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Grey Wolves Optimization for Economic Load Dispatch with Practical Constraints

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Abstract- ***This paper manifests the applicability of grey wolf's optimization (GWO) for solving economic load dispatch (ELD) problems by considering practical constraints of power generation, but effects of valve-point loading are not considered. This recommended technique is a evolutionary strategy of upgrade with fundamental structure and single control parameter to handle the complex mathematic as well as complicated engineering problems. It is a groundbreaking technique for adequately investigating the exploration and exploitation to locate the optimal solution within a low calculation time. The six generating tests-system have been utilized to exhibit the proficiency of GWO to solve ELD problem. The outcomes are contrasted with a several methods of optimization to confirm the elite of GWO for tackling the problem of ELD.***

Keywords— Economic Load Dispatch (ELD), grey wolves optimization (GWO), valve-point loading.

I. INTRODUCTION

Economic load dispatch is a noteworthy task of scheduling power system to supply the demand; its will likely diminish the fuel cost (FC) of warm units by enhancing its age under the working limit. In spite of the fact that various traditional and meta-heuristic/hybrid optimization methods have utilized to obtain numerical values for the ELD problem, the vast majority of the techniques struck into sub-optimal solution with each other for the reason that of its nonlinear characteristics in real-world systems such as prohibited operating zones (POZ), limits of ramp rate and cost functions. Practically because of physical operation confinement the load allocation can't be feasible for all the operating zone of the generator. POZ could be framed in the middle of the fall and rise limits of generation as the fault occurrence in generator is uncommon. A generating unit comprising of POZ changes over an economic load dispatch problem to a non convex optimization problem where the relevance of regular method can't be conceivable. For solving the problem of ELD in power system PSO methods considers the nonlinear attributes for power system operation exhibited by [1].
The Multiple Tabu Search calculation has been connected to handle the dynamic ELD issue taking diverse generative limitations to obtain higher quality arrangements [2]. A hybrid algorithm based on PSO and DE which achieves multi objectives is capable in clarifying multi-target advancement where various Pareto-ideal arrangements can be found in one reproduction run [3]. Intelligent water drop (IWD) algorithm tried with incremental fuel cost functions demonstrates the great convergence property and better in nature to answer for ELD problem [4]. Firefly Algorithm can offer a progressively perfect response to satisfy the load demand at less operating cost [5]. To explain environmental/economic dispatch issues another a new bare-bones PSO algorithm comprises of a operator of mutation which extend the pursuit ability and tuning of control parameters is not required [6].Modified NSGA-II calculation demonstrates the answer for the thermal generators power dispatch for both environmental and economic with consideration of valve-point loading and different precluded working zones [7].Teaching-Learning-Based Algorithm (TLBO) utilizes the best solution of the emphasis to change the current solution in the populace, in this way expanding the convergence rate [8].For tackling ELD issue backtracking search calculation (BSA) can effectively examine the request space of an improvement issue to find the ideal arrangement inside a short calculation interval [9]. Particle Swarm Optimization (PSO) ready to discover, the output power generation of all the generating units, by limiting the cost function [10]. Quantum molecule swarm optimization disentangle the combined emission economic dispatch problem figured utilizing cubic model capacity thinking about a unit astute max/max value punishment factor [11].To quicken the intermingling rate and avoid neighbourhood minima a multi-target enhancement method dependent on the discrete bacterial calculation is used to work out environmental and economic power dispatch [12]. A hybrid algorithm named bat is proposed to explain combined emission economic dispatch problem along with power flow constraints [13]. Improved chicken swarm improvement (ICSO) produces a quality solution with better convergence attributes when contrasted with PSO and chicken swarm optimization (CSO) [14]. To investigate the pursuit space successfully another PSO algorithm provides solution for convex economic dispatch Problems [15]. An enhanced method for fulfilling the power balance constraints has been introduced in differential evolution to tackle the ELD problem [16]. Economic dispatch of non-smooth figuring by self-adaptive PSO, upgraded the capacity of global search and counteracts the neighbourhood minima from convergence [17].Improved adaptive PSO presented the idea of reset of a piece of the populace by making the algorithm the global optimum from converge [18].

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GWO presents alternative possible response for quadratic and non-convex thermal working version with the compassionating of transmission line loss and the loading effect of valve point [19-20].This paper explores the usage of GWO for solving constrained economic load dispatch issue by considering practical constraints.

II. ECONOMIC DISPATCH MODEL

ELD is concerned with reducing the fuel cost (FC) of thermal units by optimizing their power generation under constrained conditions of system cost demand.The goal is to build up a structure for cost effective dispatch (CED) to a thermal power system with Non-convex quadratic cost model to minimize fuel cost by considering practical constraints.

A. Objective function

$$Minimize\ FC = \sum_{i=1}^{N} a_i P_{gi}^2 + b_i P_{gi} + c_i \left(\$/hr\right) \qquad (1)$$

Where a_i, b_i, c_i -Coefficients of cost curve

N -Number of thermal units

B. Operating constraints

Equality:

The Power balance equation is expressed below:

$$\sum_{i=1}^{N_s} P_{g,i} - P_D - P_L = 0 \qquad (2)$$

Given that

$$P_L = \sum_{m=1}^{N}\sum_{n=1}^{N} P_m B_{mn} P_n \qquad (3)$$

Where,

P_D-Load demand;

P_L-Power Loss;

P_m and P_n, – m^{th} and nth thermal generation;

B_{mn} - Loss coefficient

Inequality:

Generation limits are prescribed as follows:

$$P_i^{\min} \le P_i \le P_i^{\max} \qquad (4)$$

Where,

P_i^{min} and P_i^{max} –Lower and upper limits of thermal generation

C. Practical constraints

Prohibited operating zone:

Synchronous generators at thermal stations must maintain a strategic detachment while generating power in certain working zones due to mechanical throbbing in shaft bearings and thermal strain in the boiler. This operating zone has curbed the generation as like (5)

$$\begin{cases} P_i^{\min} \le P_i \le P_{i,1}^L \\ P_{i,k-1}^U \le P_i \le P_{i,k}^L \ ; k = 2,3,..,N_i \\ P_{i,N_i}^U \le P_{i,k} \le P_i^{\max} \end{cases} \qquad (5)$$

Where,

$P_{i,k}^U$ & $P_{i,k}^L$ are lower , upper operating zone limits

N_i is the index of prohibited zone

Ramp rate limits

The sudden rise and fall of the generation is limited by ramp rate limits and is expressed below:

$$\begin{cases} P_i - P_i^o \le UR_i \ ; if\ generation\ increases \\ P_i^o - P_i \le DR_i \ ; if\ generation\ decreases \end{cases} \qquad (6)$$

III. OPTIMIZATION TOOL

Seyedali Mirjalili has developed the Grey Wolf Optimizer (GWO) that imitates the leaders' ranking and the appliance of stalking of grey wolves. In their population, classification of grey wolves in the categories following: alpha (α), beta (β), delta (δ) and omega (ω), in which the first is the most controlled and the last two control the rest of the wolves. The essential behavior of the GWO is to encircle, hunt and attack the prey. These are modeled analytically as an optimization tool to obtain the best possible solution to any type of problem. Then, the hunting appliance of grey wolves is described as follows:

Encirclement: This is a behavior of grey wolves and is modeled as (7) and (8).

$$\vec{D} = \left|\vec{C} \cdot \vec{X}_{prey}(t) - \vec{X}_{wolf}(t)\right| \qquad (7)$$

$$\vec{X}_{wolf}(t+1) = \vec{X}_{prey}(t) - \vec{A} \cdot \vec{D} \qquad (8)$$

Where, t-specifies the iteration of current, and is position vector, and coefficient vectors indication of the grey wolf and prey, respectively. Then the vectors determined are as follows:

$$\vec{A} = 2\vec{a} \cdot \vec{r}_1 - \vec{a} \qquad (9)$$

$$\vec{C} = 2 \cdot \vec{r}_2 \qquad (10)$$

Where,

$\vec{r}_1$ and $\vec{r}_2$ are lies between 0 and 1 and is tuned to decrease linearly starting 2 to 0 during iterations.

Hunting: As a general rule, the alpha wolf presided over the hunt in association with the beta and delta wolves. In order to reproduce the hunting behavior, the three best possible candidate solutions as alpha, beta and delta wolves are considered during the iteration. Other research officers (omega) positions will be updated by themselves according to the three top search agents position. It is modeled mathematically as follows:

$$\vec{X}(t+1) = \frac{\vec{X}_1(t) + \vec{X}_2(t) + \vec{X}_3(t)}{3} \qquad (11)$$

To find

$$\begin{aligned} \vec{X}_1 &= \vec{X}_{aplha} - \vec{A}_1 \cdot \left(\vec{D}_{alpha}\right) \\ \vec{X}_2 &= \vec{X}_{beta} - \vec{A}_2 \cdot \left(\vec{D}_{beta}\right) \\ \vec{X}_3 &= \vec{X}_{delta} - \vec{A}_3 \cdot \left(\vec{D}_{delta}\right) \end{aligned} \qquad (12)$$

$$\begin{aligned} \vec{D}_{alpha} &= \left|\vec{C}_1 \cdot \vec{X}_{alpha} - \vec{X}\right| \\ \vec{D}_{beta} &= \left|\vec{C}_2 \cdot \vec{X}_{beta} - \vec{X}\right| \\ \vec{D}_{delta} &= \left|\vec{C}_3 \cdot \vec{X}_{delta} - \vec{X}\right| \end{aligned} \qquad (13)$$

Attack: In this phase, the wolves drive to attack the prey. Although mathematical modeling for the prey approach, the coefficient $\vec{A}$ plays a vital role and also the oscillation range of A decreased by $\vec{a}$.

The other hand random value $\vec{A}$ in the interval [-a, a] where, linearly $\vec{a}$ decreases from 2 to 0 during iterations. At the moment when random generations of $\vec{A}$ are in [-1, 1], the subsequent of candidate solution position may be at any position lies between its current location and the location of the prey. Which means that the candidate solution converges if, $|\vec{A}| < 1$ failing that, it diverges from the prey if, $|\vec{A}| > 1$ also hopefully, it finds a prey more in shape.

IV. IMPLEMENTATION OF GWO FOR ED

Step 1 – Structure and Initialization of the Candidate Solution: Control variable of active thermal power generation which represents the position of wolves to emerge. This is arbitrarily initialized from within as much as possible and is based on (14).

$$P_{g,i} = rand * \left(P_{gi}^{\max} - P_{gi}^{\min}\right) + P_{gi}^{\min} \quad (14)$$

Then, the matrix of initial population is created as follows:

$$X = \begin{bmatrix} P_{g1}^1 & P_{g2}^1 & . & . & P_{gi}^1 & P_{gN}^1 \\ P_{g1}^2 & P_{g2}^2 & . & . & P_{gi}^2 & P_{gN}^2 \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ P_{g1}^{SP} & P_{g2}^{SP} & . & . & P_{gi}^{SP} & P_{gN}^{SP} \end{bmatrix} \quad (15)$$

Then, the candidate solution initial position Xo is initialized as follows

$$X^o = \left[P_{g1}^1 \cdot - \cdot P_{g1}^{SP} \; P_{g2}^1 \cdot - \cdot P_{g2}^{SP} \; ....P_{gi}^1 \cdot - \cdot P_{gi}^{SP} ... P_{gN}^1 \cdot - \cdot P_{gN}^{SP} \right] \quad (16)$$

Step 2 - Enhanced objective function evaluation: The objective function is calculated from the population's initial position. To maneuver the equality constraint violation, an augmented objective function (FOF) is developed using (17) that guides the search process to the desired solution.

$$FOF = \left(objective + 1000 * \left| \sum_{i=1}^{N} P_{gi} - \left(P_D + P_L\right) \right| \right) \quad (17)$$

Step 3 - Best Position and Assessment of Fitness: The fitness estimate of all persons in the current frame of the promising solution (Xo) is determined using (18).The fitness of i^{th} entity represents distance from its (wolf's) to the prey. Sort the populace from least to more extreme; an entity that has the least fitness is imitated as alpha; beta and delta the second and third least are respectively.

Fitness = FOF (18)

Step 4- Optimal solution for Modifying wolf location: The place of the i^{th} wolf ought to be refreshed as per (11). The location of each fighter operator embodies a potential solution containing an active ELD generation difficulty. The fresh position of each wolf may not take into account range and is limited in this range.

Step 5 - Reassessment of Fitness: With the last location of each wolf, the FOF is shown as described in Step 2 and taken after Step 3 to distinguish the best overall solution.

Step 6 - Modification of the thermal generation**:** To satisfy equality restriction (2) a solution repair strategy is performed using (19). For the purpose, a d^{th} unit is assumed as slack one and the generation of N-1 units is taken as optimum value. Finally, the positive root is selected as a unit dth generation.

$$B_{dd} P_{gd}^2 + \left(2 \sum_{m=1}^{(N-1)} B_{d,m} P_m - 1 \right) P_{gd} + \left(\sum_{m=1}^{(N-1)} \sum_{n}^{(N-1)} P_m B_{mn} P_n + \sum_{m=1}^{(N-1)} B_{m,0} P_m - \sum_{\substack{m=1 \\ m \neq d}}^{(N-1)} P_m + B_{00} + P_D \right) = 0 \quad (19)$$

Step 7 - Inequality Constraint Management Mechanism: Optimal generation program for the thermal unit is maintained between its operating ranges by an appropriate procedure. If any of the thermal unit flouts its lower and upper restriction which should be fixed at that limit. Considering Prohibited Operating Zones (POZs) the generation may be handled using (20). At the same time, consideration of ramp rate limits, modify the inequality constraint as stated like (21).

$$P_i = \begin{cases} P_{i,l}^{L} & rand \le 0.5 \\ P_{i,k}^{U} & rand > 0.5 \end{cases} \quad k = 2,3,..N_i \quad (20)$$

$$\left.\begin{aligned} P_i^{r\max} &= \min\left\{P_i^{\max}, \left(P_i^o + UR_i\right)\right\} \\ P_i^{r\min} &= \max\left\{P_i^{\min}, \left(P_i^o - DR_i\right)\right\} \\ P_i^{r\min} &\le P_i \le P_i^{r\max} \end{aligned}\right\} \quad (21)$$

Step 8-Stopping criterion: If $iter < \max Cycle$, go to step 2. Otherwise, the GWO ends.

V. RESULTS OF SIMULATION

The power system envisioned for this study includes, 6 generators, twenty six buses and forty six transmission lines. Each generation of unit is limited by two prohibited operating zones, within the limits of ramp-up and ramp-down.The generation schedule is obtained for 1200MW and 1263MW. Put together all 36 inequality restriction the GWO has to be ascertained optimum generation schedule by satisfying one equality restriction. The complete data is available in [9].

A. Sustainable schedule of generation

GWO technique relevance is to find the optimal generation program of the thermal energy system is studied and it is executed 500 iterations of reiteration. Table 1 presents an optimal simulated generation demands of two loads 1200 MW and 1263 MW, consistent to the fuel cost/hour which is minimum.

. Fig.1 demonstrates the attributes of convergence objective function for both the load demands 1200MW and 1263MW to reconfirm nature of the global best solution for solving of the ELD problems.

Table 1 Optimum generation schedules two different load demands

Unit (MW)	Demand (MW)	
	1200	1263
P1	424.1016	497.7121
P2	175.8348	170.9881
P3	244.9861	252.9879
P4	129.6549	117.4982
P5	164.2364	149.4934
P6	71.9178	79.4995
Total Generation	1210.7320	1268.1792
Losses	10.5537	5.8777

CPU Time(s)	8.8	10.9
Iterations	500	500
Fuel Cost($/h)	14591.93	15368.6564

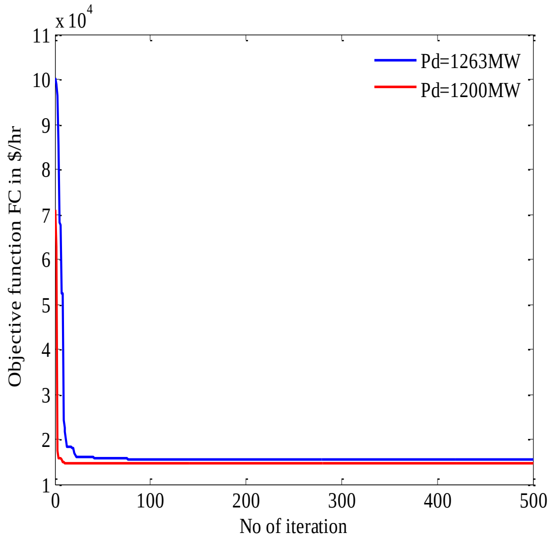

Fig. 1 Convergence characteristics of GWO

A. Comparison of feasible solution

GWO is compared with GA [16], PSO [17], MTS [2], NPSO-I [15], APSO [18], PSO-LRS [15], BSA [9], and CSO, ICSO [14] concerning total cost of generation. Comparison provides in Table 2 shows that GWO has converged on the finest solution when compared with other existing methods.

B. Improvement over state of the art literature

On Comparing with different contestant algorithms savings of fuel cost is enhanced with GWO appeared in Fig.2 beneath. Table 3 demonstrates the statistical comparison which shows that the algorithm proposed is the finest for minimizing fuel costs. In addition, low standard deviations of GWO technique indicate that the values of worst and mean are close to its best estimate and position themselves first and foremost in enhancing the objective function considered. The total cost of generation obtained by GWO approves its robustness in addressing the ELD problem for the low estimate of the standard deviation.

Table 2 Comparison of feasible solution

Demand (MW)	Methods	Total Generation(MW)	FC ($/hr)
1263	GA [16]	1276.0300	15459.0000
	PSO [17]	1276.0100	15450.0000
	MTS [2]	1276.0232	15450.0600
	NPSO-I [15]	1275.9400	15450.0000
	APSO [18]	1275.3764	15443.5751
	PSO-LRS [15]	1275.9500	15450.0000
	BSA [9]	1275.9583	15449.8995
	CSO [14]	1273.5691	15381.0860
	ICSO [14]	1271.4768	15375.2148
	GWO	1268.1792	15368.6564

Table 3 Statistical comparison of feasible solution

Total Generation Cost ($/hr)				
Method	Minimum	Average	Maximum	Standard Deviation
GA [16]	15459.00	15469.00	15524.00	32.50
PSO [17]	1545000	15454.00	15492.00	21.00
MTS [2]	15450.60	15451.17	15453.64	1.52
NPSO-I [15]	15450.00	15450.50	15452.00	1.00
APSO [18]	15443.57	15449.99	---	---
PSO-LRS [15]	15450.00	15454.00	15455.00	2.50
BSA [9]	15449.90	15449.90	---	---
CSO [14]	15381.08	15410.73	---	---
ICSO [14]	15375.22	15392.69	---	---
GWO	15368.66	15369.70	15371.28	0.81

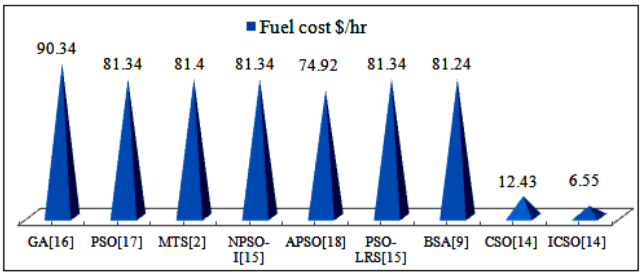

Fig.2 Fuel cost improvements

VI. CONCLUSION

In this paper, GWO is proposed to understand the deeply non-convex ELD problem taking into account constraints which is practical such as POZ's and limits of ramp rate. The relevance and quality of the proposed technique were examined. The consequences of GWO on a six-unit test system with POZ's constraints went beyond compared to other existing optimization techniques in converging towards the less minimal optimal with comparable high ideal results.

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