Self-Adaptive Firefly Algorithm for solving Unit Commitment Problem in Power System

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Abstract. Unit Commitment is one of the crucial challenges in power system for selecting generation units to operate the system economically. It is the necessary to propose efficient solution techniques to solve unit commitment problem. In this research work a new Self-Adaptive Firefly Algorithm is planned to solve unit commitment problem. The SAFA identifies the best generating units to be functioning and offers the amount of load distribution among the units to minimize the operating cost. In order to validate SAFA an IEEE ten unit system is considered. The simulation is carried out using Matlab software and the solutions are presented. The solutions indicates that the efficiency of proposed SAFA than other solution techniques.

1. Introduction
In recent decades, the process of Unit Commitment (UC) in power system is become increasingly popular in order to support the system for planning and reliable operation. UC is the process of scheduling the generators operation to meet the load demand effectively for every hour interval at least operating cost as satisfying system constraints. Therefore, solving unit commitment problem (UCP) in power system is essential, which aids the system operator to choose the generator units to dispatch the power to meet the demand. The UCP is a non-linear programming optimization problem, which determines the operating status of generators whilst satisfying system constraints for time limit of one day to one week [1-2].

Various optimization techniques of conventional and non-conventional algorithms are available for solving UCP. Conventional algorithms of priority list method, dynamic programming, mixed integer programming and Lagrangian Relaxation are well known methods to solve UCP. However, they suffer to provide solutions for large scale system with greater convergence rate and good optimal solutions [3-4]. Thus, the non-conventional optimization algorithms have drawn attention of power system researchers for solving UC problem. They are genetic algorithms (GA), tabu search (TS), simulated annealing (SA), particle swarm optimization (PSO), ant colony optimization (ACO), Artificial Bee colony algorithm (ABCA), Firefly Algorithm (FA) and Whale optimization algorithms (WOA) have been commonly employed for UCP [5-13].

A GA has been presented to solve UCP of hundred units and the results have compared with the solutions of lagrangian relaxation and dynamic programming. Although, the GA provides fascinating solutions to UCP, as its exploitation process is sluggish [5]. UCP has been solved into two sub
problem of combinatorial optimization problem by TS algorithm and a nonlinear programming problem through quadratic programming and the solutions presented in terms of operating cost comparisons [6]. A new approach of evolutionary programming-based SA has been presented to solve short term UCP with the objective of cost minimization subjected to variety of constraints and the comparative solutions have presented [7]. A novel approach of hybrid PSO has been implemented for solving UCP by considering several constraints to minimize the operating cost of generating stations [8]. Evolving ACO has been proposed employing GA to find optimal parameters of ACO for solving UCP. Two IEEE systems have considered for simulation to prove the feasibility of evolving ACO [9]. A binary/real coded ABCA has addressed for solving thermal UCP with the introduction of repair strategies to obtain feasible solution for generating units satisfying some constraints. The effectiveness of the ABCA has tested with two test systems by simulation results [10]. Xin-Xhe Yang developed Firefly algorithm to solve optimization problem and gains attraction by the researches to solve various engineering optimization problems [11]. Binary real coded FA has been proposed to find out ON/OFF status of generator units for a twenty-four hours’ time period and the simulation results have presented [12].

A novel meta-heuristic algorithm of binary WOA has been employed to solve UCP. Priority list and search mechanism has utilized for handling spinning reserve, minimum up/down time constraints respectively [13]. Transmission constrained UCP has been solved using a hybrid stochastic/interval approach and the solutions confirmed that the generation cost is least expensive for the generating schedule [14]. An uncertainty model has been developed for transmission constraint UCP addressing uncertainties to sustain the reliability of the system. The developed model improves the performance of interval UC and the solutions have compared with existing stochastic approach [15]. A risk/cost based UCP has formulated as a bi-objective optimization problem and solved by non-dimensional sorting backtracking search optimization algorithm. In addition to solving UCP the algorithm addressed demand and wind power uncertainties [16].

A hybrid optimization technique comprising binary successive approximation and civilized swarm optimization has been employed to solve profit based UCP. Results indicated that hybrid optimization technique offers better performance [17]. Memetic binary differential evolution algorithm has been implemented to solve profit based UCP and performances are verified by simulations on three test systems [18].

Based on the above literature, the said optimization algorithms provide fascinating solutions for solving UCP. However, their exploration and exploitation performances need to be improved. Therefore, A self-Adaptive Firefly Algorithm (SAFA) has been utilized for SVC, TCSC and multi-type FACTS placement [19-21]. SAFA bestows higher convergence rate and global optimal solutions. Thus, in this paper SAFA is considered to solve UCP.

2. Self Adaptive Firefly Algorithm (SAFA)

Firefly algorithm is a nature inspired meta-heuristic optimization algorithm for solving engineering optimization problem, which mimics the flashing behaviour of fireflies. The light intensity of two fireflies \(r\) and \(s\) decides the movement of attraction of fireflies. Light intensity of \(r\)th firefly is represented in below equation.

\[
L_I = \text{Fitness} \ (x_r)
\]

\[
\beta_{r,s} \text{ is the absorption coefficient between two fireflies and is represented as}
\]

\[
\beta_{r,s} = (\beta_{\text{max},r,s} - \beta_{\text{min},r,s}) \exp(-\gamma_r r_{r,s}^2)
\]

(2)

In equation (2) \(r_{r,s} = \text{Cartesian distance between fireflies } r \text{ and } s\).

\[
r_{r,s} = |x_r - x_s| = \sqrt{\sum_{v=1}^{nd}(x_{rv} - x_{sv})^2}
\]

(3)

Firefly position is being updated in each iteration by their movement. The movement of firefly ‘r’ in the direction of firefly ‘s’ at m-th iteration, if the light intensity of firefly ‘s’ is more than the firefly ‘s’ is presented in the below equation.

\[
x_r^{m+1} = x_r^m + \alpha \beta_{r,s} (L_I(s) - L_I(r))
\]

where \(\alpha\) is the step size.
In SAFA individual firefly decision variables includes firefly parameters such as random movement factor ($\alpha$), Absorption coefficient ($\beta_{\text{min}}$) and attractiveness parameter ($\gamma_r$). In each iterative step, these SAFA parameters are tuned by self-adaptive mechanism of SAFA and the firefly is represented as

$$x_r = [x_r^1, x_r^2, \ldots, x_r^{nd}, \alpha_r, \beta_{\text{min},r}, \gamma_r]$$

Each firefly with their parameters undergoes whole search process, however the equation (2) is modified as follows,

$$\beta_{r,s} = (\beta_{\text{max},r,s} - \beta_{\text{min},r,s}) \exp(-\gamma_r r_{s,c}^2) + \beta_{\text{min},r,s}$$

The advantage of SAFA includes less computational effort, avoiding the sub optimal solution and convergence enhancement.

### 3. Problem Formulation

The goal of unit commitment problem is to determine the schedule of generation in such a way to reduce the total operating cost by satisfying several constraints [5]. The mathematical notation for the objective of unit commitment problem is narrated as follows,

$$Min. T_c = \sum_{k=1}^{n} \sum_{j=1}^{N} F_c R_{jk} (I_{jk}) + S_c R_{jk}$$

#### 3.1. Fuel cost

It is the major operating cost of thermal and nuclear units and is presented in quadratic form.

$$F_c (P_{jk}) = A_j P_{jk}^2 + B_j P_{jk} + C_j$$

#### 3.2. Start-Up cost

The calculation of start-up cost depends upon the treatment method for the thermal unit during down time periods. The mathematical equation of the start-up cost is represented as follows,

$$S_c R_{jk} = \begin{cases} \text{hc} \text{when} T_{j}^{\text{off}} \leq X_{j}^{\text{off}} (jk) \leq T_{j}^{\text{off}} + c\text{sh}_j \\ \text{cc} \text{when} X_{j}^{\text{off}} \geq T_{j}^{\text{off}} + c\text{sh}_j \end{cases}$$

The minimization of objective function in unit commitment problem is provided with the following constraints.

#### 3.3. Power balance constraint

It is the one of the crucial constraint in UC problem. At any hour the power generation ought to be equal to demand.

$$P(k) = \sum_{j=1}^{n} P_{jk} I_{jk} = L_k$$

#### 3.4. Spinning reserve constraint

It is the total active power generation from all generators minus all loads plus losses. It is represented as follows,
\[
\sum_{i=1}^{n} P_{TG}^{\text{max}}(jt)U(jt) \geq (L_k + SR_k)
\]  
(11)

3.5. Generation constraints
Each generating units must satisfy the power generation range as follows,
\[
P_{TG}^{\text{min}}(jt) \leq P_{TG}(jt) \leq P_{TG}^{\text{max}}(jt)
\]  
(12)

3.6. Ramp constraints
The output of each generator unit is constrained by ramp up/down rate at every hour as follows,
\[
PT_G(jt) - PT_G(j,t-1) \leq RU(j)
\]
\[
PT_G(jt) - PT_G(j,t-1) \leq RD(j)
\]  
(13)

4. Simulation Results and Discussion
In this work, Self-adaptive firefly algorithm is used for solving UC problem and tested in an IEEE 10 unit system of power system. The scheduling period of 24 hours are considered. The necessary inputs for solving the UC problem of load demands, minimum and maximum real power generation and cost functions parameters are tabulated for 24 hours in table 1 and table 2 respectively. The simulation is performed on Matlab software. The simulation solutions are presented in Tables 3 and Table 4.

### Table 1. Load Demand for 24 Hours

| Time (hour) | Demand |
|-------------|--------|
| 1           | 700    |
| 2           | 750    |
| 3           | 850    |
| 4           | 950    |
| 5           | 1000   |
| 6           | 1100   |
| 7           | 1150   |
| 8           | 1200   |
| 9           | 1300   |
| 10          | 1400   |
| 11          | 1450   |
| 12          | 1500   |
| 13          | 1400   |
| 14          | 1300   |
| 15          | 1200   |
| 16          | 1050   |

| Time (hour) | Demand |
|-------------|--------|
| 17          | 1000   |
| 18          | 1100   |
| 19          | 1200   |
| 20          | 1400   |
| 21          | 1300   |
| 22          | 1100   |
| 23          | 900    |
| 24          | 800    |

### Table 2. Operation Data for the Ten Unit

| Unit | \(P_{\text{min}}^{\text{MW}}\) | \(P_{\text{max}}^{\text{MW}}\) | a ($/hr) | b ($/Mhr) | C ($/M^3\text{hr}) | SC (Hot) $ | SC (cold) $ | T_{on} (hr) | T_{off} (hr) |
|------|-------------------------------|-----------------------------|--------|---------|------------------|-----------|-----------|----------|----------|
| 1    | 150                           | 455                         | 1000   | 16.19   | 0.00048          | 4500      | 9000      | 8        | 8        |
| 2    | 150                           | 455                         | 970    | 17.26   | 0.00031          | 5000      | 10000     | 8        | 8        |
| 3    | 20                            | 130                         | 700    | 16.60   | 0.00200          | 550       | 1100      | 5        | 5        |
| 4    | 20                            | 130                         | 680    | 16.50   | 0.00211          | 560       | 1120      | 5        | 5        |
| 5    | 25                            | 162                         | 450    | 19.70   | 0.00399          | 900       | 1600      | 6        | 6        |
| 6    | 20                            | 80                          | 370    | 22.26   | 0.00712          | 170       | 340       | 3        | 3        |
| 7    | 25                            | 85                          | 480    | 27.74   | 0.00719          | 260       | 520       | 3        | 3        |
| 8    | 10                            | 55                          | 660    | 25.92   | 0.00413          | 30        | 60        | 1        | 1        |
| 9    | 10                            | 55                          | 665    | 27.27   | 0.00222          | 30        | 60        | 1        | 1        |
| 10   | 10                            | 55                          | 670    | 27.79   | 0.00173          | 30        | 60        | 1        | 1        |
### Table 3. Power Dispatch of 10 Unit System for 24 Hrs by SAFA

| Hours | U1  | U2  | U3  | U4  | U5  | U6  | U7  | U8  | U9  | U10 |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1     | 440 | 259.5 | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 2     | 425.4 | 324   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 3     | 420 | 405.8 | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 4     | 430 | 406.3 | 0   | 0   | 113.5 | 0   | 0   | 0   | 0   | 0   |
| 5     | 440 | 454.6 | 0   | 0   | 104.2 | 0   | 0   | 0   | 0   | 0   |
| 6     | 441.2 | 442.4 | 105.8 | 110.5 | 0   | 0   | 0   | 0   | 0   | 0   |
| 7     | 454.2 | 394.4 | 109.8 | 128.7 | 34.8 | 0   | 0   | 0   | 0   | 0   |
| 8     | 443.8 | 380.56 | 115.2 | 113.5 | 145.2 | 0   | 0   | 0   | 0   | 0   |
| 9     | 454.5 | 456.2 | 128.6 | 130.2 | 110 | 0   | 20.5 | 0   | 0   | 0   |
| 10    | 444 | 421.2 | 121.4 | 125.8 | 160 | 77 | 0   | 0   | 49 | 0   |
| 11    | 443 | 453 | 127.5 | 122 | 150 | 75 | 80 | 0   | 0   | 0   |
| 12    | 450 | 450 | 140 | 130 | 161.3 | 78.9 | 20.8 | 55 | 0   | 0   |
| 13    | 429.4 | 450 | 124.2 | 123.1 | 152.8 | 45 | 0 | 69.2 | 0 | 0   |
| 14    | 435.4 | 420.8 | 113.2 | 129.5 | 150.8 | 0 | 0 | 0 | 50 | 0   |
| 15    | 448.2 | 445.2 | 115.4 | 120.2 | 0 | 71 | 0 | 0 | 0 | 0   |
| 16    | 452.1 | 448.5 | 135 | 0 | 0 | 0 | 0 | 0 | 0 | 0   |
| 17    | 420.2 | 405.2 | 115.2 | 0 | 0 | 59 | 0 | 0 | 0 | 0   |
| 18    | 364.5 | 400.2 | 105.2 | 67.2 | 140.2 | 0 | 0 | 0 | 0 | 0   |
| 19    | 406.8 | 450.2 | 0 | 118.2 | 150.2 | 74.2 | 0 | 0 | 0 | 0   |
| 20    | 433.8 | 440.2 | 120.1 | 108.5 | 146.2 | 70.1 | 79.2 | 0 | 0 | 0   |
| 21    | 445.4 | 419.5 | 115.8 | 90.5 | 156.2 | 71.2 | 0 | 0 | 0 | 0   |
| 22    | 440.2 | 427.5 | 125.4 | 105.2 | 0 | 0 | 0 | 0 | 0 | 0   |
| 23    | 381.8 | 430.2 | 57.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0   |
| 24    | 448.5 | 351.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0   |

### Table 4. Unit Commitment Schedule

| Hour | U1 | U2 | U3 | U4 | U5 | U6 | U7 | U8 | U9 | U10 |
|------|----|----|----|----|----|----|----|----|----|-----|
| 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  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0   |
| 4    | 1  | 1  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0   |
| 5    | 1  | 1  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0   |
| 6    | 1  | 1  | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0   |
| 7    | 1  | 1  | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0   |
| 8    | 1  | 1  | 1  | 1  | 1  | 0  | 0  | 0  | 0  | 0   |
| 9    | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 0  | 0  | 0   |
| 10   | 1  | 1  | 1  | 1  | 1  | 0  | 0  | 1  | 0  | 0   |
| 11   | 1  | 1  | 1  | 1  | 1  | 1  | 0  | 0  | 0  | 0   |
| 12   | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 0  | 0  | 0   |
| 13   | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 0  | 0  | 0   |
| 14   | 1  | 1  | 1  | 1  | 1  | 0  | 0  | 0  | 1  | 0   |
| 15   | 1  | 1  | 1  | 1  | 0  | 1  | 0  | 0  | 0  | 0   |
| 16   | 1  | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0   |
Table 5 presents information about fuel cost and start-up cost for 24 hours time duration. The total fuel cost obtained as 550129.3 ($ and start-up cost is 6520($). The total operating cost obtained by purposed SAFA is 556649.3($). It can be noticed from table 5 that the operating cost for maximum load of 1500MW at twelfth hour is 32615.2 ($). Similarly the operating cost for Minimum load 700 W at first hours is 13208.5 ($). Table 6 indicates the comparison of total operating cost and computational time obtained by different solution techniques. It is obvious from the comparisons the proposed SAFA offers less operating cost of 556649.3 ($ as well as computational time than other solution techniques.

| Time (h) | Fuel cost ($) | Start-up cost ($) | Time (h) | Fuel cost ($) | Start-up cost ($) |
|----------|---------------|-------------------|----------|---------------|-------------------|
| 1        | 13208.5       | 0                 | 13       | 29515.4       | 0                 |
| 2        | 14570.5       | 0                 | 14       | 27065.2       | 60                |
| 3        | 16250.8       | 0                 | 15       | 23960.5       | 1110              |
| 4        | 18457.2       | 0                 | 16       | 20660.2       | 0                 |
| 5        | 19102.8       | 0                 | 17       | 19120.5       | 0                 |
| 6        | 24540.7       | 1220              | 18       | 21660.5       | 1780              |
| 7        | 23545.2       | 0                 | 19       | 24345.3       | 320               |
| 8        | 24153.2       | 0                 | 20       | 29540.1       | 0                 |
| 9        | 26812.4       | 1160              | 21       | 26700.2       | 0                 |
| 10       | 29706.5       | 850               | 22       | 21485.1       | 0                 |
| 11       | 30615.2       | 0                 | 23       | 17460.7       | 0                 |
| 12       | 32615.2       | 60                | 24       | 15037.4       | 0                 |

Table 6. Comparison of Total Cost and Computation Time

| Solution Techniques | Total cost ($) | computation time (s) |
|---------------------|---------------|----------------------|
| GA [5]              | 565825        | 221                  |
| HPSO[8]             | 563942.3      | -                    |
| ACO[9]              | 563938        | -                    |
| BRABC[10]           | 563,937.72    | 140                  |
| BWOA[13]            | 563,936.02    | -                    |
| SAFA                | 556649.3      | 136                  |

Figure 1 presents the variation of power generation with actual load offered by the SAFA. It can be seen from the figure that the power generation is almost equal to the load demand throughout the time period of 24 hours. Figure 2 indicates the variation of fuel cost for twenty four hour duration. It can be seen from the figure that fuel cost is higher at twelfth hour of the day since power demand is higher at the same hour.
5. Conclusion
In this work self unit commitment problem is solved using SAFA. The SAFA identifies the generating units to be functioning and offers the amount of load distribution among the units to minimize the operating cost. An IEEE ten unit system is considered to validate the proposed SAFA. The simulation is performed using Matlab software and the solutions are presented. It is witnessed from the solutions that the SAFA identifies the generating units to be functioning in order to meet the load with minimal operating cost than other solution techniques. The reliability of the proposed SAFA is evaluated by comparing the total operating cost and computational time with other solution techniques. The solutions prove that the efficacy of proposed SAFA than other optimization techniques.

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