Economic Generation of Electrical Power by using SFL Algorithm

Shaik Ghouse Basha, P B Chennaiah, Kandalam Giridhar

***Abstract:** An important criterion in power system operation is to meet the power demand at minimum fuel cost using an optimal mix of different power plants. Moreover, in order to supply electric power to customers in a secured and economic manner, unit commitment (UC) is considered to be one of the best available options. The problem of unit commitment (UC) is to decide which units to inter connect over the next T hours, where T is commonly daily or weekly duration of time. The problem is complicated by the presence of constraints and also it is complicated because it involves integer decision variables, i.e., a unit is either committed or not. In this paper SFLA algorithm is used for the solution of UC by meeting all its constraints. Minimum up and minimum down constrains are directly coded. This SFLA algorithm has been applied to 10 generating units considered for one day scheduling period.*

***Key Terms:** Economic dispatch, generation scheduling, optimization techniques, unit commitment.*

I.INTRODUCTION

The electrical unit commitment problem is the problem of deciding which electricity generation units should be running in each period so as to satisfy a predictably varying demand for electricity. The problem is interesting because in a typical electrical system there are a variety of units available for generating electricity, and each has its own characteristics and generator operational constraints [12] . Some major constraints that must be taken into account include:

- The total power generated must meet the load demand and system losses.
- There must be enough spinning reserve to cover any shortfall in generation.
- Energy constraints must be satisfied.
- The generation of each unit must be within its minimum and maximum allowable power output range.

The minimum up and minimum down times of thermal generation units must be considered. The obvious policy is that as demand increases, we first turn on the efficient, but costly to start generators and

- The limit of ramp rates for thermal generation units must not be violated.

lastly turn on the least efficient, but cheap to start.) As demand decreases, we shut down units in the reverse order. During each hour of the planning horizon, considering system capacity requirements and the quadratic programming problem of optimally dispatching the forecasted load among the committed units during each specific hour of operation. It’s not economical to run all units available to run all time .For a given load, to determine which units should be in ON state is unit commitment problem [1]**.**Many methods have been developed for solving the UC problem. In addition to the classical optimization methods such as dynamic programming (DP) and Lagrangian relaxation **[8]**,artificial intelligence method such as the expert system and the neural network have also been employed to search for optimal or sub-optimal solutions of the UC problem.

- The Priority list method [2] is fast but it has to follow many set of rules and provides schedules with relatively high operation cost.
- Dynamic programming [3] is helpful to solve many variety of problems but it leads to more converge time and has many mathematical computations.
- Evolutionary algorithms (EAs), such as genetic algorithms [4][5] and PSO [6][7] are stochastic search methods. GA has been implemented by various researchers for the solution of UC problem. The main disadvantages of this methods is, it will take more converge time and it has no guarantee of optimal solution.
- Genetic algorithms are time-consuming since they requires binary encoding and decoding to represent each unit operation state and to compute the fitness function, respectively, throughout GA procedures. This huge computation makes it difficult to apply to large-scale systems.

II. SHUFFLED FROG LEAPING ALGORITHM

The shuffled frog-leaping algorithm is a memetic met heuristic that is designed to seek a global optimal solution by performing a heuristic search. It is based on the evolution of memes carried by individuals and a global exchange of information among the population (Eusuff and Lansey 2003). In essence, it combines the benefits of the local search tool of the particle swarm optimization (Kennedy and Eberhart 1995),

Revised Manuscript Received on 30 August 2012
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and the idea of mixing information from parallel local searches to move toward a global solution [15].The SFL algorithm has been tested on several combinatorial problems and found to be efficient finding global solutions (Eusuff and Lansey 2003).The SFL algorithm involves a population of possible solutions defined by a set of frogs (i.e. solutions) that is partitioned into subsets referred to as memplexes [13]. The different memplexes are considered as different cultures of frogs, each performing a local search. Within each memplexes, the individual frogs hold ideas, that can be influenced by the ideas of other frogs, and evolve through a process of memetic evolution. After a number of memetic evolution steps, ideas are passed among memplexes in a shuffling process (Liong and Atiquzzaman 2004). The local search and the shuffling processes continue until convergence criteria are satisfied (Eusuff and Lansey 2003). The flowchart of SFLA is illustrated in Fig.1.

Procedure:

1) In the first step of this algorithm, an initial population P of frogs is randomly generated within the feasible search space. The position of the ith frog is represented as $X_{i=}(X_{i1}, X_{i2},, X_{i3,,,,,,,,,}X_{iD})$,where D is the number of variables. Then, the frogs are sorted in descending order according to their fitness.

2) Later, the entire population is partitioned into m subsets referred to as memplexes, each containing frogs n i.e.,(p=m*n). The strategy of the partitioning is as follows: The first frog goes to the first memeplex, the second frog goes to the second memeplex, the mth frog goes to the mth memeplex, the (m+1)th frog goes back to the first memeplex, and so on

3)This step is based on local search. Within each memeplex, the positions of frogs with the best and worst fitness are identified as X_b and X_w, respectively. Also the position of a frog with the global best fitness is identified as X_g. Then, within each memeplex, a process similar to the PSO algorithm is applied to improve only the frog with the worst fitness (not all frogs) in each cycle[14]. Therefore, the position of the frog with the worst fitness leaps toward the position of the best frog, as follows:

$$D_i = rand\ (X_b - X_w) \qquad 1$$

$$X_w^{new} = X_w^{current} + D_i \ \ (D_{imin} < D_i < D_{imax}) \qquad 2$$

Where $D_{imin}$and $D_{imax}$are the maximum and minimum step sizes allowed for a frog’s position, respectively

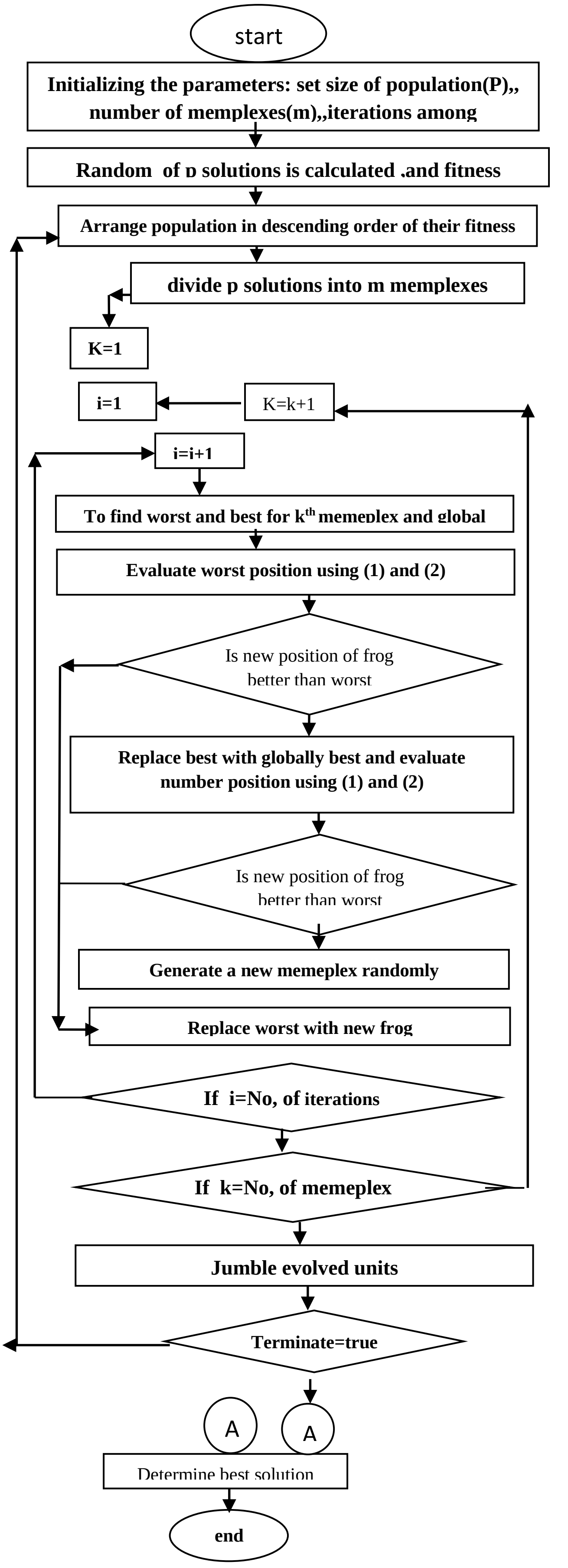
start
Initializing the parameters: set size of population(P),, number of memplexes(m),,iterations among
Random of p solutions is calculated ,and fitness
Arrange population in descending order of their fitness
divide p solutions into m memplexes
K=1
i=1
K=k+1
i=i+1
To find worst and best for kth memeplex and global
Evaluate worst position using (1) and (2)
Is new position of frog better than worst
Replace best with globally best and evaluate number position using (1) and (2)
Is new position of frog better than worst
Generate a new memeplex randomly
Replace worst with new frog
If i=No, of iterations
If k=No, of memeplex
Jumble evolved units
Terminate=true
A
A
Determine best solution
end

Fig 1 flow chart of SLFA

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If this process produces a better solution *Xw new*, it replaces the worst frog position, otherwise, the calculations in equations 1 and 2 are repeated with respect to the global best frog (i.e. replaces).If there is no improvement in this case, a new solution will be randomly generated within the feasible space to replace worst frog.

4) The calculations will continue for a specific number of iterations. Therefore, SFLA simultaneously Performs an independent local search in each memplexes using a process similar to the PSO algorithm. The flowchart of algorithm is shown in fig(1)

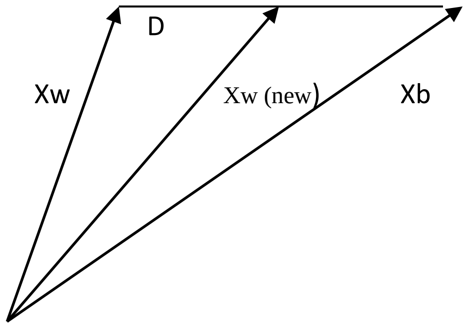

Fig 2 The original frog leaping rule

III UC PROBLEM FORMULATION

The principal objective is to prepare on/off schedule of the generating units in every sub period (typically 1h) of the given planning period (typically 1 day or 1 week) in order to serve the load demand and spinning reserve at minimum total production cost (fuel cost, startup cost, shut down cost), while meeting all unit, and system constraints. The following costs are considered:

*A. **Fuel Cost**:*

The quadratic approximation is the most widely used by the researchers, which is basically a convex shaped function. The operating fuel cost is mathematically modeled by a quadratic input/output curve.

*B. **Startup cost:***

Startup cost is warmth-dependent. Generally it is expressed as linear or exponential function of time. In this paper it is modeled by a stair case function.

*C. **Shut down cost**:*

The typical value of the shutdown cost is zero in the standard systems. This cost is considered as a fixed cost.

The system and unit constrains which must be satisfied during optimization are:

- Unit initial status +/- either already up or already down.

- The upper and lower limits of i^{th} generation unit as follows:

The generation limits represent the minimum loading limit below which it is not economical to load the unit, and the maximum loading limit above which the unit should not be loaded. Each unit has generation range, which is represented as:

$$Pi\ ^{t}min \leq Pi^{t} \leq Pi\ ^{t}max \qquad 3$$

- The minimum up and down times of each unit must be observed.nce the unit is running, it should not be turned off immediately, once the unit is de-committed, there is a minimum time before it can be recommitted.

These constraints can be represented as

$$T_i^c \geq MU_i \text{ if } T_i^c \geq 0 \qquad 4$$
$$-T_i^c \geq MD_i \text{ if } T_i^c < 0$$

- The total power generated must meet the load demand.

$$\sum_{i=1}^{N} u(t).Pi\ ^{t} = D^{t} \qquad 5$$

- There must be enough spinning reserve to cover any shortfalls in generation.

$$\sum_{i=1}^{N} u(t).Pi^{t}max \geq D^{t}+R^{t} \quad t=1,\ldots,T \qquad 6$$

IV. SFLA SOLUTION FOR UC PROBLEM

A. Frog definition

:In this algorithm, the frog position (X) consists of a sequence of integer numbers, representing the sequence of the ON/OFF cycle durations of each unit during the UC horizon. A positive integer X in the represents the duration of continuous unit operation (ON status), while a negative integer represents the duration of continuous reservation (OFF status) of the unit.

The number of a unit's "ON/OFF" cycles during the UC horizon depends on the number of load peaks during the UC horizon and the sum of the minimum up and down times of the unit. Fig. 3 shows a daily load profile with two load peaks used to determine the number of ON/OFF cycles of units. The numbers of ON/OFF cycles of the base, medium, and peak load units are equal to 2, 3, and 5, respectively. There- fore, the number of ON/OFF cycles of generating units is usually small (1 to 5 ON/OFF cycles per day). The reduction of cycles of base and medium units may restrict the search space of the optimization problem and this may lead to suboptimal solution. To overcome this problem in the proposed algorithm, the number of cycles of units per scheduling is the same and equal to the number of the cycle of peak load units (i.e.,5).For Y day scheduling ,C=Y*5.Therefore,each solution consists of N*Y*5 variables for Y day scheduling and presents the operation schedule of N units for Y*24 hours.

B. Initial Population of SFLA

The generation of the initial population of SFLA is discussed in this section. The duration of the unit operation first cycle, T_i^c,

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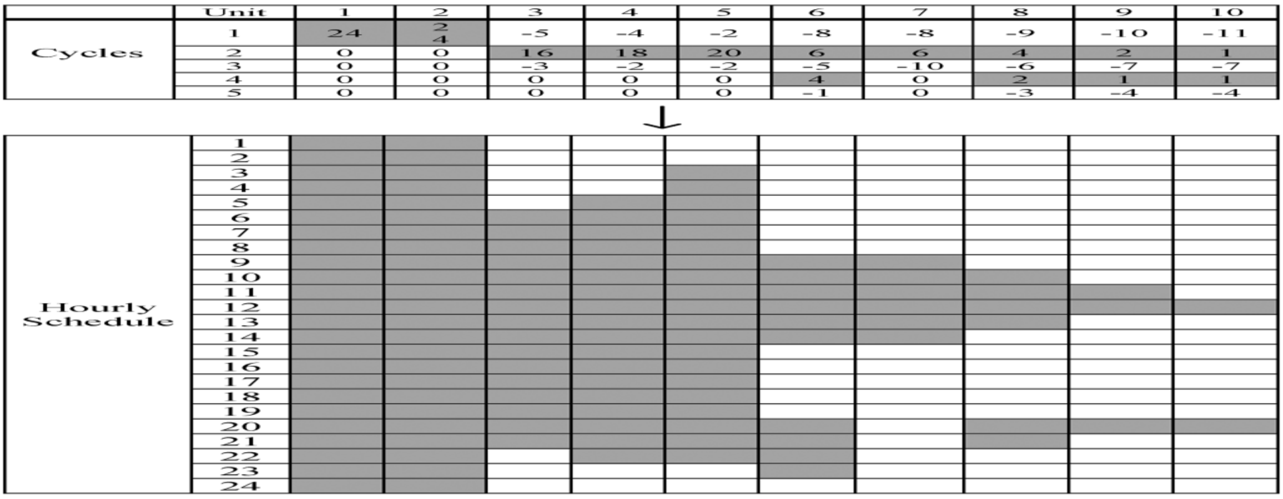
is initialized so that the unit continues the operating mode (ON/OFF) of the last cycle of the previous scheduling day for at least as many hours as required to satisfy the minimum up/down-time constraints

$$T_i^1 \;=\; +\mathrm{Rand}(\max(0,MU_i - T_i^0),T), \quad \text{if } T_i^1>0 \qquad 7$$
$$\;=\; -\mathrm{Rand}(\max(0,MU_i + T_i^0),T), \quad \text{if } T_i^1<0$$

Where T_i^0 is is the duration of last cycle of the previous scheduling day. For , c< C the operation duration of the th cycle of unit i, T_i^c, is calculated considering the minimum up and down-time (C-1) constraints of the unit, the UC horizon and the duration of the prior cycles of the unit's operation. For $T_i^{c-1}<0$, cycle is in ON mode with duration determined, as follows:

$$T_i^c \;=\; +\mathrm{Rand}(MD_i,RT_i^{c-1}), \text{ if } (RT_i^{c-1}>MD_i) \qquad 8$$
$$\;=\; +RT_i^{c-1}, \qquad \text{otherwise}$$

TABLE I Unit commitment for 24 hours



	Unit	1	2	3	4	5	6	7	8	9	10
Cycles	1	24	2 4	-5	-4	-2	-8	-8	-9	-10	-11
	2	0	0	16	18	20	6	6	4	2	1
	3	0	0	-3	-2	-2	-5	-10	-6	-7	-7
	4	0	0	0	0	0	4	0	2	1	1
	5	0	0	0	0	0	-1	0	-3	-4	-4

↓

Hourly Schedule	1	▨	▨								
	2	▨	▨								
	3	▨	▨			▨					
	4	▨	▨			▨					
	5	▨	▨		▨	▨					
	6	▨	▨	▨	▨	▨					
	7	▨	▨	▨	▨	▨					
	8	▨	▨	▨	▨	▨					
	9	▨	▨	▨	▨	▨	▨	▨			
	10	▨	▨	▨	▨	▨	▨	▨	▨		
	11	▨	▨	▨	▨	▨	▨	▨	▨	▨	
	12	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	13	▨	▨	▨	▨	▨	▨	▨	▨		
	14	▨	▨	▨	▨	▨	▨	▨			
	15	▨	▨	▨	▨	▨					
	16	▨	▨	▨	▨	▨					
	17	▨	▨	▨	▨	▨					
	18	▨	▨	▨	▨	▨					
	19	▨	▨	▨	▨	▨					
	20	▨	▨	▨	▨	▨	▨		▨	▨	▨
	21	▨	▨	▨	▨	▨	▨		▨		
	22	▨	▨		▨	▨	▨				
	23	▨	▨				▨				
	24	▨	▨								

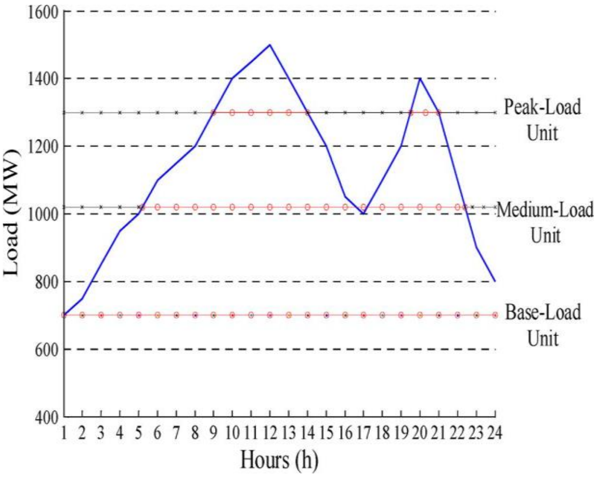


Fig 3 Base load, medium load and peak load operating cycle

C bounding of Worst Solution

In each memeplex, the solution with the worst fitness, X_w , is adjusted by adding a vector (D_i=Rand*(X_b-X_w) to it. This approach leads to the sum of values of for each unit, which is not equal to the scheduling horizon. Therefore, the operating cycles of each unit of new X_w should be corrected, as follows::

$$(T_i^1,\dots T_i^c)= \frac{T\ .}{\sum_{k=1}^{C} Ti\hat{}c}\,.\,(T_i^1,\dots T_i^c) \quad i=1,2,\dots N \qquad 9$$

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TABLE II Ten unit system operator data

	Unit 1	Unit2	Unit3	Unit4	Unit5	Unit6	Unit 7	Unit 8	Unit 9	Unit 10
p i max	455	455	130	130	162	80	85	55	55	55
Pi min	150	150	20	20	25	20	25	10	10	10
Ai	1000	970	700	680	450	370	480	660	665	670
Bi	16.19	17.26	16.60	16.50	19.70	22.26	27.74	25.92	27.27	27.79
Ci	0.00048	0.00031	0.002	0.00211	0.00398	0.00712	0.00079	0.00413	0.00222	0.00173
MUi	8	8	5	5	6	3	3	1	1	1
MDi	8	8	5	5	6	3	3	1	1	1
HCi	4500	5000	550	560	900	170	260	30	30	30
CCi	9000	10000	1100	1120	1800	340	520	60	60	60
C houri	5	5	4	4	4	2	2	0	0	0
Ini state	8	8	-5	-5	-6	-3	-3	-1	-1	-1

TABLE III Load Demand for 24 hours

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

The function Rand generates a random number between 0 and 1. As a result, the parameters of new $X_{w \text{ are}}$ only integer. Therefore, the parameters of new must be converted to integer numbers, as follows:

$$X_w^1=Round(New\ X_w) \qquad 10$$

while X_w^1 is a new solution with integer parameters. $X_w^1=Round(New\ X_w$ while X_w^1 is a new solution with integer parameters.

D. Satisfying Minimum Up and Down-Time Constraints: After generation of the new solution, the minimum up and down-time constraints are checked without using any penalty function. Suppose that the unit in cycle was in operation less than its minimum up/down-times. In order to satisfy the time constraint, first, the minimum up/down-time constraint of the cycle c+1 should be considered. In this case, the duration of the cycle will be equal to the minimum up/down-time. Then, the operation of the cycle should be changed so that the sum of T_i^1 for the i unit become equal to the scheduling horizon. The duration of the operation first cycle of unit is checked with respect to the duration of the last cycle of the previous scheduling day and minimum up and down-time constraints of unit i: For $T_i^c>0$ *if* $T_i^c<max\ (0,MU_i-T_i^0$, then the duration of cycles 1 and 2 of unit i are changed, as follows:

$$T_i^2= T_i^2- T_i^1+max\ (0,MU_i-T_i^0), \qquad 11$$

$$T_i^1= max\ (0,MU_i-T_i^0), \qquad 12$$

For $T_i^c<0$ *if* $-T_i^c<max\ (0,MU_i+T_i^0$, then the duration of cycles 1 and 2 of unit i are changed, as follows:

$$T_i^2= T_i^2- T_i^1-max\ (0,MU_i+T_i^0), \qquad 13$$

$$T_i^1= max\ (0,MU_i+T_i^0), \qquad 14$$

After leaping the worst solution and satisfying time constraints, an economic dispatch (ED) should be carried out in each hour of scheduling horizon for ON-state units. Then, the fitness function will be calculated.

D. Calculation of fitness function

The objective function of SFLA has two terms. The first term is the total operation cost over scheduling horizon and the second term is the penalty function that penalizing the violation of system constraints. All the generators are assumed to be connected to the same bus supplying the total system demand. Therefore, the network constraints are not considered. In the first step, an ED should be performed for the scheduling horizon. It is an important part of UC. Its goal is to minimize the total generation cost of a power system for each hour while satisfying constraints The penalty functions of

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reserve and generation constraints are used to solve ED for the scheduling horizon for fuel cost function of the generation
of P_i power in the t th hour

$$FC_i(P_i^t) = A_i+B_i\, P_i^t + C(P_i^t)^2 \qquad 15$$

The calculated power of each unit P_i from ED is used to Calculate the fitness of each solution in the UC problem. The start-up/shutdown costs are calculated as follows,

$$SU_t=\sum_{i=1}^{N}\sum_{c=2}^{C} \mathrm{H}\,(Ti\hat{}c)\mathrm{SUi}\,(-\mathrm{Ti}\,\hat{}(\mathrm{C}-1) \qquad 16$$

$$SD_t=\sum_{i=1}^{N}\sum_{c=2}^{C} 1-\mathrm{H}\,(Ti^{c})\mathrm{SDi} \qquad 17$$

The start-up cost depends on the instant that the unit has beenswitched off prior to start-up

$$SU_i(-T_i^{C-1})=H_{costi},\ \text{if } (MD_i - T_i^{C-1})\leq C\ hour_i \qquad 18$$
$$=C_{cost},\ \text{if } (MD_i - T_i^{C-1})>C\ hour_i$$

The total operation cost over the scheduling horizon is expressedby the following equation:

$$TC=\sum_{t=1}^{T}\ \sum_{i=1}^{N} FCi(Pit)u(t)) + \mathrm{SUt} + \mathrm{SDt} \qquad 19$$

The overall objective of SFLA is to minimize the following fitness function subject to a number of system and unit constraints:

$$\textit{fitness}=TC \qquad 20$$

V. SIMULATION RESULTS

One-Day Scheduling

This algorithm is tested on 10 generation units, and over a schedule of 24 hours. The operator data for 10 generating units and load demand for 24 hours are given in Table II and Table III, The use of penalty function is violated in this SFLA as mentioned before. The results of SFLA are compared with PSO (DSPO) and BFA algorithms which are reported in [9][10] [4]. The simulation is carried by using 2 MHz processor on MATLAB 2012.the plot between number of iterations and total operation cost shows that optimal solution is obtained after ten to sixteen iterations.

Seven-Day Scheduling

The algorithm is also tested for seven day scheduling. The test data for seven days load demand is taken from the load factors for seven days from the table V. The total operation cost of seven day schedule is given in table VIII.

TABLE V
Load factors for seven days

Days	1	2	3	4	5	6	7
Load factors	1	0.95	0.9	0.9	0.92	0.85	0.8

TABLE VI Total operation cost for 24 hours

S.no	Hours	Operation cost
1	1	16709
2	2	16709
3	3	17204
4	4	17204
5	5	17537
6	6	17867
7	7	17867
8	8	18127
9	9	19035
10	10	19295
11	11	19568
12	12	19846
13	13	19295
14	14	19035
15	15	17867
16	16	17867
17	17	17867
18	18	17867
19	19	17867
20	20	17867
21	21	17867
22	22	17537
23	23	17204
24	24	16709
	total	4,31,820

TABLE VII Execution time

SFLA	Execution time (sec)	Number of iterations
For 10 units	96 seconds	16

TABLE VIII Operation cost for 7 days scheduling

Units	Days	Total operation cost without penalty functions
10	seven	23,39,8600

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TABLE IX Comparison of total operation cost with other methods

No, of units	BFA	PSO(DPSO)	SFLA(without using penalty function)
	For best generation cost		
10	570781	565804	431820

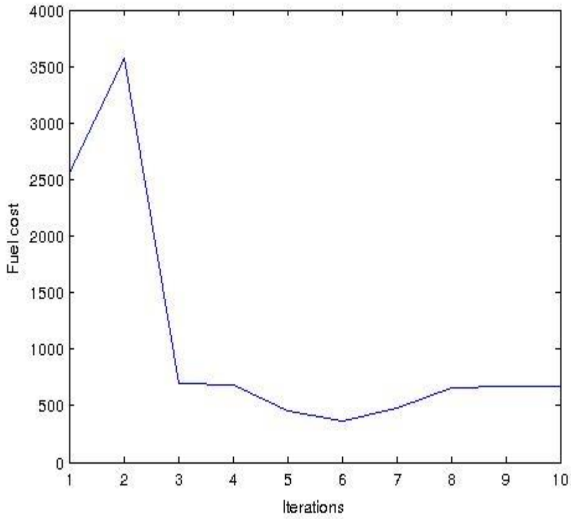
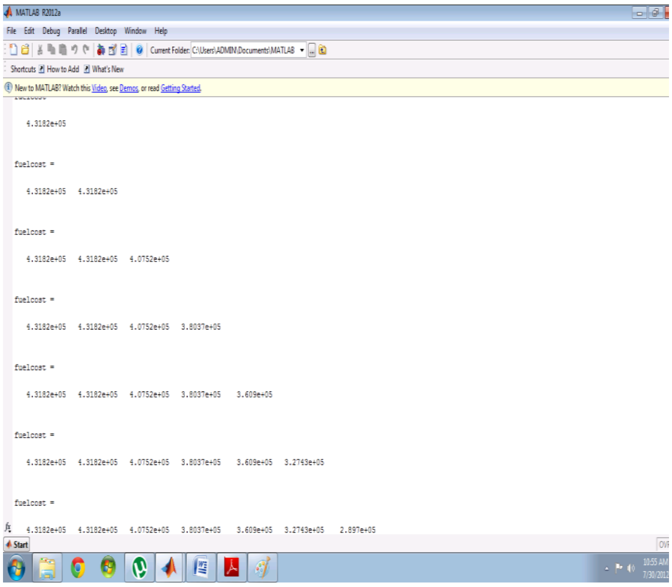


Fig 4, Convergence of SFLA


MATLAB R2012a
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Current Folder: C:\Users\ADMIN\Documents\MATLAB
Shortcuts How to Add What's New
New to MATLAB? Watch this Video, see Demos, or read Getting Started.
Start
OVR
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```
   4.3182e+05


fuelcost =

   4.3182e+05   4.3182e+05


fuelcost =

   4.3182e+05   4.3182e+05   4.0752e+05


fuelcost =

   4.3182e+05   4.3182e+05   4.0752e+05   3.8037e+05


fuelcost =

   4.3182e+05   4.3182e+05   4.0752e+05   3.8037e+05    3.609e+05


fuelcost =

   4.3182e+05   4.3182e+05   4.0752e+05   3.8037e+05    3.609e+05   3.2743e+05


fuelcost =

   4.3182e+05   4.3182e+05   4.0752e+05   3.8037e+05    3.609e+05   3.2743e+05    2.897e+05
```

Fig 5 Simulation results for seven day scheduling

VI . CONCLUSION

By using SFL algorithm electrical power is economically generated by reducing the total operation cost of generating units. This algorithm has been applied on ten generating units and is scheduled for one day and seven days. The combination of the local search with information exchange of groups results in improved performance of SFLA.

The results are compared with previous algorithms and this paper shows the efficient results in case of computation times and production costs

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