

**MULTI OBJECTIVE ECONOMIC LOAD DISPATCH  
USING  
EVOLUTIONARY PROGRAMMING**

A Thesis submitted in partial fulfillment of the requirement for the award of  
Degree of

**Master of Engineering  
In  
Power Systems and Electric Drives**



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# **CERTIFICATE**

I hereby certify that the work which is being presented in this Thesis entitled, “**Multi objective Economic Load Dispatch using Evolutionary Programming**” in partial fulfilment of the requirements for the award of degree **Master of Engineering in Power Systems and Electric Drives at Thapar University**, Patiala, is an authentic record of my own work carried out under the supervision of **Mr. Nitin Narang, Assistant Professor(EIED)**.The matter embodied in this Thesis has not been submitted for the award of any degree to any other university.

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## ABSTRACT

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In Multi objective economic load dispatch have to control the emission of pollutants in air as well as to minimize fuel consumption by allocating optimal power generation to each unit (Economic Dispatch) subjected to equality and inequality constraints. Due to non-dominating or non-inferior nature of economy and emission objectives, problem becomes multiobjective in nature.

Several strategies have been proposed to reduce the atmospheric pollution. These include installation of post combustion cleaning equipment, switching to low emission fuels, replacement of the aged fuel burners with cleaner ones, and dispatching with emission considerations.

In the thesis work, price penalty factor and weighting method is applied to convert multiobjective problem into single objective problem. The evolutionary programming technique is applied to find the best comprised solution. Results are obtained by two types of evolutionary programming techniques i.e. classical evolutionary programming and fast evolutionary programming and compared to select parents for next generation. The method is employed for the solution of multi objective economic load dispatch.

## TABLE OF CONTENTS

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	Page no.
Certificate	i
Acknowledgments	ii
Abstract	iii
Table of Contents	iv
List of Tables	vi
List of Figure	vii
<b>1. INTRODUCTION</b>	
1.1 Overview	
1.2 Literature review	
1.3 Author's contribution	
1.4 Organization of thesis	
<b>2. MULTIOBJECTIVE PROBLEM FORMULATION</b>	
2.1 Introduction	
2.2 Problem formulation	
<b>3. EVOLUTIONARY PROGRAMMING</b>	
3.1 Introduction	
3.2 EP as probabilistic optimization technique	
3.3 Types of evolutionary programming techniques	
3.4 Competition and selection	
3.5 Basic algorithm of evolutionary programming	
3.6 Advantages and disadvantages of EP	
<b>4. MULTIOBJECTIVE ECONOMIC LOAD DISPATCH OPTIMIZATION USING EVOLUTIONARY PROGRAMMING</b>	
4.1 Introduction	
4.2 Constraint handling	
4.3 Problem formulation	
4.4 Representation of the evolutionary programming	
4.4.1 Initialization	

- 4.4.2 Evaluation
- 4.4.3 Mutation
- 4.4.4 Classical evolutionary programming
- 4.4.5 Fast evolutionary programming
- 4.4.6 Better of Gaussian and Cauchy mutations
- 4.4.7 Evaluation of offspring
- 4.4.8 Competition and selection

## **5. RESULTS AND DISCUSSION**

- 5.1 Test problem
- 5.2 Case study 1
- 5.3 Case study 2

## **6. CONCLUSION AND SCOPE FOR FUTURE WORK**

- 6.1 Conclusion
- 6.2 Scope for future work

## **APPENDIX**

Appendix 1

Appendix 2

## **REFERENCES**

## LIST OF TABLES

---

	<b>Page No.</b>
Table 5.1 Cost and emission of six-unit system	28
Table 5.2 Generation ( $P_G$ ), cost, emission of six-unit system	29
Table 5.3 Cost and emission of ten-unit system	30
Table 5.4 Generation ( $P_G$ ), cost, emission of ten-unit system	30

## LIST OF FIGURES

---

Page No.

**Figure 4.1** Flow chart for multiobjective economic load dispatch using EP 27

# CHAPTER 1

## INTRODUCTION

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### 1.1 Overview

Multiobjective economic load dispatch has a common, general meaning – the practice of operating a coordinated system so that the lowest-cost generators and minimize the total operating cost of a power system while meeting the total load plus transmission losses within generator limits [1]. As per environmental concern become one of the most important issue in the present circumstances of rising threat of global warming, the electrical power systems are designed not only to meet the continuous variation of power demand to ensure economic operation, but also to minimizing the environmental damage [2]. Multiobjective problem is converted into scalar optimization with the help of weighting method and price penalty factor.

In this thesis work evolutionary programming is used as a optimization technique. This technique is based on the experience gained from the study of artificial life and psychological. Lawrence J. Fogel EP in 1960 is a stochastic optimization strategy similar to genetic algorithms, but instead places emphasis on the behavioral linkage between parents and their offspring, rather than seeking to emulate specific genetic operators as observed in nature.

### 1.2 Literature review

In power system, the operating cost can be minimized by formulating the program of economic load dispatch i.e. The real power output of each controlled generating unit in an area is selected to meet a given load and to minimize the total operating costs in the area [1]. The economic load dispatch of an electric power system attempts to determine a generation schedule which will not violate unit operating limits and is capable of minimizing the total generation cost. In the conventional economic dispatch the emission are not

considered. Emission control has received increasing attention owing to increased concern over environmental pollution caused by thermal generating units and the enforcement of environmental regulations in recent years. Many approaches [1-5] have been carried out to minimize fuel cost and emission. These studies include use of Evolutionary Algorithm, fuzzy approach, Dynamic Economic, Differential Evolution, Artificial Intelligence techniques, PSO, New Neural Network Approach etc.

The multiobjective economic load dispatch problem is conflicting nature problem, this problem has been discussed by many techniques like EP, PSO, DE, ANN, fuzzy logic etc. The literature of the multiobjective economic load dispatch problem and its solution methods are surveyed in [1-7]. Qu *et al.* [7] employed the multiobjective environmental economic dispatch problem using evolutionary programming. Asir [8] discussed economic load dispatch using an integrated algorithm based on evolutionary programming and simulated annealing on large scale power system and integrated algorithm can provide accurate solutions within reasonable time for any type of fuel cost functions. Jayabarathi *et al.* [9], Dasgupta *et al.* [10] and Sinha *et al.* [11] discussed the evolutionary programming techniques for all kinds of economic dispatch problems. A fuzzy logic controlled bacterial foraging algorithm and particle swarm optimization algorithm applied to multiobjective environmental economic dispatch by Hota *et al.* [12]. A fuzzy satisfaction-maximizing decision approach was successfully applied to solve the objective of EED problem regarding minimization of both fuel cost and environmental impact of CO<sub>x</sub> emissions [13]. Qu *et al.* [14] discussed the nonlinear constrained multiobjective environmental economic dispatch problem is solved using fast multi-objective evolutionary programming. Due to the global warming by fossil fuel, environmental concern becomes more and more important in recent years. The purpose of multi-objective optimization algorithm is minimizing all the

different objectives simultaneously and finds the best tradeoff solution for this environmental/economic dispatch problem.

A new bare-bones multi-objective particle swarm optimization algorithm [15-18] to solve the environmental/economic dispatch problems updated, it has three distinctive features: a particle updating strategy which does not require tuning up control parameters; a mutation operator with action range varying over time to expand the search capability; and an approach based on particle diversity to update the global particle leaders. Wang *et al.* [19] discussed effective artificial neural network method is developed for the solution of economic emission load dispatch. Multi-objective optimization method based on the artificial bee colony, called the MOABC, for optimizing problems with multiple objectives. The MOABC uses a grid-based approach to adaptively assess the pareto front maintained in an external archive .This optimization problem employed by Akbari *et al.* [20]. Chatterjee *et al.* [21] have proposed a novel approach to accelerate the HS algorithm.

As the optimization problems grows in dimensionally leads to development of the random search technique like EP ,GA, fuzzy, ANN, differential evolution (DE) [22].Out of these EP has fast convergence rate to find the local and global optimal solution as it searching in respect to distance of feasible optimal solution. Three types of evolutionary programming has been developed i.e. classical evolutionary programming (CEP), fast evolutionary programming (FEP) and improved fast evolutionary programming (IFEP) [23]. All the three techniques work on the basis of placement of optimum solution FEP is used and depending upon the distance of global optimum point from the starting point in search area IFEP is came into picture [24].Few research paper depicts the problems associated with power system has been solved by using EP.

Electric utility systems are interconnected to achieve the benefits of minimum production cost, maximum reliability, and better operating conditions, such as reserve sharing, improved stability and operation under emergencies. The economic operation of power system requires the minimization of the total fuel consumption of all the participating units over a period of time while delivering power to the customers. Various methods of economic dispatch [25-28] calculations are in use where there is no restriction on their fuel supply. Basu [29] employed a scheduling of power plant generation is of great importance to electric utility systems. The generation of electricity from fossil fuel releases several contaminants, such as sulfur dioxide ( $\text{SO}_2$ ), nitrogen oxides ( $\text{NO}_x$ ), and carbon dioxide ( $\text{CO}_2$ ) into the atmosphere. So the optimal scheduling of generation in a hydrothermal system involves the allocation of generation among the hydro-electric and thermal plants so as to minimize the fuel cost and emission level simultaneously of thermal plants while satisfying the various constraints on the hydraulic and power system network. The solution of optimal power flow (OPF) problem [30-31] of generator units ramp rate limits and non smooth fuel function. Evolutionary programming algorithm is devoted to solve the OPF problem with non-smooth fuel cost functions and is capable of establishing schedules for many controllable quantities in the bulk power systems (i.e., the generation and transmission system) such as transformer tap positions and VAR generation schedules. Ravi *et al.* [32] presented an attempt to explore the feasibility of an improved fast evolutionary program search technique to solve extremely challenging non-convex economic load dispatch problem with transmission losses involving variations of consumer load patterns. Economic load dispatch problem formulation is one such optimization problem to dictate an important daily activity in power system operations. The objective of economic dispatch is to minimize the overall cost of available power generation subject to the specified load demand. The amount of load demand at different buses varies continuously in a random fashion and the

generation schedule should be able to adopt promptly without much implications to the cost of operation.

The dynamic economic [33-34] dispatch problem is the essential part of real-time control of power system operation that minimizes the cost of electric power generation by assigning different load levels to the generating units. It consists of allocating the total generation required among the available thermal generating units, assuming that a thermal unit commitment has been previously determined in order to meet the required power demand for a given scheduling horizon, subject to generating unit constraints. Asir *et al.* [35] and Jeong *et al.* [36] presented the unit commitment problem by using EP, one of the most important tasks in short-term operation planning of modern power systems, has a significant influence on secure and economic operation of power systems. The unit commitment problems involve scheduling the on/off states of generating units that minimize the operating cost for a given time horizon. A multitime interval scheduling for the daily operation of a two cogeneration [37-38] system connected with auxiliary boilers, heat storage tanks, electricity chargers and independent generators. The efficiency of a cogeneration system depends on the production of thermal and electrical energy which is modeled with quadratic equation obtained by the least squares method. Cogeneration systems offer a reliable, efficient, and economic mean to supply both thermal and electrical energy. It can be constructed in urban areas and used as distributed electrical energy sources. Applications of cogeneration systems are still growing, more experience will needed regarding the efficient operation for more energy saving.

The production cost of thermal power generation can reduced by economic dispatch calculations are carried out along evolutionary programming technique discussed by Kumarappan *et al.*[39]. Doerr *et al.* [40] proposed an algorithms of EP to produce good results for a wide range of combinatorial optimization problems and the considered problems are tackled by evolutionary

algorithms that use a representation which enables them to construct solutions in a dynamic programming fashion.

Evolutionary programming techniques for all kinds of economic dispatch problems discussed by Jayabarathi *et al.* [41]. Hota *et al.*[42] discussed an efficient short-term hydrothermal scheduling algorithm based on the evolutionary programming technique and proposed three types of EP techniques considered differ in the kind of mutation they use: Gaussian, Cauchy and combined Gaussian–Cauchy mutation.

### **1.3 Author's contribution**

Multi objective economic load dispatch has been carried to minimize the cost of fuel as well as emission from fuel along with optimum dispatch of power using EP. Price penalty factor is used to convert multiobjective problem into single objective problem. Two types of EP i.e. CEP and FEP implemented for the solution of multi objective economic load dispatch problem and finally optimal generation scheduling is obtained.

### **1.4 Organization of Thesis**

The thesis work carried out has been categorized into six chapters. Chapter 1 covers the brief introduction, summary of work carried out by various researchers, author's contribution and outline of thesis. Chapter 2 describes the multi objective economic load dispatch problem. Chapter 3 explains the methodology of EP and its various types i.e. CEP and FEP. Chapter 4 covers the solution approach to multi objective economic load dispatch using evolutionary programming algorithm. Chapter 5 covers results and discussion part. Finally chapter 6 explains the conclusion and scope of future work.

# CHAPTER 2

## MULTIOBJECTIVE PROBLEM FORMULATION

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### 2.1 Introduction

The multi-objective dispatch problem is defined so as to minimize the number of objectives as the operating cost and emission to operate power systems in an efficient and reliable way, several techniques have been developed to schedule power plants and determine their production level [1].

Power dispatch is one of the techniques which adjusts some control variables and allocated the power throughout the system resulting in an optimal operation. The operating cost subjected to various equality and inequality constraints of the power system. This makes the power dispatch problem non-linear constrained optimization problem [2].

However, as a result of public awareness of environmental protection, diverse emission compliance strategies have emerged. These strategies include emission dispatching or trading, fuel switching and/or blend, installation of emission reduction equipment in the existing thermal plants, and retirement of old fuel-burning equipment or generating unit and replacement with cleaner and efficient one. Among these strategies, unit dispatch considering emission and cost minimization have received widespread attention due to its effective short-term results and smaller capital outlay [3].

### 2.2 Problem formulation

The present formulation treats economic environmental dispatch (EED) problem as a multi-objective mathematical programming problem which attempts to optimize both cost and emission simultaneously, while satisfying both equality and inequality constraints. The following objectives and constraints are taken into account in the formulation of EED problem.

## Objectives

- (i) The fuel cost function of each fossil fuel fired generator, considering the valve-point effect is expressed as the sum of a quadratic and a sinusoidal function. The total fuel cost in terms of real power output can be expressed as:

$$F = \sum_{i=1}^N (a_i + b_i P_i + c_i P_i^2 + |d_i \sin\{e_i (P_i^{\min} - P_i)\}|) \$ / h \quad (2.1)$$

where

$a_i, b_i, c_i, d_i, e_i$  are the cost coefficients.

$F$  = Fuel cost function of thermal units.

$P_i$  = Real power generated of  $i^{\text{th}}$  unit.

$N$  = Total number of generating units.

$P_i^{\min}$  = Minimum power of  $i^{\text{th}}$  unit.

- (ii) Emission of pollutants which is the sum of a quadratic and an exponential function can be expressed as:

$$E = \sum_{i=1}^N (\alpha_i + \beta_i P_i + \gamma_i P_i^2 + \eta_i \exp(\delta_i P_i)) \text{ ton} / h \quad (2.2)$$

where

$\alpha_i, \beta_i, \gamma_i, \eta_i, \delta_i$  are the emission coefficients.

$E$  = Amount of emission released by thermal unit.

**Equality constraints:** The total real power generation must balance the power demand and the real power losses in the transmission lines.

$$\sum_{i=1}^N P_i - (P_D + P_L) = 0 \quad (2.3)$$

$P_D$  is the power demand

$P_L$  is the transmission losses, which are approximated in terms of B-coefficients as:-

$$P_L = B_{00} + \sum_{i=1}^N (B_{i0} P_i + \sum_{i=1}^N \sum_{j=1}^N P_i B_{ij} P_j) \text{ MW} \quad (2.4)$$

The inequality constraints imposed on generator output are

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

where  $P_i^{\min}$  is the lower limit and  $P_i^{\max}$  is the upper limit of generator output.

The problem is converted into a scalar optimization by applying weighting along with price penalty factor.

Minimize

$$F_T = [W_1 \times F + W_2 \times h \times E] \quad (2.6)$$

$$\left[ \begin{array}{l} W_1 = 1, W_2 = 0; \text{ Economic Load Scheduling} \\ W_1 = 0, W_2 = 1; \text{ Emission Scheduling} \\ W_1 = 1, W_2 = 1; \text{ Multiobjective Scheduling} \end{array} \right]$$

where

$F_T$  = Objective function.

$W_1, W_2$  = Weight factors.

$h$  = Price penalty factor.

$s$  = Penalty factor.

Subjected to 
$$\sum_{i=1}^N P_i - (P_D - P_L) = 0 \quad (2.7)$$

$$P_i^{\min} \leq P_i \leq P_i^{\max} \quad (i=1,2,\dots,N) \quad (2.8)$$

# CHAPTER 3

## EVOLUTIONARY PROGRAMMING

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### 3.1 Introduction

The main stages of this technique include initialization, mutation, and completion and selection. A global search technique for searching a feasible optimal solution based on finite state machine model in early stages i.e. evolutionary programming (EP) suggested by L. J. Fogel and it follows the Darwin's theory of survival of fittest [43]. Evolutionary programming depicts a relationship between parents and child (offspring). Many optimization problems in real space are solved using EP. Evolutionary programming is an artificial intelligence method in which optimization algorithm is the main engine for the process of three steps as natural selection, mutation and finally competition. According to the problem the basic strategy employs the selection of best fittest offspring to be parents for next offspring and leads to optimal solution of problem. It can be implemented to real life problems or practical problems [44].

### 3.2 EP as probabilistic optimization technique

Various optimization techniques like classical technique i.e branch and bound method (BABM), priority list method (PLM), dynamic programming (DP), lagrangian relaxation method. Classical techniques although are reliable and fast in solving the various optimization problems, but these are having some limitations of becoming slow and more complex as the problem increases dimensionally . With the advancement in the field of optimization problem solution strategies, random search techniques are come forward to solve optimization problems i.e. ant colony search method (ACSM), fuzzy logic (FL), genetic algorithm (GA) artificial neural network (ANN), particle swarm optimization (PSO) and EP etc provides random search for the optimal solution

to various optimization problems . Out of above mentioned random search techniques EP is good convergence to global optimal solution to optimization problems. Evolutionary programming is a stochastic optimization strategy, which places emphasis on the behavioral linkage between parents and their offsprings. It is powerful optimization technique which does not first and second derivatives of objective function [45]. Based on probabilistic search scheme, EP generates the parent vectors distribute uniformly in the intervals within the limits and leads to global optimum solution over a number of attempts or iterations.

The main stages of EP are initialization, creation of offspring vectors by mutation and finally competition and selection to evaluate the optimal solution, so common underlying idea that come out is given a population of individuals or parents, environmental pressure causes the natural selection based on survival of fittest and finally reach the global optimum point [46]. In EP recombination or mutation is applied to each candidate or parent resulted into one or more new candidates (offspring) which competes with main parents on the basis of their fitness values and selected to undergo mutation for the next generation. This process repeats until search reaches the global optimal point. To reach the global optimum point in EP two fundamental forces are take into account i.e. variation operator that creates the necessary diversity and facilitates novelty and quality selection pushing force. The combined action of variation and selection force leads to improve the fitness value in consecutive populations. Evolutionary programming is adaptive in nature as due to the environmental requirements optimize the objective function and makes the population adapt to the environment better and better. Therefore we can say that evolutionary searching process for optimal solution is stochastic. In selection process individuals having good fitness value have more chances of selection as compared to less fit individual, but even a weak or less fit individuals have chances of being survive. Similarly mutation process generates new individuals

randomly [47]. Therefore optimization using EP can be summarized in two major steps [48]:

- Mutate the solution in main parents or population.
- Select the next generation from the mutated and current solution through competition criteria.

### **3.3 Types of evolutionary programming techniques**

Depending upon type of mutation process evolutionary programming techniques categorized into two categories [24, 46]:-

- Classical Evolutionary programming (CEP):- Gaussian mutation operator is used in this technique.
- Fast Evolutionary Programming (FEP):- Cauchy mutation operator is used in this technique.

Evolutionary programming methods are describes in detail as under.

Classical evolutionary programming technique employing Gaussian mutation operator with mean as zero and standard deviation is one. CEP with self adaptive mutation performs much better than CEP without self adaptive mutation. In CEP for generation of offspring Gaussian or normalized random variables are undertaken. For local optimal solution CEP performs better as it takes small steps to find the global optimum solution if it lies within local neighbourhood region. Due to its limitation of searching global solution in local neighbourhood region, it has slow convergence rate to the optimal solution if it lies far from local search area.

It can also be implemented into some unimodal functions and multimodal functions with some local minima as it provide fine tuning to find the global optimum solution [47]. Evolutionary programming technique using Cauchy mutation operator for the mutation or generation of offspring is termed as FEP. Fast evolutionary programming performs more efficiently and relative have

more strength to find the optimal solution. As the step size of FEP is larger, simple and straightforward to find global optimal solution. So it performs more efficiently and fast to find global optimal solution to multimodal optimization problems. Since its step size is large to find the global optimal solution, but it is only effective at the starting of evolution to find solution as the global optimal solution lies far away from starting search point. As the evolution proceeds for the solution it becomes slow or there may also be chance to selecting less optimal solution as the global solution lies very near in the searching area. Cauchy mutation operator generates offspring further away from main population or parents as compared to Gaussian mutation operator due to its long flat tails. So Cauchy mutation has more probability of escaping from local optimum and moreover a smaller hill around the centre indicates that Cauchy mutation spends less time in exploiting the local neighbourhood and thus has weaker fine tuning ability as compared to Gaussian mutation operator in small to mid range regions.

Equation for the criterion of offspring using CEP is mentioned under.

$$P_i^{(k+L)} = P_i^L + Sd_i^k \text{Nor}(0) \quad (k=1,2,\dots,L) \quad (3.1)$$

where

$Nor$  = Normalized random number

$P_i^k$  = Main parents or individuals for  $k^{th}$  individual

$Sd_i^k$  = Standard deviation for  $k^{th}$  individual

$P_i^{(k+L)}$  = Offspring generated from  $k^{th}$  individual

$L$  = Total number of main population or parents

Equation for the criterion of offspring using FEP is mentioned under:

$$P_i^{(k+L)} = P_i^k + Sd_i^k \text{Co} \quad (3.2)$$

$$Sd_i^k = Sd_i^k \exp(\tau' N(0,1) + \tau N(0,1)) \quad (3.3)$$

where

$C(0)$  = Cauchy Random number

$N(0,1)$  = Normalized random number

$$\tau = (\sqrt{2\sqrt{N}})^{-1}$$

$$\tau' = (\sqrt{2 \times N})^{-1}$$

### 3.4 Competition and selection:

The  $2L$  individuals compete with each other for selection. A weight  $w^k$  is assigned to each individual as follows:

$$\text{where } W^k = \frac{L}{\sum_{k=1}^L w^k} \quad (k=1,2,\dots,2L) \quad (3.4)$$

$$w^k = \begin{cases} 1; \text{if } \dots u_1 > \left( \frac{f^k}{f^r + f^k} \right) \\ 0; \text{else} \end{cases} \quad (3.5)$$

with  $f^r$  is the fitness of the  $r^{\text{th}}$  competitor randomly selected from  $2L$  individuals and  $u_1$  is a uniform random number ranging over  $[0,1]$ .

$r = [2L \times u_2 + 1]$  and  $u_2$  are uniform random number ranging over  $[0, 1]$ .

### 3.5 Basic algorithm of evolutionary programming

The following procedure can be used for implementing the EP algorithm:-

1. Initialization:-Generate the initial population by using uniform random number ranging over  $[P_i^{\min}, P_i^{\max}]$ .
2. Evaluation: -Evaluate the performance (fitness) of objective function by finding minimum fitness out of total population.

3. Mutation: -Mutation operator is to generate offspring. The mutation operators used for generation of offspring i.e. Gaussian mutation operators (CEP), Cauchy mutation operators (FEP) as per the eq. (3.1) and (3.2).
4. Evaluation:-Evaluate the offspring.
5. Competition: -Compute the number of wins.
6. Selection: - Select the population with higher number of wins.
7. Check for iteration index:-Until a termination criterion is met, repeat all the above steps.
8. Termination: -When searching process reaches the optimal solution then stop the execution of program.

### **3.6 Advantages and disadvantages of EP**

Evolutionary programming is a probabilistic, global search technique. It has following advantages and disadvantages are:-

- EP can find and maintain multiple solutions in one single simulation run.
- EP has a slow convergence rate for large problem.

# CHAPTER 4

## MULTIOBJECTIVE ECONOMIC LOAD DISPATCH OPTIMIZATION USING EVOLUTIONARY PROGRAMMING

---

### 4.1 Introduction

The main purpose of multi-objective generation scheduling is to minimize economic and emission dispatch simultaneously. In general power system possesses multi-objective to achieve such as economic operations and minimal impact on environment, which has inherently have different characteristics, and hence conflicting relation among these objectives [16].

A major objective for the coal-fired power plant generation loading is to minimize fuel consumption and to maintain emission within environmental license limit. Multi-objective problem is converted into scalar problem with the help of weighting method and price penalty factor.

A multi-objective constraint handling method incorporating the Evolutionary Programming (EP) algorithm has been implemented for the power generation loading optimization application to solve economic-emission load dispatch [17]. The evolutionary programming can be implemented by searching the generation of power within its limits so that total cost and emission corresponding to generation become minimum. The multi-objective economic load dispatch problem is defined as:-

Minimize

$$F = \sum_{i=1}^N (a_i + b_i P_i + c_i P_i^2 + |d_i \sin\{e_i (P_i^{\min} - P_i)\}|) \$ / h \quad (4.1)$$

where

$a_i, b_i, c_i, d_i, e_i$  = The cost coefficients

$F$  = Fuel cost function of thermal units

$P_i$  = Real power generated of  $i^{\text{th}}$  unit

$N$  = Total number of generating units

$P_i^{\text{min}}$  = Minimum power of  $i^{\text{th}}$  unit.

Minimize

$$E = \sum_{i=1}^N (\alpha_i + \beta_i P_i + \gamma_i P_i^2 + \eta_i \exp(\delta_i P_i)) \text{ ton/h} \quad (4.2)$$

where

$\alpha_i, \beta_i, \gamma_i, \eta_i, \delta_i$  = The emission coefficients

$E$  = Amount of emission released by thermal unit.

Subjected to

$$\sum_{i=1}^N P_i - (P_D + P_L) = 0 \quad (4.3)$$

The inequality constraints imposed on generator output are

$$P_i^{\text{min}} \leq P_i \leq P_i^{\text{max}} \quad (i = 1, 2, \dots, N) \quad (4.4)$$

$P_L$  is the transmission losses, which are approximated in terms of B-coefficients as:-

$$P_L = B_{00} + \sum_{i=1}^N (B_{i0} P_i + \sum_{i=1}^N \sum_{j=1}^N P_i B_{ij} P_j) \text{ MW} \quad (4.5)$$

where  $F$  and  $E$  are the objectives to be minimized over the set of admissible decision vector

## 4.2 Constraint handling

One of the committed unit is randomly selected as a depended unit to satisfy equality constraint given by eq. (4.3). The power of depended unit is calculated as:

$$P_d = P_D - \sum_{\substack{i=1 \\ i \neq d}}^N P_i - P_L \quad (4.6)$$

In order to satisfy the power balance constraint, a generator is arbitrarily selected as a dependent generator  $d$ .  $P_L = 0$  Represents transmission losses are neglected.  $P_L \neq 0$  Represents transmission losses are considered [48].

$$P_d = \begin{cases} Z & ; & P_L = 0 \\ W & ; & P_L \neq 0 \end{cases} \quad (4.7)$$

where  $W = (-Y \pm \frac{\sqrt{Y^2 - 4XZ}}{2X})$  when  $Y^2 - 4XZ \geq 0$

$$\text{with } X = \begin{cases} 0 & ; & P_L \\ B_{dd} & ; & P_L \neq 0 \end{cases}$$

$$Y = \begin{cases} -1 & ; & P_L = 0 \\ \sum_{\substack{i=1 \\ i \neq d}}^N (B_{id} + B_{di})P_i + B_{do} - 1 & ; & P_L \neq 0 \end{cases}$$

$$Z = \begin{cases} P_D - \sum_{\substack{i=1 \\ i \neq d}}^N P_i & ; & P_L = 0 \\ P_D + B_{oo} + \sum_{\substack{i=1 \\ i \neq d}}^N \sum_{\substack{j=1 \\ j \neq d}}^N P_i B_{ij} P_j + \sum_{i=1}^N B_{io} P_i - \sum_{i=1}^N P_i & ; & P_L \neq 0 \end{cases}$$

$$error = \begin{cases} (P_d - P_d^{\min})^2; P_d < P_d^{\min} \\ (P_d - P_d^{\max})^2; P_d > P_d^{\max} \\ 0; P_d^{\min} \leq P_d \leq P_d^{\max} \end{cases} \quad (i=1,2,\dots,N; i \neq d) \quad (4.8)$$

$$P_d = \begin{cases} P_i^{\min}; P_i^j < P_i^{\min} \\ P_i^{\max}; P_i^j > P_i^{\max} \\ P_i; P_i^{\min} \leq P_i \leq P_i^{\max} \end{cases} \quad (i=1,2,\dots,N; i \neq d) \quad (4.9)$$

The power of dependent unit can violate its inequality constraint, inequality constraint handling of dependent unit power is handled as given in eq. (4.8) & (4.9). Similarly, if the output of the dependent generator violates its limits then error is calculated as per eq. (4.8) and a penalty term is introduced in the objective function eq. (4.10) after limiting the value of the dependent generator.

### 4.3 Problem formulation

Objective function includes the operating cost and cost to control the emission products by using weighting method as under:

Minimize

$$F_T = [W_1 \times F + W_2 \times h \times E + (S * error^2)] \quad (4.10)$$

where

$F_T$  = Objective function

$W_1, W_2$  = Weight factors

$h$  = Price penalty factor

$S$  = Penalty factor

$errorrr$  =Error in power is defined in eq. (4.8)

$$\text{Subjected to } \sum_{i=1}^N P_i - (P_D - P_L) = 0 \quad (4.11)$$

$$P_i^{\min} \leq P_i \leq P_i^{\max} \quad (i = 1, 2, \dots, N) \quad (4.12)$$

The price penalty factor  $h$  can be found out by following steps [49]:

1. Find out the average cost of each generator at maximum power output.
2. Find out the average emission of each generator at its maximum output.
3. Divide the average cost of each generator by its average emission and thus  $h$  is given as:

$$\frac{F(I, J)}{E(I, J)} = h \text{ \$/lb} \quad (4.13)$$

#### 4.4 Representation of the evolutionary programming

Evolutionary programming is probabilistic search technique, which generates the initial parent vectors distributed uniformly in interval within the limits and obtain global optimum solution over number of iteration. Evolutionary programming is search algorithm based on the mechanics of natural selection.

##### 4.4.1 Initialization

It consists of  $P_i$  trial parent individuals. The elements of a parent are the combinations of power outputs of the generating units, which are chosen randomly in its minimum and maximum limits.

$$P_i = P_i^{\min} + rand()(P_i^{\max} - P_i^{\min}) \quad (i = 1, 2, \dots, N; i \neq d) \quad (4.14)$$

where  $rand()$  is uniform random number ranging over [0,1].

#### 4.4.2 Evaluation

All methods of evolutionary computation simulate natural evolution by creating a population of individuals, evaluating their fitness, generating a new population through genetic operations, and repeating this process a number of times.

#### 4.4.3 Mutation

The two Evolutionary Programming (EP) techniques undertaken using different kinds of mutations like; Gaussian and Cauchy mutation. The conventional EP employing the Gaussian mutation operator is known as Fast Evolutionary Programming (FEP) as it converges faster than CEP.

#### 4.4.4 Classical evolutionary programming:

Each vector element is updated by adding a normally distributed random number with mean zero and standard deviation  $Sd$  denoted as  $N(0, \sigma^2)$ . To generate offspring, the following equation is used.

$$P_i = P_i + Sd_i^k N(0,1) (i = 1, 2, \dots, N; i \neq d) \quad (4.15)$$

where

$N(0,1)$  is a normally distributed random variable with zero mean and unit variance.

The standard deviation  $Sd_i^k$  is given by the following mathematical expression

$$Sd_i^k = \beta \left( \frac{f}{f_{\min}} \right) (P_i^{\max} - P_i^{\min}) (i = 1, 2, \dots, N; i \neq d) \quad (4.16)$$

where

$\beta$  is the scaling factor which has to be tuned during the process of search for the optimum around the initial points.

$f$  is the fitness value

$f^{\min}$  is the minimum fitness among the parents.

#### 4.4.5 Fast evolutionary programming:

Using Cauchy mutation, an offspring is created by:

$$P_i = P_i + Sd_i^k C_i (0,1)(i = 1,2,\dots,N; i \neq d) \quad (4.17)$$

where

$C_i (0,1)$  is a Cauchy random variable with scale parameter  $t = 1$  centered at zero.

#### 4.4.6 Better of Gaussian and Cauchy mutations:

In this method, the better of two offspring from each parent are generated by Gaussian mutation and the other by Cauchy mutation is taken as

$$P_i = P_i + Sd_i^k N(0,1)(i = 1,2,\dots,N; i \neq d) \quad (4.18)$$

$$P_i = P_i + Sd_i^k C_i (0,1)(i = 1,2,\dots,N; i \neq d) \quad (4.19)$$

Mutation results in creation of offspring individuals. The parent individuals are candidate dispatch solutions, which satisfy all constraints. However, after mutation, the elements of offspring  $P_i$  may violate constraint eq. (4.4). This violation is corrected by using eq. (4.9).

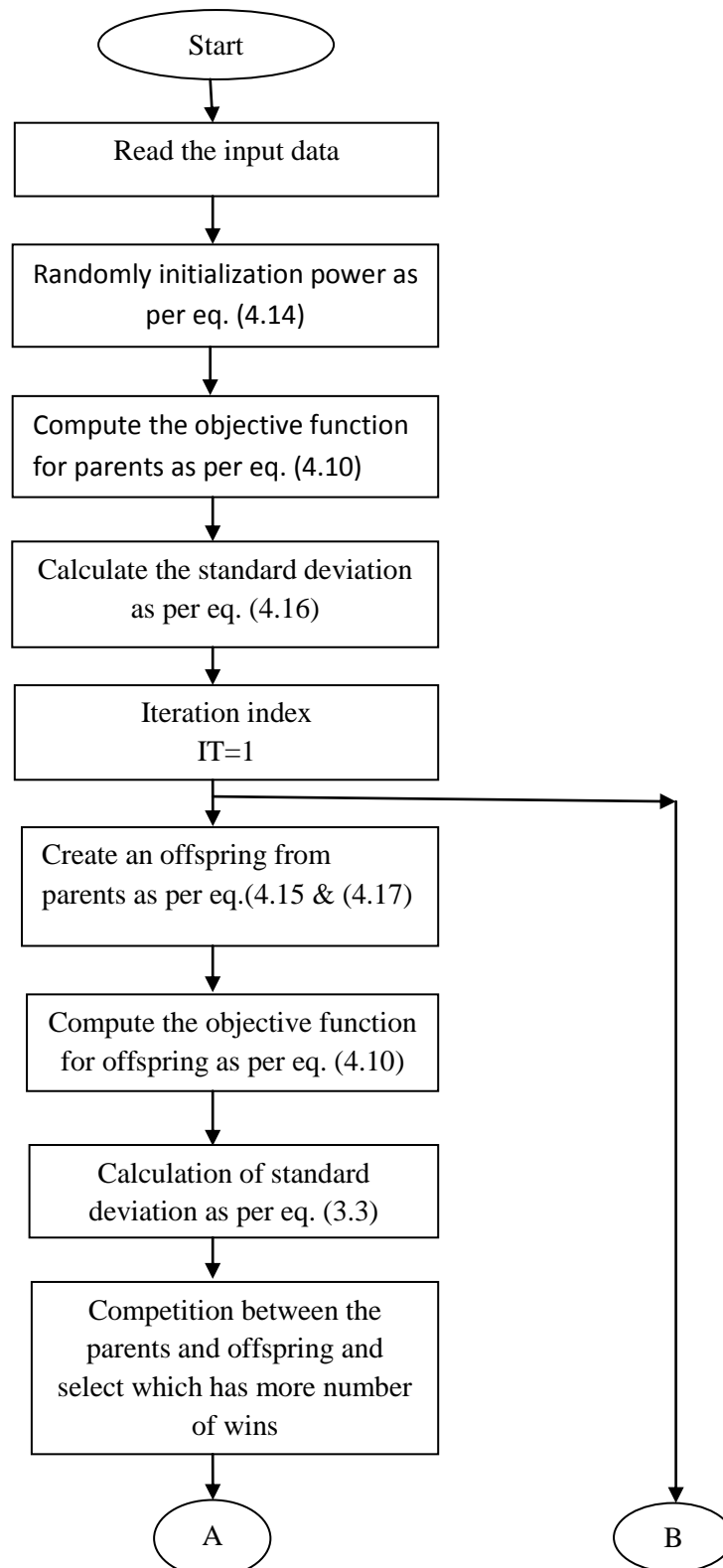
#### 4.4.7 Evaluation of offspring:

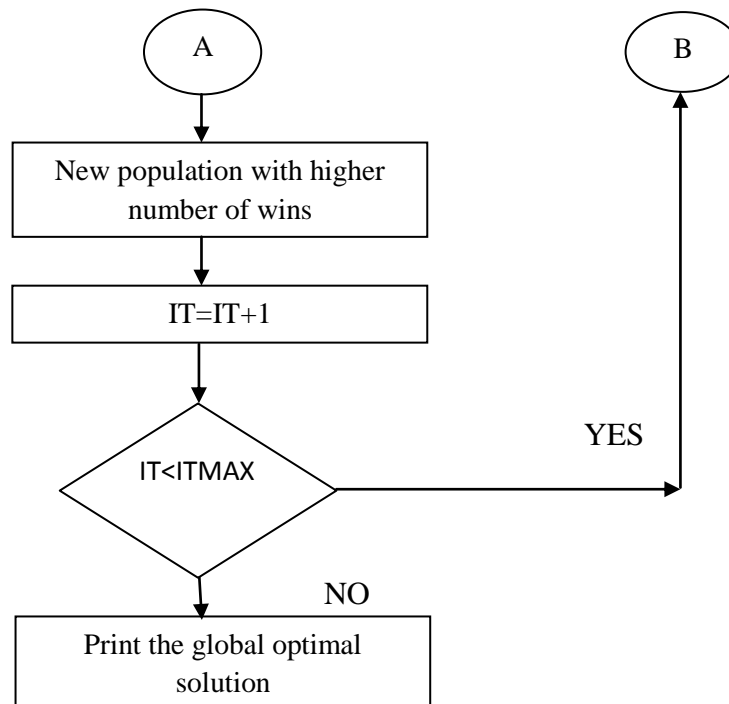
The values of the objective function of both offspring (Gaussian and Cauchy) are evaluated, compared, and the better individual is chosen as

offspring for competition and selection. The initial parent and their offspring created by mutation form a combined population of  $2L$  individuals.

#### 4.4.8 Competition and selection:

Compute the number of wins and select the population with higher number of wins as per the eq. (3.4) and (3.5). Detailed flow chart is shown in fig. 4.1.





**Figure 4.1:** Flow chart for multiobjective economic load dispatch using evolutionary programming

## CHAPTER 5

### RESULTS AND DISCUSSION

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#### 5.1 Test problem

In the thesis work, two types of evolutionary programming approaches i.e. classical evolutionary programming, fast evolutionary programming are applied for the solution of multiobjective economic load dispatch along with minimization of objective function. Evolutionary programming is tested on two problems comprising of 6 generating units and 10 generating units as given in APPENDIX-I & II.

**5.2 Case study 1:** Economic, emission and multiobjective economic load dispatch for 6 number of generating units.

In this case study, developed algorithm has been applied for economic dispatch, emission dispatch and multiobjective economic emission dispatch for 6 generating units. The inputs parameters are taken from APPENDIX-1. To find the best solution, the programme has run at different value of  $W_1$  and  $W_2$ , the total cost and emission are calculated corresponding to these weights.

**Table 5.1-** Cost, emission of six unit system for power demand ( $P_D$ ) =1200MW

$W_1$	$W_2$	Cost(\$/h)	Emission(ton/h)
1	0	64643.9864	1285.7515
0	1	66278.8387	1256.76911
1	1	65048.38087	1334.4248

As seen from the table, when  $W_1 = 1$  and  $W_2 = 0$ , the total generation cost comes out to be minimum (Economic load dispatch) at the expense of increase in emission. When  $W_1 = 0$  and  $W_2 = 1$ , the total emission comes out to be minimum (Emission dispatch) at the expense of increase in cost. When both  $W_1$

and  $W_2$  are equal to 1 at this stage both generations cost and emission (Multiobjective dispatch) are controlled equally.

The power generation corresponds to economic load dispatch, emission dispatch and multi-objective dispatch is shown in the table 5.2.

**Table 5.2:** Generation ( $P_G$ ), cost, emission of six unit system problem for power demand ( $P_D$ ) = 1200MW

$P_G(MW)$	Economic Dispatch	Emission Dispatch	Multiobjective Dispatch
$P_1(MW)$	97.33410	123.7450	99.32510
$P_2(MW)$	123.9041	150.0000	82.95670
$P_3(MW)$	210.0000	205.4902	207.8569
$P_4(MW)$	199.7894	201.6904	224.7845
$P_5(MW)$	303.4901	301.9067	314.8954
$P_6(MW)$	314.5902	273.2841	320.6734
<hr/> $Cost(\$/h)$	64643.9864	66278.8387	65048.38087
$Emission(ton/h)$	1285.75150	1256.76911	1334.424800

### 5.3 Case study 2: Economic, emission and multiobjective economic emission dispatch for 10 numbers of generating units.

In this case study, developed algorithm has been applied for economic dispatch, emission dispatch and multiobjective economic emission dispatch for 10 generating units. The inputs are taken from APPENDIX-2. TO find the best solution, the programme is run at different value of  $W_1$  and  $W_2$ , and the cost and emission are calculated corresponding to these weights.

**Table 5.3:** Cost, emission of ten unit system for power demand ( $P_D$ ) =2000MW

$W_1$	$W_2$	Cost(\$/h)	Emission(ton/h)
1	0	111601.285	4534.388
0	1	139868.3476	3962.4663
1	1	113623.3693	4122.90504

As seen from the table, when  $W_1 = 1$  and  $W_2 = 0$ , the total generation cost comes out to be minimum (Economic load dispatch) at the expense of increase in emission. When  $W_1 = 0$  and  $W_2 = 1$ , the total emission comes out to be minimum (Emission dispatch) at the expense of increase in cost. When both  $W_1$  and  $W_2$  are equal to 1 at this stage both generations cost and emission (Multiobjective dispatch) are controlled equally.

**Table 5.4:** Generation ( $P_G$ ), cost, emission of ten unit system problem for power demand ( $P_D$ ) = 2000MW.

$P_G$ (MW)	Economic Dispatch	Emission Dispatch	Multiobjective Dispatch
$P_1$ (MW)	52.9987	51.974	54.6648
$P_2$ (MW)	78.9054	75.8931	79.6738
$P_3$ (MW)	110.3801	89.3042	89.7845
$P_4$ (MW)	99.8601	86.4039	84.7894
$P_5$ (MW)	97.8965	158.9435	142.8945
$P_6$ (MW)	75.8945	237.8953	168.8941
$P_7$ (MW)	299.593	298.8045	297.6703
$P_8$ (MW)	331.8684	299.9056	305.784
$P_9$ (MW)	469.8906	393.7045	430.8068
$P_{10}$ (MW)	469.6703	391.7894	429.6904
Cost(\$/h)	111601.285	139868.3476	113623.3693
Emission(ton/h)	4534.388	3962.4663	4122.90504

# **CHAPTER 6**

## **CONCLUSION AND SCOPE FOR FUTURE WORK**

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### **6.1. Conclusion**

The multi objective power dispatch problem has been solved using an algorithm based on evolutionary programming (EP). Two test system has been taken, one has 6 thermal units and another has 10 thermal units.

Following conclusions are drawn from the study.

- The developed algorithm is capable to handle different competing objectives.
- The results drawn from applied approach are found satisfactory for economic and emission dispatch problems and multiobjective dispatch problem.

### **6.2. Scope for future work**

The scope of work after studying Power Dispatch using EP is identified as:

- This problem can be applied to Practical Systems.
- Extend the problem by incorporating more than two objectives.
- Evolutionary programming can be hybridized for the solution of MOELD with different techniques like fuzzy logic, differential evolution (DE), hybrid PSO (particle swarm optimization), ANN (artificial neural network) etc.

## APPENDIX

### APPENDIX-1,

#### 1. Input data for 6-generating units:

$Unit_{(i)}$	$P_i^{\max}$	$P_i^{\min}$	$a_i$	$b_i$	$c_i$	$\alpha_i$	$\beta_i$	$\gamma_i$
1	10	125	756.7988	38.539	0.15247	13.8593	0.32767	0.00419
2	10	150	451.3251	46.1591	0.10587	13.8593	0.32767	0.00419
3	35	210	1243.531	38.3055	0.03546	40.2669	-0.54551	0.00683
4	35	225	1049.998	40.3965	0.02803	40.2669	-0.54551	0.00683
5	125	315	1356.659	38.2704	0.01799	42.8955	-0.51116	0.00461
6	130	325	1658.57	36.3278	0.02111	42.8955	-0.51116	0.00461

#### 2. B-Coefficients for 6-generating units:

$$B = \begin{bmatrix} 0.00014 & 0.000017 & 0.000015 & 0.000019 & 0.000026 & 0.000022 \\ 0.000017 & 0.000060 & 0.000013 & 0.000016 & 0.000015 & 0.000020 \\ 0.000015 & 0.000013 & 0.000065 & 0.000017 & 0.000024 & 0.000019 \\ 0.000019 & 0.000016 & 0.000017 & 0.000071 & 0.000030 & 0.000025 \\ 0.000026 & 0.000015 & 0.000024 & 0.000030 & 0.000069 & 0.000032 \\ 0.000022 & 0.000020 & 0.000019 & 0.000025 & 0.000032 & 0.000085 \end{bmatrix}$$

### APPENNDIX-2,

#### 1. Input data for 10 generating units

$Unit_{(i)}$	$P_i^{\max}$	$P_i^{\min}$	$a_i$	$b_i$	$c_i$	$d_i$	$e_i$	$\alpha_i$	$\beta_i$	$\gamma_i$	$\eta_i$	$\delta_i$
1	10	55	1000.403	40.5407	0.12951	33	0.0174	360.0012	-3.9864	0.04702	0.25475	0.01234
2	20	80	950.606	39.5804	0.10908	25	0.0178	350.0056	-3.9524	0.04652	0.25475	0.01234
3	47	120	900.705	36.5104	0.12511	32	0.0162	330.0056	-3.9023	0.04652	0.25160	0.01215
4	20	130	800.705	39.5104	0.12111	30	0.0168	330.0056	-3.9023	0.04652	0.25163	0.01215
5	50	160	756.799	38.5390	0.15247	30	0.0148	13.8593	0.3277	0.00420	0.24970	0.01200
6	70	240	451.324	46.1592	0.10587	20	0.0163	13.8593	0.3277	0.00420	0.24970	0.01200
7	60	300	1243.531	38.3055	0.03546	20	0.0152	40.2699	-0.5455	0.00680	0.24800	0.01290
8	70	340	1049.998	40.3965	0.02803	30	0.0128	40.2699	-0.5455	0.00680	0.24990	0.01203
9	135	470	1658.569	36.3278	0.02111	60	0.0136	42.8995	-0.5112	0.00460	0.25470	0.01234
10	150	470	1356.659	38.2704	0.01799	40	0.0141	42.8995	-0.5112	0.00460	0.25470	0.01234

## 2. B-Coefficients for 10-generating units:

$$B = \begin{bmatrix} 0.000049 & 0.000014 & 0.000015 & 0.000015 & 0.000016 & 0.000017 & 0.000017 & 0.000018 & 0.000019 & 0.000020 \\ 0.000014 & 0.000045 & 0.000016 & 0.000016 & 0.000017 & 0.000015 & 0.000015 & 0.000016 & 0.000018 & 0.000018 \\ 0.000015 & 0.000016 & 0.000039 & 0.000010 & 0.000012 & 0.000012 & 0.000014 & 0.000014 & 0.000016 & 0.000016 \\ 0.000015 & 0.000016 & 0.000010 & 0.000040 & 0.000014 & 0.000010 & 0.000011 & 0.000012 & 0.000014 & 0.000015 \\ 0.000016 & 0.000017 & 0.000012 & 0.000014 & 0.000035 & 0.000011 & 0.000013 & 0.000013 & 0.000015 & 0.000016 \\ 0.000017 & 0.000015 & 0.000012 & 0.000010 & 0.000011 & 0.000036 & 0.000012 & 0.000012 & 0.000014 & 0.000015 \\ 0.000017 & 0.000015 & 0.000014 & 0.000011 & 0.000013 & 0.000012 & 0.000038 & 0.000016 & 0.000016 & 0.000018 \\ 0.000018 & 0.000016 & 0.000014 & 0.000012 & 0.000013 & 0.000012 & 0.000016 & 0.000040 & 0.000015 & 0.000016 \\ 0.000019 & 0.000018 & 0.000016 & 0.000014 & 0.000015 & 0.000014 & 0.000016 & 0.000015 & 0.000042 & 0.000019 \\ 0.000020 & 0.000018 & 0.000016 & 0.000015 & 0.000016 & 0.000015 & 0.000018 & 0.000016 & 0.000019 & 0.000044 \end{bmatrix}$$

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