GRASSHOPPER OPTIMIZATION ALGORITHM FOR SOLVING NONCONVEX ECONOMIC LOAD DISPATCH PROBLEM

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Abstract : This paper introduces an optimization algorithm known as Grasshopper Optimization Algorithm (GOA) and implements it to most complex problems in power structure i.e. economic load dispatch. This introduced technique mathematically models and simulates the behavior of grasshopper flocks in nature for resolving optimization problems. It is employed to discover the optimal solution of the nonconvex cost function in an Economic Load Dispatch (ELD) to demonstrate its applicability. Detail of problem formulation and the solution techniques are given in this paper. Result demonstrates that the GOA is capable to deliver the better result compared to other well-recognized and latest developed techniques (nature-inspired algorithms) in literature. The outcomes of existent applications also verify the qualities of GOA in resolving real problems with unidentified search spaces.

IndexTerms - Economic Load Dispatch (ELD), Grasshopper Optimization Algorithm (GOA), Equality Constraints & Inequality Constraints, Valve-Point Effects

I. INTRODUCTION

Economic Dispatch plays an important function in power system that dealing with operation in an energy management system. During the scheduling & operation of electricity generating units, the proper planning of all alternators should be necessary, for achieving the required demand. Economic Load Dispatch (ELD) is a process, helps to get an optimal grouping of electricity generating units which is selected in such a way that the overall fuel cost ought to be reduced. During minimizing the total fuel cost it must be necessary that load demand & several operational constraints must be obeyed or fulfilled. The optimization of economic dispatch has extreme economic significance for the network operator, in a deregulated electricity market. For resolving the economic load dispatch task, traditional methods viz. lambda iteration, base point participation, Lagrangian multiplier, gradient method, Newton methods are used. For these techniques, it is assumed that curve of the incremental cost function is a linear function and monotonically increasing. Practically it never happens. Actually, practical systems are usually non-linear and cannot be solved using traditional methods.

Nowadays, generating units are located very far from the load center and fuel used in power plant is different for the different power plant. The goal of every generating unit is to generate enough amount of power so as to fulfill the total load demand and then to transfer the generated power to load sites or consumers by maintaining the frequency and voltage at specified level reliably and economically. Economic Dispatch (ED) is the prime optimization actions in power structure for generation of the demanded unit with the objectives of generating power economically, whereas gratify the different constraints [1]. Practical Economic dispatch has complex and non-convex features including several equality and inequality constraints. Classic algorithms like lambda iteration, base-point participation, Lagrangian multiplier, gradient method, newton technique are able to solve the economic dispatch problem only if these functions are linear and consistently increasing. Basic economic dispatch takes the power balance constraint in consideration apart from generating capacity limit. During solving economic dispatch problem practically, one must consider ramp rate limit, prohibited operating regions, valve-point and multi-fuel option to construct a complete Economic dispatch formula. These problems cannot be solved using a classical method, so optimization techniques are used to solve such complex problems [1][2]. In general, during operation of machines, many faults may occur due to personnel operation pattern or other ancillary equipment like boilers, turbines, feed pump etc. have their own operating zones and may feel amplification outside the operating zones. Heavy load forecast error and unscheduled generator outage can be defeated by scheduling sufficient reserve capacity [3].

The most trendy algorithm are Genetic Algorithm (GA) [4], Particle Swarm Optimization(PSO) [5], Differential Evolution(DE) [6] [7], Evolutionary Program(EP) [8], Tabu Search(TS) [9], Neural Network (NN) [10], Artificial Immune Systems(AIS) [11], Honey Bee Colony Algorithm [12], Firefly Algorithm(FA) [13], and some few more.

In this paper, a new technique called grasshopper optimization algorithm is practiced to solve the economic dispatch problem. This technique has lots of merits over the other traditional techniques like its simplicity, gradient-free mechanism, high avoidance of local optima, and problems consider like black boxes etc.

Rest of the paper is arranged as follows;

Section II contains ED problem. Section III describes the GOA technique while section IV details PSO technique. Section V explains the result and discussion. Section VI concludes the paper.

II. NONCONVEX ECONOMIC LOAD DISPATCH

The Economic Load Dispatch problem helps in distribution of total demand of consumer over all the generating units economically. The function of economic dispatch is to reduce the overall cost of generation.

$$C_{total}= f\,(P_{G1}, P_{G2}, P_{G3}, \ldots\ldots\ldots\ldots, P_{GN})$$

Where, C_{total}, represents the overall cost of generation. P_{G1}, P_{G2}, P_{G3} is the output of single generator units. There are two types of system constraints during the solution of ELD problem.

I. Equality constraint
II. Inequality constraint

I. EQUALITY CONSTRAINT

The equality constraint shows load flow calculation considering both powers i.e. active and reactive.

$$\sum_{i=1}^{m} Pi - Pd - Ploss = 0 \qquad (1)$$

Here, P_{load} is the overall system demand. Overall transmission system loss, P_{loss}, depends upon overall output power that may be expressed by B-coefficients [14] [15] as shown below

$$P_{loss} = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{0i} P_i + B_{00}. \qquad (2)$$

II. INEQUALITY CONSTRAINTS

a.) Generator constraints

Loading (KVA) of generating units could be expressed as $\sqrt{P^2 + Q^2}$. This value must not exceed a pre-defined value because the overheating of generator can damage apparatus. The maximum active power that is generated by generator, is restricted according to thermal constraints to retain the heat increase not to exceed a pre-defined value. Minimum power produced by the generator is restricted by flame instability of boiler. If power produced in alternator drops to pre-quantified level known as P_{min}, plant never able to generate power and disconnect from bus bar. So,

$$P_{min} \leq P \leq P_{max} \qquad (3)$$

the maximum value of reactive power needs to be restricted due to excess heating produced in rotary part and the minimum value is restricted because of stability issue of the generator. Hence, the power Q must never cross the limit and perform steady performance.

$$Q_{min} \leq Q \leq Q_{max} \qquad (4)$$

b.) Voltage Constraints

Voltage has different magnitude, phase angle at several points. The standard performing angle for transmission lines must exist between 30 to 45 degree in order to achieve transient stable. High operational angle decreases the strength when a fault occurs. Low phase angle helps in appropriate use of the existing transmission capability.

c.) Running Spare Capacity Constraint

These restraints are important when one or more generators exist in any system get forcefully close or outage or during an unexpected load applied to the system.
Overall power generating units should be capable to fulfill load demand, losses and spare capacity that is reserved and essential, i.e.

$$T \geq P_p + P_{so}$$

Where T is overall production, P_{so} is pre-defined electrical production. Assessment of P_{so} should be very low.

d.) Transmission Line Restrictions

Both powers i.e. active & reactive is restricted by thermal capacity.

Usually, it is stated as:

$$C_p \leq C_{pmax}$$

C_{pmax} is taken as maximum loading capacity of the P^{th} bus.

e.) Transformer tap settings:

For auto-transformer, minimum and maximum value of tap changing ought to be 0 and 1 respectively, i.e.

$$0 \leq k \leq 1.0$$

Likewise, in the double winding transformer, tapings is available in the secondary winding. Thus,

$$0 \leq k \leq n$$

n represent transformation ratio.

f.) Network Security Constraints

Initially, the system is functioning acceptably then after that fault occurs. This fault can be scheduled or forced. Naturally, restraints in the system can be disturbed. The complication of those restraints (number of restraints) rises when it occurs in the huge system. A theory is prepared for the outage to occur in one part of the system or occur in more than one part in a single time. These restraints are of similar nature like voltage & transmission line constraints.

All the constraints discussed, are used for solving the economic dispatch problem using a classical method like lambda method, Newton method etc. For practically solving the economic dispatch problem, there are number of constraints that are discussed below:

g.) ELD Problem including Valve-Point Effects:

Generation plants containing steam turbines with multi-valve show huge deviation in the fuel-price curve. This effect generates ripples and price function holds higher order nonconvexity. Thus new equation for cost function including valve point effect is given as:

$$F_j(P_j) = a_j + b_j P_j + c_j P_j^2 + \left| e_j \times \sin \left(f_j \times \left(P_{j,,min} - P_j \right) \right) \right| \quad (5)$$

h.) ELD Problem involving Multi-Fuel parallel to Valve-Point:
For making any system more reliable and efficient, multi-fuel can be used in generating units. For each and different fuel, a different piecewise quadratic equation can be used. Commonly a quadratic equation represents the input-output curve of generating unit including multi-fuel and written as:

$$F_i(P_i) = \begin{cases} a_{i1} + b_{i1}P_i + c_{i1}P_i^2, & \text{fuel } 1, \quad P_{i\,\min} \leq P_i \leq P_{i1} \\ a_{i2} + b_{i2}P_i + c_{i2}P_i^2, & \text{fuel } 2, \quad P_{i1} \leq P_i \leq P_{i2} \\ \vdots & \vdots \\ a_{ik} + b_{ik}P_i + c_{ik}P_i^2, & \text{fuel } k, \quad P_{ik-1} \leq P_i \leq P_{i\,\max} \end{cases} \quad (6)$$

Fuels are delivered by fuel suppliers according to the bond between supplier and utility [21]. To get a precise and real Economic Load Dispatch solution, fuel price function must be taken including multi-fuel with valve-point influences [22].
So new formula for ED problem

$$F_i(P_i) = \begin{cases} F_{i1}(P_i), & \text{fuel } 1, \quad P_{i\,\min} \leq P_i \leq P_{i1} \\ F_{i2}(P_i), & \text{fuel } 2, \quad P_{i1} \leq P_i \leq P_{i2} \\ \vdots & \vdots \\ F_{ik}(P_i), & \text{fuel } k, \quad P_{ik-1} \leq P_i \leq P_{i\,\max} \end{cases} \quad (7)$$

Generally,

$$F_{ik}(P_i) = a_{ik} + b_{ik}P_i + c_{ik}P_i^2 - \left| e_{ik} \times \sin\left(f_{ik} \times \left(P_{ik,min} - P_i \right) \right) \right| \quad (8)$$

Where a_{jk}, b_{jk}, c_{jk} are cost coefficient of generator i with fuel k and e_{jk}, f_{jk} are cost coefficient of generator j displaying valve-point with the fuel of type k [23].

e.) Ramp Rate Limits:

The real operational range of working plants is limited according to their resultant ramp rate boundaries. The ramp up & down restraints [19] could be expressed as:

$$P_i - P_i^0 < UR_i \text{ and } P_i^0 - P_i < DR_i \tag{9}$$

Here P_i^o is the former production of i^{th} generating plant and UR_i & DR_i is the ramp up and down bounds of machines, respectively. The ramp rate and output power restraints can be rephrased as an inequality constraint [19] like this:

$$\max\{P_{i,\min}, P_i^0 - DR_i\} \le P_i \le \min\{P_{i,\max}, P_i^0 + UR_i\}. \tag{10}$$

III. GRASSHOPPER OPTIMIZATION TECHNIQUES

Grasshopper is generally considered as insects. Grasshopper is taken as a pest because of their harm to harvest production & farming. Grasshopper' Lifecycle is displayed in figure 1.

Fig. 1: Grasshoppers' Lifespan cycle

They form one of the biggest swarm in the creatures but generally found alone in nature. The unique feature of grasshopper is that they can swarm in both childhood and adulthood [20]. In their immature stage, they can jump only and move like rolling cylinder and eat all the vegetables they found in their path. In their adult stage, they got wing and then form swarm in the air [21]. In immature stage, slow movement of the swarm and small step of grasshopper is an important feature. Elongated range and sharp movement are the important characteristics in adulthood. These two features of grasshopper will move it towards exploitation and exploration. As knows, all the nature-inspired techniques split search procedure into 2 trends: exploration or exploitation. During exploration, agents are inspired to move sharply, and they often tend to travel locally while exploitation. Discussed both role and target searching are achieved by grasshopper naturally [22].
Mathematically,

$$X_j = S_j + G_j + A_j$$

This equation shows location of j^{th} grasshopper.
Where S_j is taken as social interaction, G_j is considered as gravity effect/force on position, and A_j is wind advection i.e. the effect of wind on the flying behavior and direction in which grasshopper is flying mainly in their nymph stage. To get a random behavior, we can rewrite above equation as

$$X_j = r_1 S_j + r_2 G_j + r_3 A_j \tag{11}$$

Here r1, r2, r3 are random numbers chosen from [0, 1].

$$S_i = \sum_{j=1}^{N} s\,(dij)\,(\widehat{dij}) \tag{12}$$

Where d_{ij} is the distance between i^{th} & j^{th} grasshopper, s is the strength of social forces and $\hat{d}_{ij}$ is the unit vector i i.e.

Xi − Xj/dij

$$s\,(r) \;=\; f\,e - r/l \;\;-\; e - r \tag{13}$$

Where,
f is the strength of attraction,
L is attraction length scale.

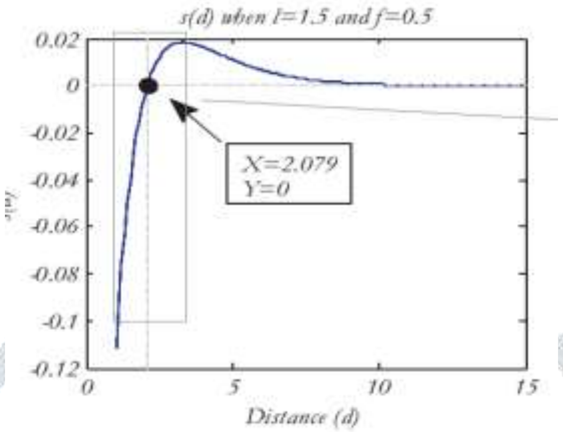

Fig. 2: Characteristics of Function S

Fig. 2 shows the variation of social interaction i.e. attraction and repulsion by taking some random value of f & L. Here in fig. 2 consider the length from 0 to 15 and it is observed that repulsion occurs in the period of 0 to 2.079. From fig. 2, it is observed that when grasshopper show 2.079 units distance far from another nearby grasshopper, it cannot feel any force like attraction or repulsion. That distance is known as comfort region. Fig. 2 displays that attraction region starts from 2.079 units space to nearby 4 and then slowly decreases and tends to be zero. By varying the values of L and f in Eqn. (13) the different social behavior of artificial grasshoppers can be observed.

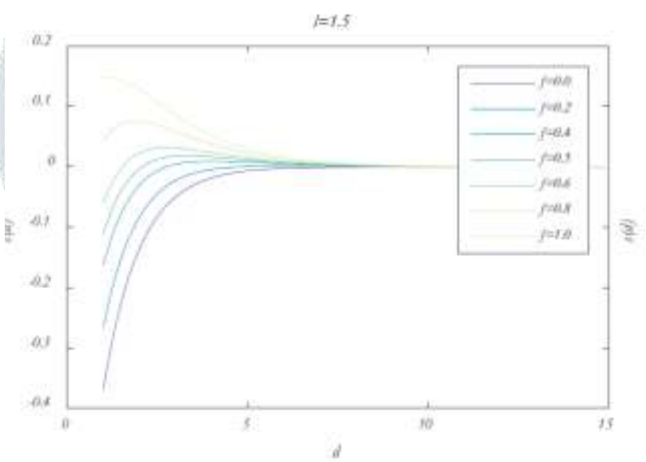

Fig. 3: Variation of function S with a different value of f

To get the outcome of both parameters i.e. f and l, element S is redrawn in fig. 4 by changing l or f individually. This demonstrates that the function l and f effects comfort region, attraction zone and repulsion zone. There must be remembered that attraction & repulsion zones are very minor for some values. So to get a clear variation, L and f are taken as 1.5 and 0.5 respectively [23].

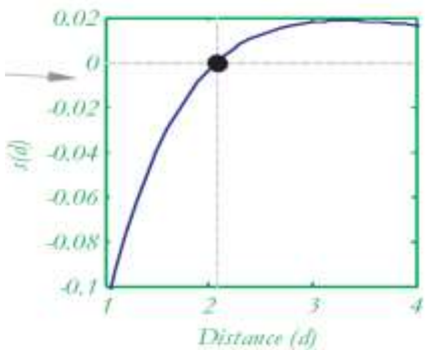

Fig 4: Actual range of function s

In fig. 2 and fig. 3 it is observed that at large distance, function s(d) nearly equals to zeros. To solve this problem, this distance is taken in the range of [0, 4] and redraw variations as shown in fig. 4.

The concept of communication between Grasshopper and comfort region with function S is shown in fig. (5). Function s help in splitting the space between two grasshoppers into attraction, repulsion and comfort region. From fig. 2 and 3, it is clear that function value approach to zero after 10 unit of distance travel. So, at large distance, function s is unable to apply large social forces because of function s approaches to zero. To overcome this difficulty, forces are taken in the period of (1, 4).

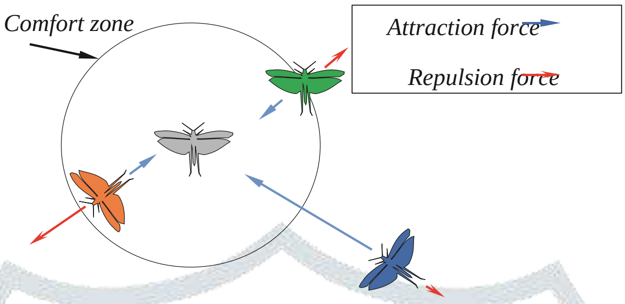

Fig. 5: Social forces between grasshoppers in a swarm

Now, the G element in Eq. (10) is considered as follows:

$$G_j = -g\hat{e}_g \tag{14}$$

Where g is constant and known as gravitational constant and $\hat{e}_g$ is the unit vector whose direction is always towards the earth. The A_i element in Eq. (10) is considered as

$$A_j = U\hat{e}_w \tag{15}$$

Here, U is drift constant and $\hat{e}_w$ is the unit vector which is present in the direction of the wind. As the nymph doesn't have wing to fly so the direction of flying is always affected by the wind advection [28].

$$X_i = \sum_{\substack{j=1 \\ j \neq i}}^{N} s(|x_j - x_i|)\frac{x_j - x_i}{d_{ij}} - g\widehat{e_g} + u\widehat{e_w} \tag{16}$$

This mathematical model cannot be used to resolve optimization problems primarily because grasshopper rapidly reach comfort zones and swarm cannot converge to a target or stated point so improved version is

$$X_i^d = c\left(\sum_{\substack{j=1 \\ j \neq i}}^{N} c\frac{ub_d - lb_d}{2} s(|x_j^d - x_i^d|)\frac{x_j - x_i}{d_{ij}}\right) + \widehat{T_d} \tag{17}$$

Where S(r) is social interaction [28], T_d is known as the value of target in D^{th} dimensions. C is the decreasing constant to contract comfort regions, repulsion & attraction zones.
S is same as that of equation (16). Gravity is not taken into account for this equation. Wind advection is always towards the target. The new equation represents the next position of a grasshopper by considering the present position and position of neighboring grasshopper.
This technique is better than PSO (Particle Swarm Optimization) because in PSO two vectors are considered for every search agent (particle) i.e. position and velocity, but in GOA only one position vector is considered which make it simple and speedy. Another important feature in GOA is that in this technique grasshopper update its position by considering the present position, personal and global best and position of another searching agent but in PSO the position of the neighboring particle is never taken into account [23].
The element C used in equation (17) is using two times and has its own significance. The first C on the left side is alike to inertial weight consider in PSO [23]. It helps in decreasing the movement of grasshopper nearby target and helps in exploring the optimal solution or one can say that this C helps in balancing between the exploration and exploitation [23]. The second C used is called as decreasing coefficient. It helps in converging, the exploring area by reducing the comfort zones, attraction zones, and repulsion zones. This means that the second C helps in minimizing the repulsion and attraction strengths. It depends upon the number of iterations while the other C present outside, decrease the search convergence area around the target [23].

$$c = cmax - l\frac{cmax - cmin}{L} \tag{18}$$

Where l is presenting iteration an L is an overall number of iteration or a maximum number of iteration. Generally, value assigned for l and L is 0.00001 and 1 respectively. Target here used for swarm can be stationary as well as mobile. The swarm is properly able to chase the mobile target as well as a stationary target due to minimizing the comfort region by changing factor C. In his final step of optimization grasshopper will move near to the target in such extent as possible and this shifting is necessary during exploitation.
In the real application, no one exactly knows where the target is i.e. where the global optimum exist so in each step of optimization it is assumed that finest grasshopper (i.e. having best fitness value) throughout the optimization is taken as a target [23].
For receiving the more random behavior multiply the equation (17) with random number r1, r2. Only one term can also be multiplied to get the arbitrary behavior.

Pseudo code for the GOA algorithm:

```
Initialize the swarm Xi (i = 1, 2, ..., n)
Initialize cmax, cmin, and maximum number of iterations
Calculate the fitness of each search agent
T=the best search agent
while (l < Max number of iterations)
    Update c using Eq. (2.8)
    for each search agent
            Normalize the distances between grasshoppers in [1,4]
            Update the position of the current search agent by the equation (2.7)
            Bring the current search agent back if it goes outside the boundaries
    end for
    Update T if there is a better solution
    l=l+1
end while
Return T
```

IV. PARTICLE SWARM OPTIMISATION

This technique based on evolutionary computation proposed by Eberhart and Kenedy, in 1995, which was motivated by the social behavior observed in flocking of birds & fish schooling. PSO has application in social phycology, synthetic life also in engineering & computational science [32]. The PSO is an algorithm based on population which simulates the social behavior of birds, bees, fish schooling, etc.
For PSO technique, every solo outcome is a "bird" but in space during search represented as "particle". Every particle takes its own fitness value that can be estimated by the fitness function and has definite velocity, by which a particle can fly in a particular track. The particle moves in search space and follows the particle which has the best optimum value in present search space. PSO started by some random particle known as a solution and then it continually searches for the ideal value while updating current value. For every iteration each particle position is modified using two "best" values. The first value is the best outcome (fitness) of every individual. This assessment is called as P_{best}. Another one is global best value, acquired far distant by some of the particles present in the population. That parameter is called as global best sometimes written as G_{best}. When a particle goes for an optimization, the best value attained during optimization is local best, known as P_{best}. Then after getting two finest value, particle modify own current speed and position.

$$V_i^{(u+1)} = w * V_i^{(u)} + C_1 * rand\,(\,) * (pbest_i - P_i(u)) + C_2 * rand\,(\,) * (gbest_i - P_i(u)) \quad (19)$$

$$P_i(u+1) = P_i(u) + V_i(u+1) \quad (20)$$

Here,

$rand\,(\,)*(pbest_i - P_i(u)$ = particle memory influence,
$rand\,(\,)*(gbest_i - P_i(u))$ = swarm influence.

Vi(u) is the speed of I_{th} particle in iteration and 'u' should lie in the range.

$$V_{min} \leq Vi(u) \leq V_{max.} \quad (21)$$

The factor used in the equation in (19), (20) and (21) are described below:

The parameter Vmax used to find the resolution or fitness values in the regions of search space between present & target position.

If V_{max} has higher value, then elements may fly historical decent solutions. If V_{min} has a smaller value, then elements don't explore satisfactorily local solutions.

From the past experiences with PSO, the value of $V_{max.}$ delimited to the 10-20% of range for every variable.

The factor C1 & C2 effort to attract each element near to P_{best} & G_{best} positions.

Acceleration constant having lesser values helps particle to roam distant from the target areas before it comes back to original position and the higher values constantly effect in rapid movements.

C1 and C2 represent acceleration constant, usually attain a value of 2 to get an optimum solution.

Proper choice of inertia weight 'w' is taken to deliver a stability between Global and local explorations, which averagely needs less iteration to get an optimum solution.

Normally, the inertial weights 'w' is fixed agreeing to succeed equation (22),

$$W = W_{max} - \left[\frac{Wmax - Wmin}{ITERmax}\right] * ITER \qquad (22)$$

Here,

W inertia weight Factor
W_{max} maximum Value of weight factor
W_{min} minimum value of weight Factor
$ITER_{max}$ maximum number of iterations
ITER present no. of iterations

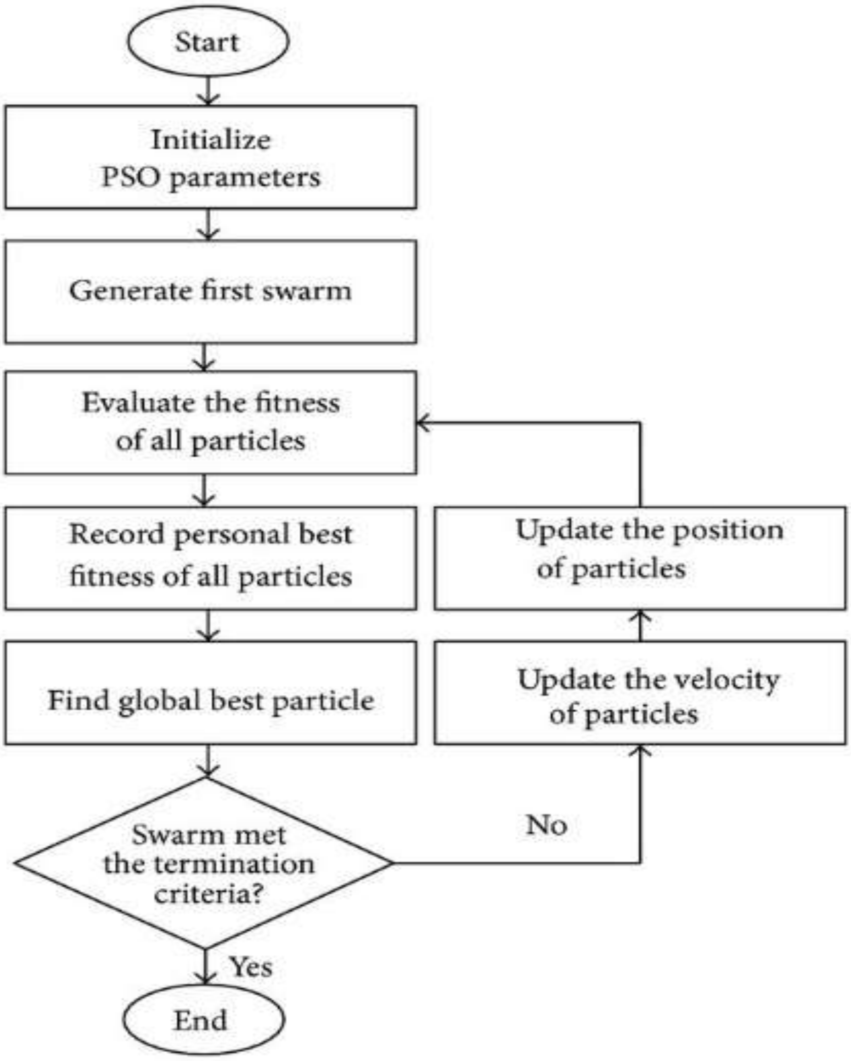

Fig. 6: Flowchart for PSO

V. RESULT AND DISCUSSION

The two different techniques studied earlier are implemented to get the minimum cost at any demand. These techniques are applied on the IEEE 30 bus system. Six generating units are considered during calculation. Outcomes of Particle Swarm Optimization (PSO) and Grasshopper Optimisation Algorithm (GOA) are then compared with each other.

Developed program for ELD is implemented in MATLAB R2016a. All the algorithms developed using PSO and GOA for resolving the ELD problem is explained in section 3 in detail. The primary objective taken for these algorithms is to minimize the overall cost of generation in parallel while satisfying the consumer demand and also these algorithms are implemented with or without including transmission losses during calculation.

A. Settings of PSO Algorithm Parameters

For this technique, the initial particle is randomly selected within predefined possible range. Elements c1, c2 and inertial weight are chosen for finest convergence features. Where, c1 = 2.00 and c2 = 2.00. C1 and C2 are cognitive acceleration & social acceleration respectively. Where the maximum value of w is selected 0.9 and the minimum value is selected 0.4. The velocity limits are selected as Vmax = 0.5*Pmax and the minimum velocity is selected as Vmin= -0.5*Pmin. 100 particles are chosen for the population. For the dissimilar value of c1 and c2, cost curve converges differently for every different region. Therefore best value is chosen for a minimum cost of Economic Load Dispatch task. For the increment in a number of particles, the curve converges quicker or rapidly. It could be detected the line losses & have no influence on cost curve characteristics. Error gradient taken here is 1e-06.

Table 1: Fuel Cost Coefficients for six generating units

Unit	a	B	c	d	e
1	10	200	100	200	0.035
2	10	150	120	140	0.04
3	20	180	40	160	0.03
4	10	100	60	100	0.042
5	20	180	40	180	0.037
6	10	150	100	120	0.025

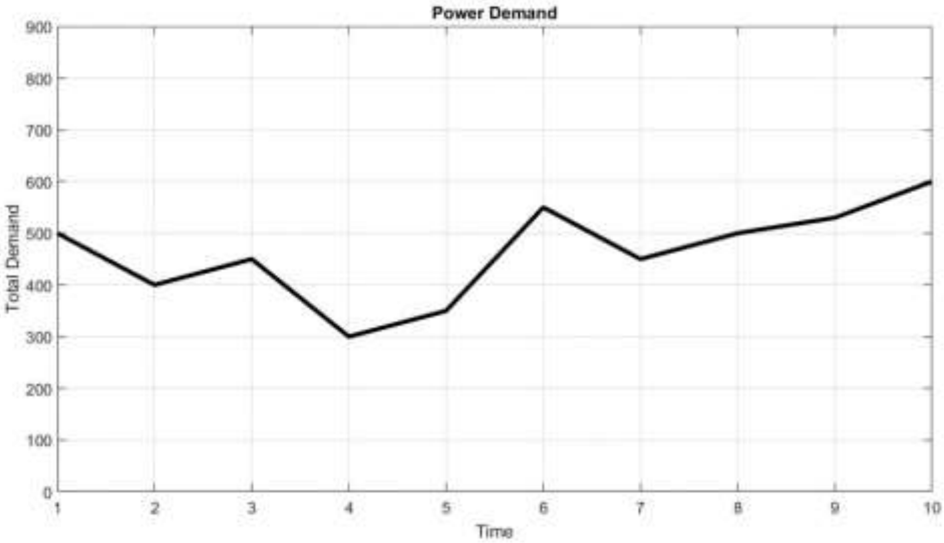

Fig. 7: Overall power demand

Table 2: Optimum Arrangement of Generators having six generating unit system using PSO Method (including losses).

Sr. No	Power demand (mw)	P1 (mw)	P2 (mw)	P3 (mw)	P4 (mw)	P5 (mw)	P6 (mw)	Fuel Cost (Rs/hr)
1	500	67.311	45.75	44.5	31.88	25.85	27.51	1357.7
2	400	35.885	46.916	36.1	16.36	12.43	12.61	1354.9
3	450	43.087	32.301	28.53	24.98	12.36	26.78	1360.5
4	300	25.179	12.109	14.37	10.63	10.78	13.45	1338.3
5	350	75.239	36.896	35.93	20.71	23.18	15.91	1348.7
6	550	120.74	79.838	43.69	41.41	17.89	20.50	1357.0
7	450	126.24	5.1347	32.03	37.21	23.53	34.56	1358.0
8	500	125.91	65.101	32.32	33.31	12.01	24.08	1360.9
9	530	130.72	92.577	38.41	21.32	23.35	15.33	1358.8
10	600	125.87	111.14	20.97	22.65	15.38	22.50	1361.9

Table 3: Optimum Arrangement of Generators having six generating unit system using PSO Method (neglecting losses).

SNo	Power demand (MW)	P1 (mw)	P2 (mw)	P3 (mw)	P4 (mw)	P5 (mw)	P6 (mw)	Fuel cost (Rs/hr)
1	500	101.175	60.818	37.9040	47.4330	13.9822	19.7300	1086.8
2	400	43.8698	56.5575	29.4018	43.1906	19.7574	25.6466	1089.0

3	450	56.2981	36.8867	53.7019	24.8992	10.9552	26.6848	1087.5
4	300	33.9162	42.9829	36.5580	27.4567	27.7292	33.9149	1080.0
5	350	54.1612	29.3889	11.1899	27.3542	28.3668	12.9188	1089.8
6	550	63.4772	65.6147	46.8919	38.1726	24.6656	28.8339	1086.3
7	450	48.2542	55.9667	43.0039	37.9774	21.7223	21.1708	1090.1
8	500	73.8799	12.5626	56.8762	45.4888	13.5496	28.1822	1085.2
9	530	64.3929	61.7362	36.0639	32.2138	18.3137	21.6807	1083.4
10	600	55.4098	49.9330	32.1061	43.1523	21.9554	30.0161	1087.8

B. Settings of GOA Algorithm Parameters

In this technique, the initial particles are randomly chosen lying in viable range. Maximum number of iteration taken for this algorithm is 500. Upper bound and lower bound is taken 100 and 0 respectively. Number of variables i.e. dimension is 3. Number of search agents are 100. Parameter f and L have value 0.5 and 1.5 which is helpful in calculating the social interaction.

Table 4: Optimum Arrangement of Generators having six generating unit system using GOA Method (neglecting losses).

Sr. No	Power demand (MW)	P1 (mw)	P2 (mw)	P3 (mw)	P4 (mw)	P5 (mw)	P6 (mw)	Fuel cost (Rs/hr)
1	500	238.8	133.59	44.37	13.590	48.56	21.022	937.21
2	400	131.27	68.957	79.80	70.604	39.35	10.000	940.87
3	450	123.01	51.596	52.02	87.998	45.26	90.112	942.60
4	300	66.297	41.801	10.00	99.982	17.42	64.490	935.01
5	350	63.969	59.688	70.35	27.293	43.17	85.514	933.44
6	550	211.78	187.5	58.07	57.655	23.96	11.011	945.39
7	450	49.472	203.74	56.22	60.527	10.06	69.961	942.60
8	500	211.71	173.9	41.99	36.149	21.95	14.216	936.21
9	530	228.05	83.720	48.02	92.25	49.59	28.35	937.64
10	600	232.96	176.86	57.38	14.156	44.92	73.70	955.72

Table 5: Optimum Arrangement of Generators having six generating unit system using GOA Method (including losses).

Sr. No	Power demand (MW)	P1 (mw)	P2 (mw)	P3 (mw)	P4 (mw)	P5 (mw)	P6 (mw)	Fuel cost (Rs/hr)
1	500	82.29	198.7	86.5	53.19	50.0	28.73	1108.3
2	400	45.51	161.7	62.1	64.78	47.1	18.5	1103.7
3	450	125.2	175.3	24.2	22.64	33.2	69.36	1105.4
4	300	160.7	17.98	11.9	50.77	42.0	16.50	1100.5
5	350	53.90	148.1	35.8	52.67	29.4	29.97	1101.2
6	550	222.3	152.7	25.4	90.70	50.7	49.98	1120.7
7	450	125.2	175.2	24.	22.64	33.2	69.31	1105.8

8	500	82.29	198.7	86.	53.19	50.0	28.73	1108.2
9	530	230.5	134.7	63.2	21.96	48.6	30.85	1121.4
1 0	600	247.6	148.6	47.0	55.98	15.7	85.06	1124.7

The GOA algorithm is used for the ELD process optimization and to meet the demand requirement at the fullest. Figure 8 displays the generated vs demand power of the GOA algorithm and from the figure, it can be seen that both the graphs are nearly overlapping each other and hence almost 100% meeting the power demand.

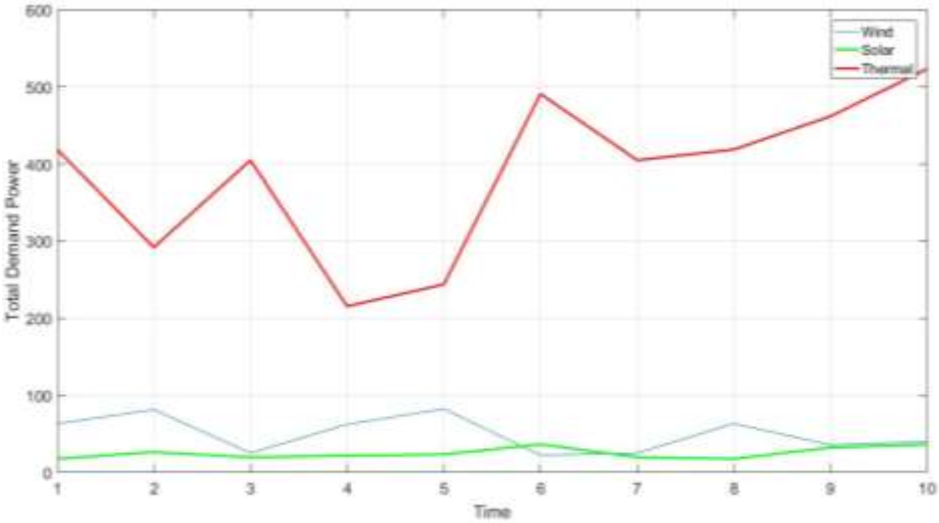

Fig.9: overall power generated

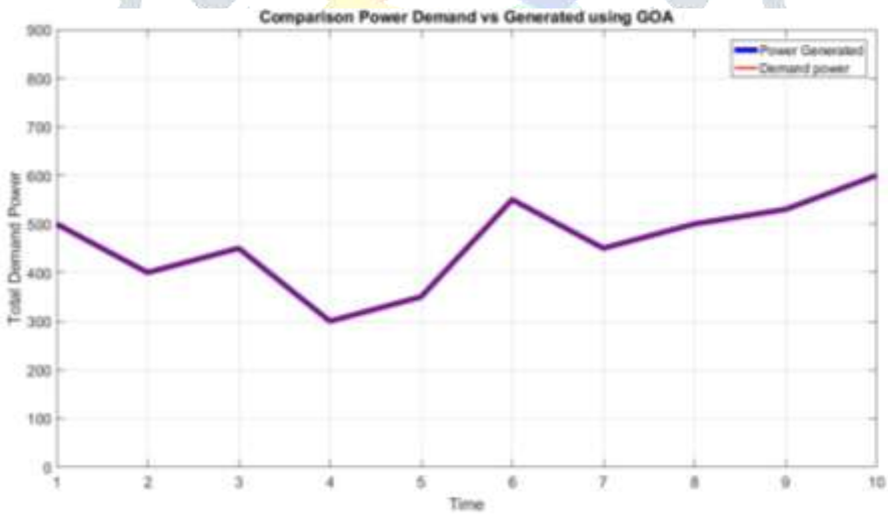

Fig. 8: Power generated vs power demand

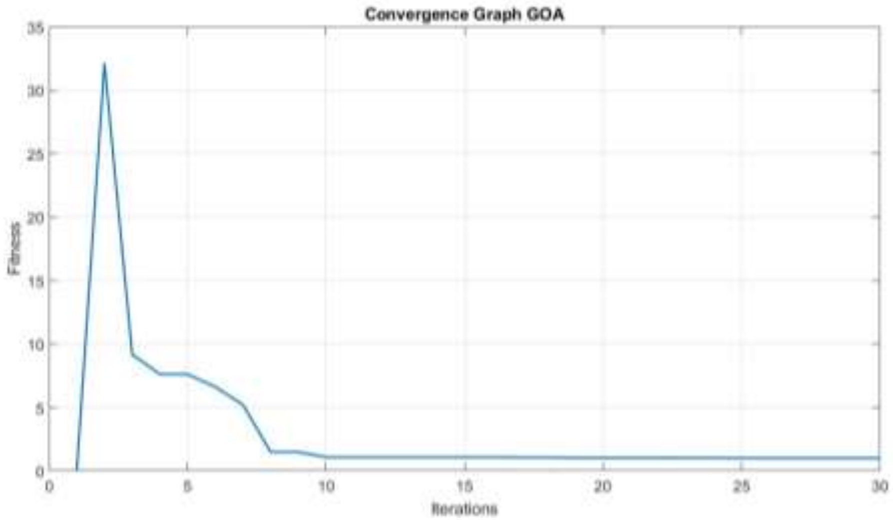

Fig 10: Convergence graph of GOA without losses

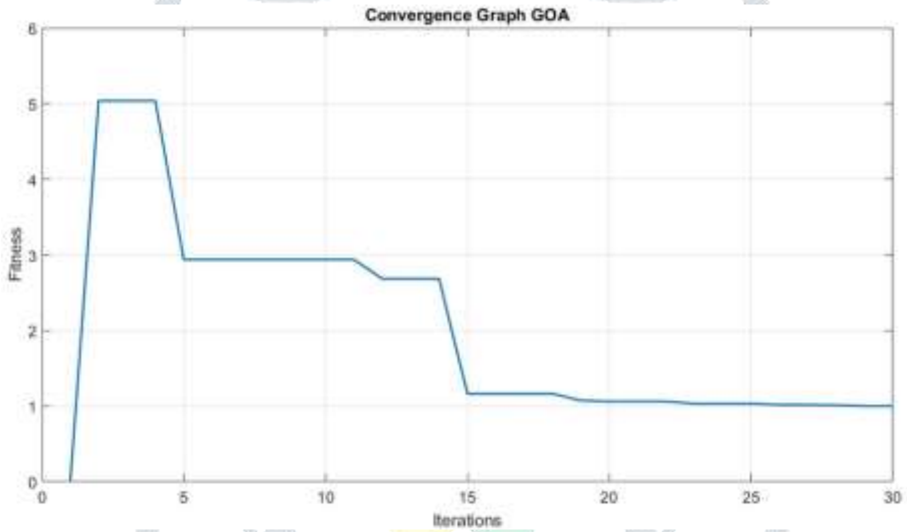

Fig 11: Convergence graph of GOA including losses

C. COMPARISION

Table 6: Evaluation of outcomes between GOA and PSO technique using six-unit system (including losses)

Sr. No.	Power demand (MW)	PSO Method (Rs/Hr)	GOA Method (Rs/Hr)
1	500	1357.7	1108.3
2	400	1354.9	1103.7
3	450	1360.5	1105.4
4	300	1338.3	1100.5
5	350	1348.7	1101.2
6	550	1357.0	1120.7
7	450	1358.0	1105.8

8	500	1360.9	1108.2
9	530	1358.8	1121.4
10	600	1361.9	1124.7

Table 7: Evaluation of outcomes between GOA and PSO technique using six-unit system (neglecting losses)

Sr. No.	Power demand (MW)	PSO Method (Rs/Hr)	GOA Method (Rs/Hr)
1	500	1086.8	937.21
2	400	1089.0	940.87
3	450	1087.5	942.60
4	300	1080.0	935.01
5	350	1089.8	933.44
6	550	1086.3	945.39
7	450	1090.1	942.60
8	500	1085.2	936.21
9	530	1083.4	937.64
10	600	1087.8	955.72

VI. CONCLUSION

In this research work, the PSO and GOA optimization algorithms are implemented on economic load dispatch problem for the electrical networks which involve the renewable sources of energy as well. The comparison of both algorithms in term of meeting demanded power has been shown on IEEE30 BUS system. GOA algorithm demonstrated greater characteristics including high-quality resolution, steady convergence features. Here an optimization technique is developed without ancillary elements and problem contains the extraction of maximum power from renewable sources and to dispense the remainder of the power on the power stations. Fuel price of the power generation with renewable sources of energy is generally less than without using this source of generation. Observably, the effective utilization of renewable sources of energy helps to minimize the fuel price in power system.

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