A Modified Shuffled Frog Leaping Algorithm for Long-Term Generation Maintenance Scheduling

G. Giftson Samuel and C. Christober Asir Rajan

Abstract This paper discuss a modified Shuffled frog leaping algorithm to Long-term Generation Maintenance Scheduling to Enhance the Reliability of the units. Maintenance scheduling establishes the outage time scheduling of units in a particular time horizon. In a monopolistic power system, maintenance scheduling is being done upon the technical requirements of power plants and preserving the grid reliability. While in power system, technical viewpoints and system reliability are taken into consideration in maintenance scheduling with respect to the economical viewpoint. In this paper present a modified Shuffled frog leaping algorithm methodology for finding the optimum preventive maintenance scheduling of generating units in power system. The objective function is to maintain the units as earlier as possible. Varies constrains such as spinning reserve, duration of maintenance and maintenance crew are being taken into account. In case study, test system consist of 24 buses with 32 thermal generating units is used.

Keywords Generation maintenance schedule · Optimization · Shuffled frog leaping algorithm

1 Introduction

The efficient operation of an electric power system requires the solution of several inter related problems. One problem that has proven to be particularly unyielding is that of determining when the thermal generating units should be taken off line

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for preventive maintenance. This is typically a long planning problem for power companies and it is recognized to be a significant part of the overall operations management of an electric power utility. As a result, utilities are interested in including a unit maintenance scheduling component as a part of an Energy management system.

The unit maintenance scheduling has been tackled by many authors using a variety of objective functions. They are maximizing the minimum reserve, leveling the risk of generation shortage, minimizing production cost and system unreliability. Most of the earlier work in maintenance scheduling uses optimization techniques have been employed to approach the problem. More specifically, these are the Dynamic Programming method (DP), the Mixed Integer Programming method (MIP),the Lagrangian relaxation method (LR), the Branch and Bound method (BB), the Fuzzy Theorem (FT), the Artificial Neural Network (ANN), the Simulated Annealing method (SA) and so on. The major limitation of these approaches is to consider each generating unit separately in selecting its outage interval, large computational time and complexity in programming.

Power system scheduling is to minimize the total generation cost subject to system demand and reserve requirement and individual unit constraints. It has been an active research over the years because of its significant economic impact. To solve this difficult MIP problem, many optimization based methods have been developed [1]. Among them, LR and its extensions are among the most successful ones [2–6]. Many new requirements such as transmission network and environment constraints have also been incorporated in the problem formation. Fuzzy optimization techniques have been developed to solve optimal power flow with fuzzy constrains [7–9], and to schedule manufacturing system with possible breakdowns [10] The Generic Algorithm method mimics the principles of natural genetics and natural selection to constitute search and optimization procedures. Simulated annealing mimics the cooling phenomenon of molten metal's to constitute a search procedure. The Generic Algorithm and Simulated Annealing approaches have been reported to solve a range of optimization problems in electrical power systems with encouraging results [11]. Fuzzy optimization techniques have been developed to solve optimal power flow with fuzzy constrains [12–14], and to schedule manufacturing system with possible breakdowns [15] The major limitation of these approaches is to consider each generating unit separately in selecting its outage interval, large computational time and complexity in programming.

2 Problem Formulation

The objective is to find the generation maintenance scheduling, such that minimize total operating cost over the operational planning period, subject to unit maintenance and variety of system constraints.

$$\text{Min } F_T = \Sigma_{t=1}^{T}\Sigma_{i=1}^{N}\{F_{it}(P_{it}) \,.\, n_t\}U_{it} + \Sigma_{t=1}^{T}\Sigma_{i=1}^{N}\{(P_{it} + R_{it}) \,.\, OMVC \,.\, n_t\}U_{it} + \Sigma_{t=1}^{T}\Sigma_{i=1}^{N}\{P_{maxi}\ OMFC\ n_t\}/8760 \quad (1)$$

$$\text{Profit } = \sum MCP * P_{it} - F_T \quad (2)$$

where

$$F_{it}(P_{it}) = A_i P_{it}^2 + B_i P_{it} + C_i \text{ Rs/hr} \quad (3)$$

The objective function represents the profit, which is calculated as the difference between its total revenues and its corresponding costs which include production cost, fixed cost and variable maintenance cost.

There are typical constraints for maintenance scheduling problems. Any maintenance timetable must satisfy a given set of constraints. In order to make the maintenance schedule feasible, certain constraints should be fulfilled. Some of basic constrains which should be set up are continuousness maintenance of some unit, maintenance manpower, maintenance window, maintenance duration and so on.

2.1 Generator Output Limit

Each unit is designed to work between minimum and maximum power capacity. The following constraint ensures that unit is within its respective rated minimum and maximum capacities.

$$U_{it}P_{imin} \leq P_{it} \leq U_{it}P_{imax} \quad (4)$$

2.2 Spinning Reserve

Spinning reserve is a safety margin that usually is given as a demand proportion. This indicates that the total capacity of the units running at each interval should not be less than the specified spinning reserve for that interval.

$$\sum_{i=1}^{N} U_{it}\ P_{imax} \geq D_t(1 + r_t\%) \quad (5)$$

2.3 Maintenance Resources

$$\sum_{i=1}^{N} R_i(k)(1 - U_{it}) \leq \propto_t (k) \quad (6)$$

2.4 Maintenance Window

The maintenance timetable stated in terms of maintenance variables (S_i). The unit maintenance may not be scheduled before their earliest period or after latest period allowed for maintenance.

$$U_{it} = \begin{cases} 1 & t \le e_i \text{ or} t \ge l_i + d_i \\ 0 & s_i \le t \le s_i + d_i \\ 0,1 & e_i \le t \le l_i \end{cases} \tag{7}$$

2.5 One-Time Maintenance

Each unit has an outage for maintenance just once along the time horizon considered.

$$\sum_{t=1}^{T} sv_{it} = 1 \tag{8}$$

2.6 Reliability Indices

For simplicity most of the time, no uncertainty is considered which means that appropriate unit are provided. Nevertheless, unit forced outage rates can be approximately taken into account derating their corresponding capacities.

$$P^{+}_{\max\,\mathrm{i}} = (1 - for_i) * U_{it} * P_{maxi} \tag{9}$$

$$\sum_{i=1}^{N} P_{\max\, i} * (1 - for_i) - \sum_{i=1}^{N} P_i(t) \ge \%r_t * d_t \tag{10}$$

$$\mathrm{I(t)} = \frac{\sum_{i=1}^{N} \sum_{t=1}^{T} P_{it}(1 - U_{it})(1 - for_i) - D_t}{\sum_{i=1}^{N} \sum_{t=1}^{T} P_{it}(1 - for_i) - D_t} \tag{11}$$

In this paper, we can see that researchers have focused much attention on maintenance scheduling problems for power systems in order to improve the economic posture of the generation companies. Reducing the total generation cost, including the fuel cost, operation and maintenance cost is one of the main objectives in power system maintenance scheduling.

3 Shuffled Frog Leaping Algorithm

The Shuffled frog leaping algorithm is a meta-heuristic optimization method which is based on observing, imitating, and modeling the behavior of a group of frogs when searching for the location that has the maximum amount of available food [16]. Shuffled frog leaping algorithm, originally developed by Eusuff and Lansey in 2003, can be used to solve many complex optimization problems, which are nonlinear, non differentiable, and multi-modal [17]. SFLA has been successfully applied to several engineering optimization problems such as water resource distribution [18], bridge deck repairs [19], job-shop scheduling arrangement [20], and traveling salesman problem (TSP) [21]. The most distinguished benefit of Shuffled frog leaping algorithm is its fast convergence speed [22]. The Shuffled frog leaping algorithm combines the benefits of the both the genetic-based memetic algorithm (MA) and the social behavior-based PSO algorithm [23, 24].

The flowchart of Shuffled frog leaping algorithm is illustrated in Fig. 1. Shuffled frog leaping algorithm is a population based random search algorithm inspired by nature memetics. In the Shuffled frog leaping algorithm, a population of possible solution defined by a group of frogs that is partitioned into several communities referred to as memeplexes. Each frog in the memeplexes is performing a local search. Within each memeplex, the individual frog's behavior can be influenced by behaviors of other frogs, and it will evolve through a process of memetic evolution. After a certain number of memetics evolution steps, the memeplexes are forced to mix together and new memeplexes are formed through a shuffling process. The local search and the shuffling processes continue until convergence criteria are satisfied (12).

The varies steps are as follows:

(1) The Shuffled frog leaping algorithm involves a population 'P' of possible solution, defined by a group of virtual frogs(n).
(2) Frogs are sorted in descending order according to their fitness and then partitioned into subsets called as memeplexes (m).
(3) Froges i is expressed as $X_i = (X_{i1}, X_{i2}, \ldots..X_{is})$ where S represents number of variables.
(4) Within each memeplex, the frog with worst and best fitness are identified as X_w and X_b.
(5) Frog with globle best fitness is identified as X_g.
(6) The frog with worst fitness is improved according to the following equation.

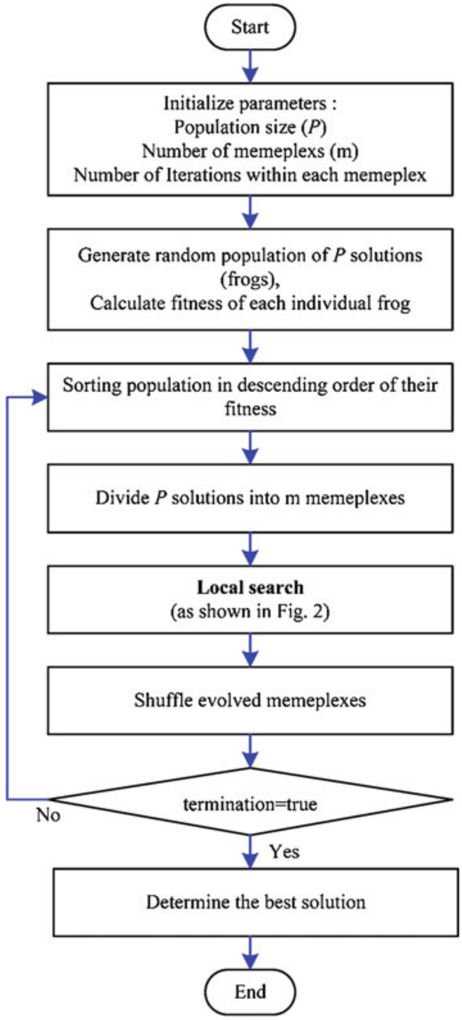
$$D_i = \text{rand}()(X_b - X_w) \tag{12}$$

$$X_{neww} = X_{oldw} + Di(-D_{max} \leq D_i \leq D_{max}) \tag{13}$$

where rand is a random number in the range of [0,1];

D_i is the frog leaping step size of the i-th frog and D_{max} is the maximum step allowed change in a frog's position. If the fitness value of new X_w is better than the

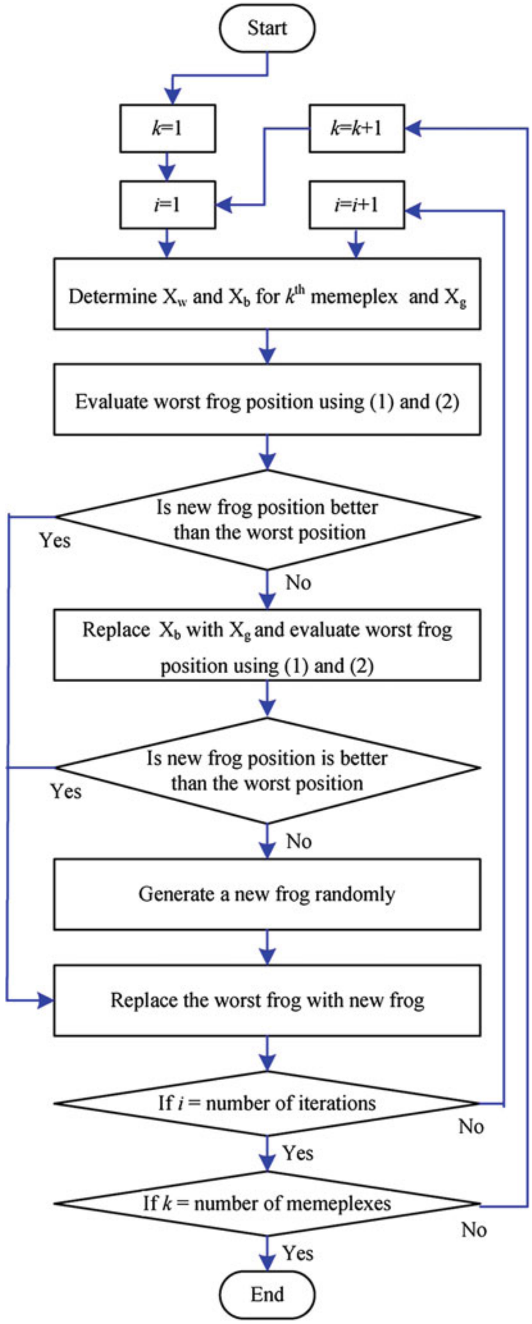
Fig. 1 Flowchart of SFLA



current one, X_w will be accepted. If it isn't improved, then the calculated (12) and (13) are repeated with X_b replaced by X_g. If no improvement becomes possible in the case, a new X_w will be generated randomly. Repeat the update operation for a specific number of iterations. The flowchart of local search of Shuffled frog leaping algorithm is illustrated in Fig. 2.

After a predefined number of memetic evolutionary steps within each memeplex, the solutions of evolved memeplexes are replaced into new population. This is called the shuffling process. The shuffling process promotes a global information exchange among the frogs. Then, the population is sorted in order of decreasing performance value and updates the population best frog's position, repartition the frog group into memeplexes, and progress the evolution within each memeplex until the conversion criteria are satisfied.

Fig. 2 Flowchart of local search



4 Simulation Result

The total operating cost of the GMS problem is expressed as the sum of fuel costs, operation and maintenance variable costs (OMVC), operation and maintenance fixed costs (OMFC) of the generating units. The fuel cost is the major component of the operating cost, which is normally modeled by a quadratic input/output curve.

The developed Shuffled frog leaping algorithm program has been carried out on a Pentium IV 2-GHz PC with a 512 Mb RAM in MATLAB 7.3. Software package and the test problem were simulated for ten independent trials using Shuffled frog leaping algorithm.

A 24 bus system with thirty two generating units has been considered as a case study. A time period of 52 weeks is considered and maintenance schedule problem is solved for the thirty two unit systems.

The proposed methodology was tested for the test system [25]. IEEE RTS (reliability test system) is a IEEE twenty four bus system with thirty two thermal units. Tables 1 and 2 show the generator data for thirty two units. When we take annual maintenance for generator, the forced outage is also considered. So the grid collapse is avoided.

The annual peak load for the thirty two generator test system is 2,850 MW. Table 3 gives data on weekly peak load in percentage of annual peak load.

The main parameters of Shuffled frog leaping algorithm have been selected as suggested in [26]. The Shuffled frog leaping algorithm has an initial population of 200 solutions, a set of 20 memeplexes, and twelve generations within each memeplex (before shuffling).

The Shuffled frog leaping algorithm has been tested on the thirty two unit systems over a scheduling period of 52 weeks. The thirty two generator units system Profit/cost factor are compared with result of DP, LR and GA are listed in Table 4.

The result of the generation Maintenance scheduling of the best solution of Shuffled frog leaping algorithm for thirty two unit systems is given in Table 5. It is obvious that the total cost obtained by Shuffled frog leaping algorithm is less than that of other methods.

EAs have a stochastic nature and in different cases do not converge to the some solution. Therefore, the average of different cases is calculated for each problem. It is obvious that the Shuffled frog leaping algorithm has satisfactory results in comparison with other methods.

Figure 3 shows the performance of objective function of the Shuffled frog leaping algorithm, when maintenance scheduling of the generating units solved for thirty two unit systems. In this figure, the average function fitness of the memeplexes is illustrated. Figure 4 show maintenance scheduling of generating units based on its desired objective. Its reliability profit is shown in Fig. 5.

Table 1 Generator data for 32 units

Units	P_{max} (MW)	Forced outage rate (for)	Schedule maintenance weeks/year	Manpower required per week
1–5	12	0.02	1	10
6–9	20	0.1	1	10
10–13	76	0.02	3	15
14–19	100	0.04	4	15
20–23	155	0.04	5	15
24–29	197	0.05	6	20
30	350	0.08	8	20
31 and 32	400	0.12	8	20

Table 2 The fixed and variable cost of 32 units

Units	P_{max} (MW)	Fixed O and M cost (Rs/MW-year)	Variable O and M cost (Rs/MWh)
1–5	12	4,50,000	18,000
6–9	20	4,05,000	15,000
10–13	76	4,00,000	13,500
14–19	100	3,50,000	11,250
20–23	155	3,15,000	9,500
24–29	200	3,10,000	9,000
30	350	2,70,000	7,300
31 and 32	400	2,25,000	5,750

Table 3 Weekly peak load in percent of annual peak

Week	Peak load	Week	Peak load	Week	Peak load	Week	Peak load
1	86.2	14	75.0	27	75.5	40	72.4
2	90.0	15	72.1	28	81.6	41	74.3
3	87.8	16	80.0	29	80.1	42	74.4
4	83.4	17	75.4	30	88.0	43	80.0
5	88.0	18	83.7	31	72.2	44	88.1
6	84.1	19	87.0	32	77.6	45	88.5
7	83.2	20	88.0	33	80.0	46	90.9
8	80.6	21	85.6	34	72.9	47	94.0
9	74.0	22	81.1	35	72.6	48	89.0
10	73.7	23	90.0	36	70.5	49	94.2
11	71.5	24	88.7	37	78.0	50	97.0
12	72.7	25	89.6	38	69.5	51	100
13	70.4	26	86.1	39	72.4	52	95.2

The reserve capacity profiles corresponding to thirty two unit systems are as shown in Fig. 5 and maintenance scheduling based on desire objective function for thirty two unit systems is shown in Table 5.

Table 4 Profit/cost factor for 32 units scheduling

System	Method	Total cost (pu)	CPU time (s)
32 units	DP	1.0535	918
	LR	1.0687	850
	EP	1.0392	422
	PSO	1.0387	417
	SFLA	1.0385	414

Table 5 Generation maintenance scheduling for 32 units

Start of outage (week)	Unit	Start of outage (week)	Unit	Start of outage (week)	Unit
1	–	19	17, 25, 31	37	32
2	24	20	17, 25, 31	38	4, 8, 22, 32
3	24	21	17, 25, 31	39	18, 22, 32
4	14, 16, 24	22	17, 31	40	12, 18, 22, 32
5	14, 16, 24	23	9, 23, 31	41	12, 18, 22, 32
6	14, 16, 24	24	6, 23, 31	42	12, 18, 22, 32
7	14, 16, 24	25	20, 23, 31	43	–
8	26	26	13, 20, 23	44	1
9	26, 27	27	2, 13, 20, 23	45	28
10	7, 26, 27, 30	28	13, 20	46	21, 28
11	26, 27, 30	29	15, 20	47	21, 28
12	26, 27, 30	30	3, 15, 19	48	21, 28
13	26, 27, 30	31	15, 19, 29	49	21, 28
14	10, 11, 27, 30	32	15, 19, 29	50	5, 21, 28
15	10, 11, 30	33	19, 29	51	–
16	10, 11, 25, 30	34	29	52	–
17	25, 30	35	29, 32		
18	25, 31	36	29, 32		

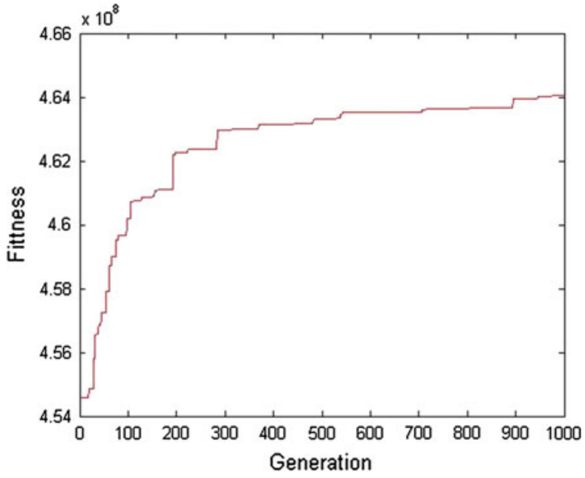


Fig. 3 Performance of object function for 32 units

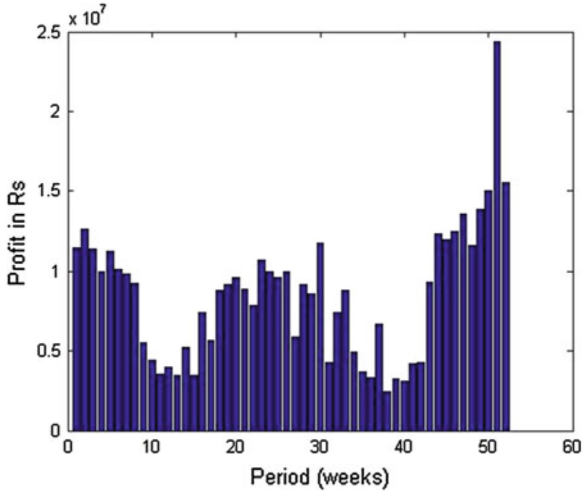


Fig. 4 Scheduling of objective function for 32 units

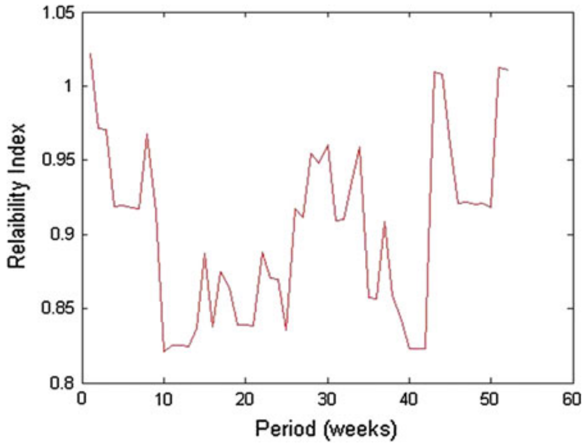


Fig. 5 Reliability index for objective function for 32 units

5 Conclusion

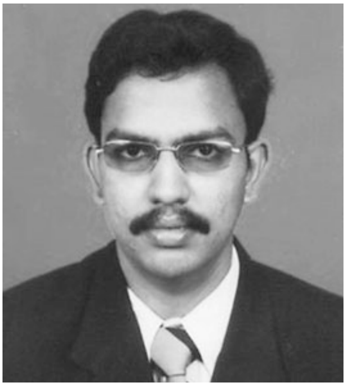
In this paper, a new approach for solving the generation maintenance scheduling problem based on modified Shuffled frog leaping algorithm and the optimum maintenance scheduling over the planning period have been presented. The algorithm has been tested on thirty two generating unit system.

The proposed method has been compared with other methods. The result obtained is compared with the results of other method such as DP, LR and PSO. From the result it is shown that the proposed algorithm provides true optimal solution for minimum fuel cost and computation timing in all cases.

Appendix

A_i, B_i, C_i	the cost function parameters of unit I (Rs/MW^2 hr, Rs/MW hr, Rs/hr)
F_{it} (P_{it})	production cost of unit I at a time t (Rs/hr)
P_{it}	output power from unit i at time t (MW)
PD_t	system peak demand at hour t (MW)
N	Number of available generating units
R_{it}	reserve contribution of unit i at time t
n_t	number of units
U_{it}	commitment state of unit i at time t (on = 1, off = 0)
OMVC	operation and maintenance variable cost
OMFC	operation and maintenance fixed cost
Ts and Te	Starting and ending stage of the time interval for jth unit
I(t)	Reliability index of grid in period t
$\alpha_t(k)$	kth maintenances resource at the tth period
β	Maximum number of maintenance generator in the same area
d_i	Maintenance duration of the ith generator
s_i	Maintenance starting period of the ith generator

Biographies



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