A Novel Approach for Maintenance Scheduling of Generating Units in a Competitive Environment

R. Eshraghnia, H. Rajabi Mashhadi, M.H. Modir Shanechi, *Senior Member, IEEE* and A. Karsaz

***Abstract*--In this paper, a new approach for maintenance scheduling of generating units of GENCOs in competitive environment is presented. In this environment, management of GENCOs and grid is separated, each maximizing its own benefit. The objective function for the GENCO is to sell electricity as much as possible, at proper time according to the market clearing price forecast. Various technical constraints such as generation capacity, duration of maintenances and maintenance continuity are being taken into account. The objective function of ISO is to maximize the reliability throughout the year; provided the energy purchase cost should be smaller than a pre-determined amount when the units of GENCOs are out for maintenance. Therefore there are two objective functions for finding an optimum maintenance schedule in restructured power systems. In this paper we apply Genetic Algorithm methodology for finding the optimum preventive maintenance schedule of generating units.**

***Index Terms*-- competitive environment, genetic algorithm, maintenance scheduling, market clearing price, purchase cost.**

I. Nomenclature

The main mathematical symbols used throughout this paper are classified below.

Variables:

$I(t)$	Reliability index of grid in stage *t*.
$P_{Gij}(t)$	Power generated (*MW*) by unit *j* of GENCOi in stage *t*
$x_{ij}(t)$	Maintenance status for unit *j* of GENCOi in stage *t* (1 if unit *j* is under maintenance in stage *t* and 0 otherwise).

Constants:

$MCP_i(t)$	Market clearing price estimate (*\$/MWh*) by GENCOi for stage *t*.
$MCP_{ISO}(t)$	Predicted market clearing price (*\$/MWh*) in stage *t* by ISO.
$I_v^{GENCOi}(t)$	Reliability index related to maintenance scheduling of GENCOi in stage *t* at iteration step *v*.
$P_{Gij}^{\max}$	Capacity (*MW*) of unit *j* of GENCOi.
$P_{Gij}^{\min}$	Minimum power output (*MW*) of unit *j* of GENCOi.
$C(P_{Gij}(t))$	Production cost (*\$/h*) of unit *j* of GENCOi in stage *t*.
FC_{ij}	Fixed cost (*\$/Kw/YR*) of unit *j* of GENCOi.
VC_{ij}	Variable cost (*\$/MWh*) of unit *j* of GENCOi.
$L_D(t)$	Power demanded (*MW*) in stage *t*.
$R^{\min}(t)$	Net minimum reserve *(MW)* in stage *t*.
$\omega_{iv}(t)$	Incentive and disincentive set up by the ISO for stage *t* at iteration *v* for GENCO$_i$ $(-1<\omega_v(t)<1)$.
$P_v^M(t)$	The permissible and impermissible maximum power for maintenance of units in stage *t* at iteration step *v*.

Numbers:

I	Number of GENCOs. (I=5)
N_i	Number of GENCO$_i$'s units
T	Number of stages. (T=52)
HW	All hours of the week. (24×7=168 hour)
FOR_{ij}	Forced outage rate of unit *j* of GENCOi
δ_v	Penalty Factor *(\$/MW*) used by ISO in iteration step *v*.
k_1	Constant used by the ISO. (k_1=0.7)
MCP_{max}	The upper limit of power price. (C_{max}=50 *\$/MWh*)
MCP_{min}	The least unit cost of power. (C_{min} =25 *\$/MWh*)
d	The upper limit of purchase cost. (d= 1.27×10^7 *\$/h*)
α	Per unit constant used by ISO

II. Introduction

PREVENTIVE maintenance scheduling of generating units is an important task in power system and plays critical role in operation and planning of the system. If the maintenance schedule is drawn up on unreasonable terms, unit maintenance will reduce the available capacity, will increase the system risk and will affect the reliability and economy of power system. Maintenance requests, therefore, in both traditional and deregulated power systems, must be carefully coordinated. With the appearance of restructuring and deregulation of modern power systems, unit maintenance scheduling in restructured power systems has assumed new characteristics and becomes quite different from that in traditional power systems [1, 2].

A deregulated power system can be divided into three main segments: generation (GENCOs), transmission (TRANSCOs) and distribution (DISCOs). The main tasks of these three components will remain the same as before, however, to comply with regulatory orders, new types of unbundling, coordination and rules are to be established to guarantee competition and non-discriminatory open access to all users. Each segment has certain responsibilities so that the system would have the required reliability. Therefore, each segment is responsible for performing the necessary maintenance on their facilities in order to sustain the competitive energy market. In this environment, unit maintenance scheduling will not be decided only by ISO any more but will be mainly decided by GENCOs. GENCOs will try to schedule their units for maintenance according to the operating conditions of their

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units [3]. It is naturally the goal of GENCOs to maximize their benefit. All of them hope to minimize the maintenance investment loss (MIL). So each GENCO hopes to put its maintenance on the weeks when the market clearing price (MCP) is lowest, so that MIL is minimized [4]. Therefore, objective function for the GENCO is to sell electricity as much as possible, according to the market clearing price forecast. In doing so, various constraints such as generation capacity, duration of maintenance and maintenance continuity are being taken into account. The goal of ISO is to maximize the reliability throughout the weeks of year. To achieve this goal, various constraints such as minimum net reserve and duration of maintenance are being taken into account. [5].

In this paper the maintenance scheduling is analyzed from the ISO point of view. Each GENCO specifies optimum maintenance scheduling according to its objective function and hands it over to ISO. The ISO compares its own optimum reliability index with reliability index related to maintenance scheduling of GENCOs. If they are close enough in terms of reliability, it will be approved; otherwise the ISO sets up incentives and disincentives for each period to encourage GENCOs to modify their maintenance schedule so that the difference between reliability indices obtained by objective function of ISO and those of GENCOs is minimized. Incentive and disincentive will be possible by the information, which is provided by the ISO from permissible and impermissible maximum power for maintenance of generating units in each period. Forced outage rates (FOR) for each generating unit is not considered zero. ISO would prefer units with high FOR within periods of high demands and units with low FOR within periods of low demands in outage for maintenance. Mentioning the energy purchase cost relationship with demand, units' benefits with lower FOR would be considered. According to this, incentives and disincentives costs are different for each GENCO (see Fig. 1 and Fig. 2). The rates of incentives and disincentives costs for each GENCO are determine according to the average forced outage rates, for GENCO's units. Therefore the necessary GENCOs encouragement for decreasing FOR and increasing units' efficiency occurs. The test system examined in this paper consists of five GENCOs with 32 generating units, which are to be scheduled for maintenance during a 52 week period.

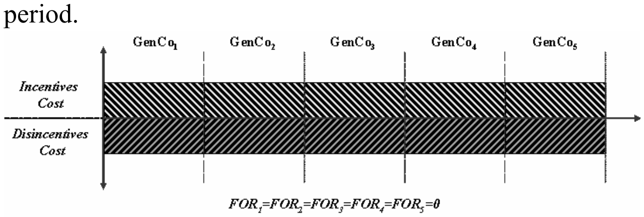

Fig. 1. Incentives and disincentives costs without FOR.

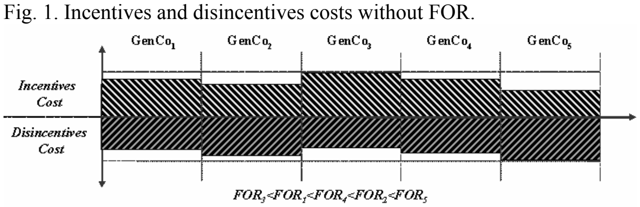

Fig. 2. Incentives and disincentives costs with FOR.

III. PROBLEM FORMULATION

To solve an optimization problem using Genetic Algorithm (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 scheduling problem, the main variables to be identified are maintenance states of the generating units. The schedule for unit *j* could be represented by a string of zeros and ones, $x_{ij}(t)$, where one means the unit *j* is under maintenance in 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. In other words, each chromosome is a possible solution for the problem. Since not every randomly built string will make a valid gene, a proper description of gene pools for each unit is necessary to ensure that the chromosomes satisfy the constraints. When chromosomes are built form valid genes, Crossover and Mutation as genetic operators are used to generate new possible solutions. Crossover cuts parent chromosomes at a point between two genes (called single point crossover) and exchanges the parent genes after the cut. Mutation changes randomly the values of some bits (genes) in each selected chromosome [6, 7].

The profit of a GENCO is defined as the total profit which is the sum of the individual unit profits from the auctions over the scheduling horizon [5]. Each GENCO solves its corresponding maintenance scheduling problem seeking to maximize its own profit. Therefore the objective function of $GENCO_i$ in maintenance scheduling can be formulated as follows:

$$
\begin{aligned}
Max \prod_{GENCO_i} = & \sum_{j\in G_i}\sum_{t=1}^{T}\left[(MCP_i(t)\times P_{Gij}(t) - C\,(P_{Gij}(t)))\times(1-x_{ij}(t))\right] HW \\
& - \sum_{j\in Gi}\sum_{t=1}^{T}\{[FC_{ij}\times\frac{1000}{8760}\times x_{ij}(t)\times P_{Gij}^{\max}] \\
& + [VC_{ij}\times P_{Gij}^{\max}\times x_{ij}(t)]\} HW
\end{aligned}
\qquad (1)
$$

The objective function (1) represents the profit of GENCOi, which is calculated as the difference between its total revenues and its corresponding costs which include production cost, fixed cost and variable cost. If needed, a more detailed cost modeling can be used [1].

To compute the objective function (1), the market clearing price should be determined. For the sake of simplicity, it is assumed that the market clearing price forecasts are known. We use the weekly electricity price of Nordpool deregulated power system for each GENCO [8].

The set of constraints of the maintenance scheduling problem of the GENCOi are specified below.

1) Maintenance Outage Duration: This constraint ensures for each unit that it is maintained the required number of time periods.

2) Continuous Maintenance: This constraint ensures that the maintenance of any unit must be completed once it begins.

In order to accelerate the GA, the constraints (1) and (2) are embedded in chromosome.

3) Capacity and Minimum Power Output: The power generated for each online unit must be within a certain range represented by its minimum power output and its capacity.

$$(1-x_{ij}(t))P_{Gij}^{\min} \le P_{Gij}(t) \le (1-x_{ij}(t))P_{Gij}^{\max} \quad \forall j \in Gi, \forall t \tag{2}$$

Table I shows a list of GENCOs Data and Table II shows operating cost data. Fuel costs are given in table III.

TABLE I
THE GENCOS DATA

NO. GENCOs	Unit Number	Unit Size (MW)		Forced Outage Rate	Scheduled Mainte-nance Wks/year
		Pmax	Pmin		
1	1	100	25	0.04	4
	2	20	4	0.1	1
	3	20	4	0.1	1
	4	12	2.4	0.02	1
	5	12	2.4	0.02	1
	6	12	2.4	0.02	1
	7	12	2.4	0.02	1
2	8	100	25	0.04	4
	9	100	25	0.04	4
	10	100	25	0.04	4
	11	76	15.2	0.02	3
	12	76	15.2	0.02	3
	13	20	4	0.1	1
	14	20	4	0.1	1
3	15	197	68.95	0.05	6
	16	155	54.25	0.04	5
	17	155	54.25	0.04	5
	18	100	25	0.04	4
	19	76	15.2	0.02	3
	20	12	2.4	0.02	1
4	21	350	140	0.08	8
	22	197	68.95	0.05	6
	23	197	68.95	0.05	6
	24	155	54.25	0.04	5
	25	155	54.25	0.04	5
	26	100	25	0.04	4
5	27	400	100	0.12	8
	28	400	100	0.12	8
	29	197	68.95	0.05	6
	30	197	68.95	0.05	6
	31	197	68.95	0.05	6
	32	76	15.2	0.02	3

TABLE II
OPERATING COST DATA

Unit Size (MW)	Fuel	Heat Rate Btu/KWh	Maintenance Cost	
			Fixed $/KW/YR	Variable $/MWh
12	Oil #6	12000	10.0	5.0
20	Oil #2	14500	0.3	5.0
76	Coal	12000	10.0	0.9
100	Oil #6	10000	8.5	0.8
155	Coal	9700	7.0	0.8
197	Oil #6	9600	5.0	0.7
350	Coal	9500	4.5	0.7
400	Nuclear	10000	5.0	0.3

TABLE III
FUEL COSTS

Fuel	Cost
Oil #6	2.3 $/Mbtu
Oil #2	3.0 $/Mbtu
Coal	1.2 $/Mbtu
Nuclear	0.6 $/Mbtu

It should be noted that the ISO's role is to ensure system security. Therefore, it must approve a generation maintenance plan for the GENCO that preserves system security. To adequately measure the degree of security throughout the weeks of year, the reliability index below is defined for period *t*. 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 [9].

$$I(t) = \frac{\sum_{i=1}^{I}\sum_{j \in G_i}\left[P_{Gij}^{\max}(1-x_{ij}(t))(1-FOR_{ij})\right] - L_D(t)}{\sum_{i=1}^{I}\sum_{j \in G_i} P_{Gij}^{\max}(1-FOR_{ij}) - L_D(t)} \quad \forall t \tag{3}$$

The ISO solves a maintenance scheduling problem involving all units, regardless of which GENCO owns which unit, with the target of maximizing the reliability throughout the weeks of the year. Sufficiently accurate demand forecasts for the whole year are considered known [8]. The objective function of the ISO can be formulated as follow [9]:

$$Max \quad \frac{1}{T}\sum_{t=1}^{T} I(t) \tag{4}$$

The objective function (4) is the average value of the reliability index defined in (3). This is an appropriate objective function provided that a sufficiently large index value is ensured for every period, which is done using constraint (5) below. The set of constraints of the maintenance scheduling problem of the ISO are specified below.

1) Minimum Net Reserve: This constraint ensures a net reserve above a specified threshold for all periods [9].

$$\sum_{i=1}^{I}\sum_{j \in G_i}\left[P_{Gij}^{\max}(1-x_{ij}(t))\,(1-FOR_{ij})\right] - L_D(t) \ge R^{\min}(t) \tag{5}$$

$$R^{\min}(t) = \alpha\, L_D(t)\frac{\sum_{t=1}^{T}\left[\sum_{i=1}^{I}\sum_{j \in G_i} P_{Gij}^{\max}(1-FOR_{ij}) - L_D(t)\right]}{\sum_{t=1}^{T} L_D(t)} \quad \forall t \tag{6}$$

In Expression (6) minimum reserve constant ensures higher reserves in periods with higher loads, which is an appropriate criterion.

2) Maximum energy purchase cost: We purpose new constraint for limit energy purchase cost. The energy purchase cost doesn't increase from a pre-determined amount when the units of GENCOs are in outage for maintenance. This new constraint can be formulated as follow:

$$\sum_{t=1}^{T} MCP_{ISO}(t) L_D(t) \le d \qquad (7)$$

Assuming the relationship of the MCP forecast and the reliability index of grid is an exponential function, which is showed in Fig. 3. This expression can be formulated as follow:

$$x(t) = I(t)\left(\frac{\sum_{i=1}^{I} \sum_{j \in G_i} P_{Gij}^{\max}}{L_D(t)} - 1 \right) \qquad \forall t \qquad (8)$$

$$MCP_{ISO}(x(t)) = MCP_{\min} + (MCP_{\max} - MCP_{\min}) e^{-k_1 x(t)} \qquad \forall t \quad (9)$$

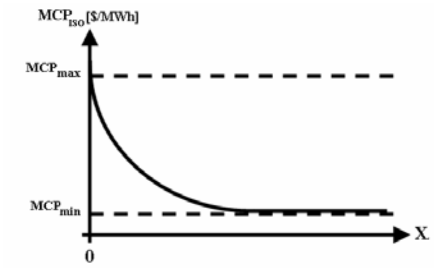

Fig. 3. The relationship of the MCP forecast and the reliability index of grid from ISO viewpoint.

3) Maintenance Outage Duration

4) Continuous Maintenance

In order to accelerate the GA, the constraints 3 and 4 are embedded in chromosome.

IV. The Proposed Approach

The ISO solves the maintenance scheduling problem with the target of maximizing the reserve throughout the weeks of the year. Each GENCO specifies optimum maintenance scheduling according to its target function and hands it over to ISO. The ISO compares its reliability index with reliability index related to maintenance scheduling of GENCOs. If they are close enough in terms of reliability, it will be approved; otherwise the ISO sets up incentives and disincentives for each period to encourage GENCOs to modify their maintenance schedule so that the difference between reliability indices obtained by objective functions of ISO and those of the GENCOs is minimized. Incentives and disincentives will be possible by the information, which is provided by the ISO from permissible and impermissible maximum power for maintenance of generating units in all of the periods. This information calculated as follow:

$$P_v^M(t) = \left[\sum_{i=1}^{I} \sum_{j \in G_i} P_{Gij}^{\max} - L_D(t) \right] \times \left[I_v^{GENCOs}(t) - I\ (t) \right] \qquad \forall t \qquad (10)$$

In this paper we consider effects of forced outage rates in the maintenance scheduling problem. Therefore FOR for each generating unit is not equal to zero. ISO would prefer units with high FOR within periods of high demands and units with low FOR within periods of low demands in outage for maintenance. Mentioning the energy purchase cost relationship with demand, units' benefits with lower FOR would be considered. According to this, incentives and disincentives costs are different for each GENCO. The rates of incentives and disincentives costs for each GENCO are determine according to the average forced outage rates, for GENCO's units. Therefore the necessary GENCOs encouragement for decreasing FOR and increasing units' efficiency occurs. The normalized penalty parameter can be formulated as follows:

$$\beta_v(t) = P_v^M(t) \times \left| P_v^M(t) \right| \qquad \forall t \qquad (11)$$

$$\omega_{iv}(t) = \frac{N_i \sum_{i=1}^{I} \sum_{j \in G_i} FOR_{ij}}{\sum_{i=1}^{I} N_i \sum_{j \in G_i} FOR_{ij}} \left[\frac{\beta_v(t) + |\beta_v(t)|}{\sum_{t=1}^{T} \left[\beta_v(t) + |\beta_v(t)| \right]} \right] - \frac{\sum_{i=1}^{I} N_i \sum_{j \in G_i} FOR_{ij}}{N_i \sum_{i=1}^{I} \sum_{j \in G_i} FOR_{ij}} \left[\frac{|\beta_v(t)| - \beta_v(t)}{\sum_{t=1}^{T} \left[|\beta_v(t)| - \beta_v(t) \right]} \right] \qquad \forall t, \forall i \qquad (12)$$

Each GENCO calculates its new maintenance scheduling including incentives and disincentives in the maintenance cost. The new objective function of $GENCO_i$ can be formulated as follow:

$$\begin{aligned} Max \prod_{GENCO_i} = & \sum_{j \in G_i} \sum_{t=1}^{T} \left[(MCP_i(t) \times P_{Gij}(t) - C\ (P_{Gij}(t))) \times (1 - x_{ij}(t)) \right] HW \\ & - \sum_{j \in G_i} \sum_{t=1}^{T} \{ [FC_{ij} \times \frac{1000}{8760} \times x_{ij}(t) \times P_{Gij}^{\max}] \\ & + [VC_{ij} - \frac{\delta_v \omega_{iv}(t)}{HW}] P_{Gij}^{\max} \times x_{ij}(t) \} HW \end{aligned} \qquad (13)$$

This new approach for maintenance scheduling problem is shown diagrammatically in Fig. 4.

We assume that payments for maintenance scheduling adjustments to GENCOs happen once a year, after the appropriate agreement among GENCOs and the ISO has been reached [6].

V. Output Result

Fig. 5 shows performance of the GA over 500 generations when maintenance scheduling of the GENCO solved from ISO viewpoint. In this figure, the fitness of the best individual and the average fitness of the population are illustrated. The load profile and its reliability profile are depicted in Fig. 6 and 7. The maintenance schedule of GENCOs by the ISO (see Fig. 8) schedules most units for maintenance during weeks 12-17 and 36-41, which are the weeks with the lowest loads. Table IV shows possible solution to this problem that covers ISO's purposes.

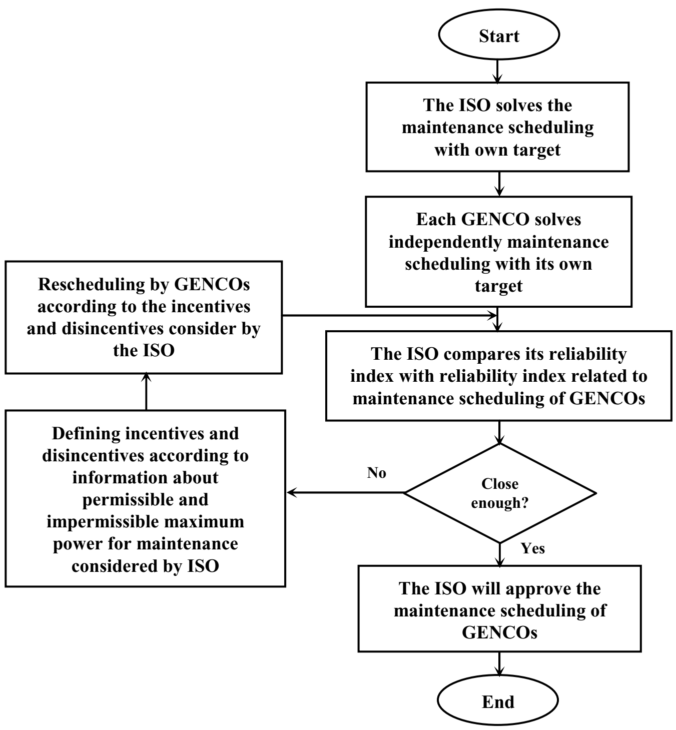

Fig. 4. The algorithm of proposed approach for maintenance scheduling of GENCOs.

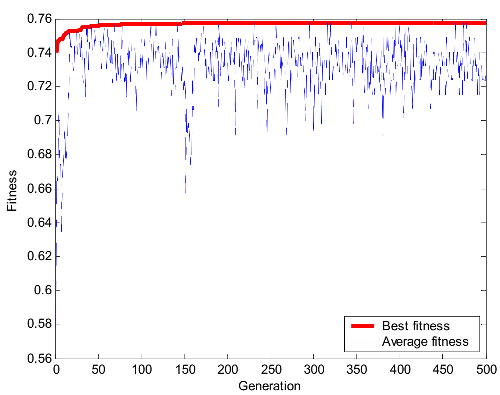

Fig. 5. Performance of GA based on ISO objective function.

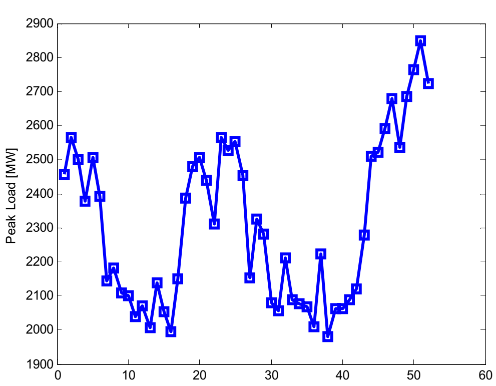

Fig. 6. The Load Profile.

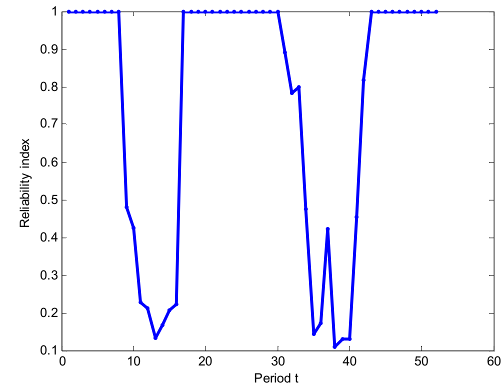

Fig. 7. Reliability index corresponding to ISO objective function.

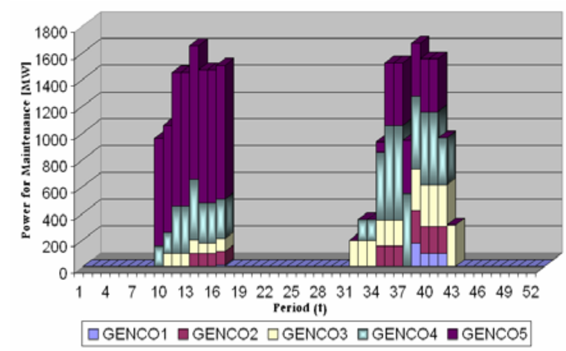

Fig. 8. Maintenance schedule of GENCOs from ISO viewpoint.

TABLE IV
GENERATION MAINTENANCE SCHEDULING BY ISO

Unit	Start of Outage (Week)	Unit	Start of Outage (Week)
25-27-28	9	15	31
18	10	24	32
23-30	11	11-12-21-32	34
9-26	13	22-29-31	35
19	14	1-2-3-4-5-6-8-10 13-14-16-17	38
7-20	16	-	-

The GENCOs hope to minimize the MIL from their own interests. So each GENCO put its maintenance on the weeks when the MCP is lower, so that MIL is decreased. The initial maintenance scheduling plan schedules most units for maintenance during weeks with the lowest energy prices. The Fig. 9 shows the initial maintenance scheduling of GENCOs. The initial maintenance schedules of GENCOs are shown clearly in Table V.

TABLE V
THE INITIAL GENERATION MAINTENANCE SCHEDULING OF GENCOS

Unit	Start of Outage (Week)
21-22-23-24-25-26	8
20	17
9	31
8-10-11-12-15	33
13-14-16-17-19-27-28-29-30-31	34
18	35
1-32	36
2-3-4-5-6-7	38

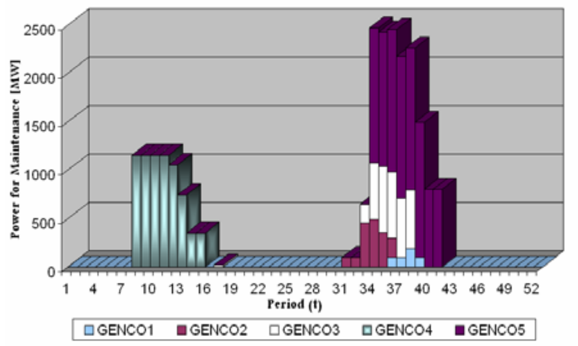

Fig. 9. The initial Maintenance scheduling of GENCOs.

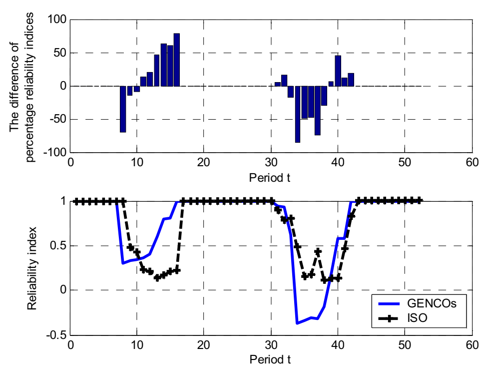

Fig. 10. The initial percentage of residual reliability and violated reliability.

Fig. 10 depicts the percentage of residual reliability and violated reliability in each period, which is calculated by the ISO considering the initial scheduling. According to this percentage the maximum power for carrying out the maintenance of the units or ending it is calculated in each period. This is clearly shown in Fig. 11. In this figure the negative power means that the maintenance is impermissible according to the calculated power in each period and the positive power means that it is permissible. According to Fig. 10 reliability index of ISO is violated in some periods. Therefore scheduling of some units of GENCOs will not be approved due to ISO demands. The ISO sets up incentives and disincentives for each period to encourage GENCOs to modify their maintenance scheduling so that the difference between reliability indices obtained by objective functions of the ISO and those of the GENCOs is minimized. Reliability index clearance of 25% in each period will be approved by ISO.

This process should be repeated till the stopping condition is met. The stopping condition is satisfied when the profiles of reliability indices are sufficient close.

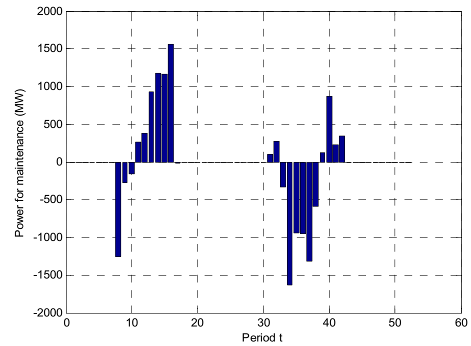

Fig. 11. The maximum permissible or impermissible power for maintenance of the units (initial iteration).

We propose new approach for finding optimal penalty factor (δv). Note that without this method we cannot find best approximation of the optimal penalty factor. Using interpolation methods and or the least squares approximation method we can obtain a good solution namely a near optimal penalty factor. For this purpose, we construct the interpolating polynomial $S(\delta)$ as follow:

$$S_v = \sum_{t=1}^{52} [I_v^{GENCOs}(t) - I(t)]^2 \tag{14}$$

Fig. 12 shows the relationship between S and δ for finding δ*.It is clear that $S(\delta)$ is strictly convex on interval [100, 350] Thus, the minimum point of the function $S(\delta)$ is the initial point δ*=259.45 and consequently we obtain the value of the function $S(\delta)$ in δ*=259.45, that is 1.149.

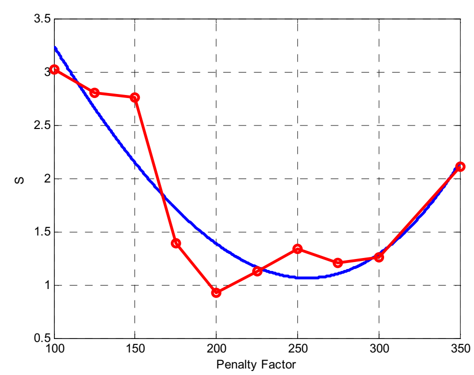

Fig. 12. The relationship between S and δ for finding δ^*.

The following figures show the incentives and disincentives costs in each period for GENCOs with δ*.

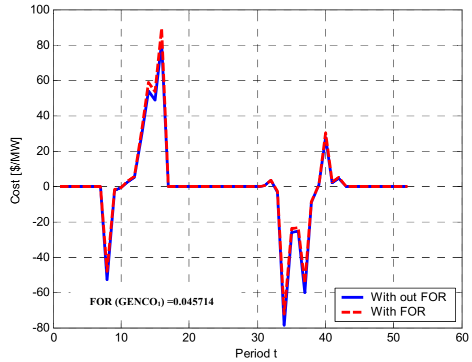

Fig. 13. The incentives and disincentives costs for GENCO$_1$ in each period with δ*.

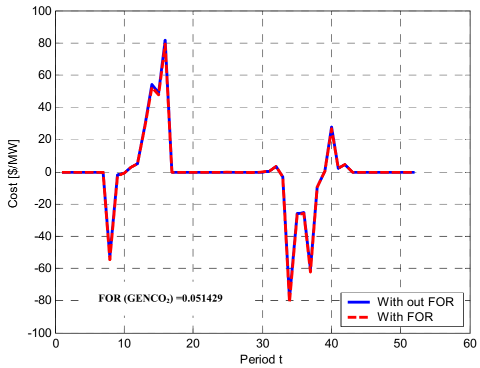

Fig. 14. The incentives and disincentives costs for GENCO$_2$ in each period with δ*.

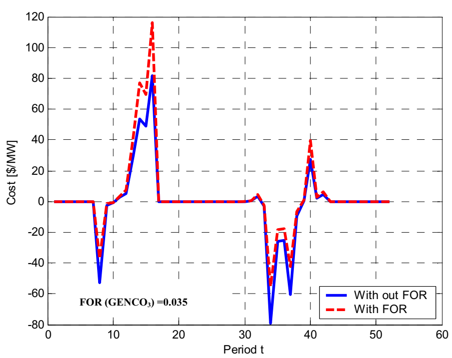

Fig. 15. The incentives and disincentives costs for GENCO$_3$ in each period with δ*.

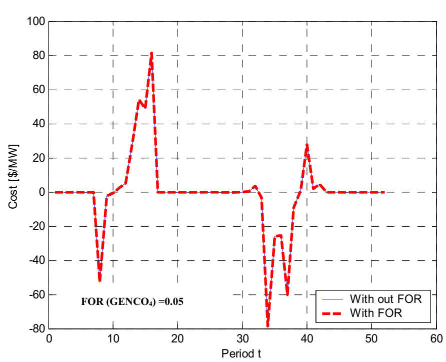

Fig. 16. The incentives and disincentives costs for GENCO$_4$ in each period with δ*.

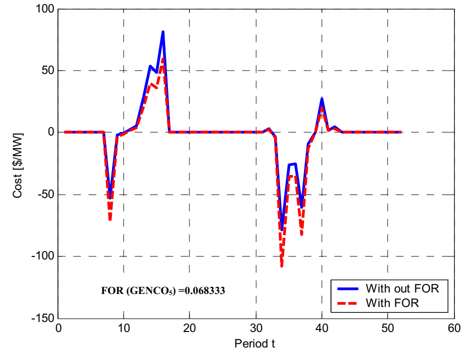

Fig. 17. The incentives and disincentives costs for GENCO$_5$ in each period with δ*.

The final maintenance scheduling plan with optimal penalty factor and the difference of percentage reliability indices in each period are illustrated in Fig. 18 and 19. The final maintenance schedules of GENCOs are shown clearly in Table VI.

TABLE VI
THE FINAL GENERATION MAINTENANCE SCHEDULING OF GENCOS

Unit	Start of Outage (Week)	Unit	Start of Outage (Week)
21	8	20	17
22-23	10	15	30
11-12-24-25	11	8-9-10-19	31
26	12	27-28-29-30-31	35
16-17	13	1-7-32	38
18	14	2-3-4-5-6	40
13-14	16	-	-

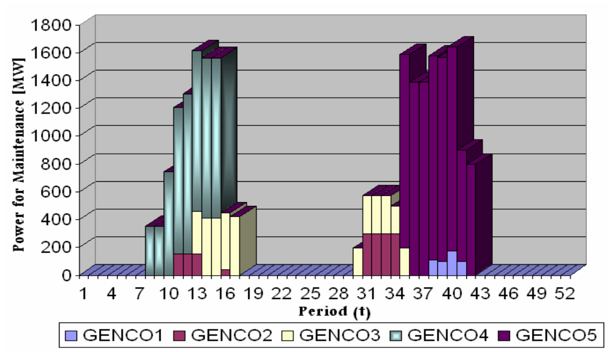

Fig. 18. The final Maintenance scheduling of GENCOs.

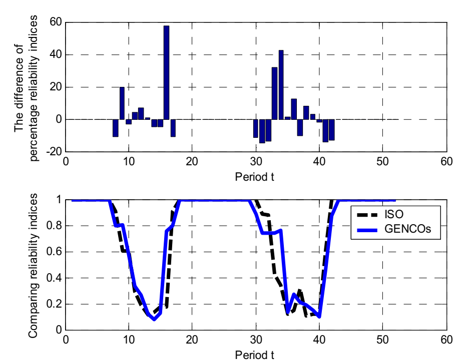

Fig. 19. The final percentage of reliability in each period.

Table VII shows the profit obtained by the five GENCOs and the reschedule payments to GENCOs. Column 2 provides profits associated to the initial maintenance schedule of GENCOs; the third column, profits associated to the final maintenance schedule of GENCOs; and the fourth column provides the payment to GENCOs for altering their initial maintenance schedules. The negative sign indicates that the GENCO transfers money to ISO to preserve its preferred maintenance schedule. The payment received by any given GENCO depends on its ability to reallocate the maintenance outage of their units and to take advantage of reallocation incentives. Rescheduling payments made to GENCOs (2321.9232$) are allocated pro rata to demands as a cost to achieve the desired level of reliability.

TABLE VII
GENCO PROFITS AND RESCHEDULING PAYMENTS TO GENCOS

GENCO	GENCO Profits: Initial M.S. [$]	GENCO Profits: Final M.S. [$]	Reschedule Payment [$]
1	1.6634×10^6	1.6792×10^6	150.5232
2	2.9677×10^7	2.9106×10^7	-2.4803×10^3
3	4.905×10^7	4.9129×10^7	3.9549×10^3
4	1.0351×10^8	1.0345×10^8	7.5260×10^3
5	1.4567×10^8	1.4132×10^8	-6.8292×10^3
Total	3.295704×10^8	3.247635×10^8	2321.9232

VI. CONCLUSION

Annual maintenance scheduling of generating units of the GENCOs in a deregulated power system is formulated and discussed from different points of view. It uses genetic algorithm to find the optimum schedule for preventive maintenance considering the forecasted market clearing price. GENCO's objective function is to sell electricity as much as possible and the goal of ISO is to maximize the reliability throughout the weeks of year; subject to the energy purchase cost doesn't increase from a pre-determined amount when the units of GENCOs are in outage for maintenance. The purpose of this algorithm is to orderly encourage moving maintenance outages from the periods of low reliability to the periods of high reliability, so that a reasonable reliability level is attained throughout the year. In this paper, for a test system of five GENCOs with 32 generating units the optimum maintenance schedule over the planning period is obtained by employing genetic algorithm.

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