience. For economic emission dispatch formulated multiobjective constrained optimization problem has been converted into single objective unconstrained optimization problem using weighted sum method.

Let particle's position and velocity indicated by P and v . The representation of j^{th} particle in n dimensional space can be defined as

$$P_i = [P_{i1}, P_{i2}, P_{i3}, \dots, P_{im}] \quad (3.1)$$

The initial best position of individual particles can be expressed as

$$Pb_i = [Pb_{i1}, Pb_{i2}, Pb_{i3}, \dots, Pb_{im}] \quad (3.2)$$

Similarly, the best particle from the initial best solution is taken as Global best and expressed as equation

$$G_i = [G_{i1}, G_{i2}, G_{i3}, \dots, G_{im}] \quad (3.3)$$

Furthermore, particles velocities can be depicted as

$$v_i = [v_{i1}, v_{i2}, v_{i3}, \dots, v_{im}] \quad (3.4)$$

The updated values of particles velocity as well as position can be furthermore computed considering the aforementioned values of velocity along with the distance between local best and global best.

$$v_{ij}^{r+1} = w * v_{ij}^r + C_1 * R_1 * (Pb_{ij}^r - P_{ij}^r) + C_2 * R_2 * (G_j^r - P_{ij}^r) \quad (3.5)$$

$$P_{ij}^{r+1} = P_{ij}^r + v_{ij}^{r+1} \quad (3.6)$$

where

($i=1,2,3,\dots,n$) and ($j=1,2,3,\dots,m$)

v_j^{\min} provide a balance between initial position and end position. Low and high values of v_j^{\max} might affect the consideration of local solutions.

The acceleration constants C_1 and C_2 have a tendency to push the particle approaching local best and global best. C_1 and C_2 values are considered to be 2 as per previous experiences.

The choice of inertia weight w maintains a balance among local and global search space, in this manner requiring less number of iterations to discover and adequately optimal solution.

$$w = w^{\max} - \left\{ \frac{w^{\max} - w^{\min}}{IT^{\max}} \right\} * IT \quad (3.7)$$

3.1.2 Implementation

The objective of economic load dispatch is to get the value of generated power by each allocated generator, along with the minimum cost of generation subjected to constraints.

The PSO is initiated by exploring power generation. The ELD is explained by equation (2.4) and transmission losses by equation (2.17).

3.1.3 Representation of Swarm

For ELD, active power generations are the decision variables. They are utilized to frame the Swarm. The active power output is expressed as particle's position in Swarm. Form number of generators and n number of particles, particle swarm is expressed as a matrix having size $n \times m$.

3.1.4 Initialization

Each particle positions and velocity is initiated by using the below equations without operating limits violations.

$$P_i^j = P_i^{\min} + \text{rand}() * (P_i^{\max} - P_i^{\min}) \quad (3.8)$$

$$v_i^j = v_i^{\min} + \text{rand}() * (v_i^{\max} - v_i^{\min}) \quad (3.9)$$

3.1.5 Objective function evaluation

Check generator limits and compute the value of objective function is corresponding to the particle position.

3.1.6 Selection of best positions

In PSO technique, the key components of particle best (P_{ij}^{best}) and global best (G_j^{best}) positions. The best position is selected as position along minimum objective function and the Global best is taken as the best from all P_{ij}^{best} .

3.1.7 Movement of particles

Particles velocities are updated by using acceleration terms and inertia weight. After calculating new velocity, positions are updated using new velocity.

$$v_{ij}^{\text{new}} = w * v_{ij}^r + C_1 * R_1 * (Pb_{ij}^r - P_{ij}^r) + C_2 * R_2 * (G_j^r - P_{ij}^r) \quad (3.10)$$

$$P_{ij}^{\text{new}} = P_{ij}^r + v_{ij}^{\text{new}} \quad (3.11)$$

3.1.8 Updating the best position

The new objective function is calculated using updated positions and comparison is done with the previous value. If objective function is better than previous value than changing the Pb_{best} and G_{best} values accordingly.

3.1.9 Stopping condition

There are different criteria accessible to stop Optimization methods. Generally, tolerance and maximum number of iterations are taken as stopping condition.

3.1.10 Flow chart of PSO Algorithm

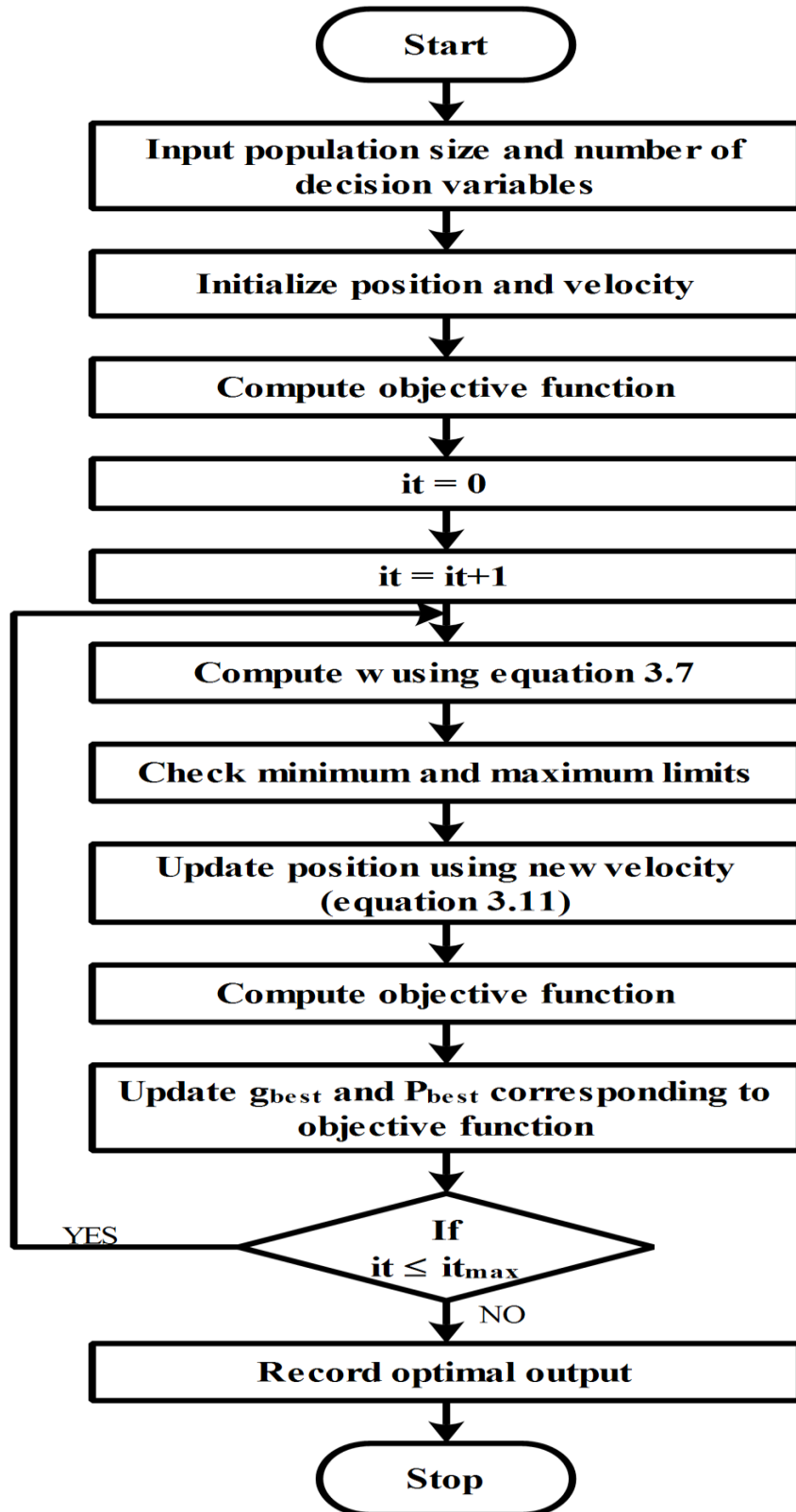


Figure 3.1 Flowchart for PSO

3.2 MULTIOBJECTIVE JAYA OPTIMIZATION TECHNIQUE

3.2.1 Introduction

Venkata *et. al* [34] proposed Jaya algorithm as a noncomplex global Optimization technique this technique applied successfully on constraints and unconstrained benchmarks functions. The proposed technique focuses on to find the best solution while evading the word solution. As compared to other techniques, Jaya algorithm depends on few control parameters like number of decision variables, maximum number of iterations and population size.

3.2.2 Algorithm

Step 1. Initialize by defining the population size, number of decision variables and the termination condition.

Step 2. Generate population of size p (candidate solution) \times q (decision variables).

Step 3. Compute the initial solution for a defined objective function.

Step 4. Find out the best and the worst solution from the initial solution calculated in step 3, defined as

Best solution $\rightarrow X_{i,best}^k$

Worst solution $\rightarrow X_{i,worst}^k$

Step5. Update the solution by using the below equation.

$$X_{i,j}^{k+1} = X_{i,j}^k + r_1(X_{i,best}^k - |X_{i,j}^k|) - r_2(X_{i,worst}^k - |X_{i,j}^k|) \quad (3.12)$$

Step6. Compare the solution of present and previous candidate

$$\text{IF } X_{i,j}^{k+1} < X_{i,j}^k$$

$$X_{i,j}^k = X_{i,j}^{k+1}$$

$$\text{Otherwise } X_{i,j}^k = X_{i,j}^k$$

Step7. Check the termination condition

If satisfied then save the optimum solution otherwise go to step 2.

The Jaya algorithm initializes by defining the input parameters such as number of decision variables, population size and maximum number of iteration (i.e. termination criteria). For an objective function $f(x)$, the main objective is to minimize or maximize the objective function Let us assume that we have p number of candidates solution (i.e. $k=1,2,\dots,p$) and q number of decision

variables (i.e. $j=1,2,\dots,q$). Assume that $f(x)_{best}$ represent the best candidate solution from the entire candidate solution for objective function $f(x)$ likewise $f(x)_{worst}$ represent worst candidate solution from the whole solution. $X_{i,j}^k$ represents value of j^{th} decision variable of k^{th} candidate at i^{th} iteration, $X_{i,j}^{k+1}$ is updated value computed by using equation (2.6). $X_{i,best}^k$ and $X_{i,worst}^k$ represent the Best and worst value of the j^{th} decision variable of k^{th} candidate at i^{th} iteration. r_1 and r_2 are random numbers having range between 0 and 1. If the updated value ($X_{i,j}^{k+1}$) is less than previous value ($X_{i,j}^k$) then previous solution is updated by new value otherwise keep the previous solution. The expression $r_1(X_{i,best}^k - |X_{i,j}^k|)$ and $[-r_2(X_{i,worst}^k - |X_{i,j}^k|)]$ shows that this technique has tendency to move towards best and evade the worst solution.

3.2.3 Flowchart for Jaya Optimization Algorithm

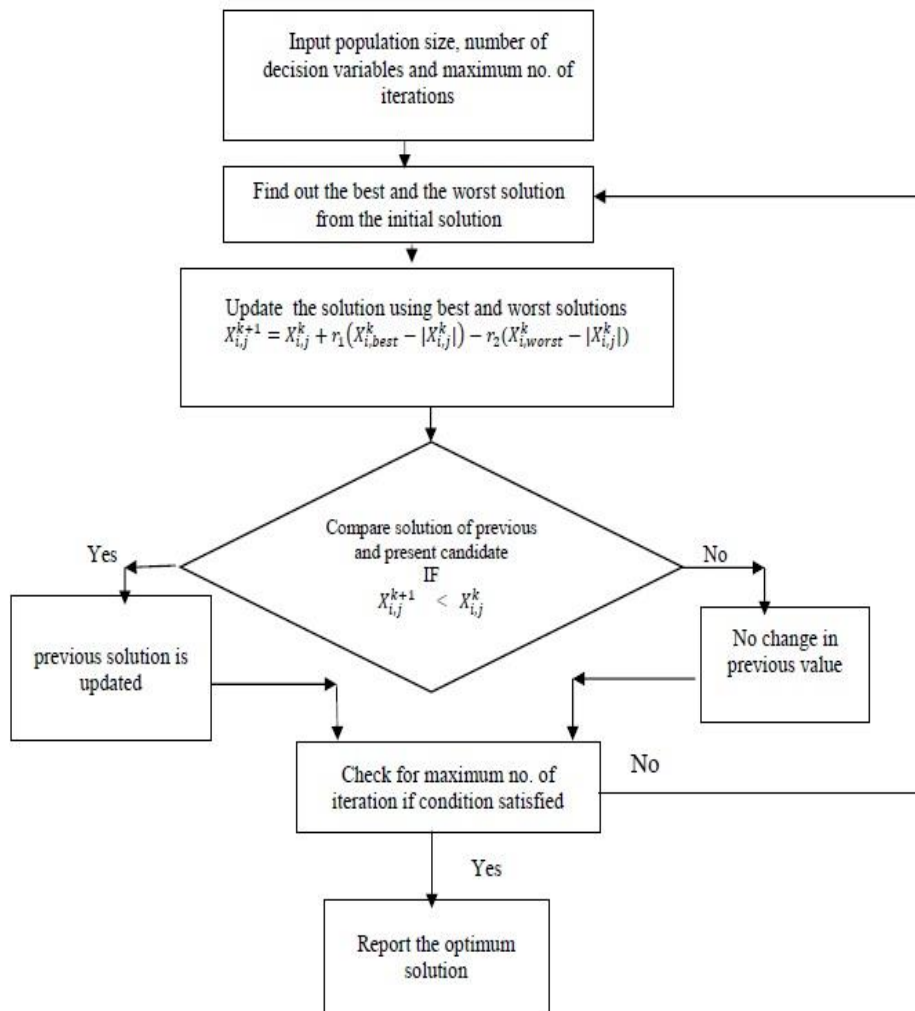


Figure 3.2 Flow chart of Jaya Algorithm

CHAPTER-4

PROBLEM FORMULATION

In this section, the problem formulation of emission as well as economic power dispatch has been discussed. The presented formulation aims at minimizing the multiobjective problem, i.e. simultaneously minimisation of both the cost and the emission function, satisfying the equality and inequality constraints.

4.1 Objective function

The mathematical formulation of minimization problem is defined as equation 4.1

$$\text{Minimisation } f_1(x) \quad i = 1, \dots, N_{obj} \quad (4.1)$$

Subjected to,

$$g_i(x) \leq 0, \quad i = 1, 2, \dots, m \quad (4.2)$$

$$h_j(x) = 0, \quad j = 1, 2, \dots, p \quad (4.3)$$

1) Cost

The fuel cost is considered as an essential measure for economic feasibility. The fuel cost curve is represented as a sum of quadratic cost function and rectified sinusoidal function (due to valve point Loading effect) and the equation is given by

$$F(P_{gk}) = \sum_{k=1}^N (a_k P_{gk}^2 + b_k P_{gk} + c_k) + |d_k * \sin[e_k(P_{gk}^{min} - P_{gk})] \quad (\$) \quad (4.4)$$

2) Emission

The objective of emission dispatch is to minimize the emission levels. Emission function is represented as the sum of a quadratic function and the exponential function.

$$E(P_{gk}) = \sum_{k=1}^N (\alpha_k P_{gk}^2 + \beta_k P_{gk} + \gamma_k + \eta_k * \exp(\delta_k * P_{gk})) \quad (lb) \quad (4.5)$$

4.2 Constraints

For economic and emission dispatch problem, there are basically two types of constraints

1. Equality constraint
2. Inequality constraint

4.2.1 Equality constraints

- 1) **Power balance constraint:** Total power generation must meet the load demand and losses in transmission lines.

$$\sum_{k=1}^N P_{gk} = P_D + P_L \quad (4.6)$$

P_D - load demand

P_L - losses in transmission lines

P_{gk} – power generation of k^{th} unit

4.2.2 Inequality constraints

- 1) **Generator limits:** The power generation of thermal plants has to be within its maximum and minimum generation limit.

$$P_{gk}^{min} \leq P_{gk} \leq P_{gk}^{max} \quad (4.7)$$

P_{gk}^{min} and P_{gk}^{max} are the least and extreme limit of power generation of thermal power unit respectively.

The augmented function for the system is given as:

$$F_T = w_1 F(P_{gk}) + w_2 E(P_{gk}) \quad (4.8)$$

where, w_1 and w_2 are the randomly generated weights and can be correlated with each other as;

$$\sum_{i=1}^{obj} w_i = 1 \quad (4.9)$$

For constant handling penalty method is used, given as below

$$\Phi_k = \begin{cases} (P_d^k - P_d^{min})^2 & P_d^k < P_d^{min} \\ (P_d^{max} - P_d^k)^2 & P_d^k > P_d^{max} \\ 0 & P_d^{min} \leq P_d^k \leq P_d^{max} \end{cases} \quad (4.10)$$

4.3 Solution methodology

MOPSO optimization algorithm and the Jaya algorithm have been used to solve the multiobjective economic emission dispatch problem. This section explains the algorithm as well as the flowchart of the proposed methodologies.

In 4.3.1, using the weighted sum method, the multiobjective problem of EED has been converted into the single objective EED problem.

4.3.1 MOPSO Algorithm for Combined EED Problem

Step 1. Read input cost coefficient matrix and emission coefficient matrix, minimum and maximum limits of generators, P_D , B-coefficients matrix. Input population size (n) and no. of particles(m), maximum number of iteration (IT^{\max}), tolerance, v_{min} and v_{max} .

Step 2. Generate particle velocity v_{ij} , position P_{ij} and weights randomly and also check boundary limits using equation (3.8), (3.9).

Step3. Compute the augmented function value corresponding to particle positions using equation (4.8)

Step 4. Find out the minimum value of augmented function and save as f_{best} .

Step 5. Set all particle position as best position.

$$P_{ij}^{\text{best}} = P_{ij}$$

Step 6. Choose particle best value as global best corresponding to f_{best} .

$$G_j^{\text{best}} = P_{ij}^{\text{best}}$$

Step 7. Set it=0.

Step 8. Increment in iteration as, it=it+1.

Step 9. Calculate weight as

$$w = w^{\max} - \left\{ \frac{w^{\max} - w^{\min}}{IT^{\max}} \right\} * IT$$

Step 10. Calculate particle updated velocity by using formula,

$$v_{ij}^{\text{new}} = w * v_{ij}^r + C_1 * R_1 * (P_{ij}^r - P_{ij}^r) + C_2 * R_2 * (G_j^r - P_{ij}^r)$$

Step 11. Check boundary violation of velocity.

$$\text{IF } v_{ij}^{\text{new}} \geq v_j^{\max}$$

$$v_{ij}^{\text{new}} = v_j^{\max}$$

$$\text{ELSE IF } v_{ij}^{\text{new}} \leq v_j^{\min}$$

$$v_{ij}^{\text{new}} = v_j^{\min}$$

Step 12. Evaluate new particle positions using formula

$$P_{ij}^{\text{new}} = P_{ij}^r + v_{ij}^{\text{new}}$$

Step 13. Calculate the new augmented function f_i^{new} corresponding to new particle positions.

Step 14. Compare the new objective function values with the previous minimum augmented function value.

$$\text{IF } f_i^{\text{new}} \leq f_{\text{best}}$$

$$f_i^{\text{new}} = f_{\text{best}}$$

Also, update G_j^{best} and P_{ij}^{best} values according to f_i^{new} .

Step 15. Check for maximum iteration condition.

Step 16. Save the optimum dispatch power for each generator and obtain the economic cost and emission dispatch.

Step 17. Vary the weights randomly to obtain pareto optimal front between economic cost and economic emission.

Step 18. Stop.

Below, the figure shows flowchart for MOPSO.

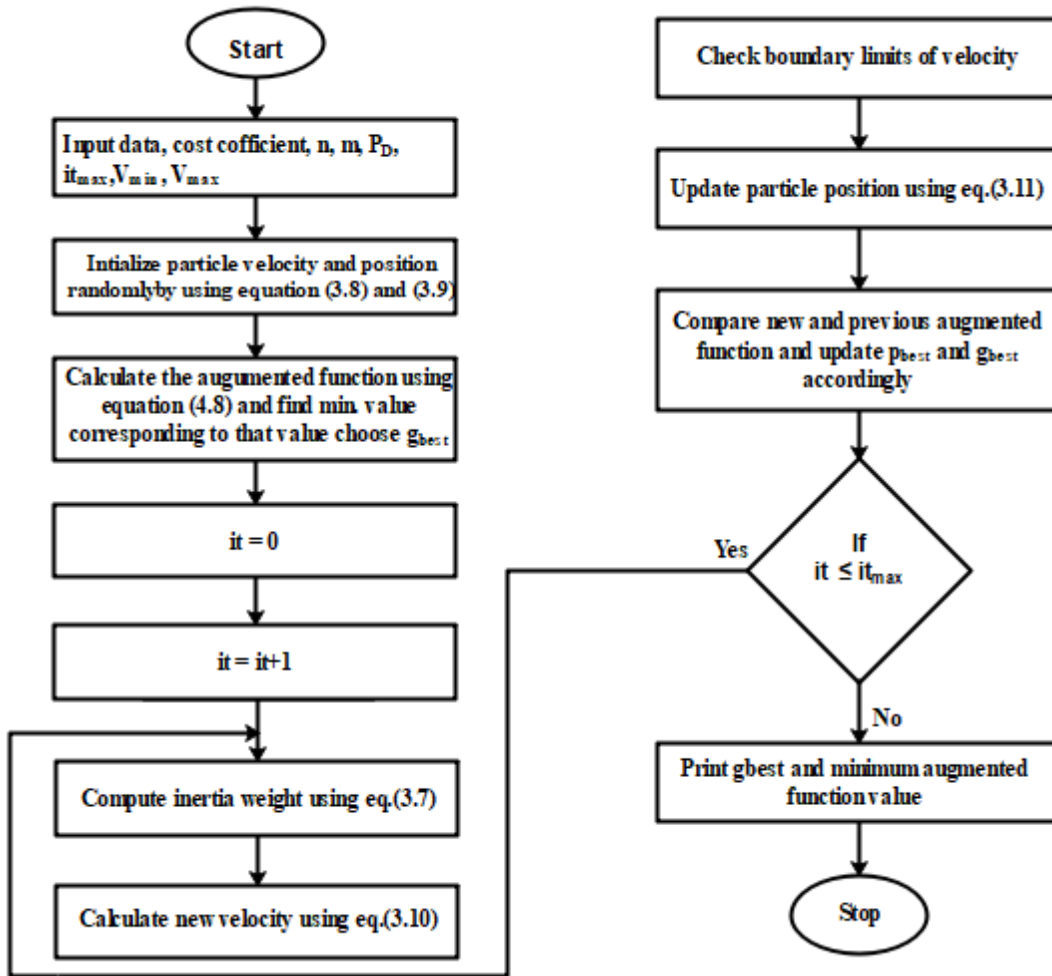


Figure.4.1 Flowchart of MOPSO for CEED problem

4.3.2 Jaya optimization for economic and emission dispatch problem

Step 1. Read input cost coefficient matrix and emission coefficient matrix, minimum and maximum limits of generators, P_D , B-coefficients matrix. Input population size (n) and no. of particles(m), maximum number of iteration (IT^{\max}), tolerance.

Step 2. Initialise the population and weights randomly according to maximum and minimum limits of each individual unit.

Step 3. A population of n (number of population size) \times m (number of generators) generated randomly

Step 4. Calculate the augmented function according to the output power of generators in step 2.

Step 5. Find out minimum and maximum value of the augmented function and set as best solution and worst solution respectively.

Step 6. set iteration counter=0

DO

Step 7. increment iteration = iteration + 1

Step 8. update the population by using formula

$$P_{i,j}^{k+1} = P_{i,j}^k + r_1(P_{i,best}^k - |P_{i,j}^k|) - r_2(P_{i,worst}^k - |P_{i,j}^k|) \quad (4.11)$$

Step 9. Check if any boundary violations of generating units and adjust using penalty factor method by using equation (4.10).

Step 10. Compute new augmented function.

Step 11 Compares the value of the augmented function for each particle with its previous value. if the new best value is better than its previous value then updates the solution otherwise keep as it is.

Step 12. Also, compare the worst values of augmented function and update similar as in step 9.

Step 13. check the termination criteria

IF iteration =maximum iteration

Step 14. Save the optimum dispatch power for each generator and obtain the economic cost and emission dispatch.

Step 15. Vary the weights randomly to obtain pareto optimal front between economic cost and economic emission.

Step 16. Stop.

Below the figure shows flowchart for multiobjective Jaya algorithm

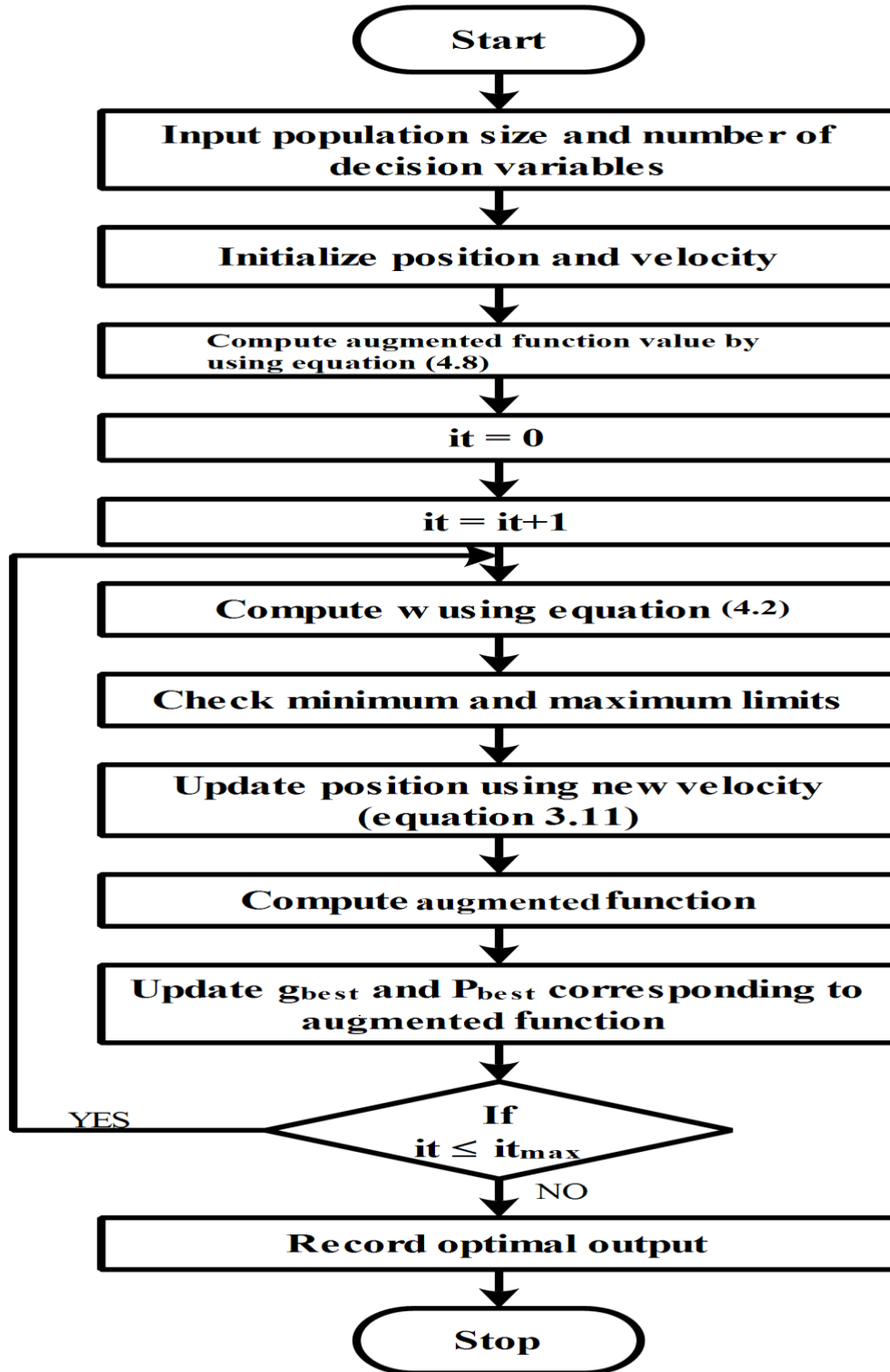


Figure 4.2 Flow chart of MO Jaya for CEED problem

CHAPTER 5

RESULTS AND DISCUSSION

Working with the multiobjective problem, i.e. solving the economic emission dispatch problem; the multiobjective Particle swarm optimization and multiobjective Jaya algorithm have been used. For the purpose of validating the proposed algorithms, two test systems (six generator based test system and ten generator based test system) have been used. Test system 1 with six generators having different maximum and minimum power ratings (Appendix-A) and 1200MW load and similarly ten generators test system have been considered.

The results for these test systems have been simulated using the MOPSO and Jaya based algorithms by varying the weights.

5.1 Test System 1

This test system comprises of six generators with fixed 1200MW load. Table 5.1 shows economic and emission dispatch for the considered test system. The results show the power generated via each generating unit and the total system losses. Comparing the performance for the proposed multiobjective Jaya based algorithm with the MOPSO, the table shows significantly better results.

Table 5.1 Comparison of cost and emission using MOPSO and MO Jaya for 6 generators system

Parameters	MOPSO		MO JAYA	
	Economic dispatch	Emission dispatch	Economic dispatch	Emission Dispatch
P_1	125	125	125	125
P_2	150	150	55.27143	55.27143
P_3	206.6409	127.6524	223.7747	225
P_4	210	210	210	210
P_5	285.0648	325	325	325
P_6	273.0699	315	315	315
Cost (\$)	645334	66086	64440	66040
Emission (lb/hr)	1355.2	1289.4	1356.1	1242.5
Loss (MW)	54.04	52.6524	54.0028	50.369

Also, considering the same test system, figure 5.1 represents the convergence characteristics showing cost and emission characteristics w.r.t. total number of iterations (i=200).

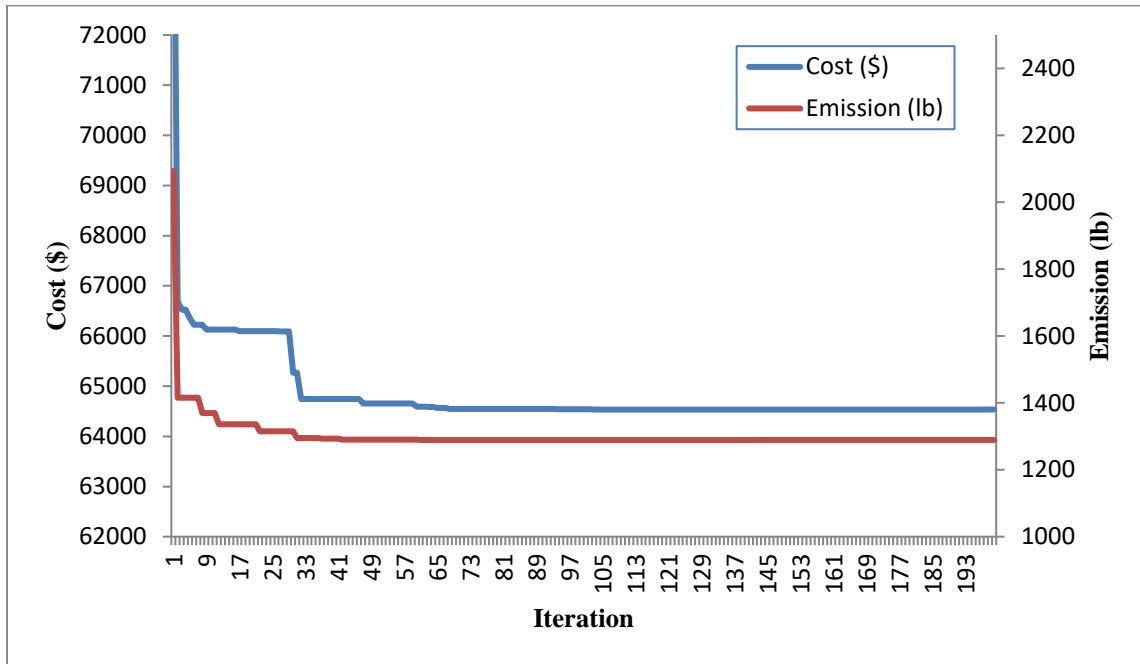


Figure 5.1 Convergence characteristics of economic emission and economic cost for 6 generator system using MOPSO

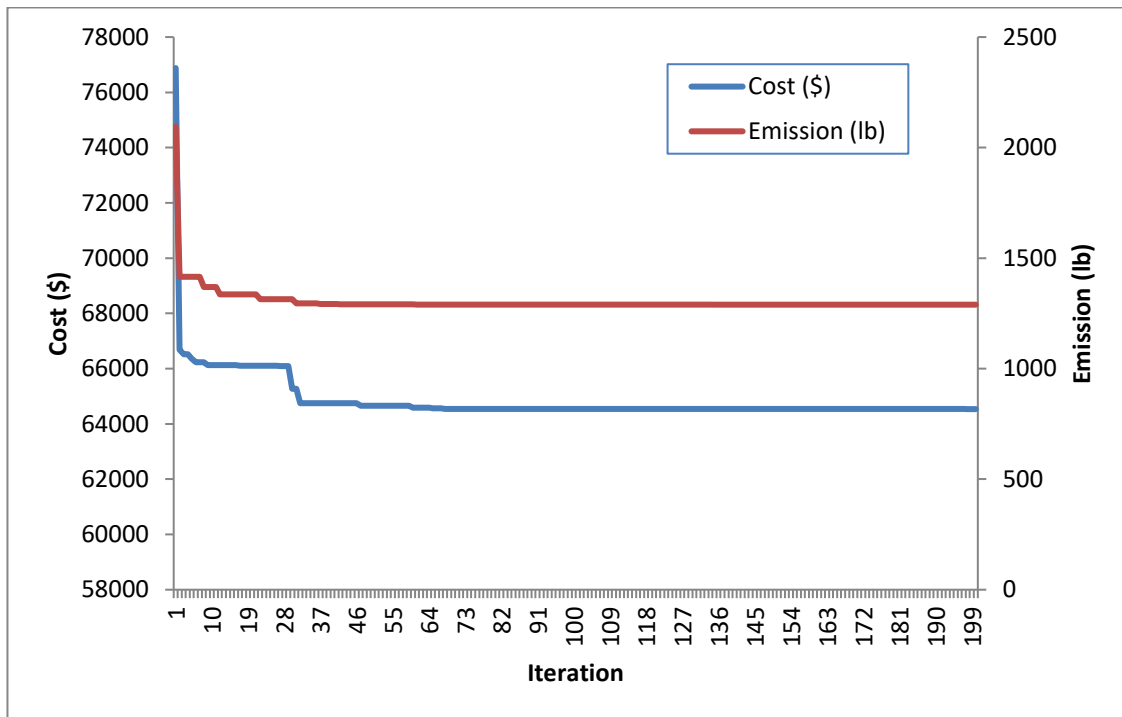


Figure 5.2 Convergence characteristics of economic emission and economic cost for 6 generator system using MOJAYA

5.2 Test System 2

This test system comprises of ten generators with fixed 2000MW load. Table 5.2 shows economic and emission dispatch for the considered test system. The results show the power generated via each generating unit and the total system losses. Comparing the performance for the proposed multiobjective Jaya based algorithm with the MOPSO, the table shows significantly better results.

Table 5.2 Comparison of cost and emission using MOPSO and MO Jaya for 10 generator system

Parameters	MOPSO		MO JAYA	
	Economic dispatch	Emission dispatch	Economic dispatch	Emission Dispatch
P_1	55	55	55	55
P_2	80	80	80	80
P_3	120	120	99.03829	95.12304
P_4	130	42.39195	130	69.07139
P_5	53.99037	141.9129	72.89123	160
P_6	70	240	70	240
P_7	298.0779	300	300	300
P_8	340	283.4487	340	229.0355
P_9	470	470	470	384.8221
P_{10}	470	349.712	470	470
Cost (\$ /hr)	109770	116050	109610	115890
Emission (lb/hr)	4742.2	4172.2	4707	4012
Loss (MW)	87.0684	82.493	87.006	82.3896

Below the figure 5.3 and figure 5.4 shows the convergence characteristics for the ten generator test system considering the cost, emission and number of iterations.

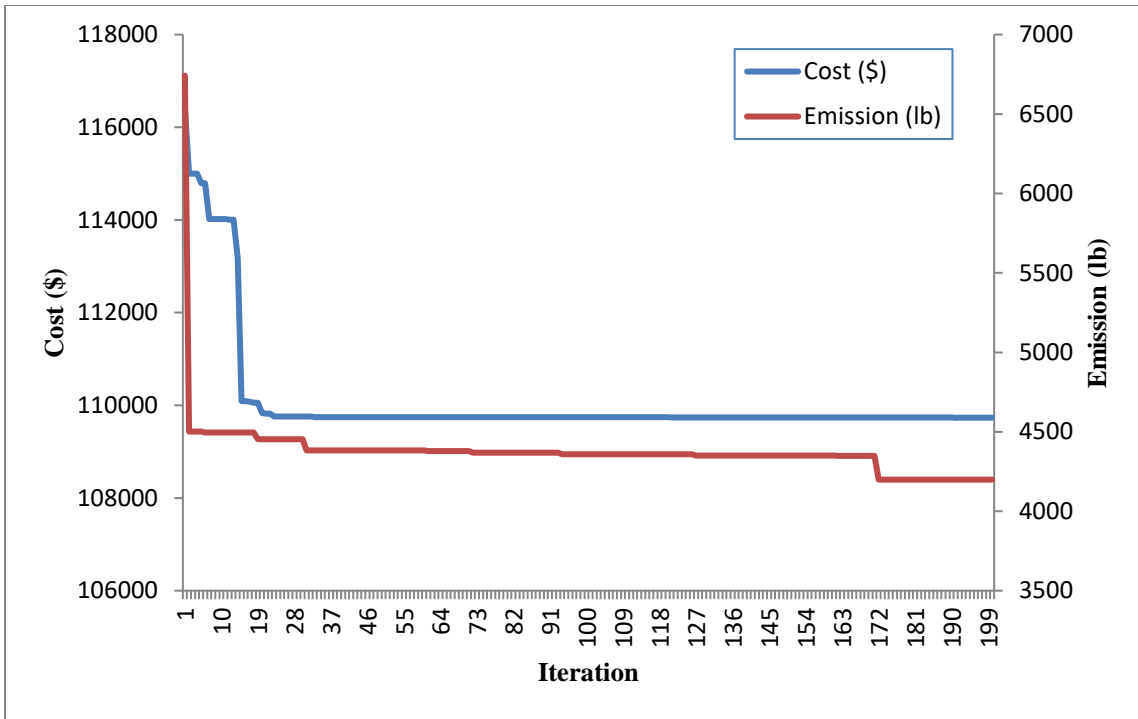


Figure 5.3 Convergence characteristics of economic emission and economic cost for 10 generator system using MOPSO

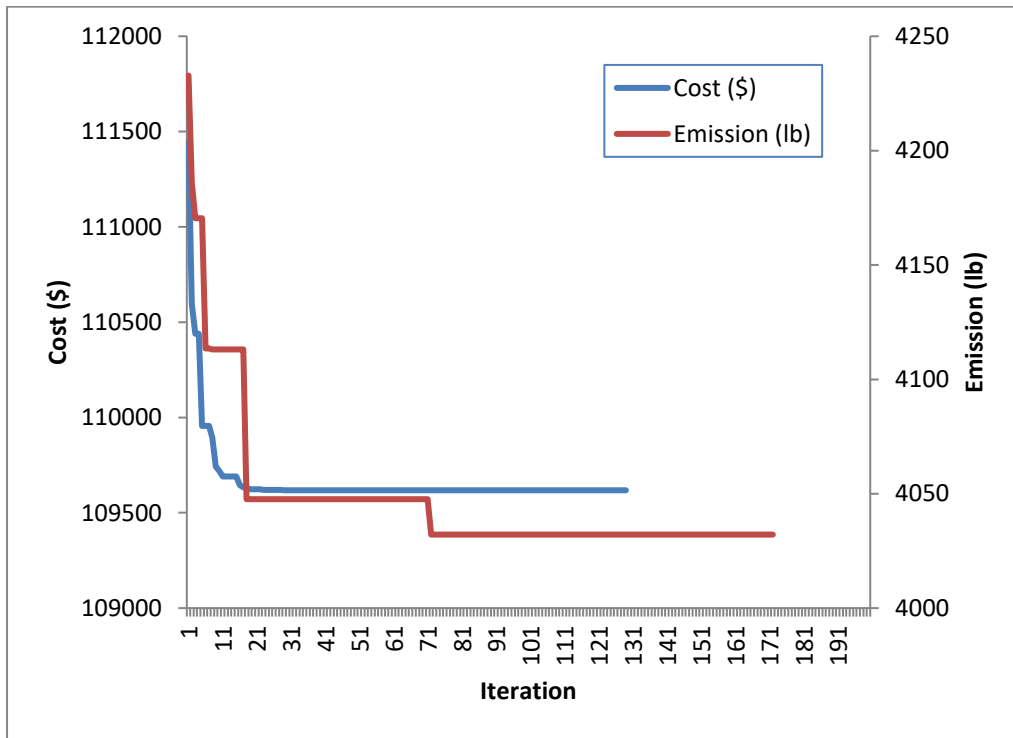


Figure 5.4 Convergence characteristics of economic emission and economic cost for 10 generator system using MO JAYA

5.3 Comparative analysis

Comparing the results for the proposed MOPSO and multiobjective Jaya, this subsection discusses the performance analysis of the six generator and ten generator test system.

Test system 1 – Six generator units

Figure 5.5 represents the cost comparison for both the algorithms, showing the plot for multiobjective Jaya to be better in terms of both cost and convergence rate.

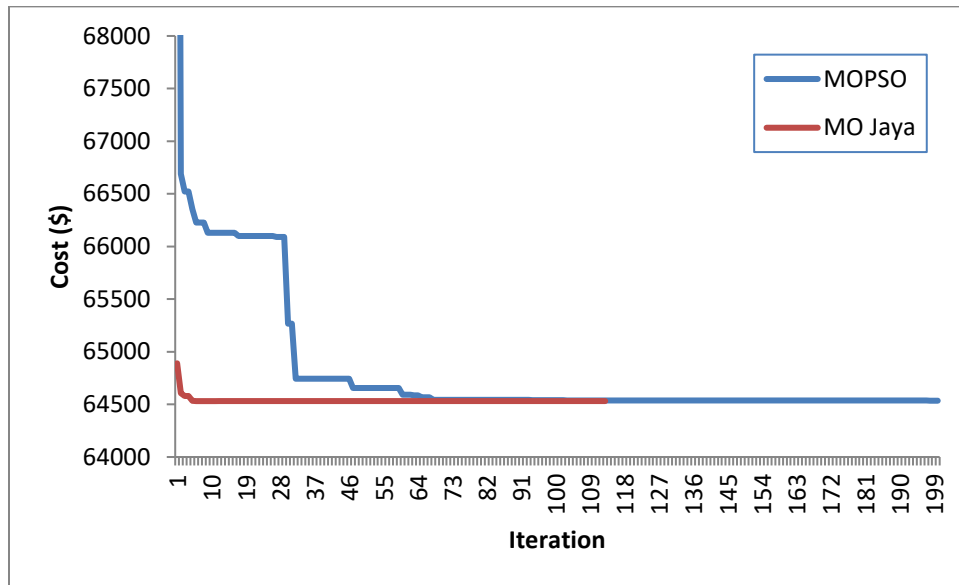


Figure 5.5 Comparison of economic cost using MOPSO and MO JAYA for 6 generator system

Similar to Figure 5.5, the below Figure 5.6 shows the emission comparison for both the algorithms. From Figure 5.6 the rate of convergence considering emission as a constraint is higher in case of multiobjective Jaya in comparison to MOPSO.

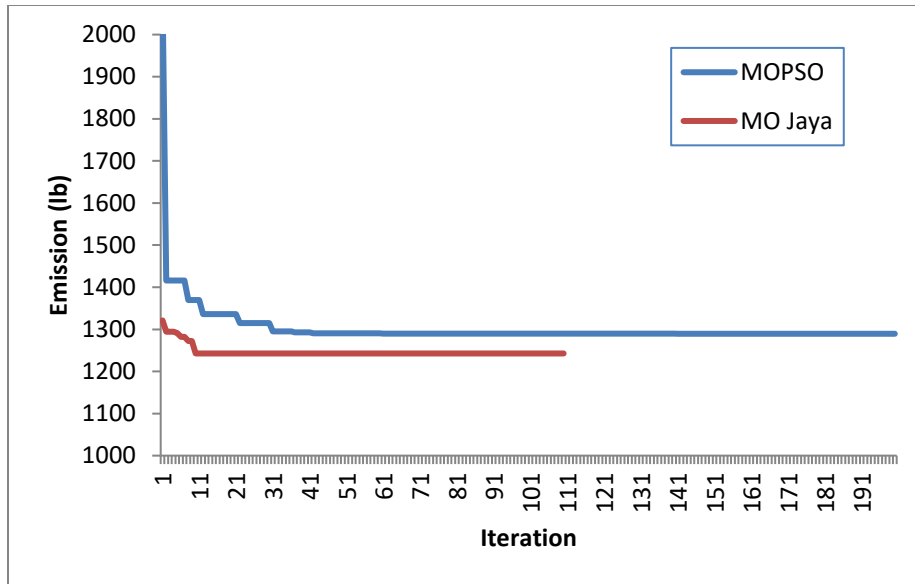


Figure 5.6 Comparison of economic emission using MOPSO and MO JAYA for 6 generator system

Considering the same test system Figure 5.7 shows the pareto front w.r.t. the cost and emission values.

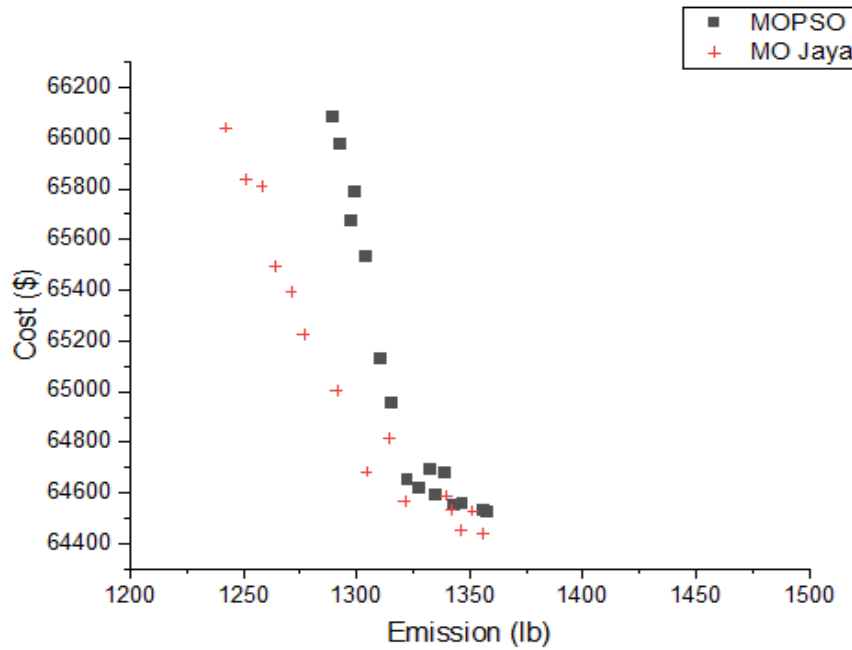


Figure 5.7 Pareto optimal front for MOPSO and MO JAYA for 6 generators system

Test system 2 – 10 generators unit

Figure 5.8 represents the cost comparison for both the algorithms for ten generator based test system, showing the plot for multiobjective Jaya to be better in terms of both cost and convergence rate.

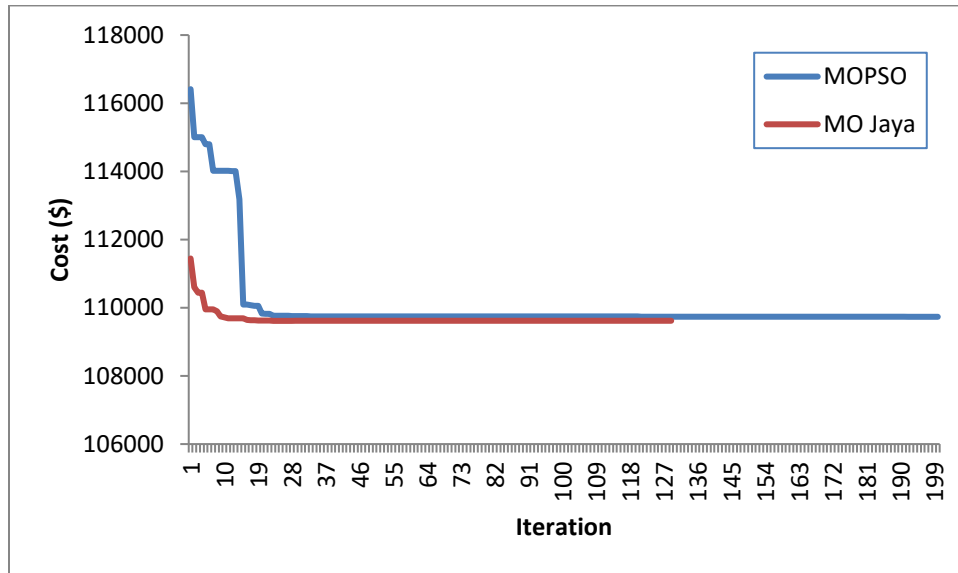


Figure 5.8 Comparison of economic cost using MOPSO and MO JAYA for 10 generator system

Similar to Figure 5.8, the below Figure 5.9 shows the emission comparison for both the algorithms. From figure the rate of convergence considering emission as a constraint is higher in case of multiobjective Jaya in comparison to MOPSO.

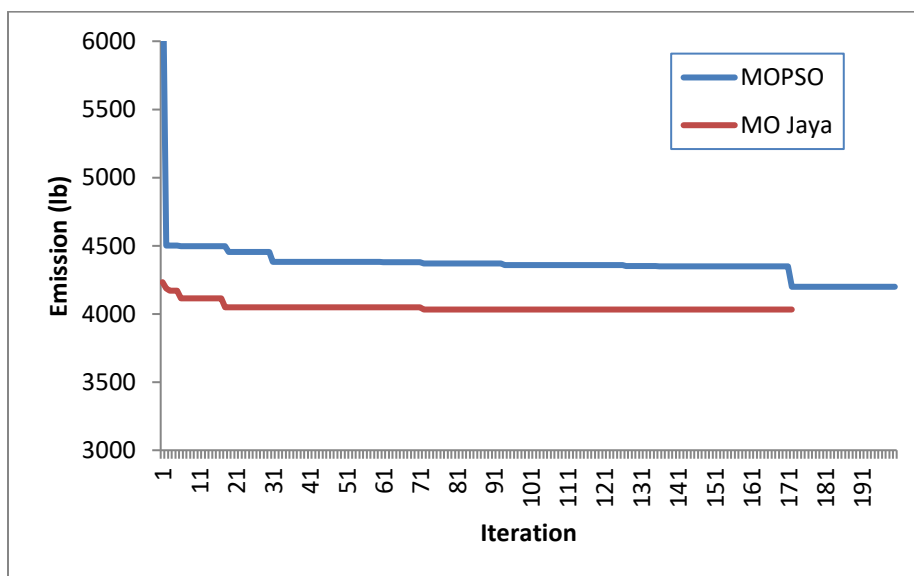


Figure 5.9 Comparison of economic emission using MOPSO and MO JAYA for 10 generator system

Figure 5.10 shows the pareto front w.r.t. the cost and emission values.

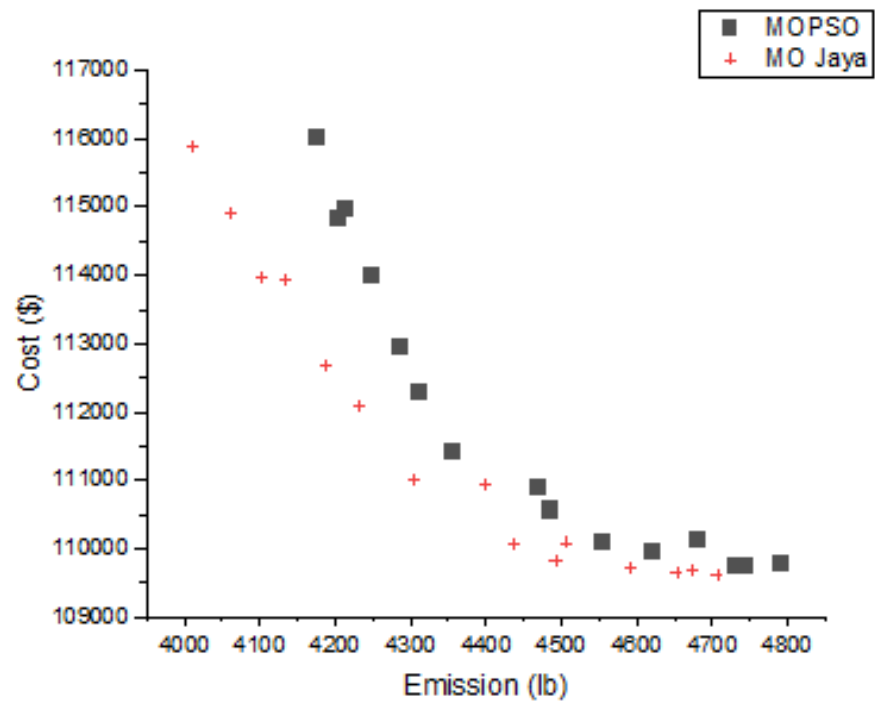


Figure 5.10 Pareto optimal front for MOPSO and MO JAYA for 10 generators system

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

Working with the problem of economic load dispatch for fuel based thermal power plants, minimizing the cost of generation has been a major concern. But with the rising increase in rate of emission the other most important objective is the emission constraint. Thus, in this work the modified version of conventional Jaya algorithm, i.e. the multiobjective Jaya algorithm and multiobjective particle swarm optimization technique has been proposed. The presented algorithm simultaneously solves the cost and the emission objective giving satisfactory results. The comparative analysis of the results shows the multiobjective Jaya optimization algorithm to be more effective and better in terms of the convergence rate and the optimized values of cost and emission.

6.2 FUTURE SCOPE

- To obtain the compromised solution of economic cost and emission from the obtained pareto front using fuzzy approach.
- Extend it to include emissions other than NO_x, like SO_x and Carbon dioxide emissions.

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APPENDIX A

A 1. Test System 1

Table A1: Cost and emission coefficients for test system 1

unit	α_k	β_k	γ_k	a_k	b_k	c_k	P_{gk}^{min}	P_{gk}^{max}
1	0.00419	0.32767	13.85932	0.15247	38.53973	756.79886	10	125
2	0.00419	0.32767	13.85932	0.10587	46.15916	451.32513	10	150
3	0.00683	-0.54551	40.2669	0.03546	38.30553	1243.5311	35	210
4	0.00683	-0.54551	40.2669	0.02803	40.39655	1049.9977	35	225
5	0.00461	-0.51116	42.89553	0.01799	38.27041	1356.6592	125	315
6	0.00461	-0.51116	42.89553	0.02111	36.32782	1658.5696	130	325

Table A2: B-coefficient matrix for test system-1($\times 10^{-6}$)

140	17	15	19	26	22
17	60	13	16	15	20
15	13	65	17	24	19
19	16	17	71	30	25
26	15	24	30	69	32
22	20	19	25	32	85

A 2. Test System 2

Table A3: Cost and emission coefficients for test system 2

unit	a_k	b_k	c_k	d_k	e_k	α_k	β_k	γ_k	η_k	δ_k	P_{gk}^{min}	P_{gk}^{max}
1	0.12951	40.5407	1000.403	33	0.0174	0.04702	-3.9864	360.0012	0.25475	0.01234	10	55
2	0.10908	39.5804	950.606	25	0.0178	0.04652	-3.9524	350.0056	0.25475	0.01234	20	80
3	0.12511	36.5104	900.705	32	0.0162	0.04652	-3.9023	330.0056	0.25163	0.01215	47	120
4	0.012111	39.5104	800.705	30	0.0168	0.04652	-3.9023	330.0056	0.25163	0.01215	20	130
5	0.15247	38.539	756.799	30	0.0148	0.0042	0.3277	13.8593	0.2497	0.012	50	160
6	0.10587	46.1592	451.325	20	0.0163	0.0042	0.3277	13.8593	0.2497	0.012	70	240
7	0.03546	38.3055	1243.531	20	0.0152	0.0068	-0.5455	40.2669	0.248	0.0129	60	300
8	0.02803	40.3965	1049.998	30	0.0128	0.0068	-0.5455	40.2669	0.2499	0.01203	70	340
9	0.02111	36.3278	1658.569	60	0.0136	0.0046	-0.5112	42.8955	0.2547	0.01234	135	470
10	0.01799	38.2704	1356.659	40	0.0141	0.0046	-0.5112	42.8955	0.2547	0.01234	150	470

Table A4: B-coefficient matrix for test system-2($\times 10^{-6}$)

49	14	15	15	16	17	17	18	19	20
14	45	16	16	17	15	15	16	18	18
15	16	39	10	12	12	14	14	16	16
15	16	10	40	14	10	11	12	14	15
16	17	12	14	35	11	13	13	15	16
17	15	12	10	11	36	12	12	14	15
17	15	14	11	13	12	38	16	16	18
18	16	14	12	13	12	16	40	15	16
19	18	16	14	15	14	16	15	42	19
20	18	16	15	16	15	18	16	19	44

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