Outage planning of electrical power system networks using genetic algorithm

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Abstract *An electrical company is responsible for the maintenance of a transmission network of high voltage electricity. The maintenance schedule must be planned so as to minimize outage costs, taking into consideration various factors such as system security/reliability, system availability, and manpower utilization. With the rapid growth of organization, planning engineers are required to fulfill additional roles in order to increase productivity. To this end, a fast response and accurate mechanism is required to assist the planning engineers in dealing with the daily operation. This paper describes how a proposed maintenance schedule can be obtained automatically by the adoption of genetic algorithm. The main aim is to determine the maintenance schedule of circuit outage with minimizing the maintenance cost and maximizing the circuit availability under certain unavoidable system constraints. Further, an additional search mechanism called "final tuning search" is developed to enhance the system performance.*

1. Introduction

In a power system, maintenance and renewal of power system facilities are continually needed to secure stable power supply, in which circuit outage will inevitably be caused (Marwali and Shahidehpour, 1998). Circuit outage is the inhibition of the electricity transmission, which will result in voltage fluctuation or even in load loss. Therefore, outage planning of power circuits should be carried out to realize a system configuration which is similar to a normal one equipped with flexibility in power system configuration.

In principle, outage planning consists of an annual plan and a weekly plan. The annual plan is arranged according to the forecasted maintenance work and project work. It is re-arranged weekly and even daily based on requests for outage work from line sections and according to the system arrangement. Planning engineers therefore ideally select the configuration of the power system during the works in consideration of supply continuity and system security (Langdon and Treleaven, 1997).

The planning engineers must sort those requests by the time and date of the submitted outage plans. Since the number of requests for outage works at a regional section will exceed 300 in half a year, thus it is a task of complex constrained scheduling process.

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Moreover, after the company's re-engineering and downsizing, the role of planning engineers is being enriched. With the enlarged work quantity, a new method of outage planning is sought to guarantee the fulfillment of basic standards such as quality, cost, and time:

- *Quality.* It should fulfill the system requirement, reliability, and security. With this connection, key performance index (KPI) of high circuit availability and 100 per cent maintenance achievement should be met.
- *Cost.* It should minimize the outage cost, i.e. engineer and tradesmen requirement and the planning engineer time. In addition, the new method should be easy to use by inexperienced staff (Allison *et al.,* 1995).
- *Time.* It should be fast in response to deal with rapid change in daily operation.

This paper proposes a supporting system for the circuit outage planning of transmission system. The proposed system has been designed to keep a high reliability during outage works. In this paper, a high reliability in the power system is defined as "a system configuration that does not incur supply shortage even when any single-line fault occurs during the outage work."

2. Problem description

In this study, the focus will be taken on the maintenance outage scheduling problem. The problem can be defined as "to determine the maintenance schedule of circuit outage with minimizing the maintenance cost and maximizing the circuit availability under the following system constraints" (Kim and Nara, 1997):

- predetermined continuous periods are necessary for each circuit;
- power must be supplied so as to meet the demands for all periods;
- some pairs of circuits cannot be maintained at the same period;
- circuit outages should be classified as different priorities to suit outage urgency.

In other words, supply continuity, load pattern, outage windows, and system security are important topics dealing with the outage planning. Hence it is necessary to comply them with the constraints in the planning process.

The problem is formulated under the assumption that power demands for each period are known deterministically. The outage duration is dependent on the work on each circuit. However, it is assumed that the manpower requirement is constant throughout the period.

2.1 Objective function

The objective function of the outage planning is the outage cost function. It is composed of both manpower cost and system cost function. The manpower cost is basically determined by the daily manpower requirements, while the system cost is based on the system availability, which can be expressed in the following equation.

2.1.1 Manpower cost

$$F(M) = \sum m(Ma + | Ma - Mi |) \tag{1}$$

Where

$F(M)$: Total manpower cost

m : Cost factor dependent on tradesmen wages and grades

Ma : Manpower availability

Mi : Manpower requirement on ith period

2.1.2 System availability cost

$$N_i = n[(\sum X_i - \sum Y_i)/\sum X_i] \tag{2}$$

Where

N_i : System availability on ith period

n : Cost factor in the system availability (Kariuki and Allan, 1996)

X_i : Total number of circuit in system on ith period

Y_i : Number of circuit outage on ith period

2.2 Constraints

2.2.1 Supply continuity. The basic requirement of outage planning is to ensure that load demands can be met at any moment. For instance, there are three 50MVA rated circuits in a group. Hence, this group can convey 150MVA electricity to the load. It is the rule that one circuit can be planned on outage in this group if and only if the demand is below 100MVA.

2.2.2 Load pattern. It is mainly dependent on the type of load to which it belongs, such as industrial, commercial or domestic. The load type will affect the demand in the circuit group. Any new development or dismantling will also affect the load demand. Moreover, the system demand will vary with seasons. In general, the load in summer is much higher than that in winter.

2.2.3 Outage window. Outage window is the forecast period that circuit outage would be carried out with the fulfillment of supply continuity rule. It is formulated under the assumption that power demands for each period are known. It depends on the load pattern in each circuit group. Therefore, it varies from one group to another. In other words, considering circuit outage, the following constraint should be fulfilled:

$$\text{(i) Date } (X_i : \text{start date}) > OW \text{ (start)} \tag{3}$$

and

$$\text{(ii) Date } (X_i : \text{end date}) < OW \text{ (end)} \tag{4}$$

Where:

Date(X_i : start date) : The outage start date of circuit groupX_i

Date(X_i : end date) : The outage end date of circuit group X_i (i.e. start date + outage duration)

OW(start) : The start date of the outage window of circuit group X_i

OW(end) : The end date of the outage window of circuit group X_i

2.2.4 System security. In order to maintain a good customer service level, we should ensure continuous supply to our customer not only in normal state, but also in case of fault or damage. Therefore, we should consider the system security during the outage planning. The requirement is:

$$\text{Demand}(X_i) < \sum_{1}^{n-1} \text{Supply } [Y(X_i)] \tag{5}$$

Where

Demand (X_i) : It is the load demand pattern of circuit group X on the ith period

Supply[$Y(X_i)$] : It is the rating of an on-load circuit Y in a circuit group X with n circuits

2.2.5 Other constraints. In order to measure the performance of the power transmission department, several key areas for recording results have been established. In general, the overall system availability should be greater than 97.5 per cent and the maintenance achievement should be 100 per cent. Moreover, the fault/damage circuit outage has a higher priority than the maintenance outage and, in particular, the manpower requirement should be evenly distributed over the period.

3. Genetic algorithm

Genetic algorithms (GAs) are computational equivalent of evolution, of the survival of the fittest (Pham and Pham, 1999). It is an interesting feature of their ability to expand the search space, to diverge, as well as converge. For this reason they are quite effective to be employed as search algorithms, particularly for solving optimization problems with large number of local minima.

The range of power system problems to which GA has been applied is relatively broad. GA is often viewed as function optimizers and if each chromosome is considered to represent a point in search space, it is seen that

GA differs from traditional techniques in several ways (Orero and Irving, 1998; Augugliaro *et al.,* 1998). The benefit is that integer solutions can be obtained by this method leading to immediate applications in operational problems such as unit commitment (Yang *et al.,* 1996; Jwo *et al.,* 1999), maintenance scheduling or network reinforcement (Chen and Chang, 1995; Lee *et al.,* 1995; Balascio *et al.,* 1998). One of the applications is maintenance scheduling for the South Wales region of the UK high voltage power network (Langdon and Treleaven, 1997).

The real-coded genetic algorithm as suggested by Denis Cormier (North Carolina State University) (Michalewicz, 1992) has been modified and applied in this project. It consists of a population of strings transformed by three genetic operators:

1. selection or reproduction;
2. crossover; and
3. mutation.

Each string represents a possible solution, with each substring representing a value for a variable of interest. The algorithm starts from an initial population generated randomly. The population will be evaluated according to the fitness of a solution that corresponds to the objective function for the problem. Afterwards, using the genetic operations, new population would be created. The fitness of solutions is improved through the operations. Figure 1 shows the flow chart of the genetic algorithms operations. When the algorithm converges, a group of solutions with better fitness is generated, and the optimal solution is obtained.

4. Outage planning

The structure of the outage planning solved by GA is described in Figure 2. The outage planning database is designed in such a way that it collects information from different sources (e.g. system operations department). It then combines and translates the data into individuals for the GA operations and the constraint evaluation. Since the outage planning consists of both annual and daily schemes, current system conditions and actual status (e.g. in progress or completion) are fed back to the database. In addition, the GA can generate an updated schedule for commission and operations.

4.1 Data requirement

Circuit group: circuits of same source and load side are treated as one group. For example, KAI-WCS 132/11TX#H1, H2 and H3 are one group. It is for the sake of system security that there is no more than one circuit on outage in the same group at the same time.

Outage window: this is the period in which the load is low enough for one circuit to be on outage and the supply reliability can still be satisfied. In fact, it is a forecasting period, which is devised from the last year's load pattern, and can be collected from system operations department.

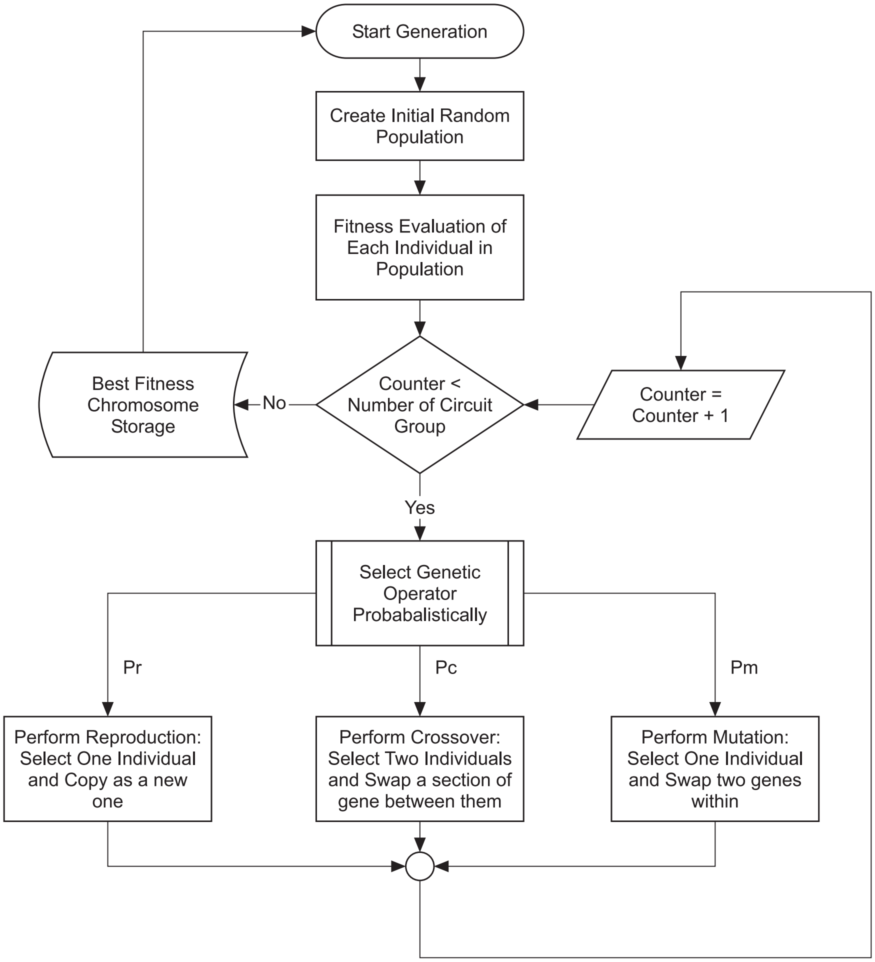

Figure 1.
The flow chart of genetic algorithms

Priority: circuit outage seniority depends on the type of work involved. The higher seniority in the same group would be scheduled first. The fault outage or the project outage would not be changed during GA process. The completed/in progress outage has the highest priority while the protection one has the lowest priority. The list of priority is defined as follows:

0 : Completed/in progress outage;

1 : Fault/project outage;

2 : Overhaul outage;

3 : General maintenance outage;

4 : Inspection outage;

5 : Protection.

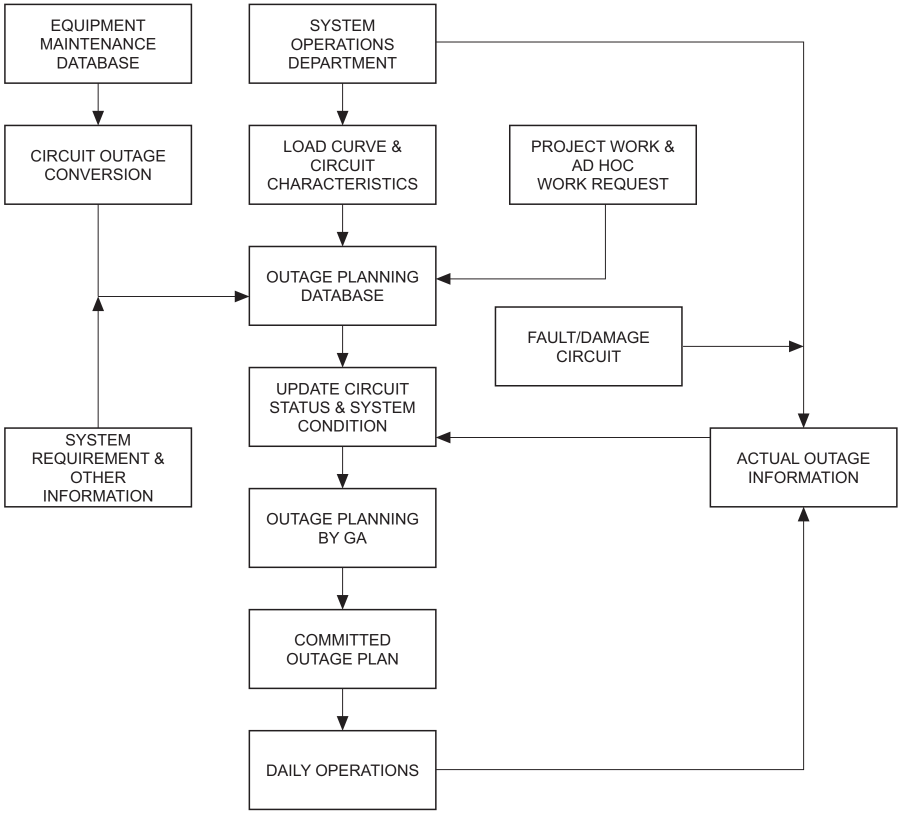

Figure 2.
The structure of outage planning

Outage duration: the duration of each outage depends on the work involved, which varies from each circuit outage. Total outage duration in a circuit group is longer than the outage window. The period will be proportionally divided to each circuit.

Manpower: same as duration, it depends on the work involved in the circuit outage. In this paper, it is assumed that constant manpower requirement throughout the circuit outage with only one trade is involved.

Start date: each circuit group's start date is a gene in a chromosome. It is used to define the outage period, to develop the overall arrangement and to evaluate the fitness of the chromosome, that is the maintenance schedule.

4.2 Proposed fitness function

The fitness is defined as a non-negative figure of merit to be minimized. It consists of both manpower evaluation and system availability review.

Minimize

$$z = [W\ (\alpha \sum (M_{avg}\ M_i)^2) + (1 - W)(\beta \sum (N_{avg}\ N_i)^2)]/L \qquad (6)$$

Where:

M_{avg} : Average manpower requirement

M_i : Manpower needed on ith day

N_{avg} : Average system availability

N_i : System availability on ith day

α : Cost conversion coefficient for variance of manpower requirement

β : Cost conversion coefficient for variance of system availability

W : Weighting coefficient between manpower requirement and system availability

L : Number of days circuit outage involved

4.3 Genetic operations

4.3.1 Chromosome structure. Annually, sets of maintenance jobs will be generated from the company database. The maintenance job will be grouped to the relevant equipment, and hence to the corresponding circuit. Therefore, the outage circuit and the duration will be obtained. The circuits are then grouped into the corresponding circuit group and the information will be combined into the relevant data. With the application of the genetic algorithm, a proposed schedule can be developed. In this case, chromosome is a proposed schedule in which each gene represents the start date of the circuit group.

4.3.2 Generation. In developing a genetic algorithm, the first step is to create initial individuals. These individuals are used as the parents to whom the various genetic operators are applied to generate new individuals. The GA typically starts from a randomly generated population of candidate solutions in which each gene is bounded by an independent specific outage window.

4.3.3 Fitness evaluation. Since the gene is the start date of each circuit group, total daily manpower requirement and number of circuit outages should be collected, and hence the fitness of the chromosomes, as described in Section 2, would be calculated. The lowest fitness chromosome among the current generation is obtained and compared with the best chromosome, in the way that the algorithm is driven towards minimizing this fitness.

4.3.4 Selection and reproduction. Two chromosomes are selected randomly from the population. One is defined for reproduction and the other is defined for replacement. The chromosome would reproduce itself to replace the other one only if its fitness is lower than that of the other one; otherwise, another two chromosomes are selected till the reproduction process is completed.

4.3.5 Crossover. Same as reproduction, two chromosomes are selected randomly. It involves choosing a section of genes in a chromosome. Crossover is performed when this section of one chromosome is swapped with the same section of the other one.

4.3.6 Mutation. In this paper, mutation is a gene-swapping operator that performs a position based exchange. That is, one chromosome is selected from the population. Thus, it randomly selects two sites on the chosen chromosome and swap the genes occupying these positions if the outage windows are satisfied.

4.4 Final tuning search

An additional search mechanism is employed in the outage planning process. Its objective is to check, test and improve the GA solution. After GA obtains the best fitness solution, the final tuning search (FTS) will proceed. It will vary each gene of the solution and then evaluate the fitness of the solution. If the fitness is improved, a new solution is obtained. The overall process of FTS is depicted in Figure 3.

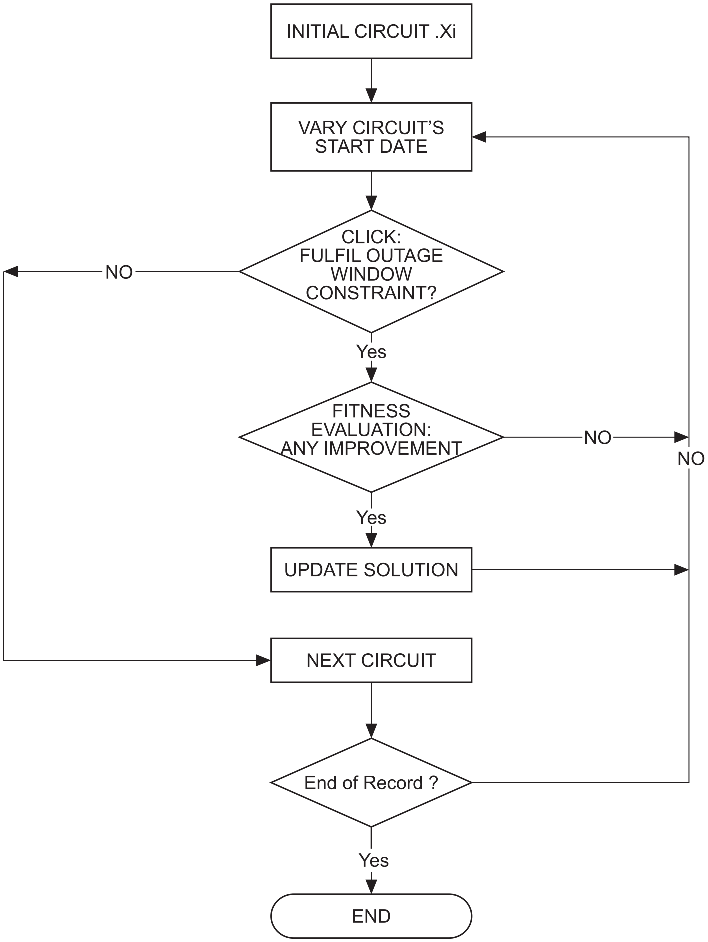

Figure 3.
The flow chart of FTS process

5. Numerical results

In order to review the program effectiveness, testing is conducted. There are two themes of tests. One is model test and the other is actual annual outage plan. The former is used to simulate performance while the other is compared with the previous results. Both tests will be based on the result of the following four statistical parameters to evaluate the performance:

1. the mean system overall availability;
2. the degree of circuit outage even distribution;
3. the mean manpower requirement; and
4. the degree of manpower distribution.

5.1 Model test

The proposed GA approach was numerically tested on a model network: 100-circuits power network, in which there are 30 independent circuit groups. Each group contains three circuits except one group has four.

To run an outage plan, only one circuit of each group needs to be scheduled, meaning that there are altogether 30 circuits needed to be scheduled in the test. All circuit outages have the same outage duration and manpower, and same system characteristics, i.e. the outage window requirement. The characteristics of the 30-circuit groups are summarized in Table I.

To develop an optimum result, the allowed outage period is designed to be the summation of all outage duration, without considering the all fault outages and project outages. Therefore, the best result would be ideally just one outage per day, or:

- mean system availability = 99 per cent;
- outage deviation = 0.

The plan was run for 100 generations. The results are shown in Table II, while the result for the system availability per day is shown in Figure 4. It reveals that all the days have a system availability equal to or above 98 per cent, and most of them are equal to 99 per cent, which is very close to the ideal one. Furthermore the running time for each five generations with a Pentium PC, was about 150 sec, which is a fairly fast performance.

5.2 Sensitivity analysis

In this section, the influences of the respective control parameters on the performance of the GA are examined. The parameters concerned included the number of circuit outages, the probabilities of crossover and mutation.

5.2.1 Variation on number circuit groups. Experiments on the variation of population size discover that the operation time increases rapidly with the number of outages as shown in Figure 5. It also reveals that more evaluation per generation is required to achieve better results as it is much farther away from optimum, rendering premature results (Figures 6 and 7).

Circuit name	Cct Group ID	Priority	Duration (Day)	Fitter	Start date	End date
cct ID #1	1	3	5	5	03-04-98	07-04-98
cct ID #2	2	3	5	5	02-02-98	06-02-98
cct ID #3	3	3	5	5	30-04-98	04-05-98
cct ID #4	4	3	5	5	18-04-98	22-04-98
cct ID #5	5	3	5	5	01-04-98	05-04-98
cct ID #6	6	3	5	5	23-05-98	27-05-98
cct ID #7	7	3	5	5	24-05-98	28-05-98
cct ID #8	8	3	5	5	04-02-98	08-02-98
cct ID #9	9	3	5	5	24-02-98	28-02-98
Cct ID #10	10	3	5	5	20-02-98	24-02-98
Cct ID #11	11	3	5	5	27-04-98	01-05-98
Cct ID #12	12	3	5	5	03-01-98	07-01-98
Cct ID #13	13	3	5	5	12-01-98	16-01-98
Cct ID #14	14	3	5	5	17-05-98	21-05-98
Cct ID #15	15	3	5	5	29-01-98	02-02-98
Cct ID #16	16	3	5	5	10-05-98	14-05-98
Cct ID #17	17	3	5	5	01-03-98	05-03-98
Cct ID #18	18	3	5	5	07-02-98	11-02-98
Cct ID #19	19	3	5	5	05-03-98	09-03-98
Cct ID #20	20	3	5	5	25-03-98	29-03-98
Cct ID #21	21	3	5	5	16-01-98	20-01-98
Cct ID #22	22	3	5	5	15-02-98	19-02-98
Cct ID #23	23	3	5	5	19-03-98	23-03-98
Cct ID #24	24	3	5	5	25-04-98	29-04-98
Cct ID #25	25	3	5	5	21-01-98	25-01-98
Cct ID #26	26	3	5	5	08-04-98	12-04-98
Cct ID #27	27	3	5	5	08-01-98	12-01-98
Cct ID #28	28	3	5	5	16-05-98	20-05-98
cct ID #29	29	3	5	5	16-03-98	20-03-98
cct ID #30	30	3	5	5	11-03-98	15-03-98

Table I.
Outage information for the 30-circuit group case

Operations	System availability		Manpower requirement	
	Mean	Deviation	Mean	Deviation
Ideal	99.00	0	5.00	0
GA only	98.69	0.00460	6.52	2.301
GA + FTS	98.77	0.00421	5.39	1.350

Table II.
FTS results and performance

As indicated by the test results, it can be concluded that the implementation of genetic algorithms has been prone to converge prematurely before the best solution. The rapid convergence can be viewed as a sudden change in which exploitation has the upper hand over the exploration. That is, exploiting the best solution currently available is faster than exploring the space. In genetic algorithms, reproduction concentrates the search in regions of high observed average fitness, whereas crossover and mutation are search operators that probe both familiar and unexplored regions of the search space with each application (Lawrence, 1990).

5.2.2 Variation on exploration rate. The crossover and mutation are search operators that increase the variety of the population. In this section, the operators' probabilities are varied in order to identify the performance of the program.

The test results of 30-circuit groups are illustrated in Figures 8 and 9, where the crossover probabilities were varied from 0.3 to 0.9. As shown in the Figures 8 and 9, faster convergence during earlier generations is observed when a high crossover probability is used. In contrast, a low value of the crossover

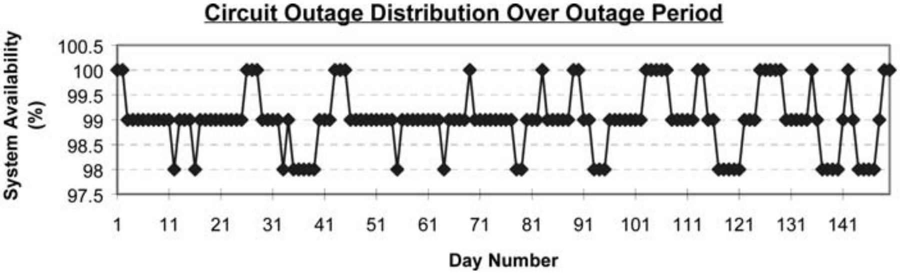

Figure 4.
The system availability distribution result

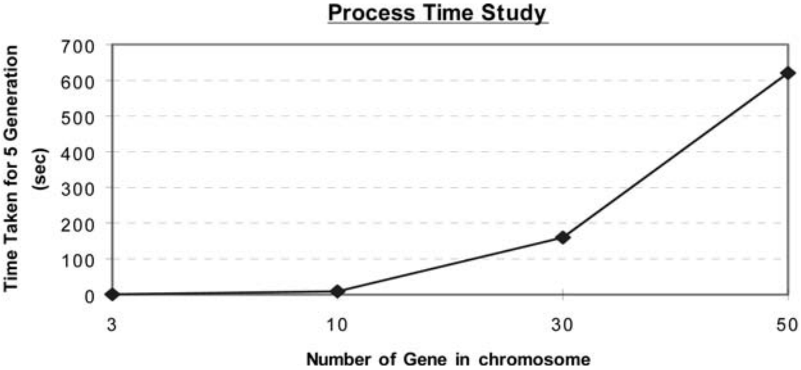

Figure 5.
Process time study

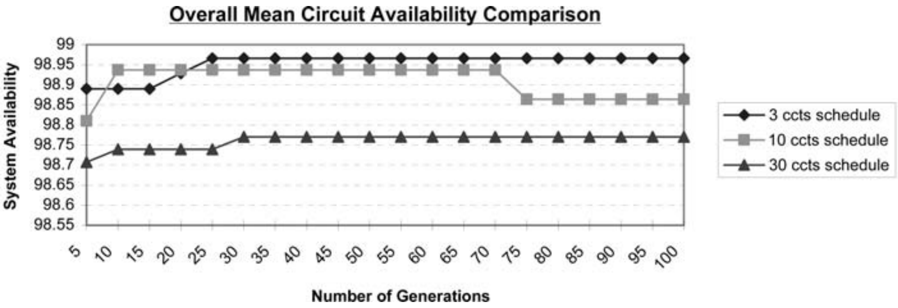

Figure 6.
SA on different number of circuit groups

probability leads to a fairly slow rate of convergence. Evolution of solutions halts and centers around a local minimum point shown in Figure 9 when crossover rate is equal to 0.6.

This is due to the fact that the higher the crossover probability, the more quickly new individuals are introduced into the population. But the possibility of moving towards a local minimum is increased since better solutions are discarded faster than selection can produce improvement. If the probability of crossover is too low, evolution would be retarded because of too much generation overlap, and the search may stagnate because of the lower exploration rate (Yang *et al.,* 1996).

On the other hand, each individual's position in the population is subjected to a random change with a probability equal to the mutation rate. Figures 10 and 11 illustrate the influences of different mutation rates on the outage planning process. High level of mutation (both 0.1 and 0.01) yields a nearly

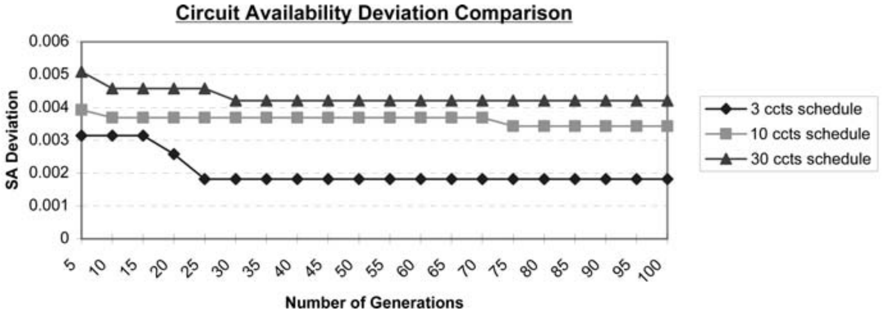

Figure 7.
SA deviation on different circuit groups

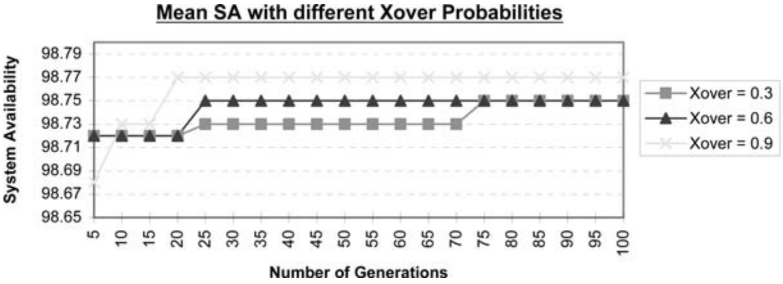

Figure 8.
SA performance on crossover rate variation

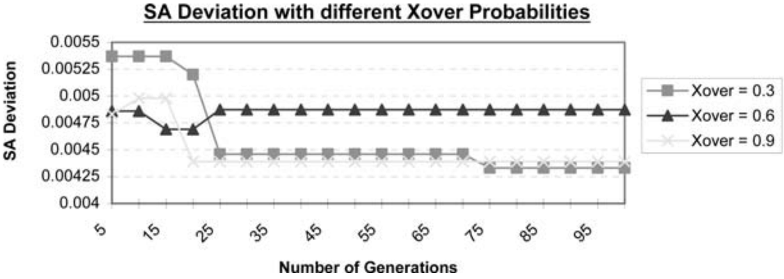

Figure 9.
SA deviation on crossover rate variation

random search, especially in the initial generations. On the contrary, a low level of mutation converges quickly to a local minimum, showing that it cannot serve to diversify the population.

Therefore, it would seem that premature convergence can be treated by an increase in the mutation rate to restore the lost genes. Nevertheless, it should be noted that higher mutation rate will disrupt the proliferation of high performance genes as well as the poor ones because of low reproductive rate (Lawrence, 1990).

From the results, it is revealed that the ability of GA to maintain an effective search depends on the continued ability of the operators to perform the search function. Unfortunately, the operators become less effective over time as the strings in the population become more similar. One factor might be due to the fact that, when two different chromosomes are in crossover operations, identical segments are also exchanged, resulting in an identical individual to the original ones.

One method is to increase the population sizes, which can be more favorable for approaching the best solution. However, this eventually will result in a relatively inefficient search as well as slowness to response. To improve the effectiveness, additional mechanism is considered.

5.3 FTS improvement

With reference to the above analysis, the operations results would be improved through the variation of crossover and mutation probabilities. However, there is still room for improvement since the results are still not at optimum.

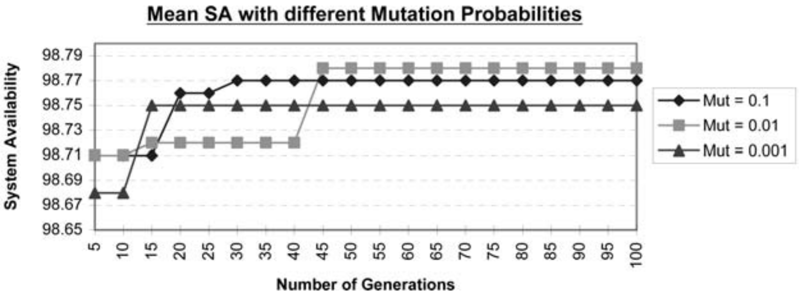

Figure 10.
SA performance on mutation rate variation

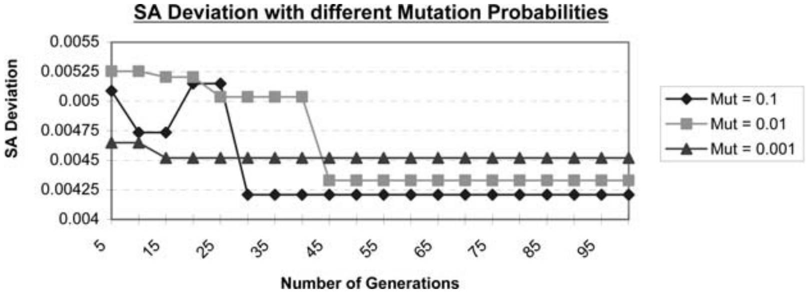

Figure 11.
SA deviation on mutation rate variation

ID	Outage window	Start date	End date
1	BCH	01-11-98	31-01-99
2	BCH066	01-11-98	31-12-98
3	CHY011	01-11-98	31-03-99
4	CWS	01-12-98	31-03-99
5	CWS011	01-01-99	28-02-99
6	CWS033	01-12-98	30-04-99
7	CWS066	01-02-99	28-02-99
8	EHV	01-10-98	30-09-99
9	GIC	01-10-98	30-09-99
10	HBR011	01-12-98	30-04-99
11	HMH	01-10-98	30-09-99
12	HMH033	01-10-98	30-09-99
13	HTK	01-01-99	30-04-99
14	HTK011	01-01-99	30-04-99
15	HWS	01-12-98	31-03-99
16	HWS011	01-12-98	31-03-99
17	HYR011	01-02-99	28-02-99
18	JUN	01-01-99	28-02-99
19	JUN011	01-01-99	28-02-99
20	KAI	01-12-98	31-03-99
21	KAI011	01-01-99	28-02-99
22	KBM011	01-10-98	30-09-99
23	KCB	01-10-98	30-09-99
24	KCR	01-10-98	30-09-99
25	KCR011	01-12-98	31-03-99
26	KCR033	01-10-98	30-09-99
27	KLT	01-12-98	31-03-99
28	KLT011	01-12-98	31-03-99
29	KPS011	01-12-98	31-01-99
30	KTS011	01-12-98	28-02-99
31	MOA	01-11-98	31-03-99
32	MOA011	01-11-98	31-03-99
33	MOB011	01-11-98	31-03-99
34	NCW011	01-12-98	30-04-99
35	NTK011	01-10-98	30-09-99
36	ONS011	01-10-98	30-09-99
37	POL	01-10-98	30-09-99
38	POL011	01-11-98	30-04-99
39	SHE	01-10-98	30-09-99
40	SHE132	01-10-98	30-09-99
41	SIU	01-02-99	31-03-99
42	SIU011	01-02-99	31-03-99
43	SLT011	01-10-98	30-04-99
44	TAH	01-10-98	30-09-99
45	TAH011	01-10-98	30-09-99
46	TAI	01-10-98	30-04-99
47	TAI011	01-10-98	30-04-99
48	TKE	01-10-98	30-09-99
49	TKE132	01-10-98	30-09-99

(continued)

Table III. List of circuit groups and its outage window

Table III.

ID	Outage window	Start date	End date
50	TKI011	01-10-98	30-09-99
51	TLA	01-11-98	31-05-99
52	TLA033	01-10-98	30-09-99
53	TLB	01-10-98	30-09-99
54	TMH011	01-10-98	30-04-99
55	TSE	01-10-98	30-09-99
56	TSE132	01-10-98	30-09-99
57	TTN011	01-11-98	30-04-99
58	TWK	01-10-98	30-09-99
59	TWK025	01-10-98	30-09-99

Therefore, FTS is introduced in such a way that any improvement from the GA results would be reviewed. The result, after 100 generations, is summarized in Table II, to which a 30-circuit group system is employed.

It can be observed that the result is much improved as compared with the original one. From the system availability review, the result obtained by GA is 98.69 whereas the availability was increased to 98.77 by GA + FTS, which is nearer to the ideal one, i.e. 99.00. On the other hand, on the manpower requirement review, the result obtained by GA is 6.52 while that by GA + FTS is 5.39 which is also nearer to the ideal one, i.e. 5.00.

The comparison reveals that GA converges prematurely as opposed to the adoption of FTS which can rectify this deficiency by neighborhood searching. Therefore, GA+FTS not only produces a better plan, but also obtains the plan with a faster running time and actually, even fewer generations, since the convergence will occur in the initial generations.

5.4 Transmission 1998/1999 outage plan – a case study

The 1998/99 annual outage plan was arranged manually by the planning engineer. In the power network, there are a total of 300 circuits, in which 63 circuit groups are formed with the plan containing 237 circuit outage requests.

Each outage request has its individual outage duration and manpower requirement since the work in each circuit will be different. The outage requests are also of different priority. The outage window information of each circuit group is depicted in Table III. In addition, Table IV gives a sample of the 1998/1999 requested outage information for reference.

Table V shows the comparison with the original plan and the result obtained by GA + FTS method. It can be expected that the results on the system availability have been much increased. Indeed the most important improvement is the running time, in this case study, the result is determined within 30 minutes using a Pentium PC. Furthermore, it took only five generations. Therefore, better results would be obtained if more generations are provided. In

Circuit name	Work requirement	cct_group ID	Priority	Duration (Day)
BCH 66/11 TX#M1	Protection and annual MTC	2	4	5
BCH-CWS#1	Protection and annual MTC	1	4	1
BCH-CWS#2	Annual MTC	1	4	2
BOU-KLT#2	Annual MTC	27	4	5
CWS 066 BC	Annual MTC	4	4	1
CWS 132/11 TX#H6	Annual MTC	5	4	1
CWS 132/11 TX#H7	Annual MTC	5	4	4
CWS 132/33 TX#H4	Annual MTC	6	4	1
CWS SWGR-RMU#3	Annual MTC	4	4	1
CWS-BCH 66/11 FTX#M3	Protection and annual MTC	2	4	2
CWS-CWS#2	Annual MTC	4	4	1
CWS-HMH#1	A/R safety valve install and annual MTC	11	3	5
CWS-HMH#2	PROT, OHL, annual MTC and A/R safety valve install	11	3	5
CWS-SHE#2	A/R survey and annual MTC	39	3	1
CWS-SHE#3	A/R survey and annual MTC	39	3	1
GIC-KAI#2	A/R safety valve install	9	3	1
GIC-KAI#3	Annual MTC, A/R safety valve install and PROT MTC	9	3	12
HMH 033 CAP BANK	Annual MTC, A/R safety valve install and PROT MTC	11	3	5
HMH 132 80MVAR SR	A/R safety valve install and annual MTC	11	3	1
HMH 132 BC	Annual MTC, A/R safety valve install and PROT MTC	11	3	6
HMH 132/33 TX#H1	Annual MTC, A/R safety valve install and PROT MTC	12	3	5
HMH 132/33 TX#H2	A/R safety valve install and annual MTC	12	3	1
HMH-HMH#2	A/R safety valve install and annual MTC	11	3	1
HMH-KCB#1	Annual MTC, A/R safety valve install and PROT MTC	11	3	12
HMH-KCB#2	Annual MTC, A/R safety valve install and PROT MTC	11	3	12
HMH-POL#1	A/R safety valve install OHL and annual MTC	37	3	11
HMH-POL#2	A/R safety valve install and annual MTC	37	3	2
HTK 132/11 TX#H1	TX tail PROJ, protection and annual MTC	14	1	8
HTK 132/11 TX#H2	TX LV tail cable replacement (02-240)	14	1	8
HWS 132/11 TX#H1	Protection and annual MTC	16	4	2

Table IV.
Sample of requested circuit outage in 1998/1999 outage plan

	System availability			
98/99 annual schedule	Lowest	Mean	Deviation	Running time
Original	93.67	98.57	0.00960	2 days
GA + FTS	97.33	98.89	0.00341	30 min

Table V.
Project achievement in 1998/1999 outage plan

addition, it should be noted that the running time of the program does not require the engineer's time. The program is running standalone. In this case, the benefit of the program is greater than two days of the engineer's cost.

6. Conclusions

An algorithm for power system circuit outage scheduling is proposed. The proposed method adopts the genetic algorithm to improve the system performance of the circuit outage schedule.

It has been shown from the results that the program obtains a fairly good schedule in terms of the system availability. It is fast to achieve a suggested maintenance schedule. In addition, the program only allows one circuit of a circuit group on outage at any time within the outage window, satisfying the system requirements – security and reliability. Therefore, it is practically feasible.

Although it converges prematurely and does not obtain the best solution, it gives a better arrangement than the original one. With the adoption of the developed genetic algorithm, it does not only help the planners in terms of fast response to the daily rapid change environments, but also enhances the job duties to our staff, which involve the scheduling of limited resources. Moreover, training the non-engineering or inexperienced staff to take the planning job can be achievable, in a way to reduce outage cost and hence the manpower requirement.

On the other hand, there is some room for improvement of the program. It can be observed that more generations are required if an optimum solution is needed, which gets worse as the circuit groups' number increases. In addition, the greater the number of circuit groups involved, the longer will be the processing time, as they are the genes forming the chromosome structure. Moreover, the manpower requirement and the trade required will not be the same throughout the outage period.

In conclusion, genetic algorithm proves to be capable to provide a simple, fast and effective way in scheduling the maintenance outage. It provides not only good quality management, but also minimizes the cost and the operation time, which finally enhance the productivity of our staff.

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