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BINARY PARTICLE SWARM OPTIMIZATION APPROACH FOR RANDOM GENERATION OUTAGE MAINTENANCE SCHEDULING

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Abstract
This paper presents a methodology for maintenance scheduling (MS) of generators using binary particle swarm optimization (BPSO) based probabilistic approach. The objective of this paper is to reduce the loss of load probability (LOLP) for a power system. The capacity outage probability table (COPT) is the initial step in creating maintenance schedule using the probabilistic levelized risk method. This paper proposes BPSO method which is used to construct the COPT. In order to mitigate the effects of probabilistic levelized risk method, BPSO based probabilistic levelized risk method is embarked on a MS problem. In order to validate the effectiveness of the proposed algorithm, case study results for simple five unit system can accomplish a significant levelization in the reliability indices that make possible to evaluate system generation system adequacy in the MS horizon of the power system. The proposed method shows better performance compared with other optimization methods and conventional method with improved search performance.

Keywords:
Maintenance Scheduling, Probabilistic Levelized Risk Method, Binary Particle Swarm Optimization, Capacity Outage Probability Table

1. INTRODUCTION

Preventive maintenance schedule of generating unit at regular maintenance intervals take place the important requirement of power system operation planning. The MS of generating units especially related with power system reliability assessment which is a challenging task in power system [1]–[2]. Modern power system is experiencing increased demand for electricity with related expansions in system size which has resulted in more number of generators making MS problem more complicated. So far, many kinds of methods have been applied to solve MS problem. In mathematical programming methods, the branch–and–bound method is appropriate for solving this problem, while other methods such as integer programming and dynamic programming have got limited application. The conventional approaches suffer from 'curse of dimensionality' with the increase of more number of system variables depend on dimension size of the problem. The computational effort and complexity grows prohibitively with the problem size. They may not lead to global optimum solution for a complex optimization problem. Many kinds of intelligence computation methods such as the GA, fuzzy systems and evolutionary optimization have been applied to solve the MS problem [3]–[4]. The typical PSO is designed for continuous function optimization problems. It is not designed for discrete function optimization problems. Kennedy and Eberhart proposed a modified version of PSO called BPSO that can be used to solve discrete function optimization problems [5]–[8]. In a global MS problem network constraints were included [9]. Mathematical models described how the loss of load probability is affected by uncertainties in the estimated forced outage rates of generating units and efficient method for calculations of the most common reliability indicator loss of load expectation (LOLE). Preventive maintenance is required for all generating units of the system, to reduce the outage probability and thus to increase over all reliability of the system [10]–[12]. An optimal unit MS problem formulation for a generation producer was presented to maximize its benefit while considering the risk associated with unexpected unit failures in the deregulated environment [13]. The probabilistic reliability objective functions are considered with random outage of generators in power system [1]. Inappropriate MS may produce undesirable circumstances in power generation planning. Probabilistic techniques are widely used in power system reliability evaluation. The probabilistic methods are introduced to include load uncertainties and generating unit forced outages [14]–[15]. The BPSO for the generator MS produces optimal maintenance schedule and overcome the drawbacks of conventional methods. Moreover, MS problem is a complex combinatorial optimization problem [16]. The BPSO is suitable to optimize binary value parameters, since MS problem is a binary value based decision making problem. From the survey of literature it is revealed that considerable effort is needed for COPT using BPSO based optimization techniques for the power system that quantitatively evaluate the impact of maintenance on reliability. In this paper, we propose a BPSO based MS problem to solve reliability objective function. The main drawback of deterministic reliability objective function is that it neglects the randomness of the available generating unit's capacity. The stochastic reliability objective function removes the above defect by taking into account the random forced outage of the generating units. In this paper probabilistic objective function has been considered for MS problem. This paper emphasizes MS problem with BPSO based COPT from the reliability perspective.

The problems in probabilistic levelized risk method are mitigated which is the challenging task has been put forward. Moreover, the BPSO is used to create COPT which is the important step for probabilistic levelized risk method since analytical method based COPT becomes monotonous process for large scale power system problems. The simulation results show the flexibility of the proposed algorithm on the five unit system to make comprehensive approach which is used to solve the MS problem. The main highlight of this paper is given as follows:

- The BPSO based COPT is used to solve complex generator MS problem that reduces computational burdens of the generation model.

- Random outage generation scheduling evaluation for power system using BPSO based COPT which is the key task in power system planning.

This paper is organized as follows. Section 2 presents objective function optimization problem with some important maintenance constraints. Section 3 describes about the PSO and BPSO. Section 4 presents the proposed algorithm and its solution method for solving MS problem. Section 5 analyses the simulation results for five unit system. Finally section 6 concludes the paper.

2. PROBLEM FORMULATION

The main goal of MS problem is to find the time table of maintenance outages in such a way that maximizes the reliability of the power system. The objective levelized risk method is that the risk is made more or less the same throughout the period under study is realized through MS optimization. The principal objective function of this method can be equated as,

$$LOLP_i = LOLP_j \;\; i \in t,\, j \in t, t = 1,2,3,......,T \tag{1}$$

$LOLP_i$, $LOLP_j$ are the system risks in maintenance interval, t is the maintenance time interval and T is the number of intervals in the maintenance period.

$$LOLE_p = \sum_{i=1}^{n} P_i(C_i < L_i) days / period \tag{2}$$

$LOLE_p$ is the value of $LOLE$ in the maintenance period p, n is the number of days in a week (n=7), C_i the available capacity on day i, L_i is the forecast peak load on day i, $P_i(C_i<L_i)$, the probability of loss of load on day i which is obtained directly from the capacity outage cumulative probability table. The annual loss of load expectation ($LOLE_a$) is calculated as follows,

$$LOLE_a = \sum_{p=1}^{52} LOLE_p \tag{3}$$

$LOLE$ is calculated for 52 weeks. Annual $LOLE_a$ is the sum of all $LOLE$ in a year. The following constraints are considered in MS problem,

(a) Time Constraint

Generators must be scheduled at the certain intervals. In addition to that, one more consideration is the continuity of maintenance activity. Maintenance must be completed in a continuous maintenance intervals once started.

$$\sum_{t=t_k}^{t_k+S_k-1} m_{kt} = s_k \;\; k \in S \tag{4}$$

m_{kt} is the maintenance state where 0 is for no maintenance in sub-interval t and 1 for under maintenance in the sub interval t, S_k is the number of intervals for maintenance (the number of weeks or months), t_K is the starting interval for maintenance (the week or month) and k is the generating unit, S is the set of generating units involved in maintenance in the period under examination.

(b) Maintenance Crew Constraint

Normally, two generating units cannot be scheduled for maintenance together in the same power plant and at the same time, i.e., V_{rt} =1. Only a few power plants with considerable maintenance resources can allow V_{rt} >1. However, the following constraint must still be met

$$\sum_{k \in V_r} m_{kt} \leq V_{rt} \tag{5}$$

V_{rt} is the maximum number of generating units that the maintenance crew V_r can work on simultaneously in the maintenance interval t.

(c) Reserve Constraint

At any maintenance interval, the total capacity of the units should be greater than the predicted load. i.e.,

$$\sum_{k=1}^{N} C_k X_{tk} \geq P_t \tag{6}$$

P_t is the predicted maximum load in MW during maintenance time interval t and C_k is the capacity of unit k in MW, N is the number of units.

$$X_{tk} - \begin{cases} 1 : \text{if the maintenanc e is done on unit } k \text{ in interval } t \\ 0 : \text{otherwise} \end{cases}$$

Eqs.(1)–(6) define a general mathematical model and maintenance constraints for MS problem.

2.1 MAINTENANCE SCHEDULING BY PROBABILISTIC LEVELIZED RISK METHOD

The probabilistic levelized risk method has two foremost characteristics. The first is that the influence of the random outages on the system's reliability is considered when dealing with generating unit maintenance. The other is that daily variations of load are considered. When a generating unit is on maintenance it is not available to generate power. This increases the power system risk [1].

2.1.1 Risk Characteristic Co-Efficient:

Using the exponential curve the risk characteristic co-efficient (m) can be found out by taking two points A and B on the curve such that $P(X_A) \approx 0.1$ and $P(X_B) \approx 0.0001$. The 'm' can be defined as the corresponding change of the generating unit's outage capacity in MW when the system's risk or $P(X)$ changes by a factor of 'e'. So 'm' is calculated as follows,

$$m = \frac{X_B - X_A}{\ln\left[\frac{P(X_A)}{P(X_B)}\right]} \tag{7}$$

$P(X_A)$ is the probability of outage at point A, $P(X_B)$ is the probability of outage at point B, X_A is the outage at point A and X_B is the outage at point B.

2.1.2 Effective Load Carrying Capacity:

Effective load carrying capacity (C_e) is the actual capacity used for meeting the load demand. It can be calculated as follows,

$$C_e = C - m * \ln(p + q\exp(c/m)) \tag{8}$$

where, p is the availability of a generator, q is the unavailability or forced outage rate of a generator and C is the capacity of the generator being added.

2.1.3 *Equivalent Load:*

In the probabilistic levelized risk method, a more appropriate load called as equivalent load (L_e) is used in the place of the maximum load. It can be computed as follows,

$$L_e = L_m + m * \ln\left(\sum_{j=1}^{n} (\exp(L_j - L_m)/m) * n\right) \tag{9}$$

where, L_j is the daily maximum load under the interval under study, L_m is the maximum load of the stage under study.

2.2 CAPACITY OUTAGE PROBABILITY TABLE

Generating capacity adequacy assessment is an important aspect of power system planning. The generation model consists of a table which contains states of capacity unavailable due to outage in ascending order [1-2]. For a system with '*N*' generating units which can be either "in service" or "out of service", the total number of probable outage system capacity outcome (states) of generators which is 2^N [14]. The outage state of the generating units in the states array are represented using Eq.(10).

$$states\ array = \begin{pmatrix} state_{11} & state_{12} & \cdots state_{1N} \\ state_{21} & state_{22} & \cdots state_{2N} \\ state_{2^N 1} & state_{2^N 2} & \cdots state_{2^N N} \end{pmatrix} \tag{10}$$

The "capacity in service" and the "capacity out of service" of the generating units are calculated for each system state from the system states array using Eq.(11)–(12).

$$state\ capacity\ in_i\ (MW) = \sum_{k=1}^{N} state_{ik} * cap_k \tag{11}$$

$$state\ cap\ out_i\ (MW) = TIC\text{-}state\ capacity\ in_i \tag{12}$$

where, cap_k is the capacity of unit *k*, state i_k is the state of unit *k* in the system state *i*, *TIC* is the total installed capacity in *MW*, *N* is the number of generating units. State probability is calculated using Eq.(13)–(14).

$$state\ probability_i = \prod_{k=1}^{N} prob_k \tag{13}$$

$$\begin{aligned} prob_k &= FOR_k \quad ; \text{if } state_{ik}=0 \\ &= 1\text{-}FOR_k \quad ; \text{if } state_{ik}=1 \end{aligned} \tag{14}$$

where, $prob_k$ is the state probability of unit *k*, FOR_k is the forced outage rate (*FOR*) of unit *k*. The total probability of the collected states "cumulative probability" is using Eq.(15).

$$Cumulative\ probability_m = Cumulative\ probability_{m-1} + \sum_{i=1}^{M} state\ probability_i \tag{15}$$

where, *M* is the total number of states at the end of iteration process.

2.3 PROBLEMS INVOLVED WITH THE PROBABILISTIC LEVELIZED RISK METHOD

The core of probabilistic levelized risk method is to replace the generating units rated capacity with 'C_e '. The probabilistic levelized risk method for calculating the 'C_e' is not accurate enough. In reality the data in the outage table will change as the generating unit scheduled for maintenance exits from operation. Therefore only the computations of the 'C_e' of the first generating unit are to be maintained are correct. The most direct method to solve the problem is to revise the COPT immediately, when one generating unit exits for maintenance and to recalculate the system '*m*'. Obviously, this will greatly increase the amount of computation of COPT and '*m*' [1].

3. PARTICLE SWARM OPTIMIZATION

PSO is motivated from the simulation of the behaviour of social systems such as fish schooling and birds flocking [5]. PSO is a population based optimization tool which is used to solve the problems. The PSO is basically developed for continuous optimization problems that require less memory space and ease of control the parameters. The PSO is based on neighbourhood principle as social network structure.

3.1 BINARY PARTICLE SWARM OPTIMIZATION

The BPSO is made possible with a simple modification to the original version of PSO. In the binary version, the particle's personal best and global best is still updated as in the typical version [6]. The major difference between BPSO and typical PSO is that the relevant variables (velocities and positions of the particles) are defined in terms of the change of probabilities and the particles are formed by integers in {0, 1}. A logistic Sigmoid transformation function $s\left(v_{ij}^{k}\right)$ shown in Eq.(16) can be used to limit the velocity in the interval [0, 1].

$$s(v_{ij}{}^{k}) = 1/(1 + e^{-V_{ij}^{k}}) \tag{16}$$

Thus real velocity is digitized (1/0) by logistic functions for binary space. The update equation of BPSO can be done in two steps. First, Eq. (16) is used to update the velocity of the particle. Second, the new position of the particle is obtained using Eq. (17).

$$X_{ij}{}^{k} = \begin{cases} 1 : \text{if } rand(\ ) \le s(v_{ij}{}^{k}) \\ 0 : otherwise \end{cases} \tag{17}$$

where, $V_{ij}^{(k)}$ is the velocity of j^{th} dimension in i^{th} particle, $X_{ij}^{(k)}$ is the current position of the j^{th} dimension in i^{th} particle at iteration *k.rand*( ) is a uniform random number in the range [0, 1].

4. IMPLEMENTATION OF THE PROPOSED MS IN POWER SYSTEM

Generation planning is very difficult task in power system. In order to find C_e and L_e, '*m*' value is calculated using Eq.(7). Generators contribute different amount of reserve capacity for the entire system reserve in the power system. For each generator the COPT will have to be created immediately after first generator exits from maintenance and '*m*' is recalculated. In this method, precise calculation of '*m*' and outage capacity of generators selected through the heuristics which create the various possibilities of the MS, among them the schedule that satisfy all the constraints is considered. The greatest computational complicatedness in obtaining in power system reliability evaluation is the creation of COPT which requires complicated mathematical modeling and more computation time for large scale system. The proposed algorithmic steps are as follows,

- **Step 1** : Get the generator data viz the number of generators, their rated capacity and respective forced outage rate.
- **Step 2** : Get the load data for 52 weeks includes the daily maximum load data.
- **Step 3** : Create the COPT for the generation system using BPSO algorithm.
- **Step 4** : Select the cumulative probability values (corresponds to the outage capacities of generator) close to $P(X_A) = 0.1$ and $P(X_B) = 0.0001$.
- **Step 5** : Compute the value of '*m*' by BPSO using Eq.(7) according to the data in the COPT.
- **Step 6** : Compute the values of 'C_e' of first generator using Eq.(8).
- **Step 7** : Find the values of 'L_e' using Eq.(9).
- **Step 8** : Take the first generator and calculate the minimum sum of 'C_e' and 'L_e' in the maintenance time interval.
- **Step 9** : Schedule the generator by searching the intervals with minimum sum of 'C_e' and 'L_e' on the load curve and schedule the generator until the maintenance intervals are exhausted for that particular generator using heuristics method.
- **Step 10** : Revise the COPT, recalculate the value of '*m*' using BPSO for all the generators using Eq.(7).
- **Step 11** : Compute the values of 'C_e' for succeeding generators according to step 10.
- **Step 12** : Repeat steps 8 and 9 for all the subsequent generators for MS.
- **Step 13** : If all the generating units are not exit for maintenance, go to step 5 to revise the MS. Otherwise go to step 14.
- **Step 14** : Terminate the program and print the optimal schedule.

4.1 PROPOSED BPSO ALGORITHM FOR OUTAGE SYSTEM STATE AND RISK CHARACTERISTIC COEFFICIENT IN MS PROBLEM

The BPSO algorithm has been used to find the global optimum solution for MS problem. The outage system state capacity of the generators and '*m*' are taken as control variables in the proposed method. Generally PSO can quickly move near optimal solution best values stagnate and it may prematurely converge on the suboptimal solution. They have not even guarantee the local optima. Better diversity can be achieved by adopting the proposed algorithm for MS. If the cumulative probability is very low, the new particles are generated using proposed algorithm. If the cumulative probability reaches the value of 1, the program gets terminated. Moreover, initial population for '*m*' values and all possibilities of system outage capacities of the power system are selected. In the proposed algorithm '*n*' particles are generated by randomly selecting a value with uniform probability over the search space between maximum and minimum outage capacities of generator. The system state probabilities are calculated using Eq.(13) and Eq.(14). The cumulative probability of system capacity outage states are calculated using Eq.(13) and Eq.(15).

5. CASE STUDY RESULTS AND DISCUSSION

In order to verify the effectiveness of the proposed method, five units system has been considered for the case study [1]. For the sake of simplicity a simple power system is considered. The maintenance operational planning horizon is 52 weeks. The proposed BPSO has been implemented in Matlab7.0 programming language and executed on Intel(R) core(TM) i3 CPU. The following control parameters have been chosen for the BPSO, maximum and minimum inertia weight *Wmax* and *Wmin* are set at 0.9 and 0.2 respectively. Maximum iteration *itermax* = 1000, acceleration constants $c_1 = 2.05$ and $c_2 = 2.05$. The proposed algorithm has been tested on a small test system which has the installed capacity of 2500 MW and there are five generating units scheduled for maintenance within 8 weeks. The generator and maintenance data are given in Table.1. The load data and equivalent load values is given in Table.2. The initial population starts with random control parameter values which are selected in the specified range that depends on all the possibilities of outage capacity of generators in the maintenance planning horizon. The proposed algorithm optimizes the value of '*m*' and system outage states of generator. As stated earlier, COPT has been built using BPSO.

The total number of probable outage system states for the five unit system is 25 i.e. 32 states. The initial created COPT for the five unit system is shown in Table.3. This table presents representative COPT results (when no generator is on maintenance) and validating the output for case study. When maintenance of first generator is completed, the COPT has to be revised. It is noticed from Table.3 that the cumulative probability of generators are obtained for all outage capacities of generator ranging from 0–2500 MW. As pointed out earlier these system states are truncated which may not influence the power system reliability. Moreover the unrepeated states are added to a system states array. The cumulative probabilities of the collected states are evaluated. Obviously, the cumulative probability starts with zero; the cumulative probability varies between 0–1. The initial population of BPSO algorithm for the first iteration is generated randomly. It is revealed from Table.3 that when the outage capacity of generator is zero the corresponding cumulative probability is 1.

Table.1. Generation system, maintenance data for case study

Generating unit	Capacity (MW)	Forced outage rate	Maintenance intervals
1	700	0.04	4
2	600	0.03	1
3	500	0.02	4
4	400	0.02	2
5	300	0.02	1

Typical practical systems contain a large number of generating units and cannot normally be analyzed by hand calculations. The BPSO search the state space to test out the most possible failure states of the generator and store them in a state array using Eq.(10). The state probabilities of each outage capacity of the units are calculated using Eq.(13).

Table.2. Load data for case study

Maintenance interval (Week)	Load (MW)
1	2000
2	1920
3	1800
4	1740
5	1640
6	1500
7	1580
8	1620

The fitness values for the repeated state are assigned a very small value and appears as zero, it is revealed that the state probability of system outage states which are identical for large systems. However, it is not practical to incorporate all of the outage of generator system states in the COPT for the large scale systems. Iterations are performed until the cumulative probability value reaches the value of 1 and all the significant states with high probabilities are recovered at the end of iterations. The cumulative probability approaches the value of 1.0 corresponding to the maximum outage capacity of the generator in the power system.

In order to revise the COPT the generating units are removed using convolution process and new COPT is created using the proposed method. For example first generating unit which has a capacity of 700 MW exits for maintenance, the COPT has been revised immediately and the system 'm' is recalculated. Similarly other generating units are removed and the COPT is to be revised. Revised COPT (when first generator is under maintenance) results after removal of generating unit 1 for case study is shown in Table.4. If the outage states have low probability of occurrence which means that they are unusually to occur. They do not influence significantly on the power system reliability evaluation. The *LOLP* values for five unit power system and the corresponding reserve in MW (without scheduled outage) are given in Table.5. It is evident from Table.5 that the risk gradually increases, when load is increased. The obtained *LOLP* value is 0.3287790 (maintenance time interval 2).

Table.3. COPT results for case study

Outage Capacity(MW)	Cumulative Probability
0	1.000000000000000
300	0.020000000000000
400	0.019600000000000
500	0.019208000000000
600	0.028235760000000
700	0.036918249600000
800	0.000392000000000
900	0.000968240000000
1000	0.001321510400000
1100	0.001321510400000
1200	0.000753270400000
1300	0.001141190400000
1400	0.000026969600000
1500	0.000026969600000
1600	0.000038259200000
1700	0.000023049600000
1800	0.000023289600000
1900	0.000000310400000
2000	0.000000470400000
2100	0.000000470400000
2200	0.000000470400000
2500	0.000000009600000

It is observed from Table.5 that the risk is higher than the other maintenance time interval and the corresponding reserve value is 271.51 MW. It is shown that the probabilistic levelized risk method significantly reduces the total risk of the system. The effective load carrying capacity for the case study is shown in Table.6 for different values of 'm' according to the new COPT which is created using the BPSO. Then each unit is removed from the system and 'C_e' is recomputed using the updated COPT. In order to find new values of 'C_e' the procedure will be repeated for each generating unit.

Table.4. Revised COPT results

Outage Capacity(MW)	Cumulative Probability
0	1.000000000000000
300	0.020000000000000
400	0.019600000000000
500	0.019208000000000
600	0.028235760000000
700	0.000400000000000
800	0.000392000000000
900	0.000968240000000
1000	0.000576240000000
1100	0.000576240000000
1200	0.000008000000000
1300	0.000011760000000
1400	0.000011760000000
1500	0.000011760000000
1800	0.000000240000000

A reliable power system should have adequate reserve capacity to overcome power interruptions caused by random failures of generators. It is seen from Table.6 that each generator contributes a specific amount of its capacity for the entire system's reserve to ensure the reliability of the power system.

Table.5. LOLP values in the maintenance time interval

Maintenance Interval (Week)	Reserve(MW) (without scheduled outage)	LOLP
1	769.37	0.0161329
2	271.51	0.3287790
3	658.03	0.0313084
4	714.56	0.0324749
5	495.74	0.0196317
6	639.87	0.0387600
7	557.48	0.0021557
8	516.31	0.0953115

The equivalent load for the case study is shown in Table.7. The optimal maintenance schedule obtained for case study is given in Table.8. The committed generating units are used to satisfy the power balance constraints in the real–time operation of power system. It starts with the random initial control parameters which are generated using heuristics by avoiding the cumbersome computational effort required by the conventional methods.

Table.6. Effective load carrying capacity of generators

Generating unit(MW)	Capacity (MW)	*m*	Effective load carrying capacity (MW)
1	700	93.05	298.32
2	600	94.57	326.39
3	500	96.78	354.75
4	400	97.34	323.34
5	300	99.56	267.42

More number of revisions in COPT's is necessary in order to evaluate the 'C_e' of generators. The obtained optimal 'm' is 117.1085 MW using Eq.(7). The first generating unit which has the capacity of 700 MW contributes more amount of reserve (401.68 MW) when compared with other generating units. The 'C_e' of generators are quite different even though they have same forced outage rate and capacity for various value of 'm' based on the COPT revision. The obtained *LOLE* value is 4.359442 days per year. The 'C_e' for all generators are recalculated based on the new values of 'm' and the revised COPT. However, the 'm' is sensitive to changes in the load level, averaging the peak loads will lead to an inaccurate maintenance schedule. Hence, 'L_e' is taken into consideration in which the daily peak load variation is considered. The removal of generating units for maintenance can create excessive risk to the system under certain load conditions. It is clear that all generators are scheduled in the specified maintenance time intervals. Moreover, all the constraints are satisfied.

Table.7. Load and Equivalent load values

Maintenance Interval (Week)	Load (MW)	Equivalent Load (MW)
1	2000	1730.63
2	1920	1648.59
3	1800	1525.43
4	1740	1463.80
5	1640	1360.99
6	1500	1216.86
7	1580	1299.25
8	1620	1340.41

The proposed method checks various possibility of maintenance outage schedule. Table.9 shows the optimum solution of the BPSO after 10 runs under different particle numbers. It is found that the average solution of 'm' is optimum after 10 runs when the particle number is increased to 300 particles.

It is observable that the conventional method takes more CPU time to find optimal MS which involves more number of variables and complexity of the MS problem increases dramatically with the large scale power system problems.

Table.8. Optimal MS results

Maintenance Interval (Week)	Generating Units Scheduled
1	---
2	4,5
3	4
4	2
5	3,1
6	3,1
7	3,1
8	3,1

The proposed method has been correctly addressed to mitigate the effect of probabilistic levelized risk method which is prerequisite of power system reliability assessment.

Table.9. Solution of BPSO after 10 runs under different particles

Run	100 particles	200 particles	300 particles
	Risk Characteristic Co-efficient	Risk Characteristic Co-efficient	Risk Characteristic Co-efficient
1	121.2676	117.3322	116.0823
2	119.5522	118.1204	116.6413
3	120.6773	120.5608	118.8976
4	118.4423	117.6512	116.4551
5	122.5213	119.4342	117.6522
6	119.9901	117.9804	115.0914
7	120.4281	116.7340	118.2233
8	121.3201	116.4893	117.1056
9	119.8806	118.1532	114.9642
10	118.1243	116.6532	119.8877
Average	120.22038	118.21089	117.10007

The BPSO took more execution time than classical PSO for convergence to the global optimal solution, the MS results are so significantly improved the quality of the solution. The BPSO approach avoids the entrapping the solution from the local optimum.

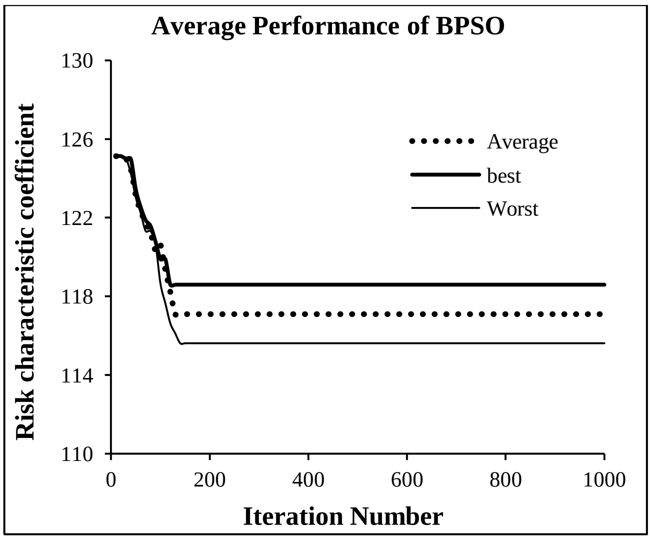

Fig.1. Average performance of BPSO

Table.10. Comparison of LOLE and CPU time

Test system	Methods	LOLE (days/year)	CPU time (seconds)
Five unit system	PSO	7.986547	12
	BPSO	4.359442	24
	Classical probabilistic levelized risk	9.964217	44

Comparison of *LOLE* and CPU time for five unit system is shown in Table.10. It is found from Table.10 that the BPSO finds the optimal solution with other compared techniques. Several runs were accomplished for the proposed method and hence average, best, and worst behavior can be analyzed.

It utilizes the global and local exploration capabilities of BPSO to search for the optimal setting of the state variables. Average performance '*m*' is shown in Fig.1. It is evident from Fig.1 that whenever the population size is 300 the proposed BPSO will provide better results when compared with other population sizes (100,200). The proposed developed algorithm may be used by power generating companies to solve the MS problem.

6. CONCLUSION

A new BPSO based MS methodology has been presented using the probabilistic levelized risk method. However, the problems in the probabilistic levelized risk method are mitigated using the proposed algorithm. Its computational difficulty is reduced while computing the '*m*' and outage capacity of the generators using BPSO. The proposed method enables to find the fundamental reliability indicators such as *LOLP* and *LOLE* for generation capacity planning that determines availability of power system utilities. The proposed method has been tested comprehensively on the five unit system. Moreover, this paper uses the exploitation of BPSO to explicitly create the COPT which is used to create the generation model COPT. The proposed MS model possibly incorporates the probabilistic nature of generating units with forced outage rate of generators and daily peak load variation which are used in power system expansion planning. The BPSO method is used to obtain the optimal solution from the diversified solutions in the search space. It is concluded that BPSO based MS which is used to decide how much generation capacity is required to guarantee the required reliability level in the power system utilities. It is envisaged that the proposed algorithm is suitable for any practical large scale power system for capacity generation planning and its potential to solve the MS problem while considering the random failures in the maintenance model.

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