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Implementation of Moderate Random Search Particle Swarm Optimization on Economic Load Dispatch Problems Considering Various Constraints

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***Abstract*: This paper proposes a new PSO with moderate random search criteria for an extensive study of economic load dispatch problems with valve point loading, ramp rate limit & prohibited zones. This paper is excluding of transmission losses but other above mentioned non–linear effects have been considered. This results in higher order nonlinearities in the i/p-o/p characteristics of a generator. For demonstrating the effectiveness of the proposed method ten, thirteen, fifteen and lastly forty generators (two cases) have been considered. The performance of MRPSO method has been compared with the various optimization methods in the corresponding system with test data. The result shows that the proposed MRPSO strategy provides comparatively better solutions in terms of total fuel cost as compared to other optimization methods.**

***Keywords*: Economic load dispatch (ELD), Equality & in-equality constraints, MRPSO, PSO, Prohibited zones (PZ), Ramp rate limit, Valve point loading effect (VPL).**

1. Introduction

Electrical power systems are designed and operated to meet the continuous variation of power demand. The remote location of power plant from the load center has been identified as one of the reasons which caused high cost. The increase in fuel cost these days has also contributed to this phenomenon. Therefore, economic loads dispatch (ELD) is implemented in order to determine the output(generating) of each generator so that total generation cost will be minimized. The generator's output has to be varied within limits so as to meet a particular load demand & losses within minimum fuel cost. Thus ELD is one of the important topics to be considered in power system engineering. ELD is a method schedule the power generation outputs with respect to the load demands, and to operate the power system most economically, or in other words, we can say that main objective of ELD is to allocate the optimal power generation from different unit at the lowest cost possible while meeting all the system constraints.

Economic dispatch is the short-term determination of the optimal output of a number of electricity generation facilities, to meet the system load, at the lowest possible cost, subject to transmission & operational constraints. The ELD problem is solved by specialized computer software which should honor the operational & system constraints of the available resources and corresponding transmission capabilities. In the US Energy Policy Act of 2005, the term is defined as "the operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognizing any operational limits of generation and transmission facilities."

The main idea is that in order to serve load at minimum cost, the set of generators with the lowest marginal costs must be used first, with the marginal cost of the final generator needed to meet load setting the system marginal cost. This is the cost of delivering one additional MW of energy onto system. The historic methodology for ELD was developed to managed fossil fuel burnings power plants, relying on calculations involving the input/output characteristics of power stations.

This paper is concerned with the ELD problems of all thermal systems only. It is to be noted that all generating units in a system do not participated in the economic dispatch. Nuclear units & very large stem units are run at constant MW setting as it is desirable (due to some technical reasons) to maintain the output such units at as constant a level as possible. Rest of the units those participate in ELD will be called controllable units. Fuel costs in base-load units then appear as a fixed cost and do not appear in the economic load dispatch problem. We consider the minimization of those costs that, by proper strategy, we can control i.e. the fuel costs in the controllable units.

In the real world power systems, electrical power generation units are not located at the same distance from the center of the load. Apart from that, electrical power generation costs for each of these units are also different in terms of fuel, maintenance, labor etc. Due to this variety of power generations costs, the most important problem is to prepare a schedule which is the most efficient and economical that can be followed by a power system. In recent years many optimization methods on the problem of ELD as a constraint optimization problem, have been studied where all researchers try to find which method is more efficient & faster in execution and also easier to implement.

2. Literature Survey

A method is devolved [1] for solving the Economic Load Dispatch (ELD) by changing it from constrained nonlinear programming problem to a sequence of constrained linear programming problems. Proposed Hessian based optimization [2] method has much higher convergence efficiency that those techniques based on the gradient of the objective function. In the literature this handling equality constraints through penalty functions added to the cost. A several approaches have been discussed to overcome the drawbacks of classical economic load dispatch ELD problem. Some of these methods have been based on successive linear programming and successive quadratic programming described by different authors in literature. Different methods for power system operation has been discussed by Miller and Malinnowski [3].The economic load dispatch problem [4] is a quadratic programming problem and solved using Wolfe's algorithm. The quadratic programming algorithm does not require the use of penalty factors or the determination of gradient step size which can cause convergence difficulties. The parametric quadratic programming method [5] is a solving an economic load dispatch problem with dc load flow type network security constraints.

The method is handling real power transmission constraints on branch flows and inter-area exchanges to supplement the classic ED formulation using dual quadratic programming [6]. The proposed Improved Differential Evolution (IDE) algorithm to solve Economic Load Dispatch (ELD) problem with non-smooth fuel cost curves considering transmission losses, power balance and capacity constraints. The proposed IDE varies from the Standard Differential Evolution (SDE) algorithm in terms of three basic factors. Operation has been discussed by Surekha P, and S. Sumathi [8]. Simulated Annealing (SA) algorithm is applied to solve economic load dispatch (ELD) problems. The proposed method for solving ELD problems is verified by using 3, 13, 40 and 18 generator test systems, out of which the first three test cases are with valve-point loading effects [9].A method of traditional approach to solve the ELD problem using Lambda iteration method (LIM) in MATLAB environment for two generator units and four separate cases has to be considered with and without transmission losses and generator constraints [10].

Presentation of robust [11] and efficient method for solving transient stability constrained optimal power flow problems based on DE, which is a new branch of evolutionary algorithms with strong ability in searching global optimal solutions of highly nonlinear and non-convex problems. The Economic Load Dispatch (ELD) problem[12] with security constraints in thermal units, which are capable of obtaining economic scheduling for utility system, the PSO method, a new velocity strategy equation is formulated suitable for a large scale system and the features of constriction factor approach are also incorporated.DE algorithm [13] for solving ELD problems in power systems, DE has proven to be effective in solving many real worlds constrained optimization problems in different domains. The coordination to the economic load dispatch [14] and regulation functions of automatic generation control in power systems. The point of view taken is that such coordination appropriately taken place at the regulation or load frequency control level. The genetic-based algorithm [15] to solve an economic dispatch problem for valve point discontinuities, thus the constrains of classic Lagrange technique on unit curve are circumvented.

Kumari and Sydulu [16] presented Genetic Algorithm (FGA) for solving Economic Load Dispatch (ELD) problem, GA's perform powerful global searches, but their long computation times limit them when solving large scale optimization problems. Analysis of efficient and reliable modern programming approach is using quadratic programming (QP) and general algebraic modeling system (GAMS) to solve economic load dispatch (ELD) problem. It easily takes care of different equality and inequality constraints of the power dispatch problem to find optimal solution [17]. Particle swarm optimizer [18] combined with roulette selection operator to solve the economic load dispatch problem of thermal generators of a power system. Several factors such as quadratic cost functions with valve point loading, transmission Loss, generator ramp rate limits and prohibited operating zone are considered in the computation models. A novel binary successive approximation-based evolutionary search strategy has been proposed to solve the economic-emission load dispatch problem by searching the generation pattern of committed units [19]. The proposed method minimizes the fuel cost of generators using a hybrid quantum-inspired PSO. Inclusion of such constraints presents ELD as a non-smooth and non-convex optimization problem. The problem formulations with objective function and considered constraints will describes the hybrid quantum-based particle swarm optimization (HQPSO) with a little discussion about traditional PSO and its transformation towards HQPSO [20].

A novel modified Bacterial Foraging Technique (BFT)[21] is used to solve economic load dispatch problems. A new optimization technique efficient hybrid simulated annealing algorithm (EHSA) for both convex & non-convex ELD problem. The mutation operator of differential evolution is used in particle swarm optimization to improve its performance & it is hybridized with simulated annealing to get EHSA technique [22]. An efficient and reliable Biogeography–based optimization (BBO) algorithm (23) is used to solve both convex and non-convex Economic load dispatch problem (ELD) with Ramp rate limit of thermal power plants. Normally proposed power generation, spinning reserve and emission costs are simultaneously considered in the objective function of the proposed ELD problem. In this condition, if the valve-point effects of thermal units are considered in the proposed emission, reserve and economic load dispatch (ERELD) problem, a non-smooth and non-convex cost function will be obtained. A hybrid method that combines the bacterial foraging

(BF) algorithm with the Nelder–Mead (NM) method (called BF–NM algorithm) is used to solve the problem [24].An economic emission load dispatch (EELD) problem is solved to minimize the emission of nitrogen oxides (NOX) and fuel cost, considering both thermal generators and wind turbines. To find the optimum emission dispatch, optimum fuel cost, best compromising emission and fuel cost, a newly developed optimization technique, called Gravitational Search Algorithm (GSA) has been applied. IEEE 30-bus system having six conventional thermal generators has been considered as test system [25].

Ant Colony Optimization (ACO) technique [26] is proposed to be combined with Differential Evolution (DE) and cloning process, and Differential Evolution Immunized Ant Colony Optimization (DEIANT) technique in solving economic load dispatch problem. The combination creates a new algorithm that will be termed as Differential Evolution Immunized Ant Colony Optimization (DEIANT). DEIANT was utilized to optimize economic load dispatch problem. In order to overcome the drawbacks of conventional methods, Artificial Intelligent (AI) techniques likes like Genetic Algorithm (GA), Neural Networks (NN), Artificial Immune systems (AIS) and Fuzzy Logics etc. are used. One such AI technique used is Artificial Bee Colony optimization (ABC) inspired from the foraging behaviour of bees. The ABC [27] is applied for ELD and compared with the other AI techniques. Weight-Improved Particle Swarm Optimization (WIPSO) [28] method is proposed for computing Optimal Power Flow (OPF) and ELD problems, to evaluate the accuracy, convergence speed and applicability of the proposed method. The OPF results of IEEE 30 bus system by WIPSO are compared with traditional particle swarm optimization, genetic algorithm, and Differential Evolution (DE) and Ant Colony Optimization (ACO) methods.

The performance [29] of the proposed algorithm is compared with standard Improved Fast Evolutionary Programming (IFEP) techniques, to used genetic algorithm (GA) tuned differential evolution (DE) method for solving economic dispatch (ED) problem with non-smooth cost curves. This Evolutionary optimization techniques [31] namely Genetic Algorithm (GA) and Differential Evolution (DE) is proposed to solve ELD in the electric power system. According to Palanichamy and Shrikrishna [30] discussed Simple algorithm for economic power dispatch for optimizing the problem while satisfying a set of system operating constraints, including constraints dictated by Wood and Woolenberg [31]. Heuristic optimization method and Quantum-inspired Particle Swam Optimization (QPSO) [32] is used to solve valve-point Economic load dispatch problem. It has stronger search ability and quicker convergence speed, not only because of the introduction of quantum computing theory, but also due to two special implementations: self-adaptive probability selection and chaotic sequences mutation. Alsumit et. al. proposed a hybrid GA-PS-SQP method [33]to solve power system valve-point economic dispatch problems. The applied multi-objective differential evolution (MODE) algorithm [34] is proposed to solve environmental/economic power dispatch (EED) problem.

3. Economic load dispatch

ELD can be defined as the process of allocating generation levels to the generating units, so that the system load is supplied entirely & most economically. For an interconnected system, it is necessary to minimize expenses. The ELD is used to define the production level of each plant, so that the total cost of generation & transmission is minimum for a prescribed schedule of load. The objective of economic load dispatch is to minimize the overall cost of generation. The method of ELD foe generating at different loads must have total fuel cost at minimum point.

In a typical power system, multiple are implemented to provide enough total output to satisfy a given total consumer demand. Each of these generating stations can and usually does, have unique cost-per hour characteristics for its output operating range. A station has incremental operating costs for fuel & maintenance and fixed costs associated with the station itself that can be quite considerable in the case of a nuclear power plant, for example things get even more complicated when utility try to account for transmission line losses, in the seasonal change associated with hydroelectric plants.

A. Fuel cost

The primary objective of the ELD problem is to minimize the cost function and determine the most economical loadings of the generators such that the load demand in a power system can be met. It can be described as an optimization process with the following objective function and equality &in-equality constraints.

$$\begin{cases} Min.F = \sum_{i=1}^{N} F_i(P_i) \\ \sum_{i=1}^{N} P_i - (P_D + P_L) = 0 \end{cases} \quad (1)$$

Where,

$F_i(P_i)$	Fuel cost function
P_i	Generated power of unit
N	Number of online units
P_D	system load demand
P_L	transmission loss

When transmission losses are neglected, $P_L = 0$.
The fuel cost function of ith unit can be defined by

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i \quad (2)$$

Where a_i , b_i , c_i are the cost coefficients of unit i.

B. Fuel cost including valve point loading effect

Economic load dispatch is one of the most important problems to be solved on the operation and planning of a power system the primary concern of an ELD problem is the minimization of its objective function. The total cost generated that meets demand & satisfies all other constraints associated is selected as the objective function. The ELD problem objective function is formulated mathematically in (1) & (2) if given conditions are satisfied. Due to presence of valve point loading effect non-linearity & discontinuity of the ELD is increased, that why equation 2 can be modified as (3) and (4)

$$F_i'(P_i)=F_i(P_i)+abs\left(e_i\sin\left(f_i\left(P_i^{\min}-P_i\right)\right)\right) \quad (3)$$

$$F_i'(P_i)=a_iP_i^2+b_iP_i+c_i+abs\left(e_i\sin\left(f_i\left(P_i^{\min}-P_i\right)\right)\right) \quad (4)$$

e_i and f_i the valve point loading effect coefficients of the i_{th} generator?

C. Constraints

Generally, there are two types of constraints viz. (i) Equality constraints (ii)in-equality constraints

(i) Equality constraints:

System Power Balance

The total power output of generator should be able to satisfy the load demand & transmission loss. At a particular time interval t, mathematically this constraint can be defined as

$$\sum_{i=1}^{N}P_i(t)=P_D(t)+P_L(t) \quad (5)$$

where $P_D(t)$ is the load demand at time t and $P_L(t)$ is the system's transmission loss. The system transmission network loss is computed by the Kron's loss formula, which represents loss as a function of the output level of the system-generating units.

$$P_L(t)=P^T[B]P+B_0P+B_{00} \quad (6)$$

Here B is the matrix of loss coefficients. The above equation can be broken down as follows

$$P_L(t)=\sum_{j=1}^{N}\sum_{k=1}^{N}P_j(t)B_{jk}P_k+\sum_{j=1}^{N}P_jB_{j0}+B_{00} \quad (7)$$

(ii) In-equality constraints:

(a) Operating power limit

The generator's output should operate within their ranges.

$$P_i^{\min}\le P_i\le P_i^{\max} \quad (8)$$

Where $P_i^{\min}$ and $P_i^{\max}$ are the minimum and maximum operating limits of generator i.

(b) Ramp Rate limit

Normally in ELD, generators' outputs were assumed to be handled instantaneously. Generally, the output are bounded by the ramp up or ramp down limits which depends on the nature of generators' power increasing or decreasing stage. According to the increasing and decreasing operation of the generators, ramp rate limit constraints are described below.

As generation increases

$$P_i(t)-P_i(t-1)\le UR_i \quad (9)$$

As generation decreases

$$P_i(t-1)-P_i\le DR_i \quad (10)$$

Where UR_i and DR_i are the up and down rate limit for generation i respectively. If we combine this equation with operating power limit equation, then,

$$\max(P_i^{min},P_i(t-1)-DR_i)\le P_i(t)\le \min(P_i^{max},P_i(t-1)+URi) \quad (11)$$

(c) Generator's Prohibited Zone

The prohibited operating zones in the input–output performance curve for a typical thermal unit contains some prohibited operating zones due to the steam valve operation or vibration in a shaft bearing. Mathematically those zones for i_{th} unit are defined as

$$P_i^{\min}\le P_i(t)\le P_{i,1}^l$$
$$P_{i,k-1}^u\le P_i(t)\le P_{i,k}^l;\quad k=2,3,\ldots\ldots\ldots\ldots\ldots\ldots nz_i \quad (12)$$
$$P_{i,nz_i}^u\le P_i(t)\le P_i^{\max}$$

Where $P_{i,k}^l$ and $P_{i,k}^u$ are the lower and upper bound of the kth prohibited zone of generator i.

nz_i represents the number of prohibited zones for ith generation.

4. Introduction to Particle Swarm Optimization (PSO) & Moderate Random Search Particle Swarm Optimization (MRPSO)

Most of the conventional computing algorithms are not effective in solving real-world problems because4 of having an inflexible structure mainly due to incomplete or noisy data and some multi-dimensional problems. Natural computing methods are the best suited for solving such problems. In general, natural computing methods can be divided into three categories

viz. (i) Epigenesis (ii) Phylogeny (iii) Ontogeny. PSO belongs to the Ontogeny category in which the adaptation of a special organism to its environment is considered.

A. Classical PSO

PSO, developed by Eberhart and Kennedy in 1995, is one of the evolutionary computation techniques. PSO, like GA, is a population based optimization algorithm. Instead of the survival of the fittest, it is the simulation of social behavior that motivates PSO. Here, the population is called 'swarm'. Each potential solution, called particle, is given a random velocity and is flown through the solution space (similar to the search process for food of a bird swarm) looking for the optimal position. The particles have memory and each particle keeps track of its previous best position, called *pbest* and corresponding fitness. The swarm remembers another value called *gbest*, which is the best position discovered by the swarm. If a particle discovers a promising new solution, all the other particles will move closer to it. Based on PSO concept, mathematical equations for the searching process are:

Velocity updating equation:

$$v_{id}^{k+1} = w * v_{id}^{k} + c1 * r1 * (pbest_{id} - x_{id}^{k}) + c2 * r2 * (gbest_{id} - x_{id}^{k}) \quad (13)$$

Position updating equation:

$$x_{id}^{k+1} = x_{id}^{k} + v_{id}^{k+1} \quad (14)$$

where x_{id}^{k}, x_{id}^{k+1} are the position of d^{th} dimension (variable) of the i^{th} particle at k^{th} and $(k+1)^{th}$ iteration; v_{id}^{k}, v_{id}^{k+1} are the velocity of the d^{th} dimension of the i^{th} particle at the k^{th} and the $(k+1)^{th}$ iteration; $c1, c2$ are the cognitive and the social parameters; $r1 \& r2$ are random numbers uniformly distributed within [0, 1]; $pbest_{id}$ is the best position of the d^{th} dimension of the i^{th} particle; $gbest_{d}$ is the group best position of the d^{th} dimension and w is the inertia weight factor.

B. Moderate random search particle swarm optimization (MRPSO)

After discovering PSO in 1995, a large no of optimization techniques has also been developed. As a result, particle swarm optimization with inertia weight approach(PSOIWA), New particle swarm optimization techniques with time varying acceleration coefficient(NPSOTVAC) and many of other hybrid PSO based optimization methods developed. In this paper a new PSO technique has been introduced calls, Moderate random search PSO(MRPSO). MRPSO, first proposed by Hao Gao *et.al* in the year of 2011[36]. In this method we need not do any velocity updation only position update is required. This method also increases the global search capacity of PSO. As a result, we have seen that MRPSO performs better than any other optimization techniques. Some pseudo codes of MATLAB programming have been given below:

mbest=(sum(Pbest))/n; (15)
*Pd=rand*Pbest(i,j)+(1-rand)*Gbest(j);* (16)
lambda=(rand-rand)/randn; (17)
*P1(i,j)=Pd+a1*lambda*(mbest(j)-PP(i,j));* (18)

Where,
i= iteration no i.e. *ith* iteration
j= generator no i.e. *jth* generator
PP(i,j)= previous position vector
P1(i,j)= current position vector
Gbest(j)=global best position vector
mbest=moderate best position vector which also known as average best position vector
$0.35 \leq a1 \leq 0.45$, *a1* changes linearly.
Pd=attracting factor in the direction of moving particle.
rand= uniformly distributed random variable in the range between 0 & 1.
randn= uniformly distributed random variable in the range between -1 & 1.
n=population size.

5. Result and Discussion

The applicability of MRPSO for practical has been tested in four cases excluding losses. Case study 1 is the ten units system considering valve point loading effect (VPL) [38], Case study 2 is the thirteen units system considering valve point loading effect (VPL) for two different load demands[42], Case study 3 for fifteen generating units including generator ramp rate limits & prohibited zones [43,50] and lastly for Case study 4 forty units system of Tai-Power system [45] with load demand 8500MW. We also considered IEEE 40 generating units system including valve point loading effect [46] for the load demand 10,500MW. The programs are developed using MATLAB 7.01 and the system configuration is Pentium processor 3.2 GHz speed and 2 GB RAM personal computer.

A. Case study 1

The description of the results by utilizing MRPSO with valve point loading effect for 10 generating units. The input parameters have been taken from [38]. The result of the MRPSO compares with the classical PSO.

Table 1 gives the input data, table 2 gives comparative output results. The load demand took 2006.8 MW. MRPSO gives the result minimum cost 106490 \$/hr but classical PSO gives 107620 \$/hr.

Table 1
Cost coefficient for 10 units system [38]

Unit	Pmin	Pmax	ai	bi	ci	ei	fi
P1	10	55	0.12951	40.5407	1000.403	33	0.0174
P2	20	80	0.10908	39.5804	950.606	25	0.0178
P3	47	120	0.12511	36.5104	900.705	32	0.0162
P4	20	130	0.12111	39.5104	800.705	30	0.0168
P5	50	160	0.15247	38.539	756.799	30	0.0148
P6	70	240	0.10587	46.1592	451.325	20	0.0163
P7	60	300	0.03546	38.3055	1243.531	20	0.0152
P8	70	340	0.02803	40.3965	10498.998	30	0.0128
P9	135	470	0.02111	36.3278	1658.569	60	.0136
P10	150	470	0.01799	38.2704	1356.659	40	0.0141

Table 2
Comparative study of 10 generating units system with valve point loading effect

Parameters	MRPSO	Classical PSO[38]
P1	55.00	53.1
P2	80.00	79.2
P3	95.4039	112
P4	89.9952	121
P5	50.0000	98.8
P6	70.0000	100
P7	300.0000	299
P8	330.8500	320
P9	470.0000	405467
P10	465.5509	356
Load demand	2006.8	2006.8
Cost($/hr)	106490	107620

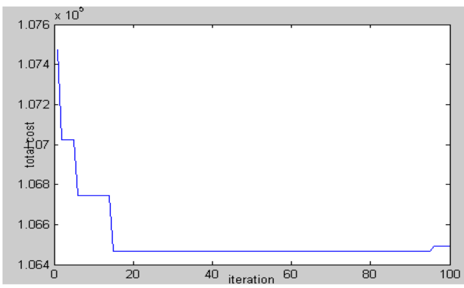

Fig. 1. Convergence characteristics of 10 generating unit system with VPL effect for MRPSO

B. *Case study 2*

In this case study we have used thirteen-unit system including valve point loading effect for two different types of load demand viz. 1800MW & 2520MW. For both the cases it has been seen that MRPSO represents more better convergence optimum results compare with the other optimization techniques. For 1800MW load demand MRPSO gives cost 18483 $/hr whereas the Cuckoo Search Algorithm(CSA) gives cost of 18809 $/hr [39], PSO-IF gives cost 18605 $/hr [40]. In the second case for 2520MW load demand the MRPSO gives 24178 $/hr cost whereas Improved Teaching Learning Based Algorithm(I-TLBO) gives the cost of 24529 $/hr [41].

Table 3
Cost coefficient for IEEE 13 units system [42]

Units	Pmin	Pmax	ai	bi	ci	ei	fi
P1	0	680	0.00028	8.10	550	300	.0350
P2	0	360	.00056	8.10	309	200	0.0420
P2	0	360	0.00056	8.10	307	200	0.0420
P3	60	180	0.00324	7.74	240	150	0.0630
P4	60	180	.00324	7.74	240	150	0.0630
P5	60	180	.00324	7.74	240	150	0.0630
P6	60	180	0.00324	7.74	240	150	0.0630
P7	60	180	0.00324	7.74	240	150	0.0630
P8	60	180	0.00324	7.74	240	150	0.0630
P9	40	120	0.00284	8.60	126	100	0.0840
P10	40	120	0.00284 0.0028/4	8.60 8.60	126	100	0.0840
P11	55	120	0.00284	8.60	126	100	0.0840
P12	55	120	0.00284	8.60	126	100	0.0840

Table 3 gives the input parameters for IEEE 13 generating units system with concerned load demands, table 4 gives the comparative study between MRPSO & CSA and lastly table 5 gives another comparative study for only cost of 1800MW load demand. In case of 2500MW load demand table 6 gives the comparative study between MRPSO & I-TLBO.

Table 4
Comparative study of 13 generating units system with valve point loading effect with load demand 1800 MW

Parameters	MRPSO	CSA[39]	MEHO [48]
P1	532.5588	369.0548	460.21
P2	307.3190	227.7351	230.45
P3	360.0000	62.1765	155.40
P4	60.0000	108.7713	111.61
P5	60.0000	107.4378	90.43
P6	60.0000	120	135.46
P7	60.0000	163.7386	147.15
P8	64.9853	156.2434	110.53
P9	60.0000	138.6708	136.77
P10	42.5505	108.8067	56.23
P11	40.0000	115.7574	43.15
P12	92.0000	62.2591	59.53
P13	60.5864	59.3485	63.16
Load demand(MW)	1800	1800	1800
Cost($/hr)	18483	18809	18969

Table 5
Comparative study of 13 generating units system with valve point loading effect with load demand 1800 MW for different methods

Parameters	MRPSO	CSA [39]	PSO-IF [40]	MEHO [50]
Load demand(MW)	1800	1800	1800	1800
Cost($/hr)	18483	18809	18605	18969.99

Table 6
Comparative study of 13 generating units system with valve point loading effect with load demand 2520 MW

Parameters	**RPSO**	PSO-DS [48]	I-TLBO [41]	GA-SA[49]
P1	**627.7167**	628.3094	628.2119	628.23
P2	**347.9024**	298.9996	309.1105	299.22
P3	**339.5390**	298.8181	299.0020	299.17
P4	**171.8577**	159.7441	159.8614	159.12
P5	**95.4742**	159.5509	160.7263	159.95
P6	**188.0270**	159.1718	113.8521	158.85
P7	**172.6960**	159.5712	141.6386	157.26
P8	**131.7401**	159.5940	159.9169	159.93
P9	**77.6395**	159.4003	163.0733	159.86
P10	**89.4132**	113.6156	113.9782	110.78
P11	**58.5060**	113.2250	77.4274	75.00
P12	**108.3306**	55.0000	93.8515	60.00
P13	**111.1574**	55.0000	99.3500	92.62
Load demand(MW)	**2520**	2520	2520	2520
Cost($/hr)	**24178**	24182.55	24529	24275.71

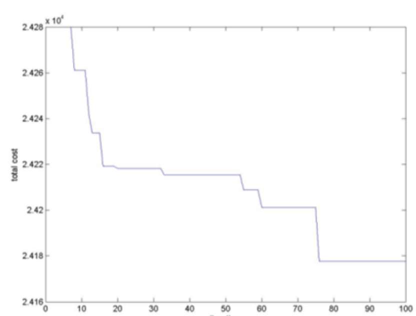

Fig. 2. Convergence characteristics of 13 generating unit system with VPL effect for MRPSO load demand 2520 MW

C. Case study 3

In this case study we have used fifteen-unit system including generator ramp rate limit & Prohibited zone (PZ) for 2630 MW load demand. In this case it has been seen that MRPSO represents more optimum result compare with the other optimization technique. For 2630MW load demand MRPSO gives cost 32090 $/hr whereas the Traditional Optimization Technique (GAMS)gives cost of 32756.754 $/hr [43], as well as with the NPSOTVAC with costing 32450.39 $/hr [43] & lastly compare with GA with costing 33113 $/hr [44]. Table 7 & table 8 give the input parameters for IEEE 15 generating units system, table 9 gives the comparative study among MRPSO, GAMS [43], NPSOTVAC [43] & GA [44] for the load demand 2630MW. Another load demand 2650MW were considered. In this case The MRPSO compared with Genetic Algorithm(GA). MRPSO gave the cost of 32249 $/hr. whereas GA gave the cost with 32517$/hr [44]. Table 10 represented the test results.

Table 7
Cost coefficient for IEEE 15 units system [43,50]

Unit	Pmin	Pmax	ai	bi	ci	ei	fi
P1	150	455	0.000299	10.1	671	100	.084
P2	150	455	0.000283	10.2	574	100	.084
P3	20	130	0.001126	8.8	374	100	.084
P4	20	130	0.001126	8.8	374	150	.063
P5	150	470	0.000205	10.4	461	120	.074
P6	135	460	0.000301	10.1	630	100	.084
P7	135	465	0.000364	9.8	548	200	.042
P8	60	300	0.000338	11.2	227	200	.042
P9	25	162	0.000807	11.2	173	200	.042
P10	25	160	0.001203	10.7	175	200	.042
P11	20	80	0.003586	10.2	186	200	.042
P12	20	80	0.005513	9.9	230	200	.042
P13	25	85	0.000371	13.1	225	300	.035
P14	15	55	0.001929	12.1	309	300	.035
P15	15	55	0.004447	12.4	323	300	.035

Table 8
Ramp Rate & Prohibited Zones [43]

Units	Pi	URi	DRi	PZ
P1	400	80	120	
P2	300	80	120	[185,225] [305,335] [420,450]
P3	105	130	130	
P4	100	130	130	
P5	90	80	120	[180,200] [305,335] [390,420]
P6	400	80	120	[230,255] [365,395] [430,455]
P7	350	80	120	
P8	95	65	100	
P9	105	60	100	
P10	110	60	100	
P11	60	80	80	
P12	40	80	80	[30,40] [55,65]
P13	30	80	80	
P14	20	55	55	
P15	20	55	55	

Table 9
Comparative study of 15 generating units system with ramp rate limit & prohibited zones with load demand 2630 MW

Parameters	MRPSO	GAMS [43]	NPSOTVAC [43]	GA [44]
P1	451.6641	455.00	455.00	415.31
P2	372.6036	455.00	375.00	359.72
P3	103.3414	130.00	130.00	104.42
P4	112.9970	130.00	135.28	74.98
P5	153.7374	271.00	165.77	380.28
P6	430.0000	460.00	460.00	426.79
P7	429.7147	465.00	424.52	341.31
P8	134.1464	60.00	65.00	124.78
P9	129.2821	25.00	25.00	133.14
P10	81.0458	25.00	157.00	89.25
P11	65.1002	43.389	84.23	60.5
P12	76.8865	55.431	74.68	49.99
P13	36.7895	25.00	25.00	38.77
P14	24.0279	15.00	24.98	41.94
P15	33.6635	15.00	34.00	22.64
Load demand(MW)	2630	2605.00	2630	2630
Cost($/hr)	32090	32256.754	32450.39	33113

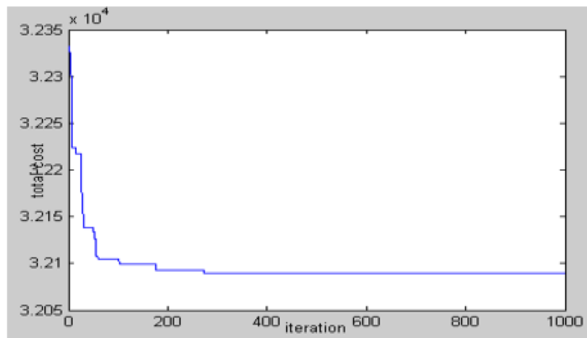

Fig. 3. Convergence characteristics of 15 generating unit system with ramp rate limit & prohibited zones for MRPSO load demand 2630 MW

Table 10
Comparative study of 15 generating units system with ramp rate limit & prohibited zones with load demand 2650 MW

Parameters	MRPSO	GA [44]
P1	452.7702	452.4
P2	374.7315	455
P3	93.4421	130.963
P4	126.3982	129.1
P5	155.5332	337.1
P6	430.0000	428.5
P7	419.3063	466.4
P8	123.7629	60
P9	108.2657	27.6
P10	105.8857	27.1
P11	72.9504	25.7
P12	74.1120	54
P13	44.2710	25
P14	36.1788	15
P15	32.3919	15
Load demand(MW)	2650	2650
Cost($/hr)	32249	32517

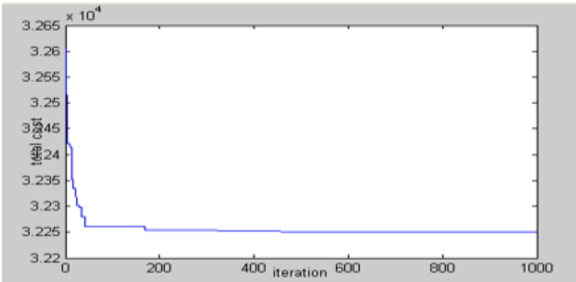

Fig. 4. Convergence characteristics of 15 generating unit system with ramp rate limit & prohibited zones for MRPSO load demand 2650 MW

Table 11
Comparative study of 15 generating units system with valve point loading effect for load demand 2630 MW

Parameters	MRPSO	MEHO [50]	EHO [50]	ACO [50]	PSO [50]
P1	455.0000	422.45	405.345	435.46	451.7
P2	455.0000	435.82	415.341	431.62	410.06
P3	130.0000	82.61	102.484	87.04	52.08
P4	130.0000	122.43	127.421	129.31	125.02
P5	470.0000	386.15	354.79	368.53	287.437
P6	445.0000	437.25	459.98	427.29	452.63
P7	301.3208	409.47	376.508	393.25	363.98
P8	60.0000	55.26	64.35	52.14	76.816
P9	28.1789	31.14	25.4005	28.16	39.91
P10	33.7367	104.51	136.705	114.43	142.903
P11	20.0000	34.14	40.7512	55.42	72.71
P12	43.9553	42.36	36.6468	32.47	50.281
P13	25.0000	22.48	31.148	21.48	23.98
P14	17.8083	19.41	22.4836	21.17	47.12
P15	15.0000	24.57	30.656	32.31	33.40
Load demand(MW)	2630	2630	2630	2630	2630
Cost($/hr)	32960.00	33747.42	33888.57	34019. 445	34339. 42

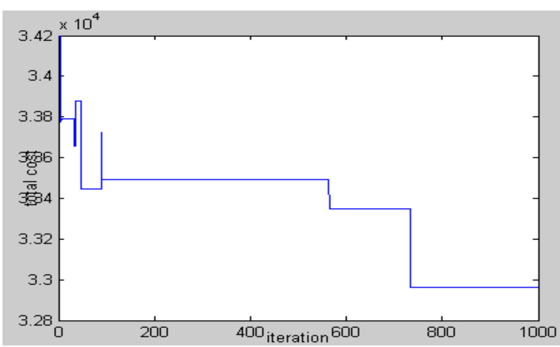

Fig. 5. Convergence characteristics of 15 generating unit system with valve point loading effect for MRPSO load demand 2630 MW

D. *Case study 4*

Here we considered a large 40 generating units system, calls Tai-Power (Taiwan Power) [45]. It is a practical system. Due to large system we only consider the quadratic cost function not any non-smooth cost function i.e. valve point loading, generator ramp rate limit & prohibited zone. The input parameter for the system have been given in the table 11. We took load demand 8550MW

Table 12
Cost coefficient for Tai-Power 40 units system [45]

Units	Pmin	Pmax	ai	bi	ci
P1	40	80	0.03073	8.3360	170.44
P2	60	120	0.0208	7.0706	309.54
P3	80	190	0.00942	8.1817	369.03
P4	24	42	0.08482	6.9467	135.48
P5	26	42	0.09693	6.5595	135.19
P6	68	140	0.01142	8.05463	222.33
P7	110	300	0.00357	8.0323	287.71
P8	135	300	0.00492	6.999	391.98
P9	135	300	0.00573	6.602	455.76
P10	130	300	0.00605	12.908	722.82
P11	94	375	0.00515	12.986	635.2
P12	94	375	0.00569	12.796	654.69
P13	125	500	0.00421	12.501	913.4
P14	125	500	0.00752	8.8412	1760.4
P15	125	500	0.00708	9.1575	1728.3
P16	125	500	0.00708	9.1575	1728.3
P17	125	500	0.00708	9.1575	17428.3
P18	220	500	0.00313	7.9691	647.85
P19	220	500	0.00313	7.955	649.69
P20	242	550	0.00313	7.9691	647.83
P21	242	550	0.00313	7.9691	647.83
P22	254	550	0.00298	6.6313	785.96
P23	254	550	0.00298	6.6313	785.96
P24	254	550	0.00284	6.6611	794.53
P25	254	550	0.00284	6.6611	794.53
P26	254	550	0.00277	7.1032	801.32
P27	254	550	0.00277	7.1032	801.32
P28	10	150	0.52124	3.3353	1055.1
P29	10	150	0.52124	3.3353	1055.1
P30	10	150	0.52124	3.3353	1055.1
P31	20	70	0.25098	13.052	1207.8
P32	20	70	0.16766	21.887	810.79
P33	20	70	0.26350	10.244	1247.7
P34	20	70	0.030575	8.3707	1219.2
P35	18	60	0.18362	26.258	641.43
P36	18	60	0.32563	9.6956	1112.8
P37	20	60	0.33722	7.1633	1044.4
P38	25	60	0.23915	16.339	832.24
P39	25	60	0.23915	16.339	834.24
P40	25	60	0.23915	16.339	1035.2

Table 13
Comparative study of 40 generating units Tai-Power system with load demand 8500 MW without VPL effect

Parameters	MRPSO	PSO-ETIP [45]
P1	55.8143	80.00
P2	88.1929	120.00
P3	187.6886	190.00
P4	35.0452	24.00
P5	29.8474	26.00
P6	108.8766	68.00
P7	204.4544	300.00
P8	201.9241	300.00
P9	287.0135	300.00
P10	185.4785	300.00
P11	294.1744	94.00
P12	168.3305	94.00
P13	313.8789	125.00
P14	440.6668	356.34
P15	412.6393	358.73
P16	438.9677	355.93
P17	343.6929	125.00
P18	394.9757	500.00

P19	349.4084	500.00
P20	405.7798	242.00
P21	545.2825	550.00
P22	382.0293	550.00
P23	469.9015	550.00
P24	531.0759	550.00
P25	261.7952	550.00
P26	385.0012	550.00
P27	475.7923	550.00
P28	54.9364	10.00
P29	25.5676	10.00
P30	33.4532	10.00
P31	69.7340	20.00
P32	55.6293	20.00
P33	20.9953	20.00
P34	30.1780	20.00
P35	37.3463	18.00
P36	40.6476	18.00
P37	54.4821	20.00
P38	52.0809	25.00
P39	39.1911	25.00
P40	38.0335	25.00
Load demand(MW)	8550	8550
Cost($/hr)	115390	116943

Table 14
Comparative study of generation cost among various methods of 40 generating units Tai-Power system with load demand 8500 MW without VPL effect

Parameters	MRPSO	PSO-ETIP [45]	PSO [45]	GA [45]
Load demand(MW)	8550	8550	8550	8551.32
Cost($/hr)	115390	116943	121430	135070

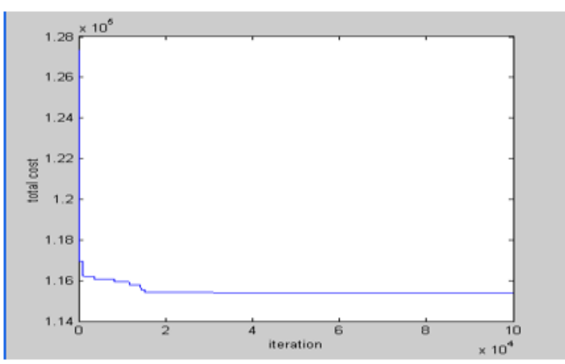

Fig. 6. Convergence characteristics of 40 generating unit of Tai-Power system for MRPSO load demand without VPL effect 8500MW

E. Case study 5

Here we considered a large IEEE-40 generating units system. It is a practical system. In this case study we included the valve point loading effect (VPL) for load demand 10,500MW. The MRPSO result compared with C-GRASP [46], GA [46] & SA [46].

Table 15
Cost coefficient for IEEE-40 units system with VPL effect [46]

Unit	Pmin	Pmax	ai	bi	ci	ei	fi
P1	36	114	0.0069	6.73	94.705	100	0.084
P2	36	114	0.0069	6.73	94.705	100	0.084
P3	60	120	0.02028	7.07	309.54	100	0.084
P4	80	190	0.00942	8.18	369.03	150	0.063
P5	47	97	0.0114	5.35	148.89	120	0.077
P6	68	140	0.01142	8.05	222.33	100	0.084
P7	110	300	0.00357	8.03	287.71	200	0.042
P8	135	300	0.00492	6.99	391.98	200	0.042
P9	135	300	0.00573	6.6	455.76	200	0.042
P10	130	300	0.00605	12.9	722.82	200	0.042
P11	94	375	0.00515	12.9	635.2	200	0.042
P12	94	375	0.00569	12.8	654.69	200	0.042
P13	125	500	0.00421	12.5	913.4	300	0.035
P14	125	500	0.00752	8.84	1760.4	300	0.035
P15	125	500	0.00708	9.15	1728.3	300	0.035
P16	125	500	0.00708	9.15	1728.3	300	0.035
P17	220	500	0.00313	7.97	647.85	300	0.035
P18	220	500	0.00313	7.95	649.69	300	0.035
P19	242	550	0.00313	7.97	647.83	300	0.035
P20	242	550	0.00313	7.97	647.81	300	0.035
P21	254	550	0.00298	6.63	785.96	300	0.035
P22	254	550	0.00298	6.63	785.96	300	0.035
P23	254	550	0.00284	6.66	794.53	300	0.035
P24	254	550	0.00284	6.66	794.53	300	0.035
P25	254	550	0.00277	7.1	801.32	300	0.035
P26	254	550	0.00277	7.1	801.32	300	0.035
P27	10	150	0.52124	3.33	1055.1	120	0.077
P28	10	150	0.52124	3.33	1055.1	120	0.077
P29	10	150	0.52124	3.33	1055.1	120	0.077
P30	47	97	0.0114	5.35	148.89	120	0.077
P31	60	190	0.0016	6.43	222.92	150	0.063
P32	60	190	0.0016	6.43	222.92	150	0.063
P33	60	190	0.0016	6.43	222.92	150	0.063
P34	90	200	0.0001	8.95	107.87	200	0.042
P35	90	200	0.0001	8.62	116.58	200	0.042
P36	90	200	0.0001	8.62	116.58	200	0.042
P37	25	110	0.0161	5.88	307.45	80	0.098
P38	25	110	0.0161	5.88	307.45	80	0.098
P39	25	110	0.0161	5.88	307.45	80	0.098
P40	242	550	0.00313	7.97	647.83	300	0.035

Table 16
Unit generations & generation cost of IEEE-40 generating units system including valve point loading effect

Parameters	MRPSO
P1	114.0000
P2	114.0000
P3	120.0000
P4	166.9039
P5	88.4070
P6	140.0000
P7	300.0000
P8	300.0000
P9	300.0000
P10	187.3127
P11	94.0000
P12	142.5532
P13	139.4039
P14	125.0000
P15	227.5219
P16	165.6893
P17	500.0000
P18	492.7596
P19	550.0000
P20	514.2967
P21	510.4972
P22	550.0000
P23	550.0000
P24	550.0000
P25	550.0000
P26	550.0000
P27	150.0000
P28	150.0000
P29	82.0000

P30	92.7102
P31	190.0000
P32	182.3454
P33	184.6078
P34	198.6673
P35	200.0000
P36	200.0000
P37	110.0000
P38	65.7054
P39	101.8523
P40	549.7663
Load demand(MW)	10,500
Cost($/hr)	124510

Table 17
Comparative study of generation cost among various methods of IEEE-40 generating units system with load demand 10500 MW including valve point loading (VPL)

Parameters	MRPSO	C-GRASP [46]	SA [46]	GA [46]	PSO [47]	TLBO [47]
Load demand(MW)	10500	10500	10500	10500	10500	10500
Cost($/hr)	124510	128883.1965	138975.7844	163401.9977	124959.12	124517.27

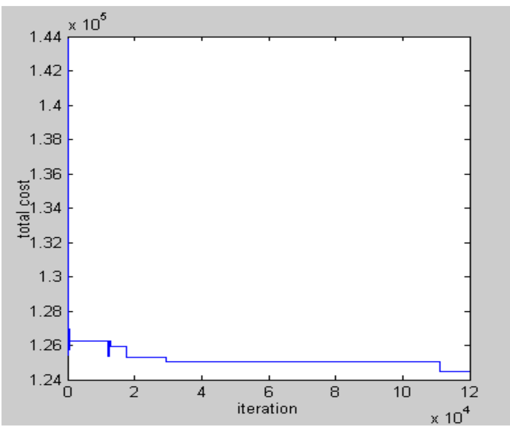

Fig. 7. Convergence characteristics of 40 generating unit of IEEE-40 generating units system for MRPSO load demand with VPL effect 10,500MW

6. Conclusion

The economic load dispatch problems is to determine the optimal combination of power outputs of all generating units so as to meet the needed demand at minimum cost while satisfying the constraints.

In this paper MRPSO is implemented on solving of ELD problems. MRPSO algorithm is a population based optimization technique like GA, ACO etc. The results clearly show the effectiveness of the method in solving ELD problems. Economic load dispatch problem here solved for five different cases. One ten units, one thirteen units with two types load demands, one fifteen units system with two different conditions, and two forty units system considering valve point loading effect, ramp rate limit and prohibited zones.

References

[1] Megahed I, Abou-Taleb N and Iskandrani M, "A modified method for solving the economicdispatch problem", IEEE Transaction on Power Apparatus and System, Vol. PAS-96(I), pp.124-133, January/February, 1977.
[2] Bottero M H, Galiana F D, and Fahmideh-Vojdani A R, "Economic dispatch using the reduced hessian", IEEE Transaction on Power Apparatus and System, Vol. PAS-101 pp.3679-36688, October, 1982.
[3] Miller R H, and Malinnowski J H, "Power System Operation," McGraw-Hill, Inc., 1994.
[4] Reid Gerald F and Hasdorff Lawrence, "Economic dispatch using quadratic programming," IEEE Transaction on Power Apparatus and System, Vol. PAS-92, pp.2015-2023, 1973.
[5] Aoki K and Satoh T, "Economic dispatch with network security constraints using parametric quadratic programming", IEEE Transaction on Power Apparatus and System, Vol. PAS-101, No.12, December 1982.
[6] Fink L H, Kwatny H G and Mcdonald J P, "Economic dispatch of generation via valve-point loading", IEEE Transaction on Power Apparatus and System, Vol. PAS-88, No.6, June 1969.
[7] Surekha P and Sumathi S, "Solving Economic Load Dispatch problems using Differential Evolution with Opposition Based Learning", WSEAS Transactions on Information Science and Applications, Vol. 9, no. 1, January 2012.
[8] Vishwakarma K K, Dubey H M, Pandit M and Panigrahi B K, "Simulated annealing approach for solving economic load dispatch problems with valve point loading effects", International Journal of Engineering, Science and Technology Vol. 4, No. 4, pp. 60-72, 2012.
[9] Dhamanda1 A, Dutt A, Prakash S, Bhardwaj A K, "A Traditional Approach to Solve Economic Load Dispatch Problem of Thermal Generating Unit Using MATLAB Programming", International Journal of Engineering Research and Technology, Vol. 2, Issue 9, September 2013.
[10] Cai H R, Chang C Y and Wong K P, "Application of Differential Evolution Algorithm for Transient Stability Constrained Optimal Power Flow", IEEE Transactions on Power Systems, Vol. 23, No. 2, pp. 719-728, 2008.
[11] Coelho L S, Bora T C, Mariani V C, "Differential evolution based on truncated Lévy-type flights and population diversity measure to solve economic load dispatch problems", Electrical power and Energy System, Vol. 57, pp.178-188, 2014.
[12] Noman, Nasimul and Iba H, "Differential evolution for economic load dispatch problem", International Journal of Electrical Power Systems Research, Vol. 78, No. pp.1322-1335, 2002.
[13] Kwanty H G and Athay T A, "Coordination of economic dispatch and load frequency control in electric power system," Proceedings,18th IEEE conference on Decision and control, 1979.
[14] Walters D C and Sheble G B, "Genetic algorithm solution of economic dispatch with valve point loading," IEEE Transactions on Power Systems, Vol. 5, No. 4, November 1990.
[15] Sailaja K M and Sydulu M, "A fast computational genetic algorithm for economic load dispatch," International Journal of Recent Trends in Engineering Vol. 1, No. 1, May 2009.
[16] Bisen D, Dubey H M, Pandit M and Panigrahi B K, "Solution of Large Scale Economic Load Dispatch Problem using Quadratic Programming and GAMS: A Comparative Analysis", Journal of Information and Computing Science, Vol. 7, No. 3, pp. 200-211, 2012.
[17] Sharma J and Mahor A, "Particle Swarm Optimization Approach for Economic Load Dispatch", IJERA, Vol. 3, pp. 013-022, January-February 2013.
[18] Bhattacharya A and Chattopadhyay P K, "A Modified Particle Swarm Optimization for Solving the Non-Convex Economic Dispatch", IEEE Transaction on ECTI-CON, 6th international conference, pp. 78-81, 2009.
[19] Chakraborty S, Senjyu T, Yona A, Saber A Y, Funabashi T, "Solving economic load dispatch problem with valve-point effects using a hybrid quantum mechanics inspired particle swarm optimization", IET Generation, Transmission & Distribution.
[20] Ahmed Y S, Ganesh K. V, "Economic Load Dispatch using Bacterial Foraging Technique with Particle Swarm Optimization Biased Evolution", 2008 IEEE Swarm Intelligence Symposium St. Louis Mousa, September 21-23, 2008.
[21] Vanitha M, Thanushkodi K, "An New Hybrid Algorithm to Solve Non convex Economic Load Dispatch Problem", IEEE, 2012.

[22] Agrawal N, Agrawal S, Swarnkar K K, Wadhwani S and Wadhwani A K, "Economic Load Dispatch Problem with Ramp Rate Limit Using BBO" International Journal of Information and Education Technology, Vol. 2, No. 5, October 2012.
[23] Hooshmand R A and Morshed M J, "Emission, reserve and economic load dispatch problem with non-smooth and non-convex cost functions using the hybrid bacterial foraging nelder mead algorithm", Applied Energy, Vol. 89, pp. 443-453, 2012.
[24] Mondal S, Bhattacharya A and Dey S H N, "Multi-objective economic emission load dispatch solution using gravitational search algorithm and considering wind power penetration", Electrical power and Energy System, Vol. 44, pp. 282-292, 2013.
[25] Rahmat N A, Musirin I, "Differential Evolution Immunized Ant Colony Optimization Technique in Solving Economic Load Dispatch Problem", Engineering, 2013, 5, 157-162.
[26] Brindha B T, "Artificial Bee Colony Optimization for Economic Load Dispatch of a Modern Power system", National Conference on Emerging Vistas of Electrical Electronics and Communication Technologies, Vol. 203, No. 2-3, pp. 243–278, 15th &16th June 2013.
[27] PhanTu Vu, DinhLuong Le, NgocDieu Vo and Tlusty J, "A Novel Weight-Improved Particle Swarm Optimization Algorithm for Optimal Power Flow and Economic Load Dispatch Problems", IEEE, Transmission and Distribution conference & exposition, 2010.
[28] Sinha N, Ma Y and Lai L L, "GA Tuned Differential Evolution for Economic Load Dispatch with Non-convex Cost Function", Proceedings of the 2009 IEEE International Conference on Systems, Man, and Cybernetics, San Antonio, TX, USA - October 2009.
[29] Palanichamy C and Shrikrisna K, "Simple algorithm for economic power dispatch" Electrical Power System Res, Vol. 21, pp 174-153,1990.
[30] Wood A J and Wallenberg B F, "Power Generation, Operation, and Control," John Wileyand Sons, 1984.
[31] Meng K, Wang H G, Dong Z Y and Wong K P, "Quantum-Inspired Particle SwarmOptimization for Valve –Point Economic Load Dispatch", IEEE Transaction on Power System, Vol. 25, No. 1, February, 2010.
[32] Alsumit J S, Sykulski J K, Al-Othman A K, "A hybrid GA-PS-SQP method to solve power system valve-point economic dispatch problems", Applied Energy Vol. 87, pp. 1773-1781, 2010.
[33] Basu M, "A simulated annealing base goal-attainment method for economic emission load dispatch of fixed head hydrothermal power system", Electrical Power and Energy systems, Vol.27, no.2, pp.147-153, February 2005.
[34] T. Gupta, M. Pandit, "PSO-ANN for Economic Load Dispatch with Valve Point Loading Effect", IJETAE, Vol. 2, 2012.
[35] N. Singh, Y. Kumar, "Economic Load Dispatch with Valve point Loading Effect &Generator Ramp Rate Limits Constraint using MRPSO", IJARCET, Vol. 2, 2013.
[36] N. Solanki, N. P. Patidar, K. T. Chaturvedi, "A New PSO Technique for non-convex Economic Dispatch", ISOR-JEEE, Vol 9, 2014, pp. 81-88.
[37] Bhullar P. S. et. al. "PSO Based ELD with Valve Point Loading", IJERT, Vol. 4, May 2015.
[38] Nagaraju S, Sankar M. M, Ashok G, S Reddy A, "Economic Load Dispatch considering Valve Point Loading using Cuckoo Search Algorithm", IJSDR, Vol. 1, July 2016.
[39] Coelho L. D. S, Mariani V C, "Economic Dispatch Optimization using Hybrid Chaotic Particle Swarm Optimizer". IEEE International Conference Systems, Man and Cybernetics, 2007.
[40] S. Banerjee et al. "Improved Teaching Learning Based Optimization for Economic Load Dispatch Problem Considering Valve Point Loading Effect", IEI.IEEE-13 units ELD test system by POWER, April 21,2016.
[41] Bhatnagar P, Singh R, Yadav R "Economic Load Dispatch with Prohibited operating zone using Traditional Optimization Technique (GAMS)", IJMTER, 2015.
[42] Jain P, Swarnkar K K, Wadhwani S, Wad'hwani A K, "Prohibited Operating Zones Constraints with Economic Load Dispatch using Genetic Algorithm", IJEIT, March 2012.
[43] Rahami R et. al. "Solving Economic Dispatch Problem using PSO by an Evolutionary Techniques for Initializing Particles", JATIT, December 2012.
[44] Radziukyniene I "C-GRASP Application to the Economic Dispatch Problem," Master of Science Thesis, University of Florida, 2010.
[45] Labbia Y, Attousa D B, Gabbarb H A, Mahdadc B, Zidanb A, "A new rooted tree optimization algorithm for economic dispatch with valve-point effect," Electrical Power & Energy Systems, vol. 79, pp. 298-311, July 2016
[46] Victoire T. A. A, Jeyakumar E, "Hybrid PSO-DS for Non-Convex Economic Dispatch Problems", Digest of the proceedings of the WSEAS conferences, 2003.
[47] Arunagam P, Ravichandran C S "Hybrid Optimization Approaches to Economic Load Dispatch Problems-A Comparative Study", IRJET, Dec-2017.
[48] Singh N, Kumar M P, Kumar B S, "Effect of Valve Point Loading on the Thermal Power Economic Load Dispatch Using New Elephant Herding Optimization", IJRTE, April 2019.