Comparison of Genetic Algorithm and Harmony Search for Generator Maintenance Scheduling

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ABSTRACT

GMS (Generator Maintenance Scheduling) ranks very high in decision making of power generation management. Generators maintenance schedule decides the time period of maintenance tasks and a reliable reserve margin is also maintained during this time period. In this paper, a comparison of GA (Genetic Algorithm) and HS (Harmony Search) algorithm is presented to solve generators maintenance scheduling problem for WAPDA (Water And Power Development Authority) Pakistan. GA is a search procedure, which is used in search problems to compute exact and optimized solution. GA is considered as global search heuristic technique. HS algorithm is quite efficient, because the convergence rate of this algorithm is very fast. HS algorithm is based on the concept of music improvisation process of searching for a perfect state of harmony. The two algorithms generate feasible and optimal solutions and overcome the limitations of the conventional methods including extensive computational effort, which increases exponentially as the size of the problem increases. The proposed methods are tested, validated and compared on the WAPDA electric system.

Key Words: **GMS, Power System, Optimization, GA, HS Algorithm.**

1. INTRODUCTION

To avoid premature failure of generators in a power generation system, it is important to perform maintenance at consistent intervals. GMS is vital to provide secure and reliable operation of a power generation system. The main aim of GMS is to specify an optimized generators maintenance timetable in order to achieve system reliability, decrease total operating costs, maximize the reserve margin and enhance generator life span, while, satisfying maintenance window constraints, crew constraints and load constraints.

GMS is a large-scale, nonlinear and stochastic optimization problem with many constraints and conflicting objective functions [1]. Different mathematical, heuristic and other optimization techniques are applied to solve GMS problem. Thus, much earlier work relied on methods such as dynamic programming [2-3], mixed integer nonlinear programming [4], integer programming [5-6] and branch and bound technique [7] with their performances demonstrated with respect to simple case studies. In order to obtain approximate solution of a complex GMS, new concepts

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have emerged in recent years. They include applications of decomposition technique [8-9] and heuristic approach [10]. GMS is done on priority basis. EL-Sheikhi and Billinton presented a method for GMS in two inter conected power [11]. Contaxis et al. presented a software package for interactive risk calculation and GMS by using two approximation techniques: levelized effective reserve and levelized incremental risk [12]. Lin, et. al. have presented a prototype knowledge based expert system for solving the optimized generators maintenance scheduling problem in TPC (Taiwan Power Corporation) system [13]. Momoh, and Tomsovic, have presented an overview and literature survey of fuzzy set theory in power systems [14]. In fact Lin, et. al. were the first to introduce a fuzzy concept to solve the generator maintenance problem [15].

The heuristic approach is based on trial-and-error method to calculate the GMS objective function, generally by considering each unit on individual basis. It needs momentous operator input and often, it fails to create feasible solutions. Whereas, the mathematical techniques are rigorously limited with handling the nonlinear objective and constraint functions that exemplify the GMS problem. Expert systems become inappropriate in case when heuristic suppositions are applied on rules. Fuzzy approach can be applied to practical power systems, but cannot be generalized. To overcome the limitations of heuristic, mathematical, expert system and fuzzy methods a number of meta-heuristic techniques for solving GMS problem are studied. These include genetic algorithm [16-17], simulated annealing [18] and evolutionary programming [19]. Park, et. al. have presented flexible maintenance scheduling of generation system by multi probabilistic reliability criterion in Korean power system [20]. Changyou, et. al. have presented power plant maintenance scheduling considering unit failure [21]. It is observed that the performance of meta-heuristic approaches for solving GMS problem is more promising as compared to other techniques.

This paper presents two different meta-heuristic techniques (GA and HS) to solve complex GMS problem. Both techniques are quite efficient and distinct from these of conventional methods.

The rest of the paper is organized in five main sections. Section 2 describes the GMS mathematical model. Proposed GA and HS algorithms are presented in Section 3 and 4, respectively. Implementation of proposed algorithms and results are presented in Section 5. Finally, some concluding remarks are presented in Section 6.

2. GMS PROBLEM FORMULATION

WAPDA GMS problem consists of scheduling the maintenance of 136 generators over a time period of 52 weeks (one year). Table 1 gives the generating capacities, maintenance allowed periods, maintenance durations, available manpower and the crew needed for each generator of WAPDA system. The power system weekly peak loads are given in Table 2. The reliability criterion of power system is achieved by maximizing the minimum net reserves along with the satisfaction of maintenance window constraint, crew constraint and load constraint. The following notations are used in GMS mathematical model:

$T_{(weeks)}$ = Total number of weeks (periods) in the planning horizon.

$N_{(units)}$ = Total number of generators/units in the power production system.

$I_{(units)}$ = Set of generators indices.

ind = Index of generators.

tnd = Index of weeks.

ear_{ind} = Earliest week of generator *ind* to start maintenance.

lat_{ind} = Latest week of generator *ind* to end maintenance.

dur_{ind} = Duration of maintenance of *ind* generator.

$cap_{ind,tnd}$ = Generating capacity of generator *ind* in week.

tnd, lod_{tnd} = Load demand for period *tnd*.

$NM_{ind,tnd}$ = Man power needed by generator *ind* at period *tnd*.

AM_{ind} = Man power available at period *tnd*.

TABLE 1. DATA OF WAPDA SYSTEM (GENERATIONS, DURATION, ETC.)

No.	Power Stations	Capacity (MW)	Earliest Period	Latest Period	Outage Weeks	Available Man	Required Manpower	No.	Power Stations	Capacity (MW)	Earliest Period	Latest Period	Outage Weeks	Available Man	Required Manpower
1	TPS GUDDU: ST-1	50	7	23	4	40	10+10+10+10	69	GT-8	77	38	52	3	20	10+5+5
2	ST-2	75	29	45	4	40	10+10+10+10	70	SGT-9 (GT1,3)	105	28	43	3	20	10+5+5
3	ST-3	150	36	52	10	100	20+20+20+10 +5+5+5+5+5+5	71	SGT-10 (GT2,4)	99	1	18	8	50	10+10+5+5 +5+5+5+5
4	ST-4	150	24	50	14	150	20+20+20+20 +10+10+10+10 +5+5+5+5+5+5	72	SGT-11 (GT5,6)	86	28	46	6	35	10+5+5+5+5+5
5	CC-5 (GT7-8)	70	39	52	3	30	10+10+10	73	SGT-12 (GT7,8)	84	38	52	3	20	10+5+5
6	CC-6 (GT9-10)	65	1	20	10	100	20+20+20 +10+5+5+5 +5+5+5	74	GT-13	113	32	52	9	125	25+25+20 +20+10+10 +5+5+5
7	GT-7	75	42	52	1	30	30	75	GT-14	115	33	52	9	125	25+25+20 +20+10 +10+5+5+5
8	GT-8	80	8	21	1	30	30	76	SGT-15 (GT13,14)	126	33	52	9	125	25+25+20 +20+10+10 +5+5+5
9	GT-9	75	1	20	10	100	20+20+20 +10+5+5+5 +5+5+5	77	HCPC	129	35	48	1	50	50
10	GT-10	75	1	20	10	100	20+20+20 +10+5+5+5 +5+5+5	78	AES PAKGEN	350	28	48	4	250	100+50+50+50
11	GT-11	80	13	36	11	110	20+20+20 +10+10+5+5 +5+5+5+5	79	AES LALPIR	350	24	40	4	250	100+50+50+50
12	GT-12	115	16	39	11	110	20+20+20 +10+10+5+5 +5+5+5+5	80	SABA	125	30	46	4	120	50+25+25+20
13	CC-13 (GT11-12)	95	16	41	13	145	20+20+20+20 +10+10+10+10 +5+5+5+5+5	81	ROUSCH : Half Complex	197	1	12	1	100	100
14	TPS JAMSORO: ST-1	180	20	45	13	200	25+25+25+25 +20+20+20+10 +10+5+5+5+5	82	Half Complex	197	7	20	1	100	100
15	ST-2	180	1	14	6	200	50+50+25+25 +25+25	83	Half Complex	197	16	27	1	100	100
16	ST-3	170	1	20	4	200	50+50+50+50	84	Half Complex	197	24	37	1	100	100
17	ST-4	170	1	15	4	200	50+50+50+50	85	Half Complex	197	33	46	1	100	100
18	GTPS KOTRI: GT-1	10	1	9	3	15	5+5+5	86	Half Complex	395	38	52	2	200	100+100
19	GT-2	10	1	16	3	15	5+5+5	87	SEPCOL : U # 1	21	15	30	3	20	10+5+5
20	GT-3	20	30	45	3	25	10+10+5	88	U # 2	21	15	30	3	20	10+5+5
21	GT-4	20	14	36	10	65	10+5+5+5+5 +5+5+5+5+5	89	U # 3	21	15	30	3	20	10+5+5
22	GT-5	20	7	27	8	50	10+10+5+5 +5+5+5+5	90	U # 4	21	20	35	3	20	10+5+5
23	GT-6	20	11	26	3	25	10+10+5	91	U # 5	21	20	35	3	20	10+5+5
24	GT-7	40	1	19	13	65	10+10+5+5 +5+5+5+5 +3+3+3+3+3	92	U # 6	17	20	35	3	15	5+5+5
25	TPS M.GARH: ST-1	185	35	51	4	125	50+25+25+25	93	JAPAN	120	7	21	2	100	50+50
26	ST-2	200	35	51	4	175	50+50+50+25	94	CNPP	300	30	52	3	200	100+50+50
27	ST-3	160	1	23	13	155	50+25+20 +10+10+5+5 +5+5+5+5+5+5	95	TERBELA :1	175	1	16	4	150	50+50+25+25
28	ST-4	245	33	52	13	155	50+25+20 +10+10+5+5 +5+5+5+5+5+5	96	2	200	10	25	4	150	50+50+25+25
29	ST-5	170	40	52	4	200	50+50+50+50	97	3	200	5	20	4	150	50+50+25+25
30	ST-6	170	30	52	13	155	50+25+20 +10+10+5+5 +5+5+5+5+5+5	98	4	175	1	13	4	150	50+50+25+25
31	NGPS MULTAN: ST-1	30	29	52	17	81	10+10+5+5+5 +5+5+5+5+5+3 +3+3+3+3+3+3	99	5	200	30	52	4	150	50+50+25+25
32	ST-2	30	40	52	4	20	5+5+5+5	100	6	200	30	52	4	150	50+50+25+25

No.	Power Stations	Capacity (MW)	Earliest Period	Latest Period	Outage Weeks	Available Man	Required Manpower	No.	Power Stations	Capacity (MW)	Earliest Period	Latest Period	Outage Weeks	Available Man	Required Manpower
33	ST-4	30	26	52	4	20	5+5+5+5	101	7	200	10	26	4	150	50+50+25+25
34	GTPS F. ABAD: GT-1	19	20	40	8	30	5+5+5+3+3 +3+3+3	102	8	175	5	21	4	150	50+50+25+25
35	GT-2	19	11	31	8	30	5+5+5+3 +3+3+3+3	103	9	175	46	52	1	100	100
36	GT-3	19	2	22	8	30	5+5+5+3 +3+3+3+3	104	10	432	36	52	4	150	50+50+25+25
37	GT-4	19	31	51	8	30	5+5+5+3 +3+3+3+3	105	11	432	1	12	3	150	50+50+50
38	GT-5	23	2	20	4	20	5+5+5+5	106	12	432	43	52	3	150	50+50+50
39	GT-6	23	3	15	5	19	5+5+3+3+3	107	13	432	2	17	3	150	50+50+50
40	GT-7	23	2	17	1	20	20	108	14	432	5	21	3	150	50+50+50
41	GT-8	23	5	25	3	11	5+3+3	109	G.BAROTTHA : 1	240	1	25	5	110	50+25+20+10+5
42	CC-9	42	40	52	4	30	10+10+5+5	110	2	290	1	10	4	120	50+25+25+20
43	SPS F. ABAD: ST-1	50	37	52	4	40	20+10+5+5	111	3	290	43	52	3	125	50+50+25
44	ST-2	50	42	52	4	40	20+10+5+5	112	4	290	1	14	4	120	50+25+25+20
45	KEL : U # 1	15	21	36	3	20	10+5+5	113	5	290	2	17	3	125	50+50+25
46	U # 2	15	15	30	3	20	10+5+5	114	MANGLA : 1	100	1	14	5	95	25+20+20+10+10
47	U # 3	15	20	35	3	20	10+5+5	115	2	100	42	52	3	125	50+50+25
48	U # 4	15	5	20	3	20	10+5+5	116	3	100	30	46	3	120	50+50+20
49	U # 5	10	1	13	3	20	10+5+5	117	4	100	25	40	3	120	50+50+20
50	U # 6	15	2	17	3	20	10+5+5	118	5	100	43	52	3	125	50+50+25
51	U # 7	15	1	9	3	20	10+5+5	119	6	100	1	9	3	125	50+50+25
52	U # 8	15	41	52	3	20	10+5+5	120	7	100	1	12	2	100	50+50
53	STG	6	2	18	4	12	3+3+3+3	121	8	100	41	52	1	50	50
54	FKPCL: Full Complex	151	24	37	1	50	50	122	9	100	40	52	2	100	50+50
55	Full Complex	151	37	52	3	150	50+50+50	123	10	100	30	52	2	100	50+50
56	LIBERTY	211	1	12	2	200	100+100	124	WARSAK : 1	40	37	52	6	29	10+5+5+3+3+3
57	UCH	551	37	52	4	250	100+50+50+50	125	2	40	41	52	4	21	10+5+3+3
58	HUBCO : U # 1	300	22	39	5	255	50+50+50+50+25	126	3	40	1	14	6	29	10+5+5+3+3+3
59	U # 2	300	38	52	2	100	50+50	127	4	40	2	17	3	18	10+5+3
60	U # 3	300	33	50	5	255	50+50+50+50+25	128	5	41	2	16	2	15	10+5
61	U # 4	300	4	26	10	200	50+25+25 +20+20+20 +20+10+5+5	129	CHASHMA : 1	23	1	12	2	15	10+5
62	KAPCO : GT-1	93	28	43	3	95	50+25+20	130	2	23	1	14	6	22	5+5+3+3+3+3
63	GT-2	92	1	20	10	97	25+20+20 +10+5+5+3 +3+3+3	131	3	23	7	21	2	15	10+5
64	GT-3	81	1	18	7	49	20+10+5+5 +3+3+3	132	4	23	1	14	2	15	10+5
65	GT-4	80	1	18	8	50	10+10+5 +5+5+5+5+5	133	5	23	42	52	3	18	10+5+3
66	GT-5	78	28	46	6	35	10+5+5+5+5+5	134	6	23	41	52	4	16	5+5+3+3
67	GT-6	78	28	46	6	35	10+5+5+5+5+5	135	7	23	4	18	2	15	10+5
68	GT-7	79	33	52	8	50	10+10+5+5 +5+5+5+5	136	8	23	1	16	4	16	5+5+3+3

2.1 Objective Function and Constraints Formulation

Reserve based objective function is the most appropriate to solve the GMS problem. So GMS objective function maximizes the minimum reserve margin during each generation. Let $T_{(weeks)ind} \subset T_{(weeks)}$ is the set of weeks when maintenance of generator ind may start. So for each unit ind:

$$t_{(week)ind} = \{tnd \subset T_{(weeks)}: ear_{ind} < tnd < lat_{ind} - dur_{ind} + 1\} \quad (1)$$

Equation (1) gives the specified time period during which a generator is maintained. If a generator is off-line for maintenance then '1' is used to represent that the generator is on maintenance whereas, '0' indicates that generator is not on maintenance.

$$U_{ind,tnd} = \begin{cases} 1 & \text{if unit } ind \text{ starts maintenance in } tnd \text{ weeks,} \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

For each unit ind $I_{(units)}$ and tnd $\in T_{(weeks)ind}$. Let $S_{ind,tnd}$ is the set of start time periods. If maintenance of a unit starts at week j, that unit must be maintained at period tnd. So:

$$S_{ind,tnd} = \{j \in T_{(weeks)ind}: tnd - dur_{ind} + 1 < j < tnd\} \quad (3)$$

The net reserve of the power generation system during generators maintenance scheduling can be formulated as:

$$net\_reserve = \underset{U_{ind,tnd}}{Min}\left(\sum_{ind \in I_{(units)}} cap_{ind,tnd} - \sum_{ind \in I_{(units)tnd}}\left(\sum_{j \in s_{ind,tnd}} U_{ind,j}\, cap_{ind,j}\right) - lod_{tnd}\right) \quad (4)$$

Subject to the maintenance window constraint:

$$\sum_{tnd \in T_{(weeks)ind}} U_{ind,tnd} = 1 \qquad \forall\, ind \in I_{units} \quad (5)$$

The crew constraint:

$$\sum_{ind \in I_{(units)tnd}} \sum_{j \in S_{ind,tnd}} U_{ind,j}\, NM_{ind,j} \le AM_{tnd} \qquad \forall\, tnd \in T_{(weeks)} \quad (6)$$

The load constraint,

$$\sum_{ind \in I_{(units)}} cap_{ind,tnd} - \sum_{ind \in I_{(units)tnd}} \sum_{j \in S_{ind,tnd}} U_{ind,j}\, cap_{ind,j} \ge lod_{tnd} \qquad \forall\, tnd \in T_{(weeks)} \quad (7)$$

In case of constraints violation some penalty value is added in the objective function.

3. PROPOSED GENETIC ALGORITHM

GA is superb for large sized problems, which have potentially vast search space and the optimal combinations are obtained by navigating through the search space. GA is a rigorous approach to solve GMS problem. In the proposed GA, a chromosome of fixed length is used to solve the GMS problem. The chromosome consists of a number of genes and each gene represents the maintenance start period of a generator. The size of chromosome depends upon the number of generators used in the power generation system. The value of each gene in the chromosome is bounded by the earliest and latest start period (week) of each generator.

A power generation system consists 'N'of number of generators, the chromosome is:

$$t_1, t_2, \ldots t_i, \ldots, t_N \quad (8)$$

Where t_i is a gene of chromosome, which represents the maintenance start week of generator i and is bounded by:

$$ear_i < t_i < (lat_i + d_{uri} + 1) \quad (9)$$

TABLE 2. PEAK LOADS OF WAPDA SYSTEM

Interval No.	Peak Load	Interval No.	Peak Load	Interval No.	Peak Load
1	6043	19	6,796	37	7429
2	5888	20	6,798	38	7510
3	6410	21	7146	39	7592
4	6440	22	7183	40	7539
5	6396	23	7251	41	7431
6	6650	24	7134	42	7352
7	6674	25	7467	43	7499
8	6408	26	7467	44	7566
9	6620	27	7351	45	7464
10	6604	28	7525	46	7401
11	6436	29	7513	47	7354
12	6550	30	7351	48	7354
13	6514	31	7584	49	6839
14	6478	32	7589	50	6701
15	6502	33	7653	51	6600
16	6631	34	6964	52	6691
17	6587	35	7364		
18	6791	36	7514		

Where ear_i is the earliest start week, lat_i is the latest start week and dur_i is the outage duration of generator i. The evaluation function for the proposed GMS solution is shown in Equation (10):

$$fx\_val = net\_reserve + w_1 \ x \ con_1 + w_2 \ x \ con_2 + w_3 \ x \ con_3 \quad (10)$$

Where fx_val is the fitness value and net_reserve represents the net reserve of a chromosome, which is calculated by using Equation (4). w_1, w_2 and w_3 represent the weights of violations of con_1, con_2, and con_3. The weights are the penalty values of the constraint violation. con_1 represents the maintenance window constraint, which is calculated by using Equation (5). con_2 represents the crew constraint, which is computed by using Equation (6). Crew constraint guarantees that required crew is less than or equal to available crew in each week. con_3 represents the load constraint, which is calculated by using Equation (7). The weight values for the constraint violations are dominated over the objective function to make unfit chromosome a highly unfeasible solution.

3.1 Genetic Algorithm

The pseudo of proposed GA to solve GMS problem of WAPDA is:

(i) Represent a chromosome of fixed length (for 136-generators).

(ii) Reserve based evaluation function is defined.

(iii) Initialize the GA with randomly selected population of size n.

(iv) Calculate the fitness of each individual.

(v) Select the parent strings from the current population.

(vi) Offsprings are created from the parent strings, which are selected in step 5. GA stochastic operators, such as crossover and mutation, generate these offsprings.

(vii) These new offsprings are kept in the new population.

(viii) Step 5 is repeated unless the fixed size (n) of new population is achieved.

(ix) Update the previous population with the new population.

The flowchart of proposed GA to solve GMS problem of WAPDA power generation system is shown in Fig. 1.

4. PROPOSED HARMONY SEARCH ALGORITHM

HS algorithm comprises of three main factors, which are: harmony memory, pitch adjustment and randomization. HM (Harmony Memory) is used to store the best harmonies, which are selected as new solution vectors. HM accepting rate α_{accept} is responsible to store the best harmonies in memory. Pitch adjustment is used to generate slightly different notes by adjusting the frequency. There are two important pitch adjustment's parameters, which are: pitch bandwidth $p_{bandwidth}$ and pitch adjusting rate $p\alpha_{rate}$. In HS, pitch is adjusted linearly using Equation (11):

$$R_{new} = hold + p_{bandwidth} \ x \ \gamma \quad (11)$$

Randomization is the last important component of the HS algorithm. It is used to increase the diversity of the solutions. The probability of randomization is computed by using Equation (12):

$$R_{prob} = 1 - \alpha_{accept} \quad (12)$$

The pitch adjustment probability is:

$$p_{prob} = \alpha_{accept} \ x \ p\alpha_{arate} \quad (13)$$

Generally, HM and pitch adjustment explores the local best solutions, while the randomization computes the global best solutions. HS explores the best harmonies by using Equation (10).

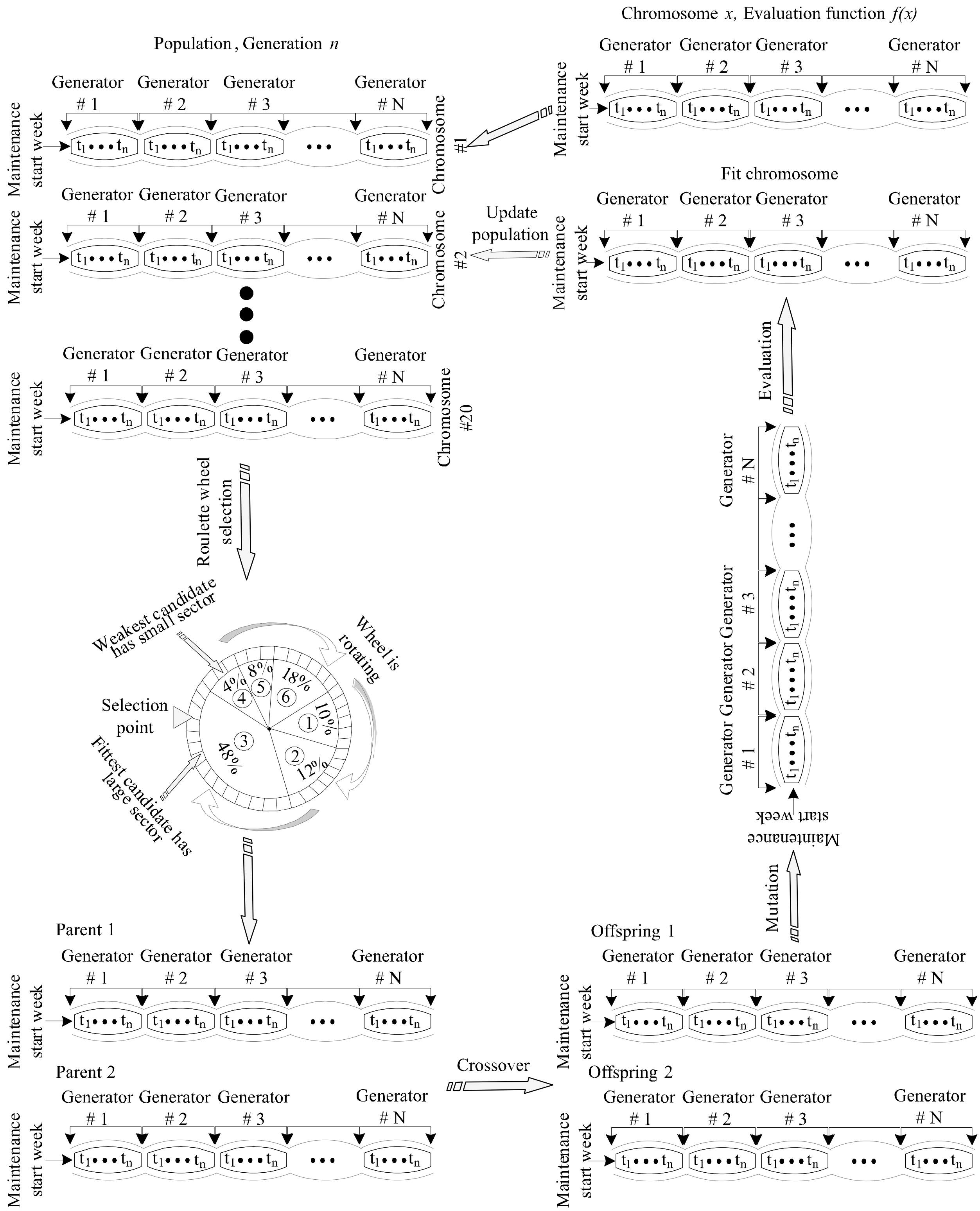

FIG. 1. A COMPLETE GA CYCLE FOR WAPDA GMS SOLUTION

4.1 HS Algorithm

The pseudo of proposed HS to solve GMS problem of WAPDA is:

(1) The lower and upper limits of each generator for allowed maintenance period are defined.

(2) HM is initialized with random solutions.

(3) Each harmony is evaluated.

(4) New harmonies are improvised using the existing best harmonies.

(5) HM is updated with these new harmonies.

The flowchart of proposed HS to solve GMS problem of WAPDA power generation system is shown in Fig. 2.

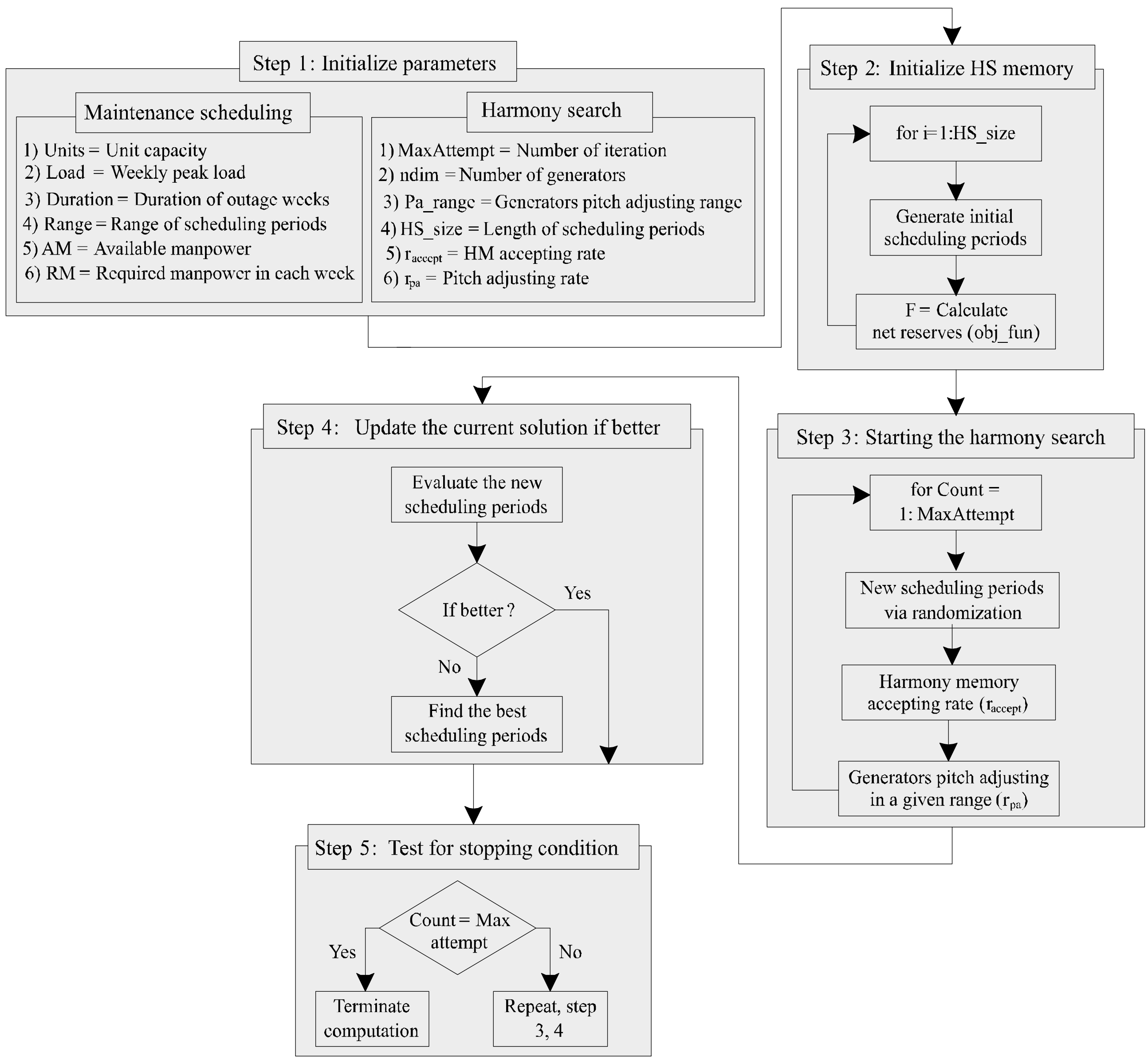

FIG. 2. HS FLOW CHART FOR WAPDA GMS SOLUTION

5. RESULTS

The important parameters for both proposed optimization approaches are listed in Table 3. GA and HS both are executed for 500 iterations with a population size of 20. The particular selection of parameters of both algorithms generate the optimum maintenance schedule for generators of WAPDA power production system. Figs. 3-4 show the results obtained using GA and HS respectively, which comprise of objective function convergence, weekly generation versus load demand, reserve margin of each week, available crew required by each generator, weekly manpower required for maintenance and optimal schedule for each generator. It is clear from Figs. 3-4 that the load constraint and crew constraint are completely satisfied. The main aim of this research is to achieve the maximum reserve margin in a week, so that load shedding problem should be avoided. The maximum reserve margin obtained from GA is 11,100 MW and HS is 10,800 MW, whereas the minimum reserve margin obtained from both algorithms is 7,800 MW. The elapsed time of GA is 45 minutes, whereas, the elapsed time of HS is 5 minutes. GA objective function converges at 7,550 and HS converges at 7,400. If HS is executed for 45 minutes, then extremely better results can be achieved as compared to GA.

6. CONCLUSIONS

GMS is the most important component in the decision making of power generation management. This paper presents a comparison of results of GA and HS to solve GMS problem for WAPDA system. Both proposed algorithms compute the generator's best maintenance schedule and reserve margin with the complete satisfaction of all mentioned constraints. It is concluded that the performance of these algorithms is quite satisfactory but HS is quite fast and takes very less time for execution. The results obtained using HS are quite better than GA, therefore, HS gives a robust solution for generator maintenance schedule problem.

TABLE 3. GA AND HS PARAMETERS

No.	GA Parameter	Value	HS Parameter	Value
1.	Population size	20	HS size	20
2.	Crossover rate	4	HM accept rate	0.95
3.	Mutation rate	8	Pitch adjusting rate	0.7
4.	Max generation	500	Pitch adjusting range	200
5.	-	-	Time Steps	500

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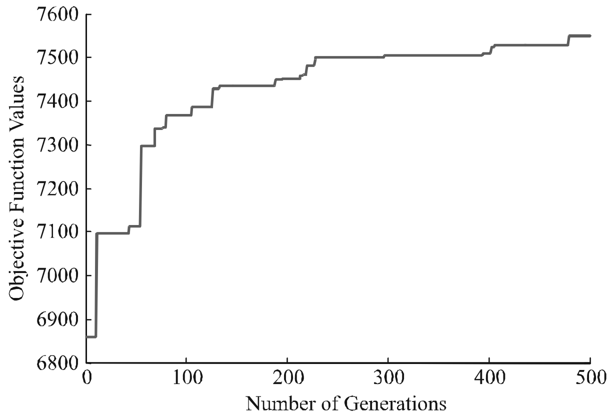
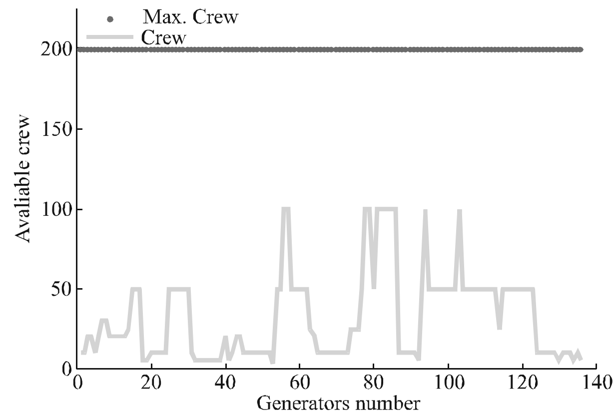
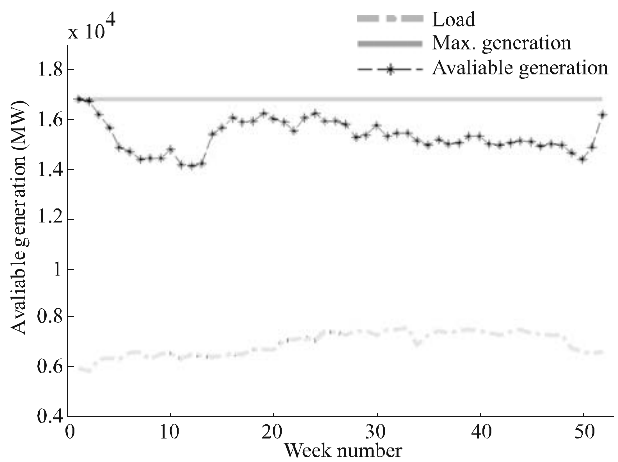


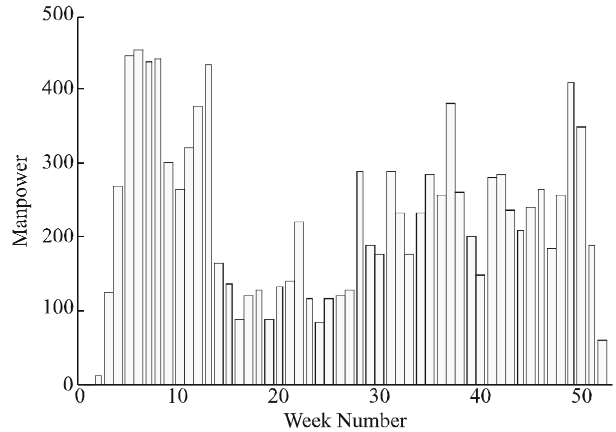
(a) OBJECTIVE FUNCTION TRACE



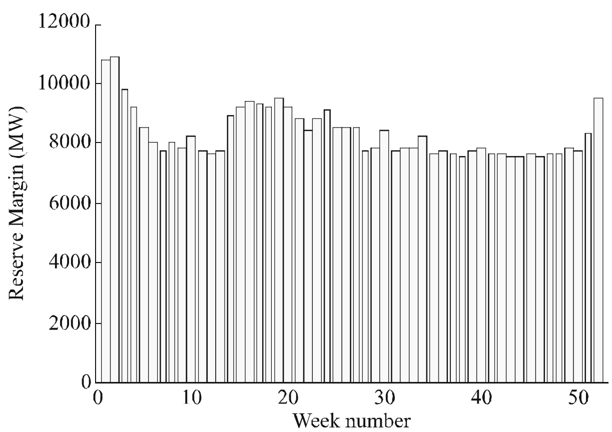
(D) CREW REQUIRED



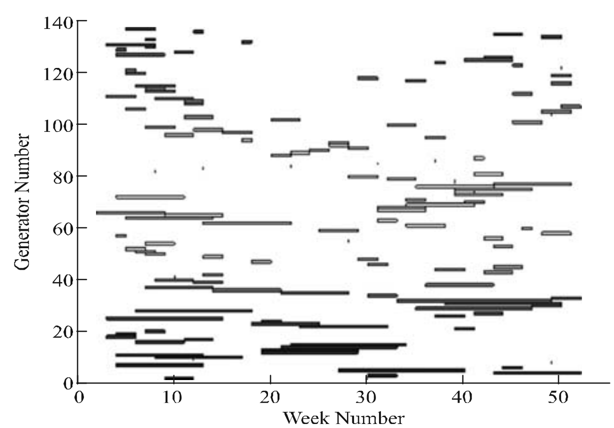
(B) AVAILABLE GENERATIONS AND LOADS



(E) MANPOWER



(C) RESERVE MARGIN



(F) OPTIMAL MAINTENANCE SCHEDULE)

FIG. 3. RESULTS FOR WAPDA SYSTEM USING GA

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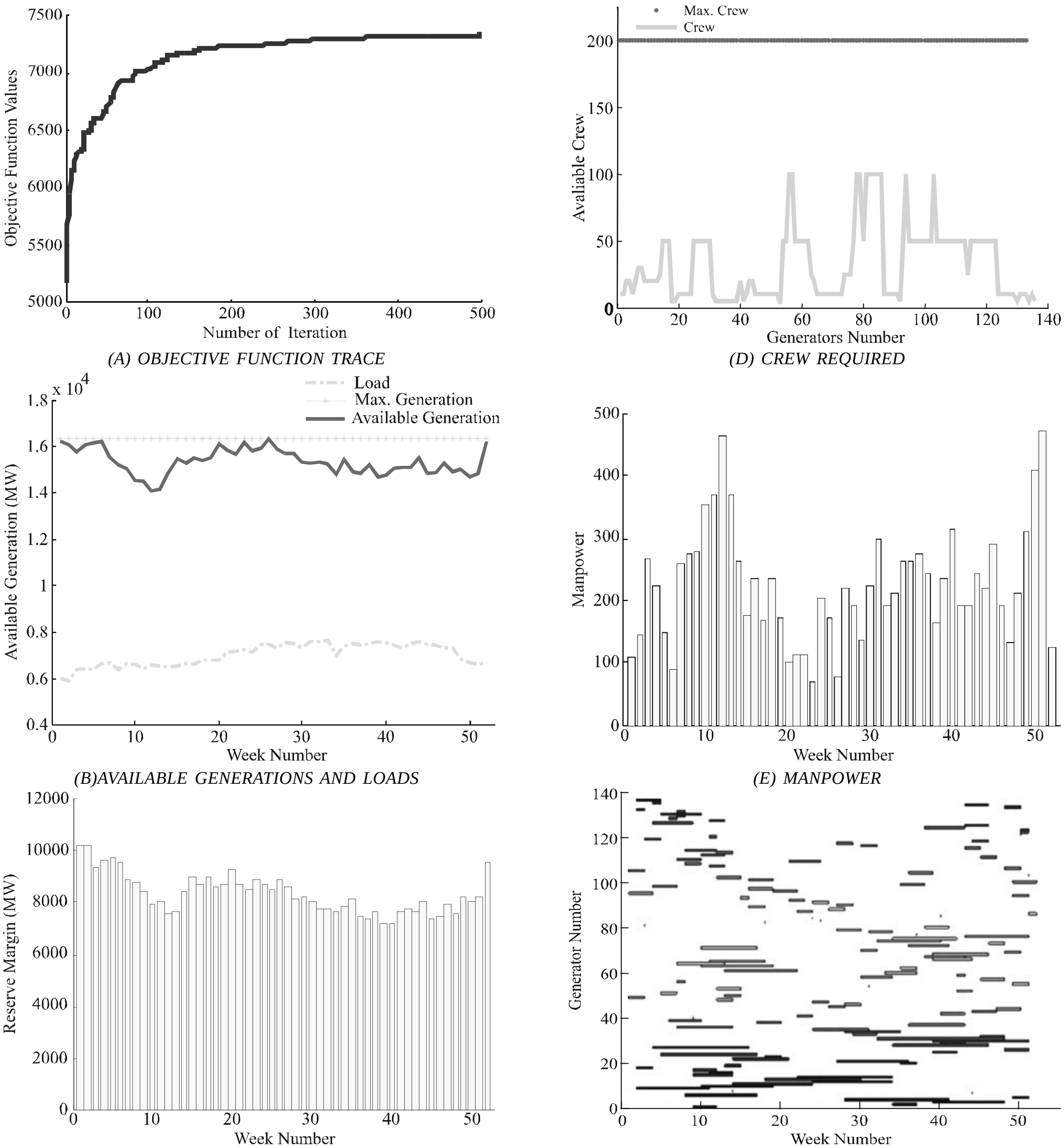

(A) OBJECTIVE FUNCTION TRACE

(D) CREW REQUIRED

(B)AVAILABLE GENERATIONS AND LOADS

(E) MANPOWER

(C) RESERVE MARGIN

(F) OPTIMAL MAINTENANCE SCHEDULE)

FIG. 4. RESULTS FOR WAPDA SYSTEM USING HS

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