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# Promoting the Optimal Maintenance Schedule of Generating Units in a Competitive Environment Based on Genetic Algorithm

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**Abstract:**
This paper presents a Genetic Algorithm methodology for finding the optimum preventive maintenance schedule of generating units of GENCOs in a restructured power system. In this environment, management of GENCOs and grid is separated, each maximizing its own benefit. Therefore, the principle to draw up the unit maintenance scheduling will be changed significantly. The profit of GENCO is defined as the total profit, which is the sum of the individual units' profits from the auctions over the horizon. So each GENCO hopes to schedule its maintenance on the weeks when the spot marginal price (SMP) is lower, so that maintenance investment loss (MIL) is minimized. Therefore, objective function for the GENCO is to sell electricity as much as possible, according to the market clearing price forecast. Various technical constraints such as generation capacity, duration of maintenances and maintenance continuity are being taken in to account. The objective function of ISO is to maximize the reliability throughout the weeks of year. Various constraints such as minimum net reserve, duration of maintenance are being taken in to account. Therefore there are two objective functions for finding an optimum maintenance schedule in restructured power systems. Each GENCO specifies optimum maintenance schedule according to its objective function and hands it over to ISO. The ISO compares its own reliability index with reliability index related to maintenance schedule 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 the GENCOs is minimized.

## 1. 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 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 spot marginal price (SMP) is lower, so that maintenance investment loss 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 in to 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. 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.

## 2. GENETIC ALGORITHM

Recently, genetic algorithms have received a lot of attention, and they currently account for many successful applications. Genetic algorithms are search algorithms that reflect in a primitive way some of the processes of natural evolution. Genetic algorithms often provide very effective search mechanisms that can be used in optimization and classification applications. Genetic algorithms work with a population of points, rather than a single point; each point is actually a vector in hyperspace representing one potential, or candidate, solution to the optimization problem. A population is thus, just an ensemble, or set, of hyperspace vectors. Each vector is called an individual or sometimes a choromosome in the population.

Because real numbers are often encoded in genetic algorithms using binary numbers, the dimensionality of the problem vector might be different from the dimensionality of the bit string chromosome. The number of elements in each vector (individual) equals the number of real parameters in the optimization problem. A vector element generally

corresponds to one parameter, or dimension, of the numeric vector. Each element can be encoded in any number of bits, depending on the representation of each parameter. The total number of bits defines the dimension of hyperspace being searched.
The series of operations carried out when implementing a genetic algorithm paradigm is:

1. Initialize the population,
2. Calculate fitness for each individual in the population,
3. Reproduce selected individuals to form a new population,
4. Perform crossover and mutation on the population,
5. Loop to step 2 until some condition is met.

The two main steps for the translation of an optimization problem to an evolutionary optimization problem are chromosome representation and chromosome evaluation. In the first step, which is problem specific, the solution of the optimization problem is represented in the form of a binary string, i.e. a chromosome. In the second step, an evaluation function serving as fitness function, is introduced in order to compare the chromosomes in the evolution process. The encoding of the problem and the selection of a proper fitness function have important effects on the success of the GA method.

### 3. Problem Formulation

To solve an optimization problem using 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 stsge $t$. 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 (see Fig. 1). Mutation changes randomly the values of some bits (genes) in each selected chromosome (see Fig. 2) [6].

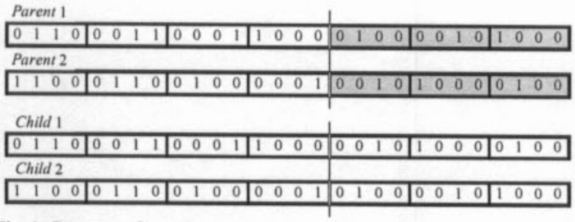

Fig. 1. Crossover Operator

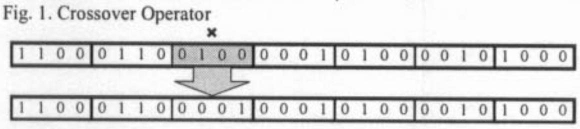

Fig. 2. Mutation Operator

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 [7]. 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:

**Objective function of GENCOs :**

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

where,

$MCP_i(t)$ : Energy price estimate ($\$/MWh$) for period $t$

$P_{Gij}(t)$ : Power generated ($MW$) by unit $j$ in period $t$

$P_{Gij}^{max}$ : Capacity ($MW$) of unit $j$ of GENCOi

$C(P_{Gij}(t))$: Production cost ($\$/h$) of unit $j$

$FC_{ij}$ : Fixed cost ($\$/Kw/YR$) of unit $j$ of GENCOi

$VC_{ij}$ : Variable cost ($\$/MWh$) of unit $j$ of GENCOi

$T$ : Number of periods of time. ($T$=52)

$HW$ : All hours of the week. ($24\times7=168$ hour)

$x_{ij}(t)$ : Maintenance status for unit $j$ of GENCOi in period $t$. (1 if unit $j$ is on maintenance in period $t$ and 0 otherwise)

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].

In order to make the maitenance schedule feasible certain constraints should be satisfied. Some of basic constraints which should be set up are the continuity of maintenance activity, spesific time interval for maintenance of some generating units, maintenance crew constraint and the maximum & minimum capacity of each generating unit. 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 genetic algorithm, 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 $P_{Gij}^{min}$ and its capacity $P_{Gij}^{max}$.

In this paper it is assumed that GENCOi offers the price in a way that wins all the auctions and in all the period uses its energy. 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 norpool deregulated power system for each GENCO [8]. Forced outage rates for each generating unit is not considered zero. Because the unit forced outage rates can be approximately taken into account derating their corresponding capacities. Table 1 shows a list of GENCOs Data and Table 2 shows operating cost data. Fuel costs are given in table 3.

**Table 1: The GENCOs Data**

| NO. GENCOs | Unit Number | Unit Size (MW) | | Forced Outage Rate | Scheduled Maintenance 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 2: 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 3: 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 $t$ [5].

$$I(t) = \frac{\sum_{i=1}^{I}\sum_{j\in G_i}\left[P_{Gij}^{\max}(1-x_{ij}(t))(1-FOR_{ij})\right]-P_D(t)}{\sum_{i=1}^{I}\sum_{j\in G_i}P_{Gij}^{\max}(1-FOR_{ij})-P_D(t)} \qquad (2)$$

where, $I(t)$ : Reliability index in period $t$.

$P_D(t)$ : Power demand (MW) in period $t$.

$FOR_{ij}$ : Forced outage rates of unit $j$ of GENCOi.

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.

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 [5]:

**Objective function of ISO:**

$$Max \quad \frac{1}{T}\sum_{t=1}^{T} I(t) \qquad (3)$$

The objective function (3) is the average value of the reliability index defined in (2). This is an appropriate objective function provided that a sufficiently large index value is ensured for every period, which is done using constraint (4) 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].

$$\sum_{i=1}^{I}\sum_{j\in G_i}\left[P_{Gij}^{\max}(1-x_{ij}(t))\,(1-FOR_{ij})\right] - P_D(t) \geq R^{\min}(t) \qquad (4)$$

$$R^{\min}(t) = \alpha\, P_D(t)\frac{\sum_{t=1}^{T}\left[\sum_{i=1}^{I}\sum_{j\in G_i}P_{Gij}^{\max}(1-FOR_{ij})-P_D(t)\right]}{\sum_{t=1}^{T}P_D(t)} \qquad (5)$$

where, $R^{\min}(t)$ : Net minimum reserve (MW) in period $t$.

$\alpha$ : Per unit costant ($0<\alpha<1$).

In Expression (5) minimum reserve constant ensures higher reserves in periods with higher loads, which is an appropriate criterion.

***2) Maintenance Outage Duration***

***3) Continuous Maintenance***

In order to accelerate the genetic algorithm, the constraints 2 and 3 are embedded in chromosome.

## 4. A SOLUTION ALGORITHM FOR MAINTENANCE SCHEDULING IN RESTRUCTURED POWER SYSTEMS

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. The incentives and disincentives ($\delta_v(t)$) are calculated as follow:

$$\delta_v(t) = \left[I_{v-1}^{GENCOs}(t) - I(t)\right] \left|I_{v-1}^{GENCOs}(t) - I(t)\right| \qquad (6)$$

where, $I_v^{GENCOs}(t)$: reliability index related to maintenance scheduling of GENCOs at iteration $v$.

It should be noted that $\delta_v(t)$ cannot be either all positive or all negative. The reason is as follows. All $\delta_v(t)$ positive/negative means that in the corresponding iteration the security indices of all periods improve/deteriorate, which requires less/more units in maintenance throughout the year, which contradicts the fact that all units should be maintained during the year. The normalized penalty parameter can be formulated as follows [5]:

$$\omega_v(t) = \frac{\delta_v(t) + |\delta_v(t)|}{\sum_{t=1}^{T}\left[\delta_v(t) + |\delta_v(t)|\right]} - \frac{|\delta_v(t)| - \delta_v(t)}{\sum_{t=1}^{T}\left[|\delta_v(t)| - \delta_v(t)\right]} \qquad (7)$$

the first term of the right hand side of (7) is zero for negative quadratic differences, while the second term is zero for positive quadratic differences. Therefore, positive and negative penalties are normalized independently so that their corresponding signs are preserved. Each GENCO, calculates its new maintenance scheduling including incentives and disincentives in the maintenance cost. This approach for maintenance scheduling problem is shown diagrammatically in fig. 3. The new objective function of GENCO can be formulated as follow:

$$\begin{aligned} Max \prod_{GENCO} = & \sum_{j\in G_i}\sum_{t=1}^{T}\left[(MCP_i(t)\times P_{Gij}(t) - C(P_{Gij}(t)))\times(1-x_{ij}(t))\right]HW \\ & - \sum_{j\in Gi}\sum_{t=1}^{T}\{[FC_{ij}\times\frac{1000}{8760}\times x_{ij}(t)\times P_{Gij}^{max}] \\ & + [VC_{ij} - \frac{\gamma_v\omega_v(t)}{HW}]P_{Gij}^{max}\times x_{ij}(t)\}HW \end{aligned} \qquad (8)$$

where, $\gamma_v$: Constant (\$/MW) used by the ISO in iteration $v$.

The parameter $\gamma_v$, which must be positive, is selected as small as possible but large enough to influence GENCO maintenance schedules. 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. Expression (9) provides the payment to each GENCO. It can be calculated as follow:

$$P^{GENCOi} = \sum_{j\in Gi}\sum_{t=1}^{T}\gamma_v\omega_v(t)P_{Gij}^{max}x_{ij}(t) \qquad \forall i \quad (9)$$

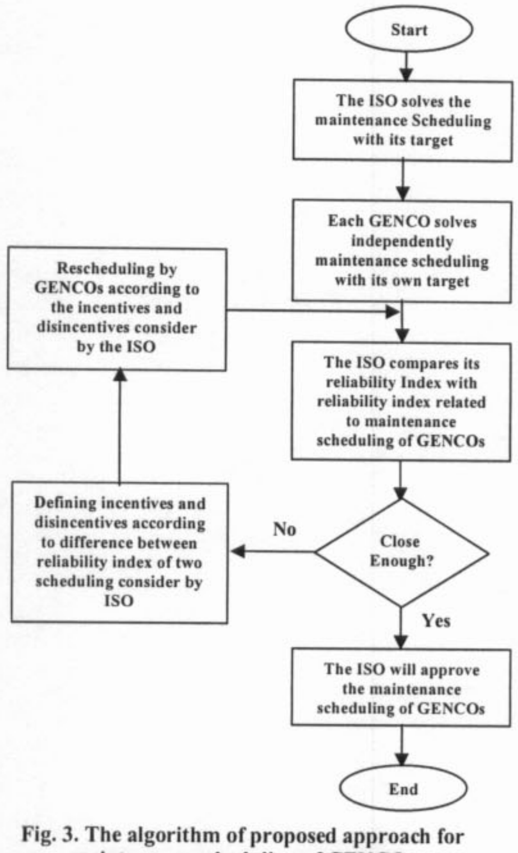


**Fig. 3. The algorithm of proposed approach for maintenance scheduling of GENCOs**

## 5.OUTPUT RESULTS

Fig. 4 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. First of all, note that the maintenance schedule of GENCOi by the ISO (see Fig.5) schedules most units for maintenance during weeks 11-16 and 35-40, which are the weeks with the lowest loads. The load profile and its reliability profile are depicted in Fig. 6 and 7. Table 4 shows possible solution to this problem that covers ISO's purposes.

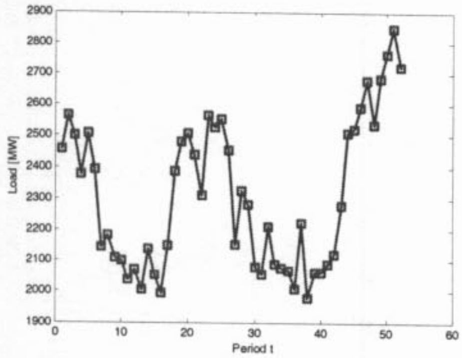


**Fig. 6. The Load Profile**

**Table 4: Generation Maintenance Scheduling by the ISO (52-weeks horizon)**

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

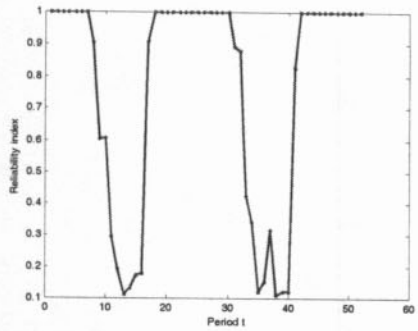


**Fig. 7. Reliability index corresponding to ISO objective function**

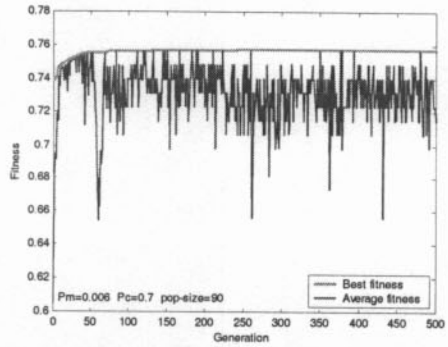


**Fig. 4. Performance of GA based on ISO objective function**

The GENCOs hope to minimize the maintenance investment loss from their own interests. So each GENCO put its maintenance on the weeks when the spot margin price is lower, so that maintenance investment loss is decreased. The initial maintenance scheduling plan schedules most units for maintenance during weeks with the lowest energy prices. The following figures show the initial maintenance scheduling of GENCOs. The initial maintenance schedules of GENCOs are shown clearly in Table 5.

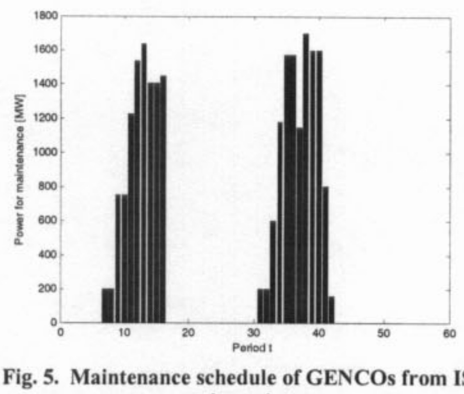


**Fig. 5. Maintenance schedule of GENCOs from ISO viewpoint**

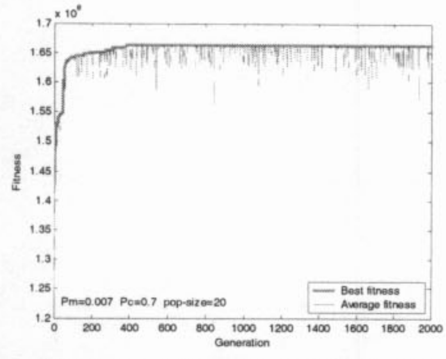


**Fig. 8. Performance of GA based on GENCO1 objective function**

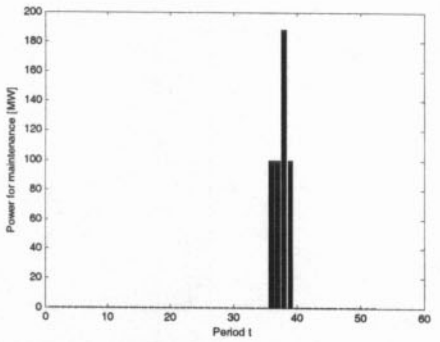


Fig. 9. The schedule of GENCO1 units from its desired objective function

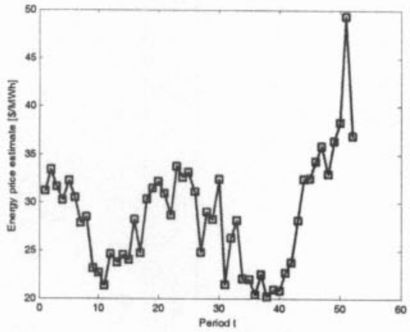


Fig. 10. Energy price estimate by GENCO1

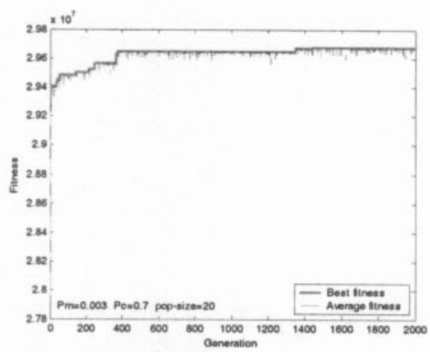


Fig. 11. Performance of GA based on GENCO2 objective function

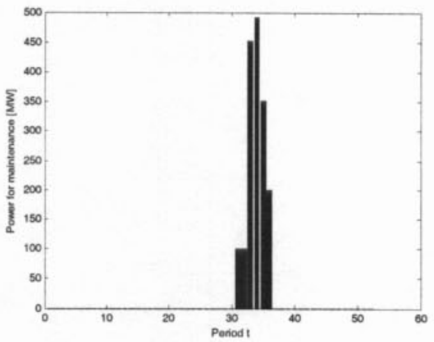


Fig. 12. The schedule of GENCO2 units from its desired objective function

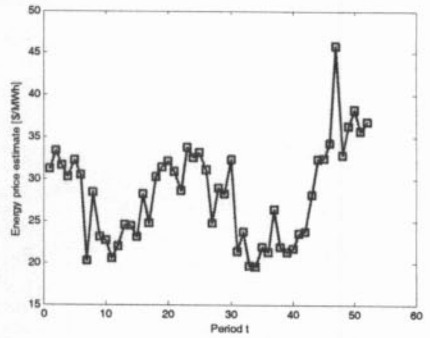


Fig. 13. Energy price estimate by GENCO2

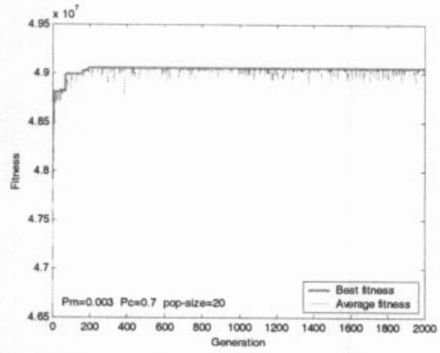


Fig. 14. Performance of GA based on GENCO3 objective function

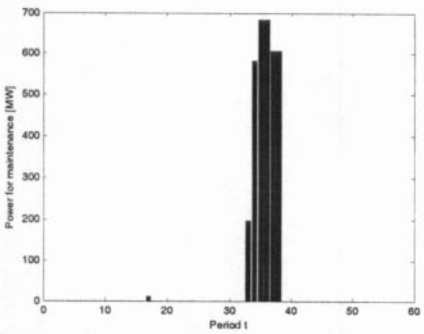


Fig. 15. The schedule of GENCO3 units from its desired objective function

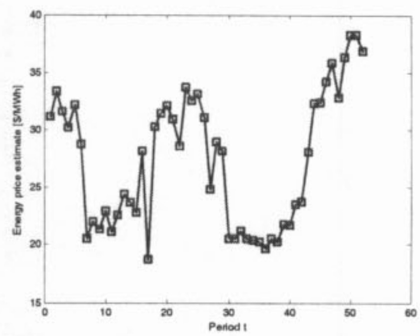


Fig. 16. Energy price estimate by GENCO3

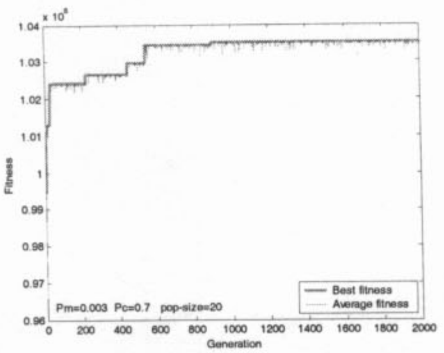


**Fig. 17. Performance of GA based on GENCO4 objective function**

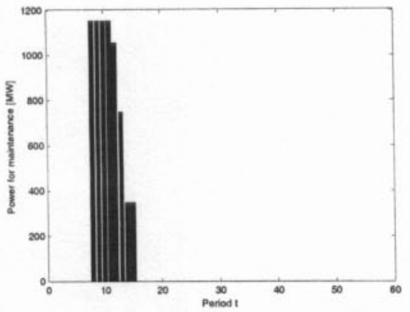


**Fig. 18. The schedule of GENCO4 units from its desired objective function**

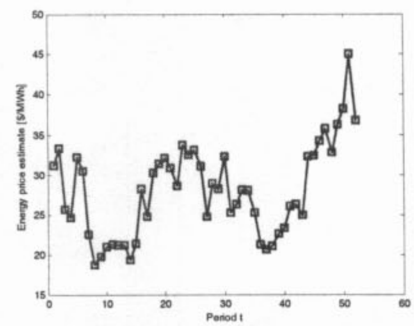


**Fig. 19. Energy price estimate by GENCO4**

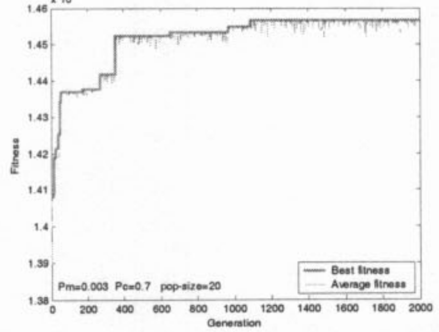


**Fig. 20. Performance of GA based on GENCO5 objective function**

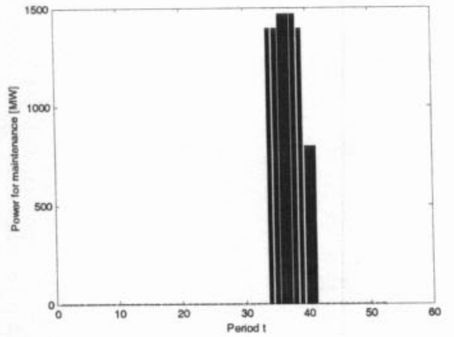


**Fig. 21. The schedule of GENCO5 units from its desired objective function**

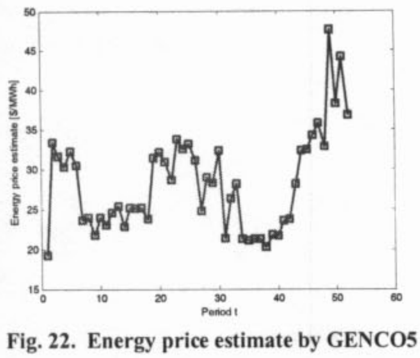


**Fig. 22. Energy price estimate by GENCO5**

**Table 5: The initial Generation Maintenance Scheduling of GENCOs (52-weeks horizon)**

| 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 |

According to Fig. 23 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. The initial maintenance schedule of GENCOs is shown in Fig. 24. Fig. 25 shows the incentives and disincentives costs in each period for all GENCOs and the other figures shows the final maintenance scheduling of GENCOs.

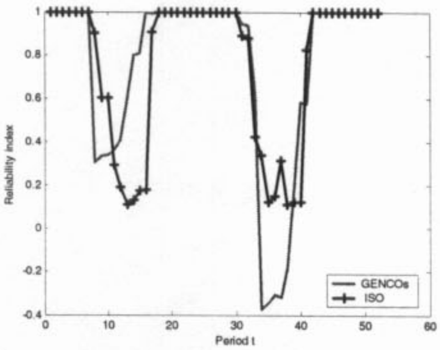


**Fig. 23. Comparing reliability indices**

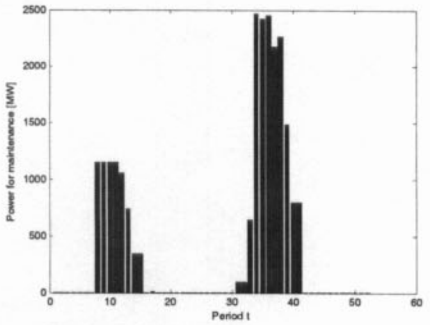


**Fig. 24. The initial Maintenance scheduling of GENCOs**

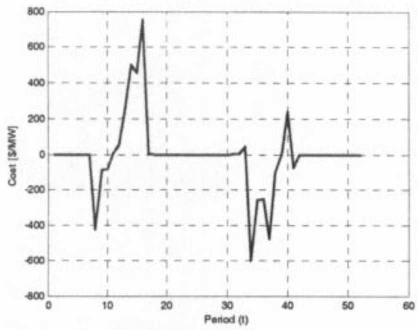


**Fig. 25. The incentives and disincentives costs in each period**

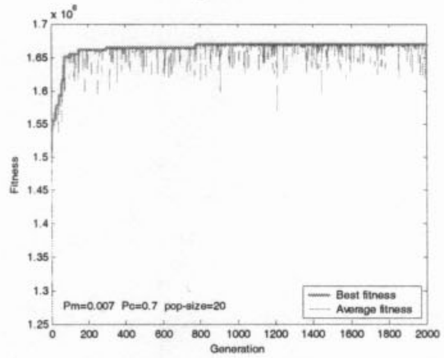


**Fig. 26. Performance of GA based on GENCO1 objective function**

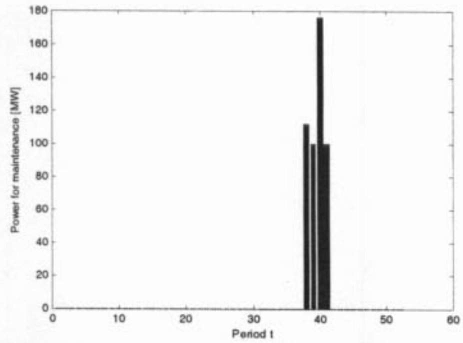


**Fig. 27. The reschedule of GENCO1 units from its desired objective function**

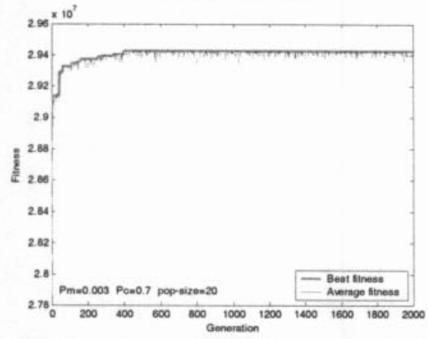


**Fig. 28. Performance of GA based on GENCO2 objective function**

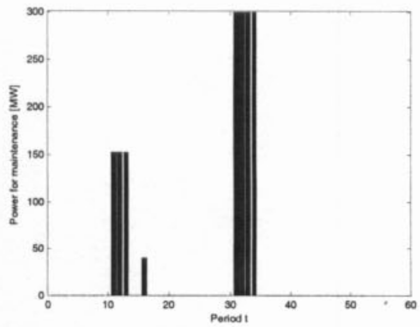


**Fig. 29. The reschedule of GENCO2 units from its desired objective function**

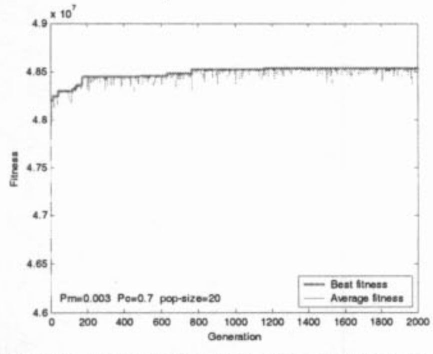


**Fig. 30. Performance of GA based on GENCO3 objective function**

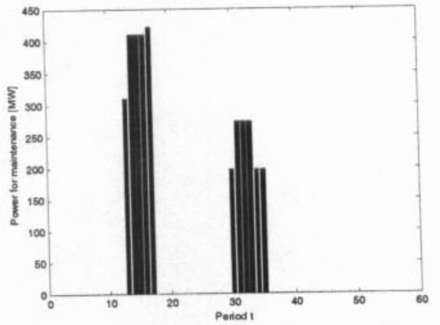


**Fig. 31. The reschedule of GENCO3 units from its desired objective function**

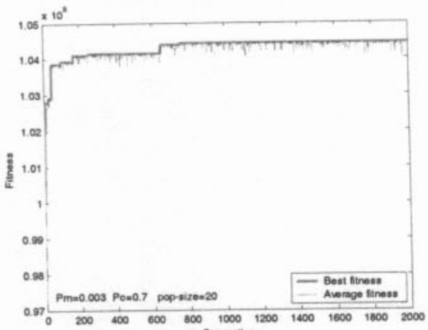


**Fig. 32. Performance of GA based on GENCO4 objective function**

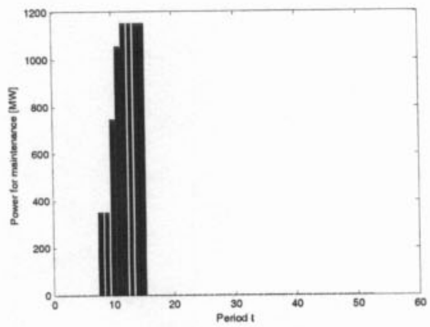


**Fig. 33. The reschedule of GENCO4 units from its desired objective function**

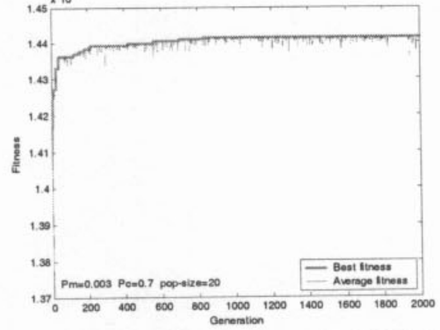


**Fig. 34. Performance of GA based on GENCO5 objective function**

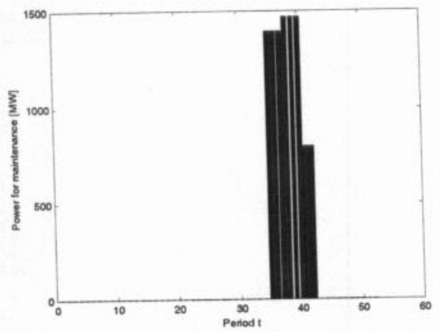


**Fig. 35. The reschedule of GENCO5 units from its desired objective function**

The final maintenance schedule of GENCOs are shown clearly in Table 6. The final maintenance scheduling plan and its reliability profile are illustrated in Fig. 36 and 37.

**Table 6: The final Generation Maintenance Scheduling of GENCOs (52-weeks horizon)**

| 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 | - | - |

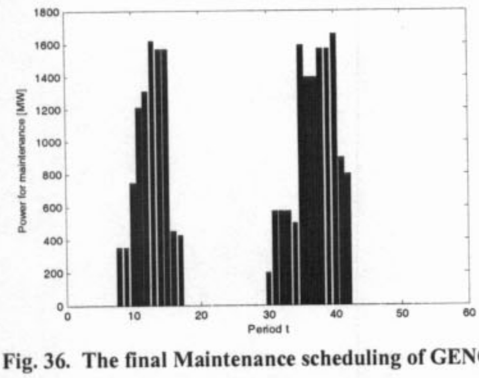


**Fig. 36. The final Maintenance scheduling of GENCOs**

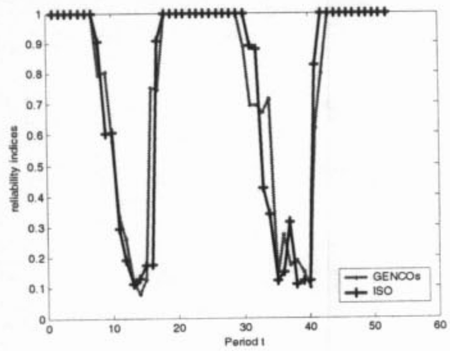


**Fig. 37. Comparing reliability indices**

Table 7 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 mony to ISO to preserve its preferred maintenance schedule.

Table 7: GENCO Profits and Rescheduling Payments to GENCOs

| GENCO | GENCO Profits: Initial M.S. [$] | GENCO Profits: Final M.S. [$] | Reschedule Payment [$] |
|---|---|---|---|
| 1 | $1.6634\times10^{6}$ | $1.6686\times10^{6}$ | $2.8098\times10^{4}$ |
| 2 | $2.9677\times10^{7}$ | $2.9424\times10^{7}$ | $4.0757\times10^{5}$ |
| 3 | $4.905\times10^{7}$ | $4.8529\times10^{7}$ | $4.6864\times10^{5}$ |
| 4 | $1.0351\times10^{8}$ | $1.0445\times10^{8}$ | $1.2420\times10^{6}$ |
| 5 | $1.4567\times10^{8}$ | $1.4415\times10^{8}$ | $-1.2384\times10^{6}$ |
| Total | $3.295704\times10^{8}$ | $3.282216\times10^{8}$ | 907908 |

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 (907908 $ ) are allocated pro rata to demands as a cost to achieve the desired level of reliability.

## 6.INFORMATION

In this paper the value of $\alpha$ and $\gamma_v$ used for scheduling are 0.15 and 3249.5. Therefore the percentage reliability index in all periods is above 10%.

## 7. 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. The purpose of this algorithm in to orderly encourage moving maintenance outages from periods of low reliability to 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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