

**EMISSION CONSTRAINED ECONOMIC LOAD
DISPATCH USING HYBRID CONSTRICTION
PARTICLE SWARM OPTIMIZATION**

A Thesis Submitted in partial fulfillment of the requirement for the award of
degree of

**Master of Engineering
In
Power Systems**



Thapar University, Patiala

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ACKNOWLEDGEMENT

CERTIFICATE

I hereby certify that the work which is being presented in Thesis entitled, "Emission Constrained Economic Load Dispatch Using Hybrid Constriction Particle Swarm Optimization", in partial fulfillment of the requirements for the award of degree of *Master of Engineering in Power Systems* 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 other degree to any other university.

under him as a student. He also provides the help in technical writing and presentation style and I found his guidance to be extremely valuable.

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also thankful to my friends who devoted their valuable time for the successful completion of thesis. I express my feeling to all faculty and staff of EIED, Thapar University, Patiala for successful completion of thesis.

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ACKNOWLEDGEMENT

Words are often less to reveal one's deep regards. With an understanding that work like this can never be the outcome of a single person. I take this opportunity to express my profound sense of gratitude and respect to all those who helped me through the duration of this work.

I would like express my gratitude and thanks to supervisor, **Mr. Nitin Narang, Assistant Professor**, department of electrical and instrumentation engineering, thapar university, patiala, for his patient guidance and support through this work. It was an honour and privilege to work under him as a student. He also provides the help in technical writing and presentation style and I found his guidance to be extremely valuable.

I would also like to thank **Dr. Ravinder Agarwal, Professor and Head**, Department of Electrical and Instrumentation Engineering, Thapar University, Patiala, for providing this opportunity to carry out Thesis work.

I am also thankful to my friends who devoted their valuable time for the successful completion of thesis. I express my feeling to all faculty and staff of EIED, Thapar University, Patiala for successful completion of thesis.

Last but not the least, thanks god for giving me a great family, friends and great teachers in all respect of life.

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ABSTRACT

Emission constrained economic load dispatch is a complex problem for optimization of thermal generating units at minimum operating cost while satisfying the load demand and other constraints including emission constraints. The problems regarding conservation of energy and green power have gained much importance in 21st century because of acute rise in energy demand and environment concerns with respect to increasing pollution. In concern environmental awareness, electrical utilities are required to reduce their emission level well below predetermined standards. So far the only criterion of economic load dispatch is to dispatch electric power economically but now minimization considering emission as constraint is also important for all generation utilities.

In this thesis work hybrid constriction particle swarm optimization has been applied for solving emission constraints economic load dispatch problem. Particle swarm optimization has good exploration capability but less exploitation capability when it is near to global solution. In the proposed hybrid constriction particle swarm optimization, the constriction particle swarm optimization has been hybrid with particle swarm optimization to increase the exploration and exploitation capability of proposed technique. Hybrid constriction particle swarm optimization algorithm applied to two test systems and result has proved the effectiveness.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In almost every sphere of life, electric energy is the basic need of today. Thus, the question of cost carries a supreme importance in all engineering works. The supplier of electric power is responsible for supplying power to the consumers in order to match the requirements of load [1]. While designing the power system, focus is mainly on to achieve the overall economy in such a way that the per unit expenses of power generation is reduce as minimum as possible. This will ensure the supply to the consumers at reasonable rates of electricity. The problem of economy occur almost in whole power system that is at generating end in order to minimize the cost of transmission, power generation and distribution to ultimate consumers of electric energy [2]. Therefore, the overall system depends on the economy and relative cost of production which ensure cheapest production by adopting most convenient schemes, but electric energy generation in an economical manner is not an easy task, rather it requires long term planning and experience to decide the ratings of generators, location type etc. This problem can be fulfilled by optimization technique which carries a great significance in allocating the electric power to various generators in the power station at minimum possible cost while fulfilling all constraints like requirement for power demand, limit of operation for a particular generator etc [3]. Thus, economic load dispatch (ELD) problem deal with the minimize of total operating expenses of power generation while consider and fulfilling all the equality and inequality constraints. Equality constraints corresponding to meet the requirement of total load demand including transmission line losses while inequality constraint deal with the power generation of each thermal units is under its extreme and least limit.

Electric energy carries a great significance in the energy hierarchy because of its innumerable application for the domestic purposes, agricultural usage, industrial applications and even for transportation [4]. Electricity is one of the form of energy which cannot be stored but can be transported form one place (probably the generating station) to the other place (area of its application) instantaneously. It can easily be controlled making it an attractive form of energy. The index for standard of living of people in a particular country depend on the per capita

electric energy consumption. Electric energy demand is following a rapid increase in trend in India since 1947. This is because of the increased industrialization and its numerous usage for other purposes like home, agriculture, transport etc. Demand for electric energy is increased due to rise in population, increased requirement for housing and rural electrification.

The cost of generation of electric energy depends mostly on the purchasing cost, installation cost, cost of erection of equipment and auxiliary, fuel cost and miscellaneous cost like repairing cost, labor cost etc [5]. Fixed cost depends on investment cost of plant financial rates irrespective of quality of energy generated and operating cost/variable cost covers fuel expenses, labor charges, supervision etc. Both fixed and operating cost comes under generation cost.

1.2 Literature review

There are three types of optimization technique:

1. Classical method
2. Stochastic search techniques
3. Hybrid techniques

Classical method is totally dependent on the parameter selection i.e. the step size with which the number of iteration vary. Thus for any inappropriate value of step size, it drives the whole system to oscillations. Newton- rapson method can be used to obtain the solution of non-linear equation in which the problem of change in the control variables can be satisfied by using Taylor series expansion using hessian matrix [3]. All such mathematical programming based algorithms such as lambda iterative method, Lagrange relaxation, gradient based method etc does not prove to be applicable for non-linear or non-convex cost functions [2]. Such techniques involve a derivative approach which does not converge. Moreover constraint handling is an issue of interest which cannot be successfully met using mathematical programming techniques. Lung *et al.* [6] have presented ELD using direct search method. This problem of constraint handling can be overcome by following dynamic programming (DP) approach [7]. Liang *et al.* [7] a dynamic programming used to solving economic dispatch including transmission losses. Dynamic programming provides an effective solution to handle the operating limits of generators. But DP approach fails to converge in case of highly dimensional problems. Thus, these classical methods does not provide solution in large scale optimization problem.

The second category of methods for solving optimization type of problems include stochastic searching algorithms. It includes genetic algorithm (GA), particle swarm optimization

(PSO), simulated annealing, artificial immune system (AIS), evolutionary programming (EP). Above optimization techniques are alternative approach which is flexible and efficient than traditional methods because of their tendency to explore new solution with appropriate satisfaction of constraints. Genetic algorithm is one of the global optimization technique based on the principles of biological evolution in which accuracy can be improved by increasing the string length. Kumar *et al.* [8] have presented non convex ELD using an efficient real coded GA. But the problem with GA is that it deals with binary operators which require sufficient time and space to convert into required form. Mandal *et al.* [9] have presented krill herd algorithm for solving ELD. Vlachos *et al.* [10] presented ELD problem based on a memetic algorithm. Silva and Nepomuceno have presented neural approach to solve ELD problem of power system [11]. Vanaja *et al.* [12] have proposed AIS based ELD with value point effect. T. Kumano presented functional optimization to solve dynamic ELD with ramp rate of power output of thermal units [13]. Orike *et al.* [14] have presented improved evolutionary algorithms for ELD. Lee *et al.* [15] have presented adaptive hopfield neural networks for ELD. Panigrahi *et al.* [16] have presented a clonal algorithm to solve ELD.

PSO approach generates solution in parallel thus preserving the overall population [17]. Its computational time is less because of its faster convergence rate. Zhang Zhisheng have presented Quantum-behaved particle swarm optimization (QPSO) algorithm for solving ELD problems [18]. Coelho *et al.* [19] presented chaotic and gaussian PSO approaches to solve ELD problems in power systems . Vahid Hosseinnzhad *et al.* [20] presented ELD using θ -PSO. The evaluation from mechanism of PSO is proposed in the novel θ -PSO by changing the speed vector with a phase angle vector. Chaturvedi *et al.* [21] presented non-convex ELD problem using PSO with time varying acceleration coefficients. To balance between the local and global search, by varying acceleration coefficients are applied so that global solutions obtained and premature convergence is avoided [21].

Ultimate aim of any optimization technique is to converge the given problem within certain limited time cycle. Hybrid approach is one such method which involve hybridization of two independent optimization algorithms [22]. By using hybrid structured search , quality of solution gets improved and computational time also. Kumar et al. [23] have proposed a hybrid multi-agent based PSO algorithm in which hybridization of the deterministic search, multiagent system, PSO and bee decision making process combine result more accurately and prove to be

robust in finding global optimum for ELD. Cai *et al.* [24] have proposed hybridization of fuzzy system and chaotic swarm optimization known as a fuzzy adaptive chaotic ant swarm optimization algorithm used for solving ELD problem. Coelho *et al.* [25] have proposed a DE based on truncated lévy-type flights and population diversity in which hybridization lead to avoiding premature convergence effectively and capable of achieving higher efficiency and better solution for solving ELD. Zhang Zhisheng presented hybridization of electromagnetism-like mechanism algorithm (EMA) and chaos theory known as chaotic electromagnetism-like mechanism algorithm (CEMA) used for solving ELD problem of power system [26]. Hybridization lead to increase the searching spaces and to avoid particle trapped into local optimum [26]. Ling *et al.* [22] have presented a hybridization of particle swarm optimization and wavelet theory based mutation operation use to solve ELD. A wavelet theory used to enrich PSO in exploration of spaces more effectively for better results. Ahmed Y *et al.* [27] presented hybridization of bacterial foraging technique and PSO biased evolution for solving ELD. De *et al.* [28] presented a hybridization of biogeography-based optimization and predator-prey approach used to solve ELD. Wang *et al.* [29] have presented a modified mutative scale chaotic optimization algorithm applied to ELD. Lai *et al.* [30] presented intelligent optimization with fuzzy control, a technique called iteration windows introduced which provide the self-terminating ability used to solve ELD. Rathi *et al.* [31] presented hybrid technique based on biogeography based optimization for solution of ELD problems in this technique searches for the global solution throughout the mutation and migration. Das *et al.* [32] presented hybridization of differential evolution and invasive weed operation for solving ELD. Nejad *et al.* [33] presented hybridization of clonal selection algorithm and PSO for solving valve- point ELD.

One of the main factor responsible for producing bulk pollutants from which environment gets polluted is power generation. Electric energy production from these power generating units is done by utilizing the energy from fossil fuels and converting it to required form by burning of fossil fuels like natural gas, coal. But because of the burning process of these fossil fuel or by fission of nuclear material, bulk amount of pollutants are produced and exposed to environment which may result in polluting the atmosphere and affecting the life of many living organisms on the earth [34]. Thus the need is to control the emission out of such generating stations in order to avoid many ecological disasters. It should be effectively tacked for preventing the problems of air pollution resulting from power generation. Several contaminants are released in atmosphere

due to the burning of fossil fuels which include sulphur oxides, carbon dioxide and nitrogen oxides etc and other green house gases that may adversely affect the environment [35].

Power generating stations utilizes the fuel as resource of energy to produce electricity regardless of emission produced [4]. But generation of power from these fossil fuels result in release of various gases in the atmosphere. Main concern out of these gases is regarding the green house gases like NO_x , SO_x , CO_2 that causes pollution in the environment [36]. The emission of these pollutants causes global warming that affect not only humans but also affect other forms of living beings like plants and animals. Thus it is required to produce electricity at minimum possible cost as well as at minimum level of pollution [37].

The level of emission can be limited by including the emission as constraint, fuel switching like switching to lower sulphur coal, limiting NO_x , SO_x emission, installing power plant emission control technologies like post combustion cleaning equipment or change of old fuel burners with cleaner ones [38]. Some of above methods require the installing of new equipments or their parts which causes increase the capital cost. But optimal generation dispatch deal with minimizing the total generation cost of system. Thus such methods are not preferable. Increased concern over environmental regulations in the recent years (clean air act 1990) enforced the consideration of emission as important factor to be considered with generation [39].

It can be concluded from the above discussion that ELD problem not only deals with minimizing the cost ensuring all constraints but at the same time limit the emission as well [34]. The conventional ELD problem deals with the allocation of power in such a way so as to carry out generation economically with all constraints ensured. However, because of a large number of generating units employed in order to satisfy the total demand, the amount of fuel like coal burnt depends on the corresponding demand and thus increases with it [35]. Ultimately it follows an increase in level of emission of gaseous pollutants from these fossil fuels. In concern environmental awareness, electrical utilities are required to reduce their emission level well below predetermined standards [38]. So far the only criterion of economic load dispatch is to dispatch electric power economically only and now minimization while considered emission as constraint is also important for all generation utilities. Ramanathan has presented emission constrained economic load dispatch (ECELD) [4]. Arya *et al.* [5] have presented emission constrained secure economic dispatch. Abou *et al.* [40] have presented DE algorithm for emission constrained economic power dispatch problem.

1.3 Constriction particle swarm optimization

Evolutionary programming search techniques are considered to be most effective methods for solving non smooth optimization problems. Particle swarm optimization is one such random search technique that explores a good local solution very quickly. The main problem with this approach is that if it get trapped at a particular solution then continues to get struck there and will not be able to come out for a number of iteration not giving global best results [41].

The velocity of particle is not stable that is it either rapidly increases or rapidly decreases i.e. oscillating. Due to rapid increase in velocity of particle the step size increased the particle fly off the search space while because of the rapid decrease in particle velocity, particle suddenly reduces its speed and stop sometimes [42]. PSO generally cannot go out of local optimal solution to reach the global best ones. This is due to more local optima, high dimensionality and large number of constraint handling [43]. Parameter setting is one of the important characteristic of PSO to obtain effective solution [44]. There exit a wide variation in results from PSO with different parameter setting. Some of these results may result in premature convergence. Thus exact balancing of the parameters in PSO is required for obtaining the desired results [45].

The convergence towards a stable solution is the main requirement of any searching algorithm in 1999, clerc introduced a factor called constriction factor [46]. Thus, step size decreases by parameterzing the PSO technique using a constriction factor and explosion is prevented ensuring stability. Constriction particle swarm optimization (CPSO) is the powerful searching technique of evolutionary programming that provide an efficient and fast solution to the optimization problem. CPSO provide convergence at a stable point as the number of iterations increases ensuring local best solution. CPSO result in steady and stable convergence because of the reduction in step size while performing iteration [47]. Due to the decrease in step size in case of CPSO , the c.p.u time reduces leading to fast results [48]. The instability of sudden rise and fall of velocity in case of PSO is overcome by CPSO using a constriction factor which improves the step size leading to stable results. Pranava *et al.* [49] have proposed constriction coefficient PSO for ELD with valve point loading effects. Saha *et al.* [50] presented PSO with constriction factor and inertia weight approach applied to IIR system identification. Raha *et al.* [51] presented constriction factor based PSO used for solving reactive power dispatch in transmission system.

Parameter setting is also one of the important characteristic of CPSO to obtain effective solution [52]. The main problem with CPSO approach is that if it get trapped at a particular solution then continues to get struck there [53] and will not be able to come out for a number of iteration not giving global best results. There exit a wide variation in results from CPSO with different parameter setting. Some of these results may result in premature convergence is still problem. Thus exact balancing of the parameters in CPSO is required for obtaining the desired results [54]. At starting of the iteration solution variation of CPSO small as iteration increases. This result in less exploring at starting of iterations and sometime not finding right solution. But after some iteration it result in a particular constant value. The proposed technique hybrid constriction particle swarm optimization (HCPSO) come into account to over come the limitation of PSO and CPSO to find optimum solution. The hybrid constriction particle swarm optimization is the combination of advantages of PSO and CPSO.

1.4 Author's contribution

Emission constrained economic load dispatch deals with scheduling of generators economically mean while limiting the emission level. The proposed HCPSO is implemented to solve this ECELD problem. Proposed technique implemented on given problem yield satisfying results which are compared with other optimization techniques and prove to be better.

1.5 Organization of the Thesis

As per the proposed thesis titled as “Emission constrained economic load dispatch using hybrid constriction particle swarm optimization” it consists of six chapters. First Chapter provides a detailed introduction, brief literature review pertaining to proposed problem and Author's contribution. Second chapter deals with the problem formulation on which the proposed technique is implemented. Third chapter describes the approach to be used i.e hybrid constriction particle swarm optimization and its algorithm. Fourth chapter provides the implementation of HCPSO on the given ECELD problem. Fiveth chapter covers the comparsion of different techniques with proposed technique. Six chapter describe the scope of future extension to the given work.

CHAPTER 2

EMISSION CONSTRAINED ECONOMIC LOAD DISPATCH

2.1 Introduction

Power generating stations utilize the fuel as a resource of energy to produce electricity regardless of the emission produced. But the generation of power from these fossil fuels results in the release of various gases into the atmosphere. The main concern about these gases is regarding the greenhouse gases like NO_x , SO_x , CO_2 that cause pollution in the environment [39]. The emission of these pollutants causes global warming that affects not only humans but also other forms of living beings like plants and animals. Thus, it is required to produce electricity at the minimum possible cost as well as at the minimum level of pollution.

The emission constrained economic load dispatch (ECELD) problem is defined so as to minimize the objective of the operating expenses with emission as constrained [5]. In concern of environmental awareness, electrical utilities are required to reduce their emission level well below predetermined standards.

The level of emission can be limited by including the emission as a constraint. The discussion of emission constraint has made the economic load dispatch problem a more complex one. This combination of ELD makes the problem of conflicting and requires the development of a rigorous mathematical optimization method. But optimal generation dispatch deals with minimizing the total generation cost of the system.

2.2 Problem formulation

The present formulation treats the emission constrained economic load dispatch problem which attempts to optimize the operating expenses with emission constraints, while fulfilling and considering both equality and inequality constraints. The given constraints and objective are taken into account for the formulation of the ECELD problem.

2.2.1 Cost function

The fuel cost function of each thermal generator, with the valve-point effect, is represented as the sum of a sine and a quadratic function. The fuel cost in terms of generation output can be expressed as:

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

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 generated power of i^{th} unit.

P_i^{\min} = Least power of i^{th} unit.

G = Total number of generating unit.

2.2.2 Emission function

Emission (lb/h) of pollutants is sum of an exponential and quadratic function can be expressed as:

$$EM = \sum_{i=1}^G (\alpha_i P_i^2 + \beta_i P_i + \gamma_i + \eta_i \exp(\delta_i P_i)) \quad (2.2)$$

where

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

EM = Amount of emission released by thermal unit.

2.3 Conflicting nature

Emission and cost function are basically conflicting in nature. It can be concluded that for the purpose of reducing the emission level, most of the costly equipments are employed to maintain emission within specified limits. This result in increase in total cost of the system with reduction of emission level and vice versa. Thus emission and cost vary as the inverse of each other.

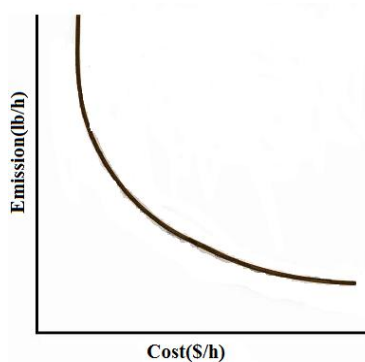


Fig 2.1 Cost versus emission curve

2.4 Constraints

Depending on the nature of power system under study, the ECELD is subjected to many constraints. In ECELD two types of constraints are:

- 1) Equality constraints
- 2) Inequality constraints

2.4.1 Equality constraints:

Power generation balance constraint

The total power generation from thermal units must meet the load demand and the real power losses in the transmission lines.

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

where

P_D is the demand load

P_L is the losses in transmission, which are approximated in terms of B-coefficient also called as Kron's loss formula:

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

2.4.2 Inequality constraints:

Power generation limit constraint

The power generation of each thermal unit is under its extreme and least limit.

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

where

P_i^{\min} and P_i^{\max} are the least and extreme limit of generator output.

Emission constraints

The emission from a generating units should be within allowed limit. The emission constraint can also be taken as.

$$EM(P_i) \leq \alpha E^{\max} \quad (2.6)$$

$$\alpha < 1 \quad (2.7)$$

where

α is emission limit factor.

E^{\max} is the maximum emission limit at minimum fuel cost.

CHAPTER 3

HYBRID CONSTRICTION PARTICLE SWARM OPTIMIZATION

3.1 Introduction

In 1995, Kennedy and Eberhart [17] proposed a bird flocking optimization technique based on random searching algorithm naming PSO. This technique deals with schooling of fishes or flocking of birds based on swarm intelligence and obtaining the globally best position following best individual in the swarm and their own best experience. Basically particle swarm optimization is a metaheuristic technique aiming at obtaining satisfactory results in practical scheduling problem. Such an approach is totally based on the selection of its appropriate parameters. Thus, suitable adaptation of parameters should be required while obtaining solution to given complex problem. Adjustability carries a great significance providing a perfect relationship between the quality and quantity of the parameters following the given algorithm. It should guarantee the correct direction of search based on pre-adjusted parameters for the given complex problem assuring robustness to the system. Thus, above discussed qualities should be desired for such a metaheuristic technique [42].

There are various EP approaches like GA, DE etc that can be applied on different problems easily. But out of all these techniques, PSO is an optimization algorithm that searches in parallel and obtain global best values very quickly [17]. It can be applied to the complex optimization problems where other traditional techniques fails to implement satisfactorily. It is an effective tool that searches randomly to solve the given ECELD problems and provides a well defined balance between local and global searching. Thus, PSO results in exploration of promising areas quickly and exploitation of these areas effectively [45].

3.2 Advantages and disadvantages of PSO

Particle swarm optimization is an effective tool in solving complicated optimization problems. Following are some advantages and disadvantages of PSO compared to other metaheuristic approaches:-

- 1) Differential equations are not included in PSO algorithm which are difficult to solve and time consuming [45].
- 2) It can be easily employed for solving complex optimization problem.

- 3) PSO searches in parallel i.e. each particle is retained throughout the algorithm [17].
- 4) It involves setting of a few parameters in its algorithm resulting in saving of time [45].
- 5) Due to rapid increase in velocity of particle, the step size increase which makes the particle fly off the search space while because of the rapid decrease in particle velocity, particle suddenly reduces its speed and stop sometimes [47]. Thus, velocity of particle is oscillating.
- 6) PSO generally cannot go out of local optimal solution to reach the global best ones. This is due to more local optima, high dimensionality and large number of constraint handling [47].
- 7) Parameter setting is one of the important characteristic of PSO to obtain effective solution [44].
- 8) As the number of iterations increases, the solution must lead to imposed results finally converging the solution of a global best value. But sometimes after some iteration it result in a particular constant value.

For the same simple PSO system, Clerc and Kennedy (1999) provided a constriction factor to obtain a stable point and ensure convergence [46]. The objective of constriction factor is to prevent the velocity to grow out from maximum limit, with this velocity in the range. Constriction particle swarm optimization (CPSO) is an stochastic search technique which produce an efficient approach in order to obtain the solution.

3.3 Overview of CPSO [3]

In CPSO, speed of each particle in swarm and corresponding location in search area are denoted by V and P. Thus, positional coordinates of each of the particle in swarm is expressed as

$$P_i = [P_{i,1}, P_{i,2}, P_{i,3}, \dots, P_{i,j}] \quad (3.1)$$

The local best value of each particle can be expressed as

$$P_i^{\text{best}} = [P_{i,1}^{\text{best}}, P_{i,2}^{\text{best}}, P_{i,3}^{\text{best}}, \dots, P_{i,j}^{\text{best}}] \quad (3.2)$$

The global best value is basically the best solution among all the particles in the swarm which can be expressed as

$$G_i^{best} = [G_1^{best}, G_2^{best}, G_3^{best}, \dots, G_i^{best}] \quad (3.3)$$

The velocity with which the particle moves in the search space is expressed as

$$V_i = [V_{i,1}, V_{i,2}, V_{i,3}, \dots, V_{i,j}] \quad (3.4)$$

The velocity of particles are updated using the global best value and personal best experience of the particle i.e. local best value and is given below:

$$V_{i,j}^{k+1} = W \times V_{i,j}^k + C_1 \times \text{rand}() \times (P_{i,j}^{best} - P_{i,j}^k) + C_2 \times \text{rand}() \times (G_j^{best} - P_{i,j}^k) \quad (3.5)$$

3.3.1 Inertia weight

The inertia weight was introduced by Shi and Eberhart [46] controls the convergent behaviour and momentum of particle by weighting contribution to the previous velocity. Selection of W help in providing a balance between local and global explorations. $W > 1$ result in increase in velocity causing divergent behaviour and $W < 0$ result in particles deceleration [53]. It can be expresses as:

$$W = W^{max} - ((W^{max} - W^{min}) \times IT) / ITmax \quad (3.6)$$

where

$ITmax$ = maximum iteration number

IT = iteration number

W^{min} = final weight.

W^{max} = initial weight

3.3.2 Velocity upgradation

A set of coefficients contained in the model of the PSO algorithm, to control the system's

system's convergence tendencies. Trajectories of single particles which depends on the value of acceleration coefficients. Constriction coefficients can prevent explosion due to high value of C_1 , C_2 , W [47]. The velocity of particles are update using the previous position and velocity in CPSO as given below:

$$V_{i,j}^{k+1} = K[W \times V_{i,j}^k + C_1 \times \text{rand}() \times (P_{i,j}^{\text{best}} - P_{i,j}^k) + C_2 \times \text{rand}() \times (G_j^{\text{best}} - P_{i,j}^k)] \quad (3.7)$$

Constriction coefficient (K): As ϕ increases, the factor K decreases and convergence becomes slower.

where

$$K = 2 / |2 - \phi - \sqrt{(\phi^2 - 4\phi)}| \quad (3.8)$$

when $\phi^2 - 4\phi \geq 0$

$$\phi = C_1 + C_2, \phi > 4 \quad (3.9)$$

The position of particles are update using the previous position and velocity as given below:

$$P_{i,j}^{k+1} = V_{i,j}^{k+1} + P_{i,j}^k \quad (i = 1,2,3 \dots PR; j = 1,2,3, \dots \dots G; k = 1,2,3 \dots \dots ITmax) \quad (3.10)$$

where

PR= number of particles in group; G= number of member in particles; ITmax = number of iteration; W= inertia weight factor; C_1 and C_2 = acceleration constant.

$P_{i,j}^k$ = current position of j^{th} member of i^{th} particles at k^{th} iteration.

$\text{rand}()$ =uniform random number in the range [0,1].

$P_{i,j}^{\text{best}}$ = local best position of j^{th} member of i^{th} particles.

G_j^{best} = Global best position of j^{th} member.

$V_{i,j}^k$ = current velocity of j^{th} member of i^{th} particles at k^{th} iteration.

P_j^{min} and P_j^{max} Least and Supreme position of j^{th} member.

According to above equation, the region which are to be searched in the area between the present and final position determined by V_i^{\min} parameter. If the maximum velocity (V_i^{\max}) is very large then particle fly past the good position and if V_i^{\max} is very small then particles may not explore sufficient area to find good solution.

$$V_i^{\min} \leq V_{i,j}^k \leq V_i^{\max} \quad (3.11)$$

$$V_i^{\min} = -0.05((P_i^{\min} + P_i^{\max})/2) \quad (3.12)$$

$$V_i^{\max} = 0.05((P_i^{\min} + P_i^{\max})/2) \quad (3.13)$$

where

V_j^{\min} and V_j^{\max} Least and Supreme velocity of j^{th} member.

The constant C_1 and C_2 is also called self confidence factor and swarm confidence factor. Pulling of each particle towards the global and local best position by these constant provided weighting of acceleration terms. High value of constant lead the particles to past the optimum solution and low value lead the particle to far from the target position [52].

3.4 Advantages and disadvantages of CPSO

- 1) Constriction particle swarm optimization provide convergence at a stable point as the number of iterations increases ensuring best solution [47].
- 2) Constriction particle swarm optimization result in steady and stable convergence because of the reduction in step size while performing iteration [47].
- 3) Due to the decrease in step size in case of CPSO , the time of cpu reduces leading to fast results [46].
- 4) The instability of sudden rise and fall of velocity in case of PSO is overcome by CPSO using a constriction factor which improves the step size leading to stable results [45].
- 5) Parameter setting is one of the important characteristic of CPSO also to obtain effective solution [52].
- 6) At starting of the iteration solution variation of CPSO small as iteration increases. This result in less exploring at starting of iterations and sometime not finding right solution.

PSO is implemented to various problems in power system. In PSO when search process reaches the local search area then convergence the rate slow for exploitation and does not find best solution this is limitation of PSO. CPSO has some limitation of less exploration for global search ability. So hybrid constriction particle swarm optimization (HCPSO) come into account to over come the limitation of PSO and CPSO to find optimum solution.

3.5 Hybrid constriction particle swarm optimization

The hybrid constriction particle swarm optimization is the combination of advantages of PSO and CPSO. During the initial search in case of PSO particle exploration area is more and solution lead to desired results. But after initial search it results in a particular constant value. CPSO result in steady and stable convergence because of the reduction in step size while performing iteration. Due to reduction in the step size, approach searches in local areas (exploitation), thus ensuring the convergence. CPSO provide convergence at a stable point as the number of iterations increases ensuring best solution.

According to the above discussion, PSO explores more area at the time of starting. The step size of particle position is reduced resulting in improved solution. CPSO increases the exploitation at local search area near the optimum solution [46]. The C factor is constant value after which exploitation is done and reduction in step size.

Then the velocity is updated in HCPSO as given below:

$$V^{k+1}_{i,j} = \begin{cases} K[W \times V^{k}_{i,j} + C_1 \times \text{rand}() \times (P^{best}_{i,j} - P^k_{i,j}) + C_2 \times \text{rand}() \times (G^{best}_j - P^k_{i,j})]; \\ \quad (C \text{ factor} < k) \text{ and } (FN(k-1) = FN(k-N)) \\ V^{k+1}_{i,j} = W \times V^{k}_{i,j} + C_1 \times \text{rand}() \times (P^{best}_{i,j} - P^k_{i,j}) + C_2 \times \text{rand}() \times (G^{best}_j - P^k_{i,j}); \\ \quad (k > 0) \text{ and } (FN(k-1) \neq FN(k-N)) \end{cases} \quad (3.14)$$

where

FN is function in which global best value of objective is put for all iteration

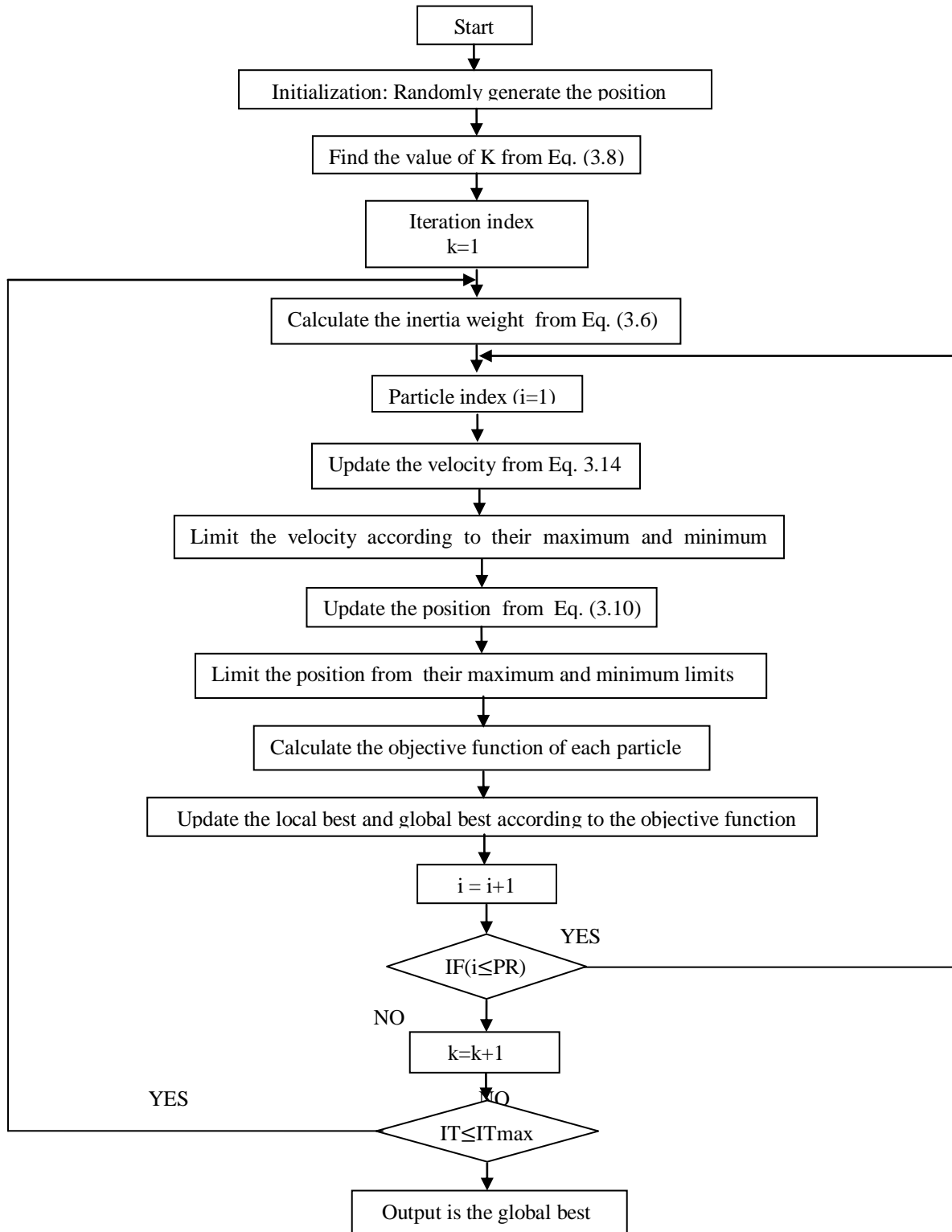


Fig. 3.1 Flowchart of HCPSO

CHAPTER 4

EMISSION CONSTRAINED ECONOMIC LOAD DISPATCH USING HCPSO

4.1 Introduction

The emission constrained economic load dispatch (ECELDT) is a optimization problem to minimize expenses while fulfilling the demand, equality and inequality constraints including emission constraint [3]. A major objective for the coal-fired power plant generation loading is to minimize fuel consumption and to maintain emission within environmental limit. In concern environmental awareness, electrical utilities are required to reduce their emission level well below predetermined standards [39]. The ECELDT dispatch problem is solved by hybrid constriction particle swarm optimization (HCPSO). In this chapter implementation of algorithm to solve ECELDT is discussed in detailed.

4.2 Problem formulation

The present formulation treated ECELDT problem which attempt to optimize the operating expenses with emission constraints, while fulfilling and considering both equality and inequality constraints. The given constraints and objective are taken into account for the formulation of ECELDT problem.

The fuel cost function of each thermal generator, with the valve-point effect is represented as sum of sine and quadratic function. The fuel cost function as discussed in Eq 2.1.

Emission (lb/h) of pollutants in terms of generation output as discussed in Eq. 2.2.

4.3 Constraints

Depending on the nature of power system under study, the ECELDT is subjected to many constraints. In ECELDT two types of constraints are:

- 1) Equality constraints
- 2) Inequality constraints

4.3.1 Equality constraints:

Power generation balance constraint

The total power generation from thermal units must meet the load demand and the real power losses in the transmission lines. The constraint as discussed in Eq 2.3.

4.3.2 Inequality constraints:

Power generation limit constraint

The power generation of thermal units is under its extreme and least limit as discussed in Eq 2.5.

Emission constraints

The emission from a generating units should be within allowed limit as discussed in equation 2.6 & 2.7.

4.4 Constraint handling

For power generation balance, equality constraints must be fulfilled. The equality constraints represent total power generation should be equal to total demand load plus total loss in transmission line. Real power balance equation should be satisfied throughout the system operation in the problem and can be represented as:

$$E1 = \begin{cases} (\sum_{i=1}^G P_i - P_D - P_L)^2; P_D + P_L \neq \sum_{i=1}^G P_i \\ 0; P_D + P_L = \sum_{i=1}^G P_i \end{cases} \quad (4.1)$$

The generation should lie within the operating limits of the respective units for their proper operation. Emission constraint indicates maximum limits for emission as indicated:

$$E2 = \begin{cases} (\alpha E^{\max} - E(P_i))^2; EM(P_i) > \alpha E^{\max} \\ 0; EM(P_i) \leq \alpha E^{\max} \end{cases} \quad (4.2)$$

4.5 Formulation of objective function

Objective function includes the operating cost and summing of penalty term which not satisfied equality and inequality constraints. The objective function is expressed as:

$$OF = F + P_1 \times E1 + P_2 \times E2 \quad (4.3)$$

where

OF is objective function.

F is cost function.

P_1 and P_2 is penalty factor.

4.6 Implementation

4.6.1 Swarm representation [3]

The deciding variables of the ECELD problems of power system are power output from thermal units, the power output (P) set for all thermal units is expressed by particle position in the swarm.

The full swarm expressed as a matrix:

$$\text{swarm} = \begin{bmatrix} P_{1,1} & P_{1,2} & \cdots & P_{1,G} \\ P_{2,1} & P_{2,2} & \cdots & P_{2,G} \\ \cdots & \cdots & \cdots & \cdots \\ P_{PR,1} & P_{PR,2} & \cdots & P_{PR,G} \end{bmatrix}$$

where G represent number of generators and PR is the number of particles in the swarm.

4.6.2 Randomly generation of power and velocity

The initial velocity and position (power) are initialized by uniform random number lying between its maximum and minimum values. Velocity and power can be represented as follows:

$$V_{i,j} = V_j^{\min} + \text{rand}() \times (V_j^{\max} - V_j^{\min}) \quad (j = 1,2,3 \dots \dots G; i = 1,2,3 \dots \dots PR) \quad (4.4)$$

$$P_{i,j} = P_j^{\min} + \text{rand}() \times (P_j^{\max} - P_j^{\min}) \quad (4.5)$$

4.7 Algorithm for emission constrained economic load dispatch using hybrid particle swarm optimization

Step 1: Read data; cost coefficients, emission coefficients, P_j^{\max} , P_j^{\min} , E^{\max} , penalty, acceleration factors, N, C factor.

Step 2: Randomly generate the velocity and position as by Eq. (4.4) and (4.5)

Step 3: Find the objective values and set as cost is OF_i^{best} and set $P_{i,j}^{\text{best}} = P_{i,j}$ and minimum objective value is set as a global value and its particles is set a G_i^{best} .

Step 4: Calculate the value of K from Eq. (3.8)

Step 5: Iteration set IT=1

Step 6: Calculate the inertia weight according to Eq. (3.6)

Step 7: IF (IT>C factor), THEN

IF(FN(IT-1)=FN(IT- N)), THEN

Calculate the new velocity according to Eq. (3.7)

ENDIF

ELSE

Calculate the new velocity according to Eq. (3.5)

ENDIF

Step 8: Check the velocity limit

IF ($V_{i,j}^{new} > V_{i,j}^{max}$), THEN

$$V_{i,j}^{new} = V_{i,j}^{max}$$

ENDIF

IF ($V_{i,j}^{new} < V_{i,j}^{min}$), THEN

$$V_{i,j}^{new} = V_{i,j}^{min}$$

ENDIF

Step 9: Calculate the new position according to Eq. (3.10)

Step 10: Check the position limit

IF ($P_{i,j}^{new} > P_{i,j}^{max}$), THEN

$$P_{i,j}^{new} = P_{i,j}^{max}$$

ENDIF

IF ($P_{i,j}^{new} < P_{i,j}^{min}$), THEN

$$P_{i,j}^{new} = P_{i,j}^{min}$$

ENDIF

Step 11: Calculate the emission according to Eq. (2.2)

IF ($E_i^{new} > \alpha E_i^{max}$), THEN

Calculate the emission error

ENDIF

Step 12: Calculate the objective value by Eq. (4.3) and minimum objective value set as OF_i^{best}

IF ($OF_i^{new} < OF_i^{best}$), THEN

$$(F_i^{new} = F_i^{best}) \text{ and } (P_{i,j}^{new} = P_{i,j}^{best})$$

ENDIF

Put $(FN(IT) = OF_i^{\text{best}})$

Step 13: IF $(IT < IT_{\text{max}})$, THEN

$IT = IT + 1$ and return to step 3

ELSE

 Global best is the optimum solution.

ENDIF

CHAPTER 5

RESULT AND DISSCUSSION

5.1 Introduction

The chapters that have been discussed provide the complete knowledge of ECELD problem and its formulation using HCPSO. The algorithms of HCPSO which are presented in chapter four, have been applied for solving ECELD problem. In this chapter, two cases are study to show the result of applied methods in terms of its solution quality. Test data is given in appendix-A [54] and appendix-B [55].

5.2 Parameter setting

In this thesis work, proporsed algorithm based on HCPSO is carried out to solve ECELD. To find the stable and optimal solution, program is run for different value of C_1 , C_2 , C_3 , C_4 , w^{\max} , w^{\min} , ITmax and C factor, which are given in table 5.1.

Table 5.1 Different values of Parameters

PR	ITmax	W^{\max}	W^{\min}	C_1	C_2	C_3	C_4	C factor
60	2000	.9	.4	2	2	2.05	2.05	150

To show the effectiveness of HCPSO method, two cases for six and ten generating units are study and results are compared with solution obtained by CPSO method indicated in table 5.2. For six generating units ECELD problem, emission obtained from HCPSO (483(lb/h)) than CPSO (485(lb/h)) and operating cost is also less. For ten generating units ECELD problem, emission obtained from HCPSO (4077.26 (lb/h)) than CPSO (4070.31(lb/h)). Result obtained using HCPSO in comparsion of CPSO are found to be more satisfactory. ECELD problem for both six and ten generating units corresponding emission level and operating cost are found to be more satisfactory using the proposed technique.

Table 5.2 Comparison between CPSO and HCPSO

	ECELD	CPSO	HCPSO
Six units	Operating Cost(\$/h)	37613.96	37500.28
	Emission(lb/h)	485.17	483.06
	P ₁ (MW)	11.78	10.28
	P ₂ (MW)	69.00	60.74
	P ₃ (MW)	150.03	140.46
	P ₄ (MW)	124.25	120.67
	P ₅ (MW)	126.29	143.09
	P ₆ (MW)	237.40	245.01
Ten units	Operating Cost(\$/h)	114345.8	114387.10
	Emission(lb/h)	4077.26	4070.31
	P ₁ (MW)	28.56	33.02
	P ₂ (MW)	61.02	80.00
	P ₃ (MW)	47.00	47.00
	P ₄ (MW)	53.04	80.64
	P ₅ (MW)	160.00	160.00
	P ₆ (MW)	159.00	165.60
	P ₇ (MW)	299.00	242.68
	P ₈ (MW)	340.00	340.00
	P ₉ (MW)	470.00	470.00
	P ₁₀ (MW)	470.00	470.00

Case system 1

Six generating units system are to be connected to meet 700MW demand. Data of the generating units and require load demand are contained in appendix-A. Results are obtaining for

economic load dispatch and emission load dispatch from CPSO and HCPSO and tabulated in table 5.3 & 5.4.

Table 5.3 Best cost and emission in six units by HCPSO

P_G (MW)	Economic Dispatch	Emission dispatch
P_1 (MW)	11.43	10.84
P_2 (MW)	14.30	111.00
P_3 (MW)	122.08	140.32
P_4 (MW)	83.16	93.95
P_5 (MW)	309.22	173.64
P_6 (MW)	181.21	189.07
Cost(\$/h)	37249.06	38308.49
Emission(lb/h)	537.29	451.87

Table 5.4 Best cost and emission in six units by CPSO

P_G (MW)	Economic Dispatch	Emission dispatch
P_1 (MW)	10.00	11.84
P_2 (MW)	28.07	107.02
P_3 (MW)	140.12	64.99
P_4 (MW)	105.51	142.67
P_5 (MW)	144.16	199.31
P_6 (MW)	181.21	189.07
Cost(\$/h)	37288.66	38305.23
Emission(lb/h)	539.79	468.69

Emission limiting value is included for the purpose of controlling the level of emission using an emission limit factor (α). For different values of α when set to .9 value, results for cost

and emissions are respectively 37500.28(\$/h) and 483.062(lb/h). For a value of $\alpha = .86$, corresponding cost and emission come out to be 37723.08(\$/h) and 461.209(lb/h). It is clear from the above discussion that with the decrease in value of α , rate of emission decreases while corresponding cost increases. This is due to the conflicting behaviour of cost and emission which make emission level within a pre-specified limit and thus leading to increased cost with decreasing of α . The graph (5.1) show the conflicting nature of cost and emission. For six unit problem, the global optimal solution is explored and exploited with in 500 iterations. In table 5.5 the real power generation is also given.

Table 5.5 Results achieved with different value α in six units

P _G (MW)	Emission constrained economic load dispatch		
	$\alpha = .9$	$\alpha = .86$	$\alpha = .84$
P ₁ (MW)	10.287	12.858	11.11
P ₂ (MW)	60.743	72.002	75.01
P ₃ (MW)	140.462	155.203	154.39
P ₄ (MW)	120.678	149.223	116.43
P ₅ (MW)	143.098	190.452	196.05
P ₆ (MW)	245.014	138.115	165.09
Cost(\$/h)	37500.28	37723.08	38084.13
Emission(lb/h)	483.062	461.209	450.28

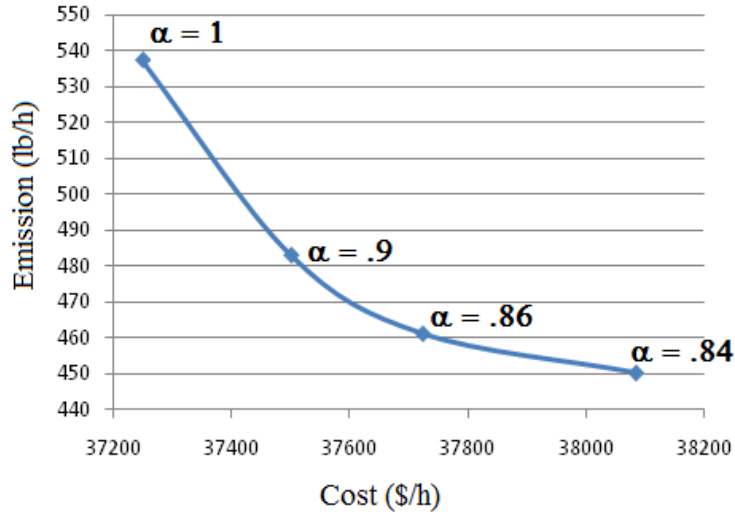


Fig 5.1 Cost versus emission curve in six units

Case system 2

Ten generating units system are to be connected to meet 2000MW demand. Data of the generating units and require load demand are contained in appendix-B. Results are obtaining for economic load dispatch and emission load dispatch from CPSO and HCPSO and tabulated in table 5.6 and 5.7.

Table 5.6 Best cost and emission in ten units by HCPSO

P_G (MW)	Economic Dispatch	Emission Dispatch
P_1 (MW)	35.84	30.54
P_2 (MW)	80.00	49.56
P_3 (MW)	120.00	71.26
P_4 (MW)	106.00	78.06
P_5 (MW)	95.00	160.00
P_6 (MW)	70.00	240.00
P_7 (MW)	300.00	241.04
P_8 (MW)	340.00	275.05
P_9 (MW)	470.00	470.00

Table 5.6 Best cost and emission in ten units by HCPSO

P ₁₀ (MW)	470.00	470.00
Cost(\$/h)	111760.20	116508.90
Emission(lb/h)	4519.76	3905.07

Table 5.7 Best cost and emission in ten units by CPSO

P _G (MW)	ELD	Emission dispatch
P ₁ (MW)	38.70	33.57
P ₂ (MW)	80.00	42.42
P ₃ (MW)	87.17	68.04
P ₄ (MW)	98.04	98.06
P ₅ (MW)	106.00	136.20
P ₆ (MW)	133.00	239.09
P ₇ (MW)	300.00	253.14
P ₈ (MW)	327.46	340.00
P ₉ (MW)	446.30	404.01
P ₁₀ (MW)	470.00	470.00
Cost(\$/h)	112307.80	116031.00
Emission(lb/h)	4384.45	3986.91

Emission limiting value is included for the purpose of controlling the level of emission using an emission limit factor (α). For different values of α when set to .9 value, results for cost and emissions are respectively 114387.10 (\$/h) and 4070.318 (lb/h). For a value of $\alpha = .86$, corresponding cost and emission come out to be 116670.30 (\$/h) and 3896.47 (lb/h). It is clear from the above discussion that with the decrease in value of α , rate of emission decreases while corresponding cost increases. This is due to the conflicting behaviour of cost and emission which make emission level within a pre-specified limit and thus leading to increased cost with decreasing of α . The graph (5.2) show the conflicting nature of cost and emission. For ten units

problem, where HCPSO is employed, the global solution is obtained after carrying exploration exploitation upto 1700 iterations. In table 5.6 the real power generation is also given.

Table 5.8 Results achieved with different value α in ten units

P_G (MW)	Emission constrained economic load dispatch		
	$\alpha=.9$	$\alpha=.88$	$\alpha =.86$
P_1 (MW)	33.02	33.57	32.067070
P_2 (MW)	80.00	42.48	80
P_3 (MW)	47.00	68.04	48.18
P_4 (MW)	80.64	98.26	64.34
P_5 (MW)	160.00	136.20	160
P_6 (MW)	165.60	238.59	240
P_7 (MW)	242.68	253.14	300
P_8 (MW)	340.00	340.00	340
P_9 (MW)	470.00	404.05	349.62
P_{10} (MW)	470.00	470.00	470
Cost(\$/h)	114387.10	116044	116947.6
Emission(lb/h)	4070.318	3987.2	3917.06

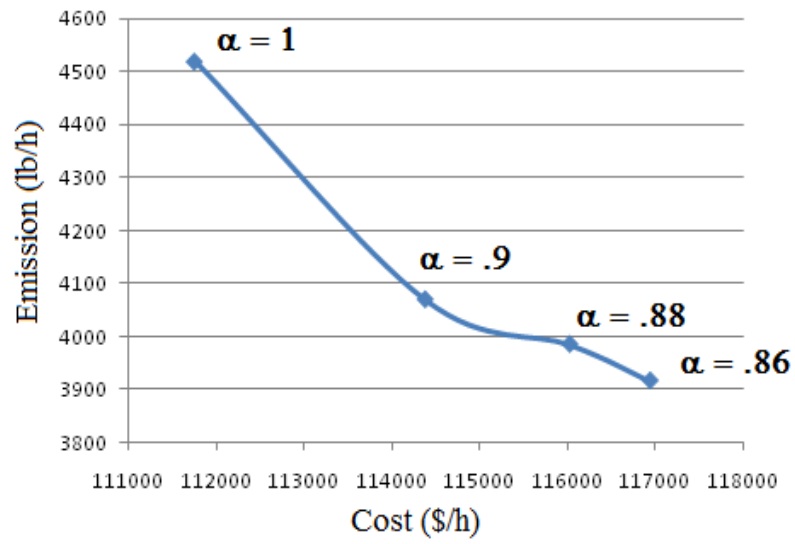


Fig 5.2 Cost versus emission curve in ten units

CHAPTER 6

CONCLUSION AND SCOPE FOR FUTURE WORK

6.1 Conclusion

A hybrid constriction particle swarm optimization (HCPSO) algorithm is implemented to solve emission constrained economic load dispatch (ECELDD). The proposed technique provide a well defined balance between exploration and exploitation property during the search. The emission constraints taken into account to limit the emission level. The performance of HCPSO was tested on six and ten generating units. The results of emission constrained economic load dispatch are compared.

6.2 Scope for future work

Scope of work after implementing ECELDD using HCPSO is summarized as:

The proposed technique can be hybridized with other random search techniques such as society civilization algorithm and differential evolution algorithm.

APPENNDIX

APPENDIX-A

1. Input data for 6-generating units:

unit(i)	P_i^{\min}	P_i^{\max}	a_i	b_i	c_i	α_i	β_i	γ_i
	MW	MW	\$/h	\$/MWh	\$/ (MW)2h	lb/h	lb/MWh	lb/(MW)2h
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-coefficient 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-B

1. Input data for 10 generating units

unit(i)	P_i^{\min}	P_i^{\max}	a_i	b_i	c_i	d_i	e_i	α_i	β_i	γ_i	η_i	δ_i
	MW	MW	\$/h	\$/MWh	\$/ (MW)2h	\$/h	rad/MW	lb/h	lb/MWh	lb/(MW)2h	lb/h	1/MW
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	40.2669	-0.5455	0.00680	0.24800	0.01290
8	70	340	1049.998	40.3965	0.02803	30	0.0128	40.2669	-0.5455	0.00680	0.24990	0.01203
9	135	470	1658.57	36.3278	0.02111	60	0.0136	42.8955	-0.5112	0.00460	0.25470	0.01234
10	150	470	1356.659	38.2704	0.0179	40	0.0141	42.8955	-0.5112	0.00460	0.25470	0.01234

2. B-coefficient for 10-generating units:

B =	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

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