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A solution to unit commitment problem using fire works algorithm

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ABSTRACT

This paper presents a new approach using swarm intelligence algorithm called Fireworks Algorithm applied to determine Unit Commitment and generation cost (UC) by considering prohibited operating zones. Inspired by the swarm behaviour of fireworks, an algorithm based on the explosion (search) process and the mechanisms of keeping the diversity of sparks has been developed to minimize the total generation cost over a given scheduled time period and to give the most cost-effective combination of generating units to meet forecasted load and reserve requirements, while adhering to generator and transmission constraints. The primary focus is to achieve better optimization while incorporating a large and often complicated set of constraints like generation limits, meeting the load demand, spinning reserves, minimum up/down time and including more realistic constraints, such as considering the restricted/prohibited operating zones of a generator. The generating units have certain ranges where operation is restricted based upon physical limitations of machine components or instability, e.g., due to steam valve or vibration in shaft bearings. Therefore, prohibited operating zones as a prominent constraint must be considered. In this paper the incorporating of complicated constraints of an optimization problem into the objective function is not considered by neglecting the penalty term. Numerical simulations have been carried out on 10 – unit 24 – hour system.

Introduction

In the recent past different types of optimization problems were considered and solved, according to the energy industry process that is involved; typically, generation, transmission and distribution of electricity, or a combination of them. The optimization problems are characterized by an objective function, variables and constraints. Generally, the economic efficiency or the utility profits curves are formulated as objective functions, system operating and other technical requirements are considered as constraints, while the variables are used to model decisions, which can be taken in long-term, medium-term, short-term or online periods.

Unit commitment problem

- In a long-time period (months and years), the Power Expansion Problem is solved, in order to determine the type, the capacity and the number of generating units that the energy system should have.
- In a medium-term period (days and weeks), the objective is to determine the best combination of generating units in terms of their status (committed or uncommitted) and their output (power). This schedule has to satisfy the forecast demand at minimum total production cost, under the operating, technical and environmental system constraints. This problem is known as Unit Commitment Problem (UC).
- In a short-term and online period (hours and minutes), the Economic Dispatch Problem (ED) is solved, in order to determine the power that each unit, scheduled in the previous phase (solving the UC problem) must produce in order to meet the real time system demand.

The Unit Commitment is one of the most important problems to be solved in order to obtain a proper energy production scheduling. The objective of this problem is to determine a combination of the available electrical generators, scheduling their respective outputs in order to satisfy the forecast load demand at minimum total production cost in a specific time period, which usually varies from 24 h to one week. The scheduling problem was solved by considering not only minimization of production cost, but also should satisfy the operating constraints of the whole electrical system. These constraints reduce the freedom in the choice of starting-up or

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Nomenclature

C_T	total fuel cost of generators
C_i	fuel input cost function of ith generator
P_i	output power of the ith generator
$U\,(i,t)$	status of the generator (for ON, $U = 1$ and for OFFU = 0)
$SU\,(i,t)$	startup cost of the ith generator at t hour
$SD\,(i,t)$	shutdown cost of the ith generator at t hour
T	number of hours
N	total number of generators
$a_0,\ a_1,\ a_2$	fuel cost coefficient of the units
P_D	total load demand
P_L	total transmission loss
P_i	generated power level from each unit
P_i^{min}	minimum power output of unit i
P_i^{max}	maximum power output of unit i
MT_i^{ON}	duration during which the ith unit is continuously on
T_i^U	minimum up time
MT_i^{OFF}	duration during which the ith unit is continuously off
T_i^D	minimum down time
$P_{i,t}$	output power of unit i at t hour
D_t	demand during hour t
SR_t	spinning reserve requirement at time t
$u_{i,t}$	ON/OFF status of unit i at hour t
$P_{i,k}^l$	lower bounds of the kth prohibited zone of unit i
$P_{i,k}^u$	upper bounds of the kth prohibited zone of unit i
X_i	number of prohibited zones of unit i
s_i	number of sparks generated
$\hat{A}$	maximum explosion amplitude
y_{max}	fitness of the worst individual
$f(x_i)$	fitness of individual x_i
T_i^1	duration of last cycle of the previous scheduling day
PT_i^{k-1}	number of hours pending after the last cycle

shutting-down the units. Usually, the constraints that have to be satisfied are related with the status of the units, to the minimum up time and minimum down time of the units, to the capacity and power production limits, to the maximum ramp up rate and to the maximum ramp down rate, to the spinning reserve, and to the other operating characteristics.

Literature survey

Traditionally, the UC problem has been solved considering only thermal units to determine when generators should beturned on or off and how to dispatch their production output in order to meet the system demand and spinning reserve requirements. The resultant schedule should satisfy technical operating constraints of units such as production and ramping limits and minimum up and down time requirements, over a specific short-term time horizon, minimizing the total operation cost. Currently, the solution of the traditional UC problem is important in the new competitive power industry, for this reason, more accurate models and more efficient methods to determine a proper power production scheduling are required in order to fulfil new requirements in the current power systems environment. UC has been an active research topic for several decades (over 30 years) due to the potential savings in operation costs that could be obtained by properly solving the problem.

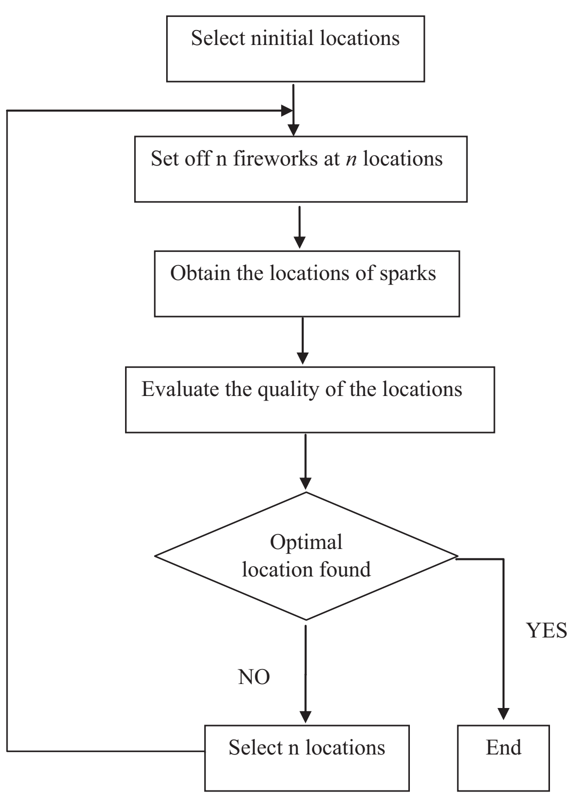

Fig. 1. Flowchart of general Fireworks Algorithm (FWA).

To solve the UC problem several solution techniques have been proposed such as Dynamic Programming, Decommitment method [1] and Lagrangian Relaxation [2], heuristic methods, mixed-integer linear programming approaches, simulated annealing and evolution-inspired approaches. The Exhaustive Enumeration approach was one of the earliest methods to be applied to solve the UC problem. This method is not suitable to solve UC problems in large scale systems, since the computational effort increases when a high number of units are considered. DP techniques as well as Lagrangian relaxation methods are among the first optimization techniques to be used extensively to solve the UC problems at industry level. The UC can be formulated and solved using Linear Programming approaches. Over the years, several models of Artificial Neural Networks (ANNs) [3] have been developed in order to model the behaviour of biological neural networks and the associated learning algorithms have been developed, and recently applied to solve combinatorial optimization problem such as the UC Problem. An Ant algorithm [4] inspired by the behaviour of the ants, have been applied to solve combinational optimization problems like UC. Nature inspired heuristic approaches such as Tabu Search [5], Branch and Bound methods [6] have been developed to solve the same UC problem. Over the last 30 years systems based on the principles of evolution and machine learning are gaining momentum. These methodologies maintain a population of potential solutions and they have a selection process based on the fitness of the individuals and some genetic operators. Genetic algorithms [7] which are involved in these systems imitate the evolution strategies and the principles of natural evolution in order to solve optimization problems, such as the UC for both small and

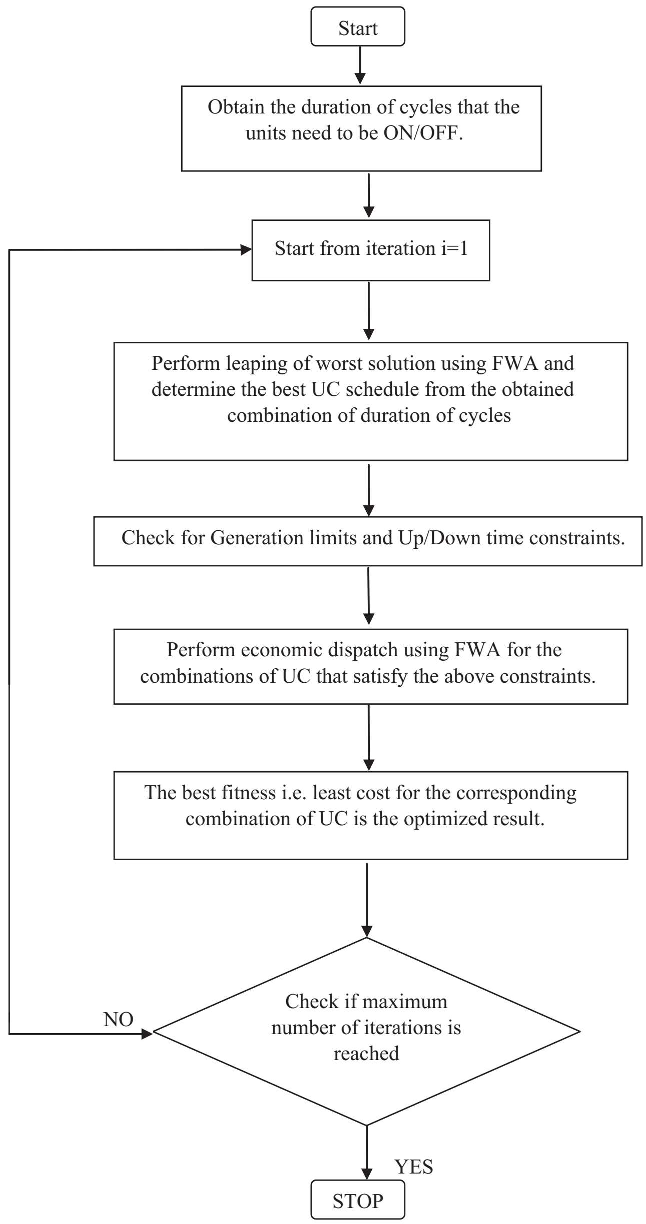

Fig. 2. FWA implementation on UC problem.

large size systems. Similarly genetic algorithms, an evolutionary algorithm approach the Particle Swarm Optimization (PSO) [8], an evolutionary optimization tool of swarm intelligence field based on swarm population where each member is seen as a particle, and each particle has a potential solution to the problem under analysis. All evolutionary Programming are also applied to Profit Based unit Commitment problems [14,15]. Fireworks Algorithm is one such swarm optimization algorithms recently developed and is being applied to solve the UC problem for the first time.

Problem formulation

Objective function

The objective of UCP is to find optimal combination of power generations that minimizes total cost generation while satisfying different equality and inequality constraints. Thus, the optimization problem is formulated as follows.

$$C_T = \text{Min} \sum_{t=1}^{T}\sum_{i=1}^{N} C_i(P_i)U(i,t) + SU(i,t) + SD(i,t), \quad i,t \in N \tag{1}$$

Fuel cost of the generating thermal unit is expressed as a second order approximate function of its output P_i.

$$(P_i) = a_0 + a_1 P_i + a_2 P_i^2 \tag{2}$$

Startup cost: The minimum cost required to start a generator from cold state.

Shut down cost: The minimum cost required to bring already ON generator to OFF cold state.

Operational limitations and constraints

The minimization of the objective function is subjected to a number of system and unit constraints such as: power balance, spinning reserve capacity of generating units, prohibited operating zones, minimum up/down time limit as well as spinning reserve requirement. Although ramp rate is one of the important parameters which has to be taken into account the effect of the same is not considered in this case considered for the study because by introducing prohibited operating zone the ramp rate limit of the generator was taken care.

Initial condition: Initial conditions of generating units include the number of hours that a unit consequently has been ON/OFF and its generation output at an hour before the scheduling.

Power balance constraint:

$$\sum_{i=1}^{N}(P_i) = P_D + P_L, \quad i \in N \tag{3}$$

Generation limits: The generating capacity constraint is given by

$$P_i^{min} \leqslant P_i \leqslant P_i^{max} \tag{4}$$

Minimum up time limit: The minimum number of hours for which a committed unit should be turned on.

$$MT_i^{ON} \geqslant T_i^U \tag{5}$$

Minimum down time limit: The minimum number of hours for which a de-committed unit should be turned off.

Table 1
System input data.

Unit	P_{max} (MW)	P_{min} (MW)	a_0	a_1	a_2	T_{up} (h)	T_{down} (h)	S_{hr} ($)	S_{cr} ($)	T_{cold} (h)	Init.status	Prohibited operating zones
1	455	150	1000	16.19	0.00048	8	8	4500	9000	5	8	[150,165], [448,453]
2	455	150	917	17.26	0.00031	8	8	5000	10,000	5	8	[90,110], [240,250]
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	[20,30], [40,45]
9	55	10	665	27.27	0.00222	1	1	30	60	0	−1	–
10	55	10	770	27.79	0.00173	1	1	30	60	0	−1	[12,17], [35,45]

Table 2
Load data for 24 h.

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

Table 3
Initial cycle values.

Units	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
1	12	−9	3	0	0
2	13	−10	1	0	0
3	−16	7	−1	0	0
4	−5	14	−5	0	0
5	−8	7	−6	0	0
6	−23	1	0	3	0
7	−18	3	−3	0	0
8	−6	6	−5	2	−5
9	−16	2	−3	3	0
10	−14	2	−3	3	−2

Table 4
Updated cycle values.

Units	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
1	24	0	0	0	0
2	24	0	0	0	0
3	−2	21	−1	0	0
4	−3	18	−3	0	0
5	−4	10	−6	3	−1
6	−8	6	−5	3	−2
7	−17	3	−4	0	0
8	−6	6	−5	3	−4
9	−11	1	−9	2	−1
10	−4	1	−14	3	−2

$$MT_i^{OFF} \leqslant T_i^D \tag{6}$$

Spinning reserve: It is the reserve capacity of the unit which is ready to take the load and it is assumed in this work as 10% of the total generation capacity

$$\sum_{i=1}^{N}(P_{i,t}) * u_{i,t} \geqslant D_t + SR_t, \quad 1 \leqslant t \leqslant T, \;\; i \in N \tag{7}$$

Prohibited Operating Zones (POZ): Because of the mechanical stress or a vibration in a shaft bearing, there may result interference and discontinuities in input–output performance-curve sections, called prohibited operating zones. Therefore in practical cases the generation output of a unit must avoid all capacity limits and unit operations in the POZ [9]. The feasible operating zones of unit i can be described as

$$P_i \in \begin{cases} P_i^{min} \leqslant P_i \leqslant P_{i,1}^l \\ P_{i,k-1}^u \leqslant P_i \leqslant P_{i,k}^l & k = (2,3\ldots X_i) \\ P_{i,X_i}^u \leqslant P_i \leqslant P_i^{max} \end{cases} \tag{8}$$

Fireworks algorithm

The Fireworks Algorithm (FWA) [10] is a recently developed swarm intelligence algorithm based on simulating the explosion process of fireworks. In analogy with real fireworks exploding and illuminating the night sky, the fireworks in FWA are let off to the potential search space. For each firework, an explosion process is initiated and a shower of sparks fills the local space around it. Fireworks as well as the newly generated sparks represent potential solutions in the search space. Similar to other optimization algorithms, the goal is to find a good (ideally the global) solution of an optimization problem with bound constraints in the form

$$\min x \in f(x), \quad \text{where } f : R^N \to R \tag{9}$$

Which is a nonlinear function.

FWA presents a new search manner which searches the potential space by a stochastic explosion process within a local space.

Steps followed in general FWA

Step 1: The sparks are randomly selected in the search space within the boundaries and are set off.

Step 2: The number of sparks (s_i) generated by each firework (x_i) is defined by the following equation

$$s_i = m * \frac{y_{max} - f(x_i) + \xi}{\sum_{i=1}^{n}(y_{max} - f(x_i)) + \xi} \tag{10}$$

where m is a parameter controlling the total number of sparks generated by the n fireworks, y_{max} = max (f (x_i)) (i = 1, 2, ..., n) is the maximum (worst) value of the objective function among the n fireworks, and, ξ which denotes the smallest constant in the computer, is utilized to avoid zero-division-error.

Step 3: The amplitude of explosion for each firework is also simultaneously calculated by the equation that follows

$$A_i = \hat{A} * \frac{f(x_i) - y_{min} + \xi}{\sum_{i=1}^{n}(f(x_i) - y_{min}) + \xi} \tag{11}$$

where $\hat{A}$ denotes the maximum explosion amplitude and y_{min} = min (f (x_i)) (I = 1, 2, ..., n) is the minimum (best) value of the objective function among the n fireworks.

Step 4: Imitating the explosion process, a spark's location x_j is first generated. Then if the obtained location is found to fall out of the potential space, then it is mapped to the potential space by calculating explosion displacement (h) as follows

$$h = A_i * rand(-1, 1) \tag{12}$$

Step 5: For each location spark value is updated by

$$x_i = x_i + h \tag{13}$$

$$\text{If } x_i < x_i^{min} \text{ or } x_i > x_i^{max}$$
$$\text{Then } x_i = x_i^{min} + x_i\%(x_i^{max} - x_i^{min}) \tag{14}$$

Step 6: The current best location x_i, upon which the objective function $f(x_i)$ is optimal among current locations, is always kept for the next explosion generation. The best individual is selected for next generation and the other individuals are selected by probability function $p(x_i)$ as follows

$$p(x_i) = \frac{y_{max} - f(x_i)}{\sum_{i \in k}(y_{max} - f(x_i))} \tag{15}$$

where y_{max} is the fitness of the worst individual and $f(x_i)$ is the fitness of individual x_i. Fig. 1 shows the detail step by step algorithm of the above explained FWA algorithm.

Application of FWA to UC problem

Spark definition

- The position of the sparks in the explosion search space in the integer coded FWA that means the sequence of ON/OFF of each unit is represented by the integer numbers ranging between $[-T,+T]$ where T is the scheduling time.
- A positive integer signifies that the unit is ON while a negative integer signifies that the unit is OFF for the cycle duration.
- The number of a unit's "ON/OFF" cycles depends on the number of load peaks during the UC horizon and the sum of the minimum up and down times of the unit.

Initial population of sparks

The durations of the units operation first cycle, T_i^0 are initially determined randomly so that the unit remains in the same operating mode (ON/OFF) of the last cycle of the previous scheduling day for at least as many hours as required to satisfy the minimum up/down-time constraints:

$$T_i^1 = \begin{cases} +Rand(\max(0, UT_i - T_i^0), T), & \text{if } \left(T_i^0 > 0\right) \\ -Rand(\max(0, DT_i - T_i^0), T), & \text{if } \left(T_i^0 < 0\right) \end{cases} \tag{16}$$

The durations of cycles are determined by the following equations.

If the duration of the previous cycle is a positive number which means the unit was ON in the previous cycle then,

$$T_i^k = \begin{cases} -Rand(DT_i, PT_i^{k-1}), & \text{if } \left(PT_i^{k-1} > DT_i\right) \\ -PT_i^{k-1}, & \text{otherwise} \end{cases} \tag{17}$$

If the duration of the previous cycle is a negative number which means the unit was OFF in the previous cycle then,

$$T_i^k = \begin{cases} +Rand(UT_i, PT_i^{k-1}), & \text{if } (PT_i^{k-1} > UT_i) \\ +PT_i^{k-1}, & \text{otherwise} \end{cases} \tag{18}$$

In some cases, it is possible that the scheduling hours are met within $k < K$ cycles itself. Then in that case, the values from $k + 1$ to K are given as zero.

Table 5
Unit commitment schedule for 10 unit 24 h system.

Unit (h)	1	2	3	4	5	6	7	8	9	10
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	1	1	0	0	0	0	0	0
5	1	1	1	1	1	0	0	0	0	1
6	1	1	1	1	1	0	0	0	0	0
7	1	1	1	1	1	0	0	1	0	0
8	1	1	1	1	1	0	0	1	0	0
9	1	1	1	1	1	1	0	0	0	0
10	1	1	1	1	1	1	0	1	0	0
11	1	1	1	1	1	1	0	1	0	0
12	1	1	1	1	1	1	0	1	1	0
13	1	1	1	1	1	1	0	0	0	0
14	1	1	1	1	1	1	0	0	0	0
15	1	1	1	1	0	0	0	0	0	1
16	1	1	1	1	0	0	0	0	0	1
17	1	1	1	1	0	0	0	0	0	0
18	1	1	1	1	0	0	0	1	0	0
19	1	1	1	1	0	0	1	1	0	0
20	1	1	1	1	0	1	1	1	0	1
21	1	1	1	1	1	1	1	0	0	1
22	1	1	1	0	1	1	0	0	1	1
23	1	1	1	0	1	0	0	0	1	0
24	1	1	0	0	0	0	0	0	0	0

Leaping of worst solution

- An iterative approach is incorporated in order to determine the best optimal solution. Then a matrix is chosen from the generated iterations that is closest to the optimum solution. The values of cycle durations are updated simultaneously.
- Since each time the duration of cycles are altered, the sum of these cycle duration values will not add up to the scheduling horizon. Therefore we scale the obtained values after leaping so that the total sum of the duration is again equal to the total number of hours. Since rand generates a number between 0 and 1 and since the duration of cycles can only be integers, we round off the obtained values to the nearest integer. In order to avoid the change of the sum of cycle durations due to the rounding off values, last non-zero integer in the cycle values is changed into the number of pending hours after the summation till the previous cycle durations.

$$T_i^l = T - \sum_{i=1}^{l-1} T_i^g \quad \text{where } i = 1, 2, \ldots, N \tag{19}$$

Satisfying minimum up/down constraints

- After the updation of new values there is a possibility that for certain duration cycles, the values violate the minimum up/-down time constraints. So UDT is checked for each cycle duration for each unit.
- For $T_i^1 > 0$ and if $T_i^1 < \max(0, UT_i - T_i^0)$, then the duration of cycles 1 and 2 of unit i are changed as follows

$$\begin{cases} T_i^2 = T_i^2 - T_i^1 + \max\left(0, UT_i - T_i^0\right) \\ T_i^1 = \max\left(0, UT_i - T_i^0\right) \end{cases} \tag{20}$$

- For $T_i^1 < 0$ and if – $T_i^1 < \max(0, DT_i + T_i^0)$, then the duration of cycles 1 and 2 of unit i are changed as follows

$$\begin{cases} T_i^2 = T_i^2 - T_i^1 - \max\left(0, DT_i + T_i^0\right) \\ T_i^1 = \max\left(0, DT_i + T_i^0\right) \end{cases} \tag{21}$$

- The duration of rest of the cycles that contain non-zero values are then checked for UDT.
- If the unit is ON in the previous cycle(positive number) then,

$$\begin{cases} T_i^{k+1} = T_i^{k+1} - T_i^k + UT_i \\ T_i^k = UT_i \end{cases} \tag{22}$$

- If the unit is OFF in the previous cycle(negative number) then,

$$\begin{cases} T_i^{k+1} = T_i^{k+1} - T_i^k + DT_i \\ T_i^k = DT_i \end{cases} \tag{23}$$

The matrix of cycle durations is updated and converted into binary number combinations of 1's and 0's to get unit commitment schedule. Then economic dispatch programming is performed on the binary table.

Fitness function evaluation

After obtaining the binary table closest to the optimal Economic Dispatch is performed with those combinations [13]. The Fireworks Algorithm is also applied to the economic dispatch. The total fuel cost in terms of $ for each hourly combination of units that satisfy the load demand is found out and simultaneously the start-up and the shut-down costs are included in the objective function.

Table 6
Generation dispatch, fuel cost and startup cost of 10 unit 24 h system.

Unit (h)	1	2	3	4	5	6	7	8	9	10	Total gen (MW)	Fuel cost ($)	Startup cost ($)	Reserve %
1	372	328	0	0	0	0	0	0	0	0	700	13,784	0	30
2	331	419	0	0	0	0	0	0	0	0	750	14,555	0	21.33
3	419	385	46	0	0	0	0	0	0	0	850	16,924	550	22.35
4	327	390	128	105	0	0	0	0	0	0	950	19,265	560	23.16
5	411	385	11	65	0	0	0	0	0	0	1000	20,621	0	17
6	422	387	100	45	146	0	0	0	0	0	1100	22,409	900	21.09
7	434	414	79	66	111	0	0	46	0	0	1150	23,706	60	20.60
8	446	440	126	68	67	0	0	53	0	0	1200	24,626	0	15.58
9	443	429	127	91	147	63	0	0	0	0	1300	25,190	340	0.094
10	454	450	110	128	159	74	0	31	0	0	1400	27,628	30	4.78
11	455	455	130	130	162	78	0	40	0	0	1450	30,296	0	1.17
12	455	455	130	130	162	80	0	55	33	0	1500	31,142	240	0.015
13	455	455	130	130	162	68	0	0	0	0	1400	27,824	0	0.857
14	455	451	113	99	158	24	0	0	0	0	1300	26,321	0	8.61
15	455	455	130	130	0	0	0	0	0	30	1200	22,951	60	0.03
16	393	431	108	73	0	0	0	0	0	45	1050	22,460	0	21.42
17	411	384	79	126	0	0	0	0	0	0	1000	21,397	0	0.19
18	426	442	89	110	0	0	0	33	0	0	1100	21,247	30	0.15
19	437	434	127	90	0	0	75	37	0	0	1200	24,596	580	9.17
20	447	437	127	125	0	78	84	53	0	49	1400	30,547	400	0.04
21	419	409	125	121	107	19	69	0	0	31	1300	28,423	0	12.85
22	392	410	117	0	121	0	0	0	31	19	1100	21,007	60	0.23
23	387	311	22	0	162	0	0	0	18	0	900	19,164	0	39.6
24	440	360	0	0	0	0	0	0	0	0	800	14,621	0	50.875
											Total	550,704	3810	

Table 7
Comparison of FWA with other algorithms.

Method	Total start-up cost ($)	Total production cost ($)	Total operational cost ($)
GA	–	–	565825.00
PSO	2095	562899.00	565804.00
HPSO	4090	559852.30	563942.30
SFLA	4090	559847.70	563937.70
IWO	4790	557495.00	562285.00
FWA	**3810**	**550704.00**	**554514.00**

Also included are Start-up costs when the unit is switched ON and shut down costs when the unit is switched OFF. If any generation value falls within the prohibited operating zones then they are replaced by the upper or lower limit of the restricted operating zones of that respective generating unit. The above steps are explained in Fig. 2 as flowchart.

Case study: 10 – Unit 24 – hour system

In this section, in order to test the FWA algorithm 10 unit system which is shown in Table 1 is used. The load for 24 h is also given in Table 2. Here the total period is considered into five cycles based on five peaks obtained in the load data. The initial values and updated values of these are given in Tables 3 and 4 respectively. The updated values are those where the total fuel cost for the combination is minimum. Table 5 gives the detail ON/OFF of each and every unit for 24 h based on Table 4 output. After finding the UC value the economic dispatch output is computed using same algorithm and the corresponding values are listed in Table 6. The available spinning reserve for various hours also shown in Table 6. The validation of the output is given in Table 7.

Validation of results

The obtained production cost by using fireworks algorithm is compared with other known algorithms like GA [7], PSO [8], SFLA [11] and IWO [12] in Table 7. Also Graphs comparing fuel costs are plotted using Microsoft Excel 2013 for FWA vs SFLA, FWA vs PSO and FWA vs IWO in Figs. 4–6 respectively.

The number of cycles is chosen to be 5 for this system because the load demand graph shown in Fig. 3 has 5 sharp points including the first and the last hour values. This varies depending upon the system and the load data. The more number of iterations of cycle values carried out before choosing the best and the search field in FWA gives the better optimized values than other evolutionary algorithms like PSO, SFLA, and IWO

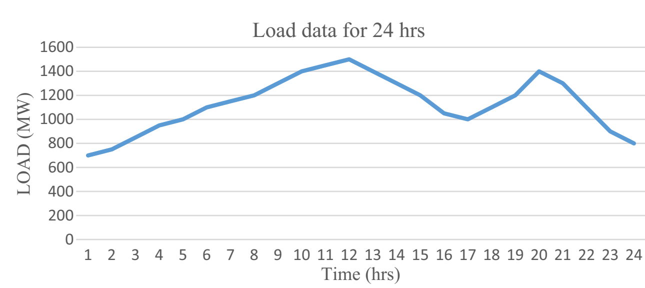

Fig. 3. Load data for of 10 unit 24 h system.

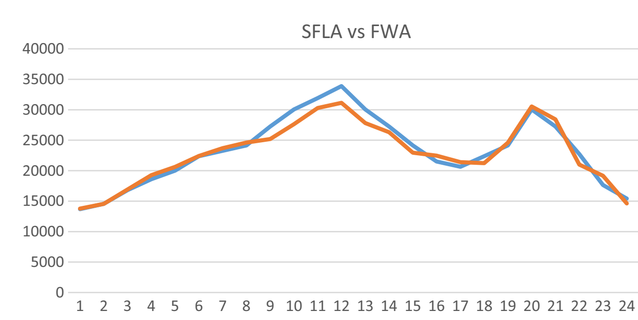

Fig. 4. Comparison of fuel cost between SFLA and FWA.

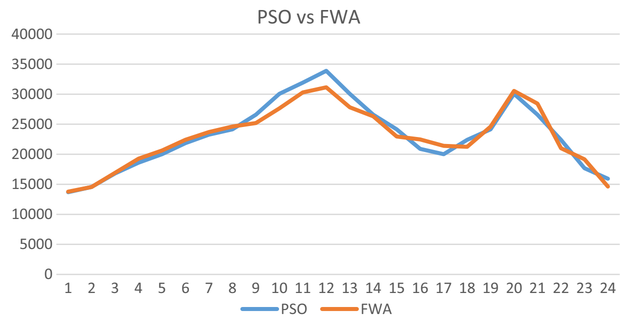

Fig. 5. Comparison of fuel cost between PSO and FWA.

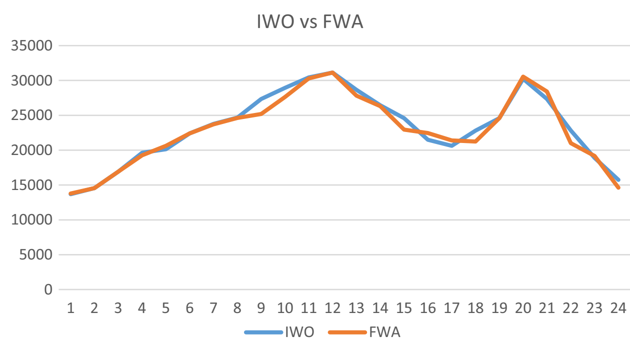

Fig. 6. Comparison of fuel cost between IWO and FWA.

Conclusion

Unit commitment is one of the decision making problem in power system to attain the main objective of minimizing the cost of operation of generator by selecting the combination or group of generator ON/OFF after meeting all the constraints. In this paper the UC problem was solved by considering one of the important constraints named prohibited operating zone (POZ). The FWA algorithm was used to find the combination and the same was used to solve economic dispatch problem where we found the level of generation of each generator which are ON. This method shows that there is no need to use the penalty functions method as the minimum up and down-time constraints have been considered during generating the feasible solutions in the UC problem. The feasibility and performance of the proposed methodology is demonstrated for 10-units 24-h system. The simulation results are also compared to the global solution from the literature.

References

[1] Tseng C-L, Li C-A, Oren SS. Solving the unit commitment problem by a unit decommitment method. J Optim Theory Appl 2000;105(3):707–30.
[2] Duo Hanzheng, Sasaki Hiroshi, Nagata Takeshi, Fujita Hideki. A solution for unit commitment using Lagrangian relaxation combined with evolutionary programming. Electr Power Syst Res 1999;51:71–7.
[3] Mokhtari S, Singh J, Wollenberg B. A unit commitment expert system. IEEE Trans Power Syst 1988;3(1):272–7.
[4] Sureshkumar C, Selvakumar K, Santhoshkumar G. Unit commitment problem solved using ant colony search algorithm. Int J Adv Innov Res 2012.
[5] Mantawy AH, Abdel-Magid Youssef L, Selim Shokri Z. A new genetic-based tabu search algorithm for unit commitment problem. Electr Power Syst Res 1999;49(2):71–8.
[6] Casado LG, Garcia I. Work load balance approaches for branch and bound algorithms on distributed systems. In: Proceedings of the seventh Euromicro workshop on parallel and distributed processing; February 1999. p. 155–62.
[7] Swarup KS, Yamashiro S. Unit commitment methodology using genetic algorithm. IEEE Trans Power Syst 2002;17(1).
[8] Rama Krishna PV, Poornachandra Rao G, Sao Sukhdeo. Particle swarm optimization technique to solve unit commitment problem. Int J Adv Comput Res 2012;2(7) [No. 4].
[9] Pourakbari-Kasmaei M, Rashidi-Nejad M, Abdollahi A. A novel unit commitment technique considering prohibited operating zones. J Appl Sci 2009;9(16):2962–8.
[10] Tan Ying, Zhu Yuanchun. Fireworks algorithm for optimization. ICSI. Springer; 2010. p. 355–64.
[11] Ebrahimi Javad, Hosseinian Seyed Hossein, Gharehpetian Gevorg B. Unit commitment problem solution using shuffled frog leaping algorithm. IEEE Trans Power Syst 2011;26(20).
[12] Saravanan B, Vasudevan ER, Kothari DP. Unit commitment problem solution using invasive weed optimization algorithm. Int J Electr Power Energy Syst 2014;55:21–8.
[13] Rao Rayapudi S. An intelligent water drop algorithm for solving economic load dispatch problem. Int J Electr Electron Eng 2011;5(1).
[14] Reglend IJ, Kumar R, Karthikeyan SP, Palanisamy K, Kothari DP. Profit based unit commitment problem under deregulated environment. In: Proceeding of AUPEC '09, Adelaide; 30th September 2009.
[15] Saravanan B, Rani C, Prabhakar karthikeyan S, Jacob Raglend I, Kothari DP. Profit based unit commitment problem with fuel and emission constraints using LR-EP approach. Emerg J Eng Sci Technol 2009;03(5).