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Hybrid particle swarm optimization: Evolutionary programming approach for solving generation maintenance scheduling problem

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This paper presents a hybrid particle swarm optimization based genetic algorithm and hybrid particle swarm optimization based evolutionary programming for solving long-term generation maintenance scheduling problem. In power system, maintenance scheduling is being done upon the technical requirements of power plants and preserving the grid reliability. The objective function is to sell electricity as much as possible according to the market clearing price forecast. While in power system, technical viewpoints and system reliability are taken into consideration in maintenance scheduling with respect to the economical viewpoint. It will consider security constrained model for preventive maintenance scheduling such as generation capacity, duration of maintenance, maintenance continuity, spinning reserve and reliability index are being taken into account. The proposed hybrid methods are applied to an IEEE test system that consist 24 buses with 32 generating unit system.

Key words: Generation maintenance schedule, optimization, evolutionary programming, particle swarm optimization, genetic algorithm

INTRODUCTION

Under the rapid development around the globe, power demand has increased drastically during the past decade. To meet this demand, the development of power system technology has become increasingly important in order to maintain a reliable and economic electric power supply. One major concern of such development is the optimization of power plant maintenance scheduling. Maintenance is aimed at extending the lifetime of power generating facilities, or at least extending the mean time to the next failure for which repair cost may be significant. In addition, an effective maintenance policy can reduce the frequency of service interruptions and the consequences of these interruptions. In other words, having an effective maintenance scheduling is very important for a power system to operate economically and with high reliability.

The focus of this paper was the maintenance decision problem for generation unit system with economic dependency. In the paper, an opportunistic maintenance policy generally applicable to the economic dependency problem was proposed for developing optimal maintenance schedule. The advances in computer and information technology have created a strong trend to integrate various operation facilities into large-scale system. As a result of this integration, the productivity and efficiency of these systems have been significantly improved. On the other hand, the integration has created a strong functional dependency between the components of the system. Failure of any one of these components could disable the entire system and hence cause significant financial loses and serious safety problems. Effective maintenance program development has become the major challenge and primary concern for today's system managers.

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Many maintenance-scheduling methods have been proposed using conventional mathematical programming methods or heuristic techniques. Heuristic approaches provide the most primitive solution based on trial-and-error approaches. These techniques may not generally lead to the global optimal for a complex problem, that is, the procedure tends to fall into a local minimum if a starting point is not carefully chosen. Heuristic methods were used earlier in solving maintenance scheduling problems for centralized power systems because of their simplicity and flexibility.

Mathematical optimization based techniques such as integer programming (Dopazo and Merrill, 1975), dynamic programming (Zurn and Quintana, 1975; Yamayee et al., 1983) and branch-and-bound (Egan et al., 1976) have been proposed to solve maintenance scheduling problems. For small problems these methods give an exact optimal solution. However, as the size of the problem increases, the size of the solution space increases greatly and hence the running time of these algorithms. These approaches tend to suffer from an excessive computational time with the increase of variables. To overcome this difficulty, modern techniques such as simulated annealing (Cerny, 1985; Kirkpatrick et al., 1983), stochastic evolution (Saab and Rao, 1991), genetic algorithms (Goldberg, 1989) and Tabu search (Rajan and Mohan, 2004) have been proposed as alternatives where the problem size precludes traditional techniques. These techniques are completely distinct from classical programming and trial-and-error heuristic methods. 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 (Mirinda et al., 1998). Fuzzy optimization techniques have been developed to solve optimal power flow with fuzzy constrains (Xiaohong and Peter, 1996; Tomsovic, 1992; Miranda and Saraiva, 1992), and to schedule manufacturing system with possible breakdowns (Li et al., 1994). 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.

A little effort has been reported to implement MOPSO for solving power system problems. A fuzzified MOPSO (Wang and Singh, 2007) to solve environmental/ economic dispatch problem with heat dispatch and with multiple renewable energy sources. The approach presents a fuzzification mechanism for the selection of global best individual with interpreting the global best as an area, not just as a point. On the other hand, only one local best solution is maintained for each particle. This will degrade the search capability and violates the principle of multiobjective optimization. A model (Baslis et al., 2012) for maintenance scheduling of generators using mixed-integer linear programming problem using commercial software (GAMS/CPLEX). The aim was to maximize yearly profit, while simultaneously satisfying the operating constraints, such that avoiding the simultaneous planned outage of generating units that belong to the same power station, and maintenance intervals that must be scheduled whenever a specific number of operating hours is completed. A modified MOPSO (Kitamura et al., 2005) to optimize an energy management system where the problem is solved in three phases by dividing the original optimization problem into partial problem. However, this approach has severe limitation in the case of strong interaction among the constraints in different subprogram. A MOPSO (Hazra and Sinha, 2007) based approach to solve the congestion management problem where the cost and congestion are simultaneously minimized. PSO has been successfully implemented to different power system optimization problem including the economic power dispatch problem with impressive success (Al-Rashidi and El-Hawary, 2007). The potential of PSO to handle non smooth and non convex economic power dispatch problem was demonstrated (Selvakumar and Thanushkodi, 2007). However, the problem was formulated as a conventional dispatch problem with the fuel cost as the only objective considered for optimization. Shuffled frog leaping algorithm has been successfully applied to several engineering optimization problems such as unit commitment (Eslamian et al., 2009) and job-shop scheduling arrangement (Rahimi-Vahed and Mirzaei, 2007).

A novel mechanism (Changyou and Xifan, 2010) for unit maintenance scheduling (UMS) in the deregulated environment, based on the different functions of power producers and the independent system operator (ISO). The proposed scheme aims to achieve a tradeoff between ensuring the producers' benefits and maintaining the system reliability, providing satisfactory maintenance windows and cost-reflective reward/charge to individual producers. Although this can extend further, such as the preventing from market power, UMS coordination mechanism and the mechanism of performing the auction sale. A novel concept (Chin and Srinivasan, 2003) for the spawning and selection mechanism in a hybrid particle swarm algorithm. The results suggest that this hybrid model converges to a better solution faster than the standard PSO algorithm. The hybrid approach proposed here (SPSOES) with spawning and selection mechanism proves to be superior over classical PSO in the cost obtained. Although SPSOES is not as time efficient as standard PSO. A model (Suresh and Kumarappan, 2013) for maintenance scheduling (MS) of generators using hybrid improved binary particle swarm optimization (IBPSO) based coordinated deterministic and stochastic approach.

Genetic algorithm (GA) operators are introduced in the IBPSO to acquire diversified solutions in the search space. Moreover, the hybrid IBPSO based economic dispatch (ED) has been decomposed as a sub-problem in the maintenance model. The authors apply their method to determine the preventive maintenance schedule in a power system. They mention that the method could produce better solutions if some changes and modification are made to the solution procedure.

The proposed algorithm is based on a sequential optimization process of both economic and reliability objectives. The economic purpose is the minimization of total variable operating costs (fuel + O&M and interruptible energy). Other economic objectives have been proposed as maintenance costs, fixed and variable costs, maintenance crew costs, etc. The second optimization run is done minimizing the sum of the differences between the thermal reserve margins of consecutive periods. The reserve margin is calculated dividing the available thermal capacity by the period peak load. This reliability index is the net reserve divided by the gross reserve in period t. The gross reserve in any period is calculated as the difference between the sum of the capacity of all units and the power demand. The net reserve is calculated as the difference between the gross reserve and the power capacity in maintenance. Generally, it is shown that optimal solutions obtained under one reliability criterion are also acceptable in terms of the others. Here, the net thermal reserve margins leveling between periods in a deterministic way, has been used; units availability is modeled derating the maximum.

From the literature review, there has been observed existing need for evolving simple and effective methods, for obtaining an optimal solution. In this paper an attempt has been made using hybrid PSO-GA and PSO-EP algorithm for meeting the above requirement, which eliminate the drawbacks. In this environment, management of generator and grid is separated, each maximizing its own benefit. Therefore, the principle to draw up the unit maintenance scheduling will be changed significantly. So every generator hopes to put its maintenance on the weeks when market clearing price (MCP) is lowest so that maintenance variable cost descends. The objective function is to sell electricity as much as possible, according to the market clearing price. But the goal of the grid is to maximize the reserve capacity at every time interval. Depending upon the fitness, profit and reliability index select maintenance scheduling by taking various technical constraints. In the application on IEEE RTS (reliability test system) consist of 24 bus (32 Units) that we can find the optimal solution effectively and these result are compared.

PROBLEM FORMULATION

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

$$\text{Profit} = \sum MCP * P_{it} - F_T$$

$$Min\, F_T = \sum_{t=1}^{T}\sum_{i=1}^{N}\{F_{it}\,(P_{it})\,n_t\}U_{it} + \{(P_{it}+R_{it})OMVC\,n_t\}U_{it} + \sum_{t=1}^{T}\sum_{i=1}^{N}\{P_{\max\,i}\,OMFC\,n_t\}/8760 \quad (2)$$

$$F_{it}\,(P_{it}) = A_i + B_iP_{it} + C_iP^2_{it}\ \text{Rs/h} \quad (3)$$

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.

Constraints of maintenance scheduling problem

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.

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.

$$U_{it}P_{i\,min} \le P_{it} \le U_{it}P_{i\,max} \quad (4)$$

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.

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

Maintenance resources

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

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.

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

One-time maintenance

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

$$\sum_{t=1}^{T} sv_{it} = 1 \quad (8)$$

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.

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

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

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

In this paper, the 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.

PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is inspired from the collective behavior exhibited in swarms of social insects. It has turned out to be an effective optimizer in dealing with a broad variety of engineering design problems. In Particle swarm optimization, a swarm is made up of many particles, and each particle represents a potential solution (that is, individual). A particle has its own position and flight velocity, which keep being adjusted during the optimization process based on the following rules:

$$V_i^{P+1} \omega * V_i^{P} + C_1 * rand() * (P_{bi}^{KP} - P_i^{KP}) + C_2 * rand() * (P_{gi}^{KP} - P_i^{KP}) \quad (12)$$

$$P_i^{KP} = P_i^{KP} + V_i^{P+1} \quad (13)$$

where V_{t+1} is the updated particle velocity in the next iteration; V_t is the particle velocity in the current iteration; ω is the inertial dampener which indicates the impact of the particle's own experience on its next movement; $C_1 * rand$ represents a uniformly distributed number within the interval [0, *c*1], which reflects how the neighbours of the particle affects its flight; P_{bi}^{KP} is the neighborhood best position; V_i^{P} is the current position of the particle; $C_2 * rand$ represents a uniformly distributed number within the interval [0, *c*2], which indicates how the particle trusts the global best position; P_{gi}^{KP} is the global best position; and V_i^{P+1} is the updated position of the particle. Under the guidance of these two updating rules, the particles will be attracted to move toward the best position found thus far. That is, the optimal solutions can be sought out due to this driving force. The major steps involved in particle swarm optimization approach are discussed as follows:

Initialization

The initial particles and velocities of each particle are also selected randomly. The size of the swarm will be (Np x n), where Np is the total number of particles in the swarm and 'n' is the number of stages.

Updating the velocity

The velocity is updated by considering the current velocity of the particles, the best fitness function value among the particles in the swarm. The velocity of each particle is modified by using Equation 12. The value of the weighting factor ω is modified by following Equation 14 to enable quick convergence.

$$\omega = \omega_{\max} - (\omega_{\max} - \omega_{\min}) / iter_{\max} * iter \quad (14)$$

The term $\omega < 1$ is known as the "inertial weight". It is a friction factor chosen between 0 and 1 in order to determine to what extent the particle remains along its original course unaffected by the pull of the other two terms. It is very important to prevent oscillations around the optimal value.

Updating the position

The position of each particle is updated by adding the updated velocity with current position of the individual in the swarm.

GENETIC ALGORITHM

The Genetic Algorithm is essentially a search algorithm based on the mechanics of natural selection and natural genetics. It combines solution evaluation with randomized, structured exchange of information between solutions to obtain optimality. The power of this algorithm comes from its ability to exploit historical information structures from previous solution guesses in an attempt to increase performance of future solution structures. By simulating "the survival of fitness" criterion of Darwinian evaluation among chromosome structures, the optimal solution is searched by randomized information exchange. While randomized, it effectively exploits historical information to speculate on new set of artificial chromosomes which is created using bits and pieces of the fittest of the old ones. The three prime operators associated with the Genetic Algorithm are reproduction, crossover and mutation.

Several modifications can be applied to the basic Genetic Algorithm to improve the performance on practical problems. One of them is Elitism; probabilistic nature of the selection process gives a chance of reproduction even to the weakest number of the population. Likewise there is a chance that the best-performing member might not be present in the next generation due to structural changes following cross over and mutation. Hence it is derivable to copy the clite structures into the next gene. Best-fit string of each gun is copied to next gun without undergoing cross over and mutation. In order to reduce the memory space requirement for storing the genes, the simple Genetic Algorithm is altered in such a way that chosen genes replace the new child genes in the current generation.

HYBRID ALGORITHM FOR PARTICLE SWARM OPTIMIZATION BASED GENETIC ALGORITHM FOR MAINTENANCE SCHEDULING

The step by step procedure to compute the global optimal solution is as follows:

Step 1: Initialize a population of particles with random positions and velocities on dimensions in the problem space.

Step 2: For each particle, evaluate the desired optimization fitness function in the variables.

Step 3: Compare particles fitness evolution with particles $Pbest$. If current value is better than $Pbest$, then set $Pbest$ value equal to the current value, and the $Pbest$ location equal to the current location in the dimensional space.

Step 4: Compare fitness evaluation with the populations overall previous best. If current value is better than $gbest$, then reset to the current particles array index and value.

Step 5: Change the velocity and position of the particle according to Equations 13 and 14 respectively.

Step 6: Loop to step 2 until a criterion is met, usually a sufficiently good fitness or a maximum number of iterations.

Step 7: The parent vector p = [p_1, p_2, … p_n], i = 1,2,…N_p such that each element in the vector is determined by p_j ~ random (p_{jmin}, p_{jmax}), j = 1,2,…N, with one generator as dependent generator.

Step 8: Calculate the overall objective function is given in Equation 12 using the trail vector p_i and find the minimum of F_{Ti}.

Step 9: Create the offspring trail solution p_i' using the following steps.

(a) Calculate the standard deviation $\sigma j = \beta(F_{Tij} / \min(F_{Ti}))(P_{j\max} - P_{j\min})$

(b) Add a Gaussian random variable to all the state variable of p_i, to get p_i'.

Step 10: Select the first N_p individuals from the total $2N_p$ individuals of both p_i & p_i' using the following steps for next iteration.

i. Evaluate r = ($2N_p$ random (0,1) + 1)

ii.Evaluate each trail vector by W_{pi} = sum (W_x) Where x = 1,2,…N_p, i = 1,2,…$2N_p$ such that $W_x = 1$ if F_{Tij} / (F_{Tij}+F_{Tir}) < random (0,1), otherwise, $W_x = 0$.

Step 11: Sort the W_{pi} in descending order and the first N_p individuals will survive and are transcribed along with their elements to form the basis of the next generation.

Step 12: The above procedure is repeated from Step 8 until a maximum number of generations N_m is reached.

CASE STUDY

A IEEE RTS (reliability test system) which is an IEEE 24-bus system with thirty-two generating units has been considered as case study. A time period of 52 weeks is considered for solving the thirty-two units. The proposed methodology was tested for IEEE-RTS.

In this paper, maintenance cost models have been developed with and without failure scenarios. Both models include different maintenance cost components which may capture a realistic scenario in a real market environment. In order to demonstrate the solution methodology using the Particle Swarm Optimization - Genetic Algorithm (PSO-GA) technique for solving Generation Maintenance Scheduling problems, a test system with twelve generating units which must be maintained over a 52 week planning horizon is described in detail here.

Table 1 show the operation and maintenance cost for IEEE-RTS, that is, IEEE 24-bus system with thirty-two generating units. Table 2 shows the generating units data for the IEEE-RTS. Table 3 gives data on weekly peak load in percentage of annual peak load (IEEE Reliability

Table 1. Operation and maintenance cost of 32 units.

Units	P_{max} (MW)	Fixed O & M cost (Rs/KW/yr)	Variable O & 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	197	3,10,000	9,000
30	350	2,70,000	7,300
31 & 32	400	2,25,000	5,750

Table 2. Generating unit data of 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 & 32	400	0.12	8	20

Test System, 1996) data).

IMPLEMENTATION OF PSO - GA

In this paper, a Particle Swarm Optimization (PSO) - Genetic Algorithm (GA) based algorithm for solving the Generation Maintenance Scheduling problems will be introduced in which the equality and inequality constraints of the Generation Maintenance Scheduling problems when modifying each particles search point in the particle swarm optimization algorithm are set. In the initialization process, a set of particles is created in a random order. The structure of a particle for Generation Maintenance Scheduling problems is composed of a set of elements (that is, thermal generations, reserve in each interval). Therefore, particles position at iteration in period of t can be represented by the vector.

To modify the position of each particle, it is necessary to calculate the velocity of each particle. In this position updating process, the value of parameters such as ω, C_1, C_2 and C_3 should be determined in advance. In this thesis, the inertial weight is defined as Equation 18. The position of each particle is based on improving fitness or achievement of objective function. Thus, each particle keeps the previous best position and corresponding fitness until the next velocity which leads to new best position and achievement. At first, this approach is

Table 3. Weekly peak load in percent of annual peak.

Week	Peak load
1	86.2
2	90.0
3	87.8
4	83.4
5	88.0
6	84.1
7	83.2
8	80.6
9	74.0
10	73.7
11	71.5
12	72.7
13	70.4
14	75.0
15	72.1
16	80.0
17	75.4
18	83.7
19	87.0
20	88.0
21	85.6
22	81.1
23	90.0
24	88.7
25	89.6
26	86.1
27	75.5
28	81.6
29	80.1
30	88.0
31	72.2
32	77.6
33	80.0
34	72.9
35	72.6
36	70.5
37	78.0
38	69.5
39	72.4
40	72.4
41	74.3
42	74.4
43	80.0
44	88.1
45	88.5
46	90.9
47	94.0
48	89.0
49	94.2
50	97.0
51	100
52	95.5

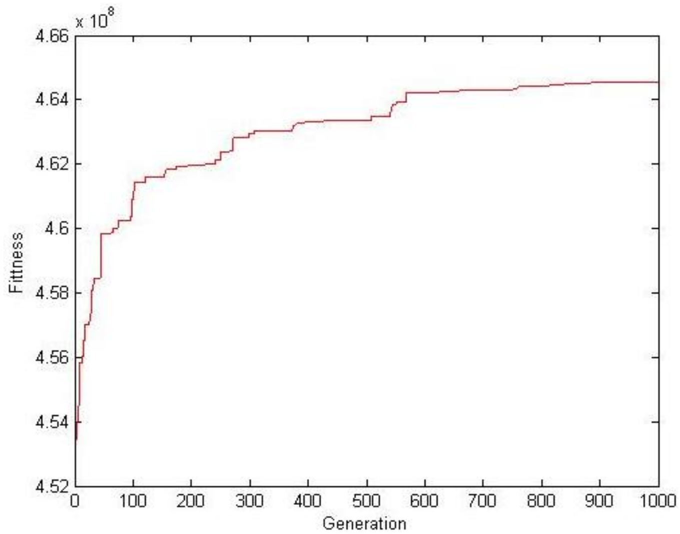

Figure 1. Performance of object function for 32 units.

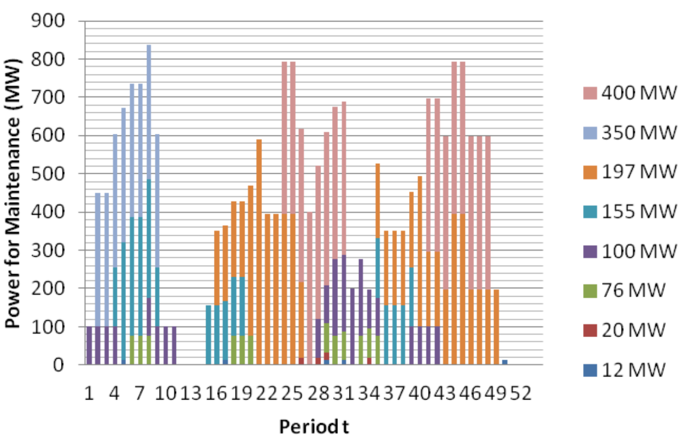

Figure 2. Maintenance Scheduling of objective function for 32 generator units.

applied to the test system to obtain the acceleration constant C1, C2 and C3. Then two different test systems were tested to verify the feasibility solution of the proposed method to solve Generation Maintenance Scheduling problem. The value of ω_{max}, ω_{min} and $iter_{max}$ are 1.0, 0,1 and 100 respectively. The other parameter such as C_1, C_2 and C_3 are selected through the evaluation of the output, after many runs on the test system.

To solve an optimization problem using Particle Swarm Optimization based Genetic Algorithm (PSO – GA), first the possible solutions of the problem have to be coded in chromosomes. Next a fitness function to compare the chromosomes has to be defined. The period of maintenance scheduling is usually one year and is divided into T stages. When a stage is one week, T is equal to 52. In solving the generation maintenance problem, the main variables to be identified are maintenance states of the generating units. The schedule for unit i could be represented by a string of zeros and ones, U_{ij} where one means the unit i is under maintenance in the stage t. We take the maintenance schedule corresponding to an individual generating unit as a gene and build the chromosome from these genes. Therefore a single chromosome will completely describe the maintenance schedules for power generating units. Next the last generation individuals are taken as input for Genetic Algorithm, and then offspring will be generated and best individuals are taken for transcribed along with their elements. Finally the selection process will be done using Genetic Algorithm. In this Genetic Algorithm a set of experiments for the twelve generator units was carried out. We use "Roulette wheel" selection method and "one-point" crossover operator as they are popular operators for small and simple application as we have here. After a number of experimentations we found that there are slight changes in the solution, however the best solution was found with Crossover Probability (CP) = 0.8, Mutation Probability (MP) = 0.01, and Population Size (PS) =100; these are in line with the recommendations made in the GA literature (Mirinda et al., 1998). Therefore, these value were used in two case studies. We define the stopping criteria at 100 generation, which seems enough to assure solution convergence. The number of generations kept 100 for all studies. For the thirty-two unit's problem, the same Genetic Algorithm operator's probabilities were used.

To solve for Generation Maintenance Scheduling problem, the proposed hybrid methodology was developed. Particle Swarm Optimization based Genetic Algorithm (PSO – GA) program has been carried out on a Pentium IV 2-GHz PC with a 512 Mbyte RAM (in MATLAB 7.3). The software provides interactive approach in dealing with the various data input required for solving the Generation Maintenance Scheduling with constraints which should be set up, such as the continuity of maintenance activity, specific time interval for maintenance of some generating units, maximum and minimum capacity of each generating unit, minimum net reserve. The annual peak load for the thirty-two generator test system is 2850 MW. Each unit must be maintained (without interruption) for a given duration within an allowed period. The allowed period for each generator is the result of a technical assessment and the experience of the maintenance personnel, which ensures adequate maintenance period.

Figure 1 shows performance of the hybrid Particle Swarm Optimization based Genetic Algorithm (PSO- GA) over 1000 generations when maintenance scheduling of the generating units formulated based on its desired objective function and figure, the fitness of the population are illustrated. For the maximization problem, fitness function is same as the objective function. Figure 2 shows during week 8 maximum generator maintenance is carried out. Figure 3 shows maintenance schedule of

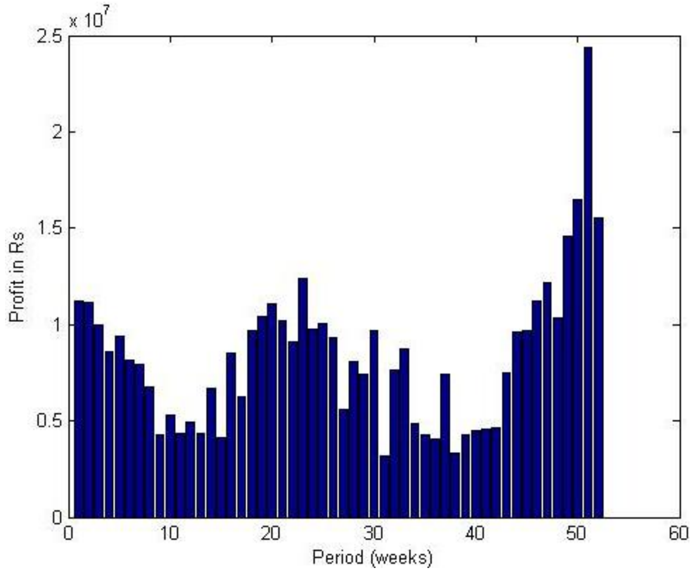

Figure 3. Scheduling of objective function for 32 units.

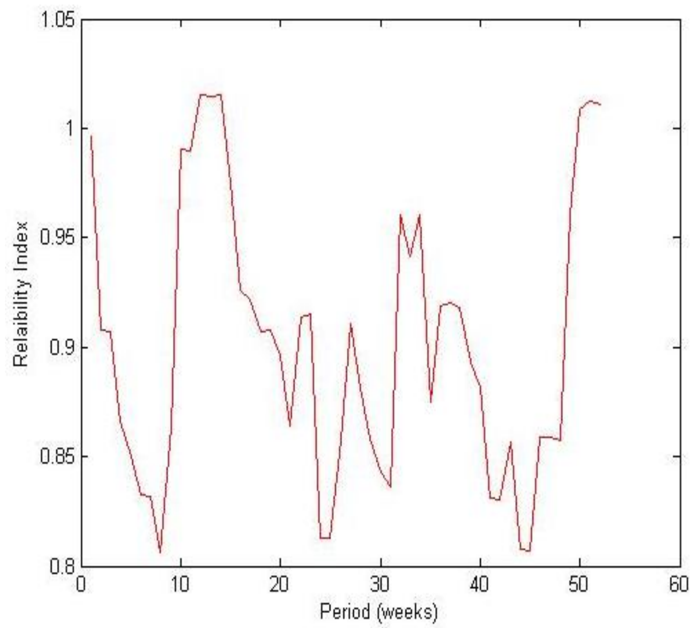

Figure 4. Reliability index for objective function for 32 units.

generating units and the profit is maximum during week 51.

To measure the degree of security throughout the weeks of the year, the reliability index is defined for period t. The reliability index is shown in Figure 4 for thirty-two generating units. This reliability index is the net reserve divided by the gross reserve in period t. The gross reserve in any period is calculated as the difference between the sum of the capacity of all units and the power demand. The net reserve is calculated as the difference between the gross reserve and the power capacity in maintenance.

EVOLUTIONARY PROGRAMMING

Evolutionary Programming (EP) can be traced back to early 1950s when Turing discovered a relationship between machine learning and evolution. Later, Bremermann, Box, Friedberg and others put the bases for the evolutionary computation as a tool for machine learning and an optimization technique. Great attention was given to Evolutionary Programming as a powerful tool when Fogal, Burgin, Atmar and others used it to create artificial intelligence to predict the events of a finite state machines (FSM) on the bases of old observation. With advance of the computer performance during 1980s, evolutionary programming was used to solve difficult real world optimization problems. In power system area, Evolutionary Programming has been used to solve a number of problems. EP is a mutation-based evolutionary algorithm (Mirinda et al., 1998; Cau and Kaye, 2002) applied to discrete search spaces. David Fogel extended the initial work of his father Larry Fogel for applications involving real-parameter optimization problems. Real-parameter Evolutionary Programming is similar in principle to evolution strategy (ES), in that normally distributed mutations are performed in both algorithms. Both algorithms encode mutation strength (or variance of the normal distribution) for each decision variable and a self-adapting rule is used to update the mutation strengths. Several variants of Evolutionary Programming have been suggested (Nidul et al., 2003).

HYBRID ALGORITHM FOR PARTICLE SWARM OPTIMIZATION (PSO) BASED EVOLUTIONARY PROGRAMMING (EP) FOR MAINTENANCE SCHEDULING

The step by step procedure to compute the global optimal solution is follows:

Step 1: Initialize a population of particles with random positions and velocities on dimensions in the problem space.

Step 2: For each particle, evaluate the desired optimization fitness function in the variables.

Step 3: Compare particles fitness evolution with particles $Pbest$. If current value is better then $Pbest$, then set $Pbest$ value equal to the current value, and the $Pbest$ location equal to the current location in the dimensional space.

Step 4: Compare fitness evaluation with the populations overall previous best. If current value is better than $gbest$, then reset to the current particles array

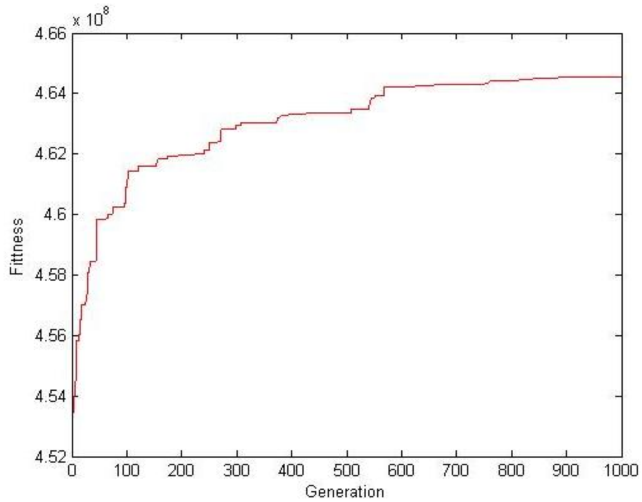

Figure 5. Performance of object function for 32 units.

index and value.

Step 5: Change the velocity and position of the particle according to Equations (3) and (4) respectively.

Step 6: Loop to step 2 until a criterion is met, usually a sufficiently good fitness or a maximum number of iterations.

Step 7: The parent vector p = [p_1, p_2, … p_n], i = 1,2,…N_p such that each element in the vector is determined by p_j ~ random (p_{jmin}, p_{jmax}), j = 1,2,…N, with one generator as dependent generator.

Step 8: Calculate the overall objective function is given in Equation (1) using the trail vector p_i and find the minimum of F_{Ti}.

Step 9: Create the offspring trail solution p_i' using the following steps.

(a) Calculate the standard deviation

$$\sigma j = \beta(F_{Tij} / \min(F_{Ti}))(P_{j\max} - P_{j\min})$$

(b) Add a Gaussian random variable to all the state variable of p_i, to get p_i'.

Step 10: Select the first N_p individuals from the total $2N_p$ individuals of both p_i & p_i' using the following steps for next iteration.

(a) Evaluate r = ($2N_p$ random (0,1) + 1)

(b) Evaluate each trail vector by W_{pi}=sum (W_x) Where x = 1,2,…N_p, i = 1,2,…$2N_p$ such that W_x = 1 if F_{Tij} / (F_{Tij}+F_{Tir}) < random (0,1), otherwise, W_x = 0.

Step 11: Sort the W_{pi} in descending order and the first N_p individuals will survive and are transcribed along with their elements to form the basis of the next generation.

Step 12: The above procedure is repeated from Step 8 until a maximum number of generations N_m is reached.

Step 13: Selection process is done using Evolutionary strategy.

IMPLEMENTATION OF PSO - EP

In this paper, a Particle swarm optimization (PSO) - Evolutionary Programming (EP) based algorithm for solving the Generation Maintenance Scheduling problems will be introduced in which the equality and inequality constraints of the Generation Maintenance Scheduling problems when modifying each particles search point in the Particle swarm optimization algorithm are set. In the initialization process, a set of particles is created in a random order. The structure of a particle for Generation Maintenance Scheduling problems is composed of a set of elements (that is, thermal generations, reserve in each interval). Therefore, particles position at iteration in period of t can be represented by the vector.

To solve an optimization problem using Particle Swarm Optimization based Evolutionary Programming (PSO – EP), first the possible solutions of the problem have to be coded in chromosomes. Next a fitness function to compare the chromosomes has to be defined. The period of maintenance scheduling is usually one year and is divided into T stages. When a stage is one week, T is equal to 52. In solving the generation maintenance problem, the main variables to be identified are maintenance states of the generating units. The schedule for unit i could be represented by a string of zeros and ones, U_{ij} where zero means the unit i is under maintenance in the stage t. We take the maintenance schedule corresponding to an individual generating unit as a gene and build the chromosome from these genes. Therefore a single chromosome will completely describe the maintenance schedules for power generating units. Next the last generation individuals are taken as input for Evolutionary Programming, and then offspring will be generated and best individuals are taken for transcribed along with their elements. Finally the selection process will be done using Evolutionary Programming.

In this Evolutionary Programming a set of experiments for the thirty-two generator units was carried out. Evolutionary Programming search technique moves from one solution to another using a probabilistic search method. However, the new solution may render infeasible. Therefore, using Evolutionary Programming alone may take a long time to reach the optimal solution or it may get trapped in a local optimum. So, the Hill-Climbing technique is used in conjunction with Evolutionary Programming to find a feasible solution in the neighborhood of the new infeasible solution. The Evolutionary Programming search ability and the feasibility watch of the Hill-Climbing motivate the sequential solution of the Generation Maintenance Scheduling problem. Selecting the individuals, which survive to the next generation, is based on the overall objective function.

Figure 5 shows performance of the hybrid Particle Swarm Optimization based Evolutionary Programming (PSO – EP) over 1000 generations when maintenance

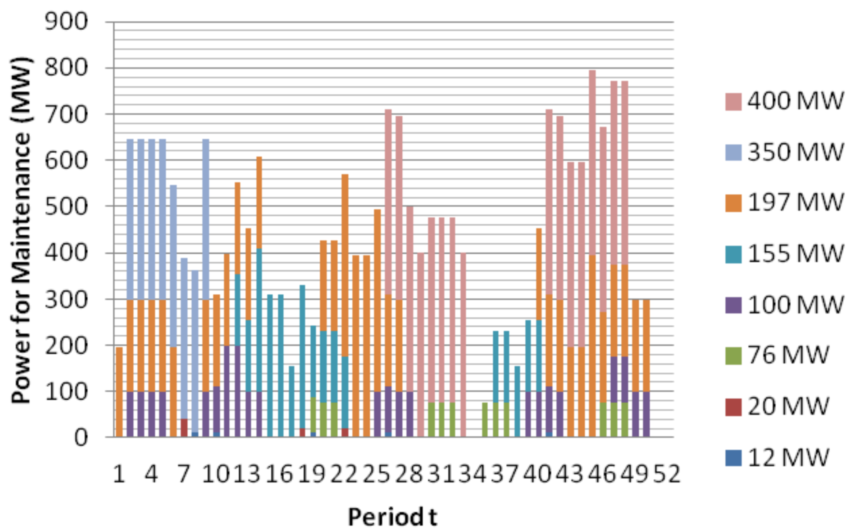

Figure 6. Maintenance scheduling of objective function for 32 generator units.

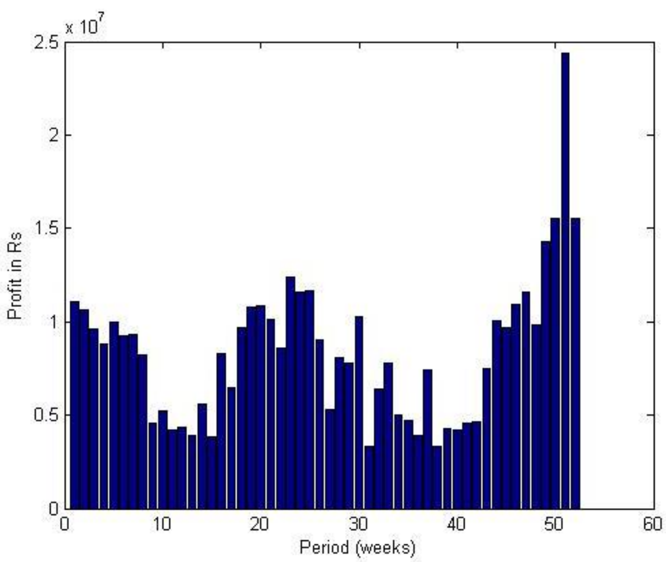

Figure 7. Scheduling of objective function for 32 units.

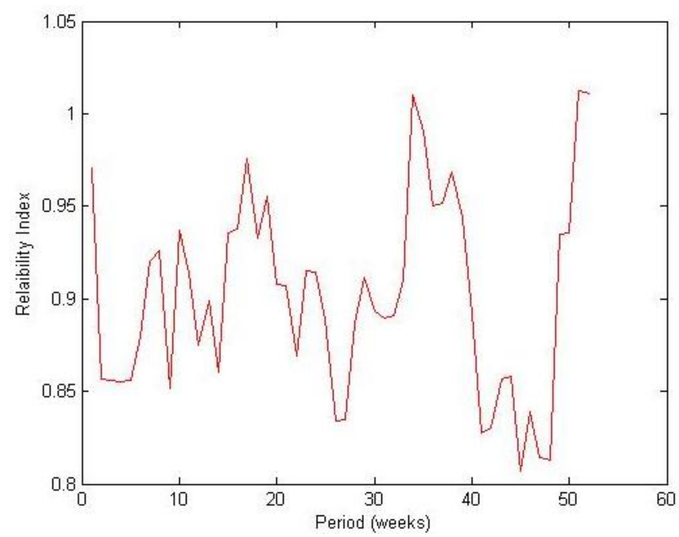

Figure 8. Reliability index for objective function for 32 units.

scheduling of the generating units formulated based on its desired objective function and figure, the fitness of the population are illustrated. For the maximization problem fitness function is same as the objective function. Figure 6 shows during the week 8 maximum generator maintenance is carried out. Figure 7 shows maintenance schedule of generating units and the profit is maximum during week 51.

To measure the degree of security throughout the weeks of the year, the reliability index is defined for period t. The reliability index is shown in Figure 8 for thirty-two generating units. This reliability index is the net reserve divided by the gross reserve in period t. The gross reserve in any period is calculated as the difference between the sum of the capacity of all units and the power demand. The net reserve is calculated as the difference between the gross reserve and the power capacity in maintenance.

NUMERICAL RESULTS AND DISCUSSION

An IEEE RTS (reliability test system) – 24-bus system with thirty-two generating units has been considered for this work. Fuel cost function of each generator is estimated into quadratic form. A time period of 52 weeks is considered for solving this maintenance problem for thirty-two units. Generation maintenance scheduling with

Table 4. Comparison of generation maintenance schedule of units for 32 generator units.

Week	Generating units scheduled for maintenance	
	PSO –GA	PSO-EP
1	16	27
2	16, 30	16, 27, 30
3	16, 30	16, 27, 30
4	16, 23, 30	16, 27, 30
5	5, 20, 23, 30	16, 27, 30
6	12, 20, 23, 30	27, 30
7	12, 20, 23, 30	7, 9, 30
8	12, 17, 20, 23, 30	5, 30
9	17, 20, 30	17, 28, 30
10	17	1, 17, 28
11	17	17, 18, 28
12	-	17, 18, 23, 28
13	-	18, 23, 28
14	-	18, 21, 23, 28
15	22	21, 23
16	22, 27	21, 23
17	2, 22, 27	21
18	10, 22, 27	6, 20, 21
19	10, 22, 27	2, 12, 20
20	10, 27, 29	12, 20, 26
21	26, 27, 29	12, 20, 26
22	26, 29	8, 20, 24, 26
23	26, 29	24, 26
24	26, 29, 31	24, 26
25	26, 29, 31	15, 24, 26
26	9, 26, 31	4, 15, 24, 31
27	31	15, 24, 31
28	7, 14, 31	15, 31
29	3, 6,11, 14,31	31
30	11, 14, 19, 31	10, 31
31	1, 11, 14, 19, 31	10, 31
32	18, 19	10, 31
33	13, 18, 19	31
34	8, 13, 18	-
35	13, 18, 21, 25	11
36	21, 25	11, 22
37	21, 25	11, 22
38	21, 25	22
39	15, 21, 25	14, 22
40	15, 25, 28	14, 22, 29
41	15, 28, 32	3, 14, 29, 32
42	15, 28, 32	14, 29, 32
43	28, 32	29, 32
44	24, 28, 32	29, 32
45	24, 28, 32	25, 29, 32
46	24, 32	13, 25, 32
47	24, 32	13, 19, 25, 32
48	24, 32	13, 19, 25, 32
49	24	19, 25
50	4	19, 25
51	-	-
52	-	-

Table 5. Comparison of cost and CPU time for 32 units.

System	Method	Total cost (pu)	CPU time (s)
32 Units	DP	1.0535	918
	LR	1.0687	850
	PSO	1.0387	417
	GA	1.0386	415
	PSO-GA	1.0384	412
	PSO - EP	1.0385	410

reserve margin is solved for thirty-two generating units by the three hybrid algorithms which gives total cost, computation timing and reliability index.

Two proposed hybrid algorithms were applied and compared with other conventional method and it is shown in Table 4. The comparison of the total cost and central processing unit (CPU) time are as shown in Table 5. The comparison of the total profit with reserve margin for all weeks is as shown in Table 6. The comparison of reliability index is shown in Table 7 for thirty-two generating units. Here, total cost computed by using hybrid Particle Swarm Optimization based Evolutionary Programming (PSO-EP) is higher than hybrid Particle Swarm Optimization based Genetic Algorithm (PSO-GA), but computation time is less than hybrid Particle Swarm Optimization based Genetic Algorithm (PSO-GA). When comparing the profit, hybrid Particle Swarm Optimization based Genetic Algorithm (PSO-GA) is higher than hybrid Particle Swarm Optimization based Evolutionary Programming (PSO-EP). When comparing the reliability index for reserve, the hybrid Particle Swarm Optimization based Genetic Algorithm (PSO-GA) has maximum value in week thirty-one and minimum value in week eight. When compared with average reserve hybrid Particle Swarm Optimization based Genetic Algorithm (PSO-GA) has higher value than Particle Swarm Optimization based Evolutionary Programming (PSO-EP). As a result of maximum profit and better reserve margin, hybrid Particle Swarm Optimization based Genetic Algorithm (PSO –GA) is the best of achieving objective function among the three proposed algorithms in all IEEE (RTS) systems.

Conclusions

This paper shows a new approach for solving the generation maintenance scheduling problem based on hybrid modified algorithm and the optimum maintenance scheduling over the planning period was obtained. The algorithm has been tested on thirty-two generating unit systems. The proposed method has been compared with the results of other method such as Lagrangian Relaxation, Dynamic Programming, Genetic Algorithms, Particle Swarm Optimization and Evolutionary Programming which gives an idea regarding how generator schedule

Table 6. Comparison of profit/cost for 32 generator units in each week.

Week	Generating units scheduled for maintenance	
	PSO –GA (in million Rs)	PSO-EP (in million Rs)
1	1.250	1.124
2	1.111	1.039
3	1.000	0.955
4	0.861	0.871
5	0.944	1.011
6	0.806	0.955
7	0.778	0.969
8	0.667	0.815
9	0.444	0.478
10	0.528	0.520
11	0.444	0.421
12	0.500	0.449
13	0.444	0.393
14	0.667	0.562
15	0.417	0.365
16	0.861	0.843
17	0.625	0.646
18	0.972	0.955
19	1.028	1.067
20	1.111	1.070
21	1.014	1.011
22	0.917	0.857
23	1.250	1.236
24	0.972	1.152
25	1.000	1.152
26	0.931	0.899
27	0.556	0.534
28	0.806	0.815
29	0.750	0.787
30	0.972	1.039
31	0.319	0.337
32	0.778	0.646
33	0.889	0.758
34	0.500	0.506
35	0.431	0.449
36	0.389	0.393
37	0.750	0.758
38	0.333	0.337
39	0.431	0.421
40	0.472	0.421
41	0.472	0.449
42	0.486	0.463
43	0.750	0.758
44	0.958	1.011
45	0.972	0.955
46	1.139	1.096
47	1.222	1.152
48	1.056	0.983
49	1.458	1.433
50	1.639	1.545
51	2.444	2.444
52	1.556	1.573
Total in Million `	44.069	43.879

Table 7. Comparison of reliability index for objective function for 32 units.

System	Method	Maximum value	Week	Minimum value	Week	Average value
32 Generating Units	PSO - GA	0.989	13	0.805	8	0.913
	PSO - EP	0.987	51	0.81	45	0.911

and reserve should be maintained to maximize profit reduce the computation timing. To conclude, hybrid particle swarm optimization based Genetic Algorithm (PSO – GA) gives the best solution quality, robust, cost-effective, reserve margin and consumes minimum computation time for generation maintenance scheduling of thermal units.

NOMENCLATURES

A_i, B_i, C_i - Constant fuel cost coefficients of the i^{th} unit.
e_i - Earliest maintenance period for the beginning of unit i th generator.
for_i - Forced outage rate of the unit i.
F_{it} - Fuel consumed by the i^{th} unit in the t^{th} period.
$R_i(k)$ - k^{th} maintenance resource requirement of the i^{th} generator.
$\alpha_t(k)$ - k^{th} maintenances resource at the t^{th} period.
l_i - Latest maintenance period for the beginning of unit i^{th} generator.
d_i - Maintenance duration of the i^{th} generator.
s_i - Maintenance starting period of the i^{th} generator.
sv_{it} - Maintenance startup variable of unit i^{th} at period t.
M_{it} - Maximum number of maintenance crew in area for maintenance of unit i at time t.
P_{imax} - Maximum power output of the i^{th} generator.
Y_i - Maximum yearly fuel assignment to the i^{th} unit.
P_{imin} - Minimum power output of the i^{th} generator.
u - Number of generator in the same area.
N - Number of generators.
n_t - Number of hours in the week.(168 h)
M - Number of study periods.
OMVC - Operation and maintenance variable cost.
OMFC - Operation and maintenance fixed cost.

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