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Firefly based Unit Commitment

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***Abstract*—Unit commitment (UC) problem is considered one of the most vital problems for daily economic operation and planning of present power systems that optimize the operation cost with respect to the load demands. UC decision incorporates the determination of the generating units to be committed during each hour of the planning period, by considering system capacity requirements, reserve, and the constraints on the start-up and shut-down of units. Economic Load Dispatch (ELD) is a constrained non-linear optimization problem. ELD schedules the outputs of available generating units for a specific time that reduces the production cost while fulfilling equality and inequality constraints. In this paper, a firefly (FF) algorithm has been proposed for solving UC problem. The FF algorithm decides the ON-OFF status of all the available generating units while Lambda Iteration method solves the ELD problem among the committed units in each hour. The proposed algorithm has been tested with the systems having 10, 20 and 40 units.**

Keywords*— *Unit Commitment; Economic Load Dispatch; Firefly

I. INTRODUCTION

UC is a combinatorial optimization problem in a power system, which incorporates finding a start-up and shut-down schedule of the generating units to fulfill the hourly fluctuating forecasted system demand and different requirements such that the total cost is minimized. UC can be considered as two linked optimization sub-problems namely the unit scheduling problem and the ELD problem. The UC problem is a binary-variable power system optimization problem which incorporates determining on/off status of all the available generating units whereas the ELD is a real-variable power system optimization problem which incorporates allocating the loads among the online units to balance the forecasted load demand. Various methods are proposed to determine the status of the generating units in the UC problem. The conventional methods such as dynamic programming (DP) [1], Lagrangian relaxation (LR) [2], integer programming (IP) [3], and branch and bound [4] have been applied to solve the UC problem. These days meta-heuristic methods like artificial neural network (ANN) [5], genetic algorithm (GA) [6], simulated annealing (SA) [7], particle swarm optimization (PSO) [8], and tabu search [9] are able to produce better solutions than the conventional methods like mixed integer linear programming used in the load dispatch center.

In recent years, a new biologically-inspired meta-heuristic algorithm, known as the firefly algorithm was developed by Xin-She Yang. FA is an optimization algorithm inspired by the behavior and motion of fireflies.

In this paper, the firefly (FF) algorithm has been implemented to solve the UC problem. Main objective of this paper is to minimize the production cost of generators by optimizing the schedule of generation. A set of power systems up to 40 units system are used to test over 24 hr. time horizon.

II. PROBLEM FORMULATION

UC can be characterized mathematically as an optimization problem as follows:

A. Objective Function

The objective function is specified as a sum of fuel cost and start- up cost of each generating unit over 24 hours scheduled period and mathematically is expressed as equation (1):

$$minCF = \sum_{t=1}^{T} \sum_{i=1}^{N} [F_i(P_i(t))+SC_i(t)] \qquad (1)$$

Where,

$F_i(P_i(t))$ = fuel cost of unit i at hour t expressed as a quadratic function of each unit output $=a_i + b_i{*}P_i(t) + c_i{*}P_i(t)^2$, where a_i, b_i and c_i represent cost coefficients of the unit.

N = number of units;
T = total scheduling period;
i = index of unit ($i=1.2....N$);
t = index of hour ($t=1.2....T$);
$P_i(t)$ = power generation of unit i at hour t;
CF = aggregate cost;
$SC_i(t)$ = startup cost of unit i;

The startup cost depends on the duration during which the generating unit has been decommitted. A cold start-up cost is applied, if the unit has been off for a long period. A hot start-up cost is applied, if the unit has been off for a short period.

As per the two-step function, the time dependent start-up cost is simplified using H_i^{off} defined as equation (2):

$$\begin{aligned} SC_i(t) &= h\text{-}cost_i: MDT_i \le X_i^{off}(t) \le H_i^{off} \qquad (2) \\ &= c\text{-}\,cost_i: X_i^{off}(t) > H_i^{off} \end{aligned}$$

Where, $H_i^{off} = MDT_i + c\text{-}s\text{-}hour_i;$
MDT_i = minimum down time of i^{th} unit;
$h\text{-}cost_i$ = hot start cost of i^{th} unit;

c- cost$_i$ = cold start cost of i^{th} unit;
c-s-hour$_i$ = cold start hour of i^{th} unit;

For each generating unit, shut down cost is usually a constant value. In the standard systems the typical value of the shut down cost is zero.

B. Constraints

In minimizing the objective function, following constraints must be satisfied.

(a) *Power balance:*

The generated power from all the online units must fulfill the forecasted load demand, which is defined as equation (3):

$$PD\,(t) = \sum_{i=1}^{N} Pi\,(t) \qquad (3)$$

(b) *Spinning Reserve requirements:*

The spinning reserve is the additional real power generation accessible from all the synchronized unit to provide the load in the event of any fault or sudden tripping or maintaining any generating units:. The mathematical equation is expressed by equation (4):

$$\sum_{i=1}^{N} U_i\,(t).\, P_{maxi} \geq PD\,(t) + RE\,(t) \qquad (4)$$

Where, $U_i\,(t)$ = ON/OFF status of unit i at hour t;
$PD\,(t)$ = load demand in the hour t;
$RE\,(t)$ =spinning reserve requirement in the hour t;

(c) *Real power generation limits:*

The generation of the accessible unit must lie between its minimum and maximum limit. The formulation can be expressed by equations (5) and (6):

$Pmin_i \leq P_i\,(t) \leq Pmax_i$ (without ramp-rate constraint) (5)

$ModPmin_i(t) \leq P_i(t) \leq ModPmax_i(t)$ (with ramp-rate constraint) (6)

Where,
$Pmax_i$=maximum real power generation limit of unit i;
$Pmin_i$= minimum real power generation limit of unit i;
$ModPmin_i(t)$ =modified minimum generation limit of unit i at t;
$ModPmax_i(t)$ =modified maximum generation limit of unit i at t;

(d) *Unit minimum up/down time:*

Once unit is committed/decommited, there is a pre-defined minimum time after it can be decommitted/committed. The formulation of these constraints can be seen in equations (7) and (8):

$$MUT_i \leq X_i^{ON} \qquad (7)$$

$$MDT_i \leq X_i^{OFF} \qquad (8)$$

Where,
MUT_i = minimum up time of i^{th} unit;
MDT_i = minimum down time of i^{th} unit;
$X_i^{ON}(t)$ =duration for which unit i is continuously on;
$X_i^{OFF}(t)$ =duration for which unit i is continuously off;

(e) *Unit initial status:*

The initial status at the beginning of the planning period must be taken into account.

III. FIREFLY ALGORITHM

Firefly algorithm uses the following three idealized rules: (1)All the fireflies have a distinct characteristic of being attracted to other fireflies whatever may be the other's sex i.e. they are unisexual; (2) the level of the attractiveness of a firefly is related to its brightness or light intensity, therefore the less brighter one will be attracted to the brighter one for any two flashing fireflies. Both attractiveness and brightness will be more if the distance between two fireflies decreases. If no one is brighter one than a specific firefly, it will move randomly; (3) the brightness of a firefly is determined by the value of the objective function to be optimized. For a maximization problem, the intensity of light of each firefly is proportional to the value of the objective function whereas it is converse in case of minimization problem.

Firefly algorithm involves three important parameters which are given as follows.

(a) *Attractiveness and light intensity*:

There are two important points associated with the firefly algorithm: the variation of the light intensity and the formulation of the attractiveness. As the intensity of light 'I(r)' varies with distance 'r' monotonically and exponentially, that is expressed as equation (9):

$$I(r) = I_0\, e^{-\gamma r2} \qquad (9)$$

Where I_0 is the initial light intensity and γ is the light absorption coefficient. Since attractiveness of a firefly is proportional to the light intensity seen by adjacent fireflies, now the attractiveness 'β' of a firefly can be expressed by equation (10):

$$\beta(r) = \beta_0\, e^{-\gamma r2} \qquad (10)$$

(b) *Distance between fireflies*:

The distance between any two fireflies u and v at x_u and x_v respectively, can be characterized as Cartesian distance by equation (11):

$$r_{uv} = \sqrt{\textstyle\sum^{d}_{n=1}} (x_{u,n} - x_{v,n})^2 \qquad (11)$$

Where d is the number of dimensions and $x_{u,n}$ is the n^{th} component of the spatial coordinate of x_u the u^{th} firefly.

(c)*Movement of firefly*:

The movement of a firefly u is attracted by another brighter firefly v and is determined by equation (12):

$$x_u^{/} = x_u + \beta(r)\,(x_u - x_v) + \alpha\,(\text{rand}-0.5) \qquad (12)$$

Where the second term is due to the attraction while the third term indicates randomization with the randomization parameter α and rand is a random number which is uniformly distributed in [0, 1].

IV. PROPOSED ALGORITHM

The main steps of the proposed algorithm are as follows:

(1) Initialize randomly the individuals of the population (N by T matrix) and set the initial values of FF control parameters.
(2) These schedules (individuals) are checked for solution feasibility (generation >= load+reserve) in which infeasible strings are prohibited and a new random individuals are created.
(3) If the above solution is feasible, then checked for the satisfaction of minimum up time/down time constraints.
(4) Evaluate the level of attractiveness of each firefly using the equation (10).
(5) Modify the firefly position by using the equation (12).
(6) Calculate the fitness function $[F=\sum (FC_T + SC_T)]$.
(7) Selection of more brighter/attractive firefly and minimum cost.
(8) Reinsert best commitment/generation schedule for the next generation.
(9) If the maximum number of iteration is reached, the running process is stopped. Otherwise jump to step (3).

The flowchart of the proposed algorithm is presented in Fig. 1.

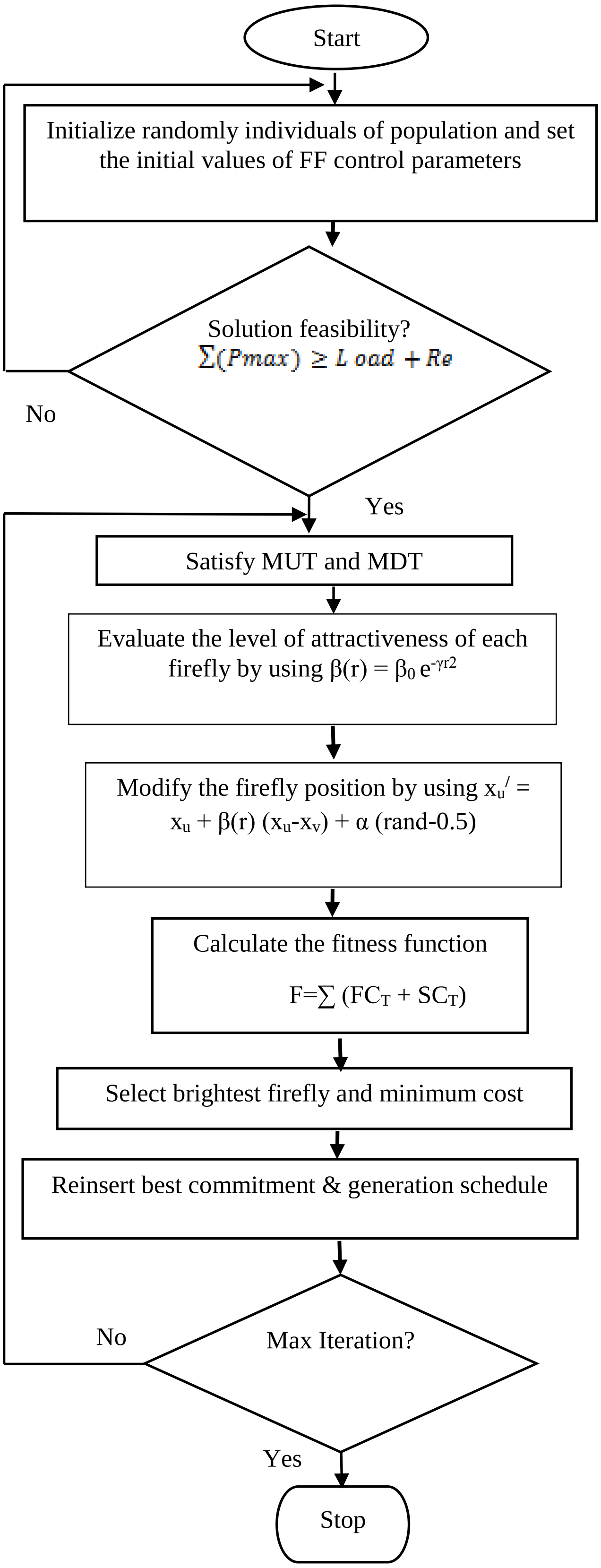

Fig.1. Flowchart of the proposed algorithm

V.RESULTS AND DISCUSSIONS

The proposed method has been tested on systems with 10, 20 and 40 generating units. The unit data and load demand data for 24 hours for the systems with 10 units has been shown in the Tables A.1 and A.2 of the appendix respectively. The data for other bigger systems has been acquired by copying the data of 10 unit system and modifying the load demand in extent to the system size. The generation-load curve is shown in Fig.2. The best production cost of the proposed method is compared with ICGA [10], SFLA [11], EPL [12] and LR [13] and shown in Table 1. The analysis of this table demonstrates that the proposed method gives global ideal solution which compares to lower production cost than that of different techniques. In this paper population size, absorption coefficient, randomness parameter, attraction coefficient base value and maximum generations for 10, 20 and 40 units has been considered as 30, 1,0.2,0.9 and 500 respectively. The final commitment schedule and generation schedule for 10 unit system are presented in the Tables 2 and 3 respectively.

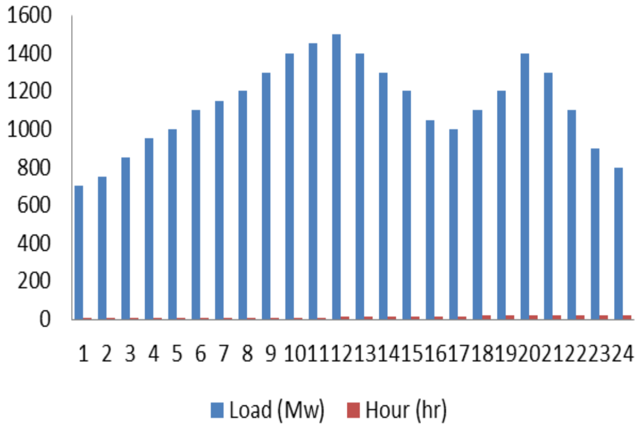

Fig. 2.Generation- load Curve

TABLE 1

No. of unit	Total Operating Cost ($)				
	ICGA [10]	SFLA [11]	EPL [12]	LR [13]	Proposed Algorithm
10	566404	564769	563977	565825	562490
20	1127244	1123261	1124369	1130660	1126900
40	2254123	2246005	2246508	2258503	2246000

TABLE 2

Hour	Unit1	Unit2	Unit3	Unit4	Unit5	Unit6	Unit7	Unit8	Unit9	Unit10
1	1	1	0	0	0	0	0	0	0	0
2	1	1	0	0	0	0	0	0	0	0
3	1	1	1	0	0	0	0	0	0	0
4	1	1	0	0	1	0	0	0	0	0
5	1	1	1	0	1	0	0	0	0	0
6	1	1	1	1	1	0	0	0	0	0
7	1	1	1	1	1	0	0	0	0	0
8	1	1	1	1	1	0	0	0	0	0
9	1	1	1	1	1	1	1	0	0	0
10	1	1	1	1	1	1	1	1	0	0
11	1	1	1	1	1	1	1	1	1	0
12	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	0	0
14	1	1	1	1	1	1	1	0	0	0
15	1	1	1	1	1	0	0	0	0	0
16	1	1	1	1	1	0	0	0	0	0
17	1	1	1	1	1	0	0	0	0	0
18	1	1	1	1	1	0	0	0	0	0
19	1	1	1	1	1	0	0	0	0	0
20	1	1	1	1	1	1	1	1	0	0
21	1	1	1	1	1	1	1	0	0	0
22	1	1	0	0	1	1	1	0	0	0
23	1	1	0	0	1	0	0	0	0	0
24	1	1	0	0	0	0	0	0	0	0

TABLE 3

Hour	Unit1	Unit2	Unit3	Unit4	Unit5	Unit6	Unit7	Unit8	Unit9	Unit10
1	455	245	0	0	0	0	0	0	0	0
2	455	295	0	0	0	0	0	0	0	0
3	455	265	130	0	0	0	0	0	0	0
4	455	455	0	0	40	0	0	0	0	0
5	455	395	130	0	20	0	0	0	0	0
6	455	360	130	130	25	0	0	0	0	0
7	455	410	130	130	25	0	0	0	0	0
8	455	455	130	130	30	0	0	0	0	0
9	455	455	130	130	80	30	20	0	0	0
10	455	455	130	130	162	38	20	10	0	0
11	455	455	130	130	162	78	20	10	10	0
12	455	455	130	130	162	85	20	43	10	10
13	455	455	130	130	162	38	20	10	0	0
14	455	455	130	130	85	25	20	0	0	0
15	455	455	130	130	30	0	0	0	0	0
16	455	315	130	130	20	0	0	0	0	0
17	455	265	130	130	20	0	0	0	0	0
18	455	360	130	130	25	0	0	0	0	0
19	455	455	130	130	30	0	0	0	0	0
20	455	455	130	130	162	33	25	10	0	0
21	455	455	130	130	80	25	25	0	0	0
22	455	455	0	0	140	25	25	0	0	0
23	455	420	0	0	25	0	0	0	0	0
24	455	345	0	0	0	0	0	0	0	0

VI. CONCLUSION

This paper has presented a firefly algorithm for determination of optimal solution of UC with respect to load demand. The feasibility of the proposed method has been implemented with the system of 10, 20 and 40 generating units in respect to load demand. Finally, the obtained result of the proposed method is compared with that of other different methods. From the results, it is observed that the proposed method provides the quality solution which is low cost.

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APPENDIX

TABLE A.1. Unit data for 10 unit system

Unit No.	pmax (MW)	pmin (MW)	a ($)	b ($/MWh)	c ($/MWh^2)	MUT (hr.)	MDT (hr.)	Hot SUC ($)	Cold SUC ($)	T Cold (hr.)	Initial cond. (hr.)
1	455	150	1000	16.19	0.00048	8	8	4500	9000	5	8
2	455	150	970	17.26	0.00031	8	8	5000	100000	5	8
3	130	20	700	16.60	0.00200	5	5	550	1100	4	-5
4	130	20	680	16.50	0.00211	5	5	560	1120	4	-5
5	162	25	450	19.70	0.00398	6	6	900	1800	4	-6
6	80	20	370	22.26	0.00712	3	3	170	340	2	-3
7	85	25	480	27.74	0.00079	3	3	260	520	2	-3
8	55	10	660	25.92	0.00413	1	1	30	60	0	-1
9	55	10	665	27.27	0.00222	1	1	30	60	0	-1
10	55	10	670	27.79	0.00173	1	1	30	60	0	-1

TABLE A.2. Load Demand Data for 10 unit system (Reserve is taken as 10% of load demand)

Hour	1	2	3	4	5	6	7	8
Demand(MW)	700	750	850	950	1000	1100	1150	1200
Hour	9	10	11	12	13	14	15	16
Demand(MW)	1300	1400	1450	1500	1400	1300	1200	1050
Hour	17	18	19	20	21	22	23	24
Demand(MW)	1000	1100	1200	1400	1300	1100	900	800