Substation Maintenance Using Tabu Search and Genetic Algorithm Methods

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Abstract

This paper reports on the application of AI tools, such as tabu search (TS) and genetic algorithm (GA) for the solution of the substation maintenance scheduling (MS) problem. The objective was mainly to maximize the work progress of tasks in the scheduling period which minimize the carry-over work to the next scheduling period and minimize deviations of the work date from that requested by local maintenance centers. There are two key constraints that should be satisfied: one is the power flow constraint; the other is the constraint on work combinations. Constraints on work combinations are the avoidance of outage facility interference, and the requirements that some tasks cannot be done at the same time. An optimization model has been formulated and applied. The methods were applied to 5-Bus and 24-Bus test systems for MS. The results show that these tools are suitable for the MS problem.

Keywords

Maintenance scheduling, substation, tabu search, genetic algorithm, Artificial Intelligent tools

1. Introduction

An electric utility is required to provide customers with electric energy as economically as possible and with an acceptable degree of reliability and quality. This is especially true in the new deregulated and competitive environment. The growing complexity in power systems, the need for high service reliability, and low production costs, has focused additional interest in maintenance scheduling (MS) techniques of generation, transmission, and distribution components [1]. The utility operators must inspect and maintain these systems regularly. The scheduling is based on the starting date requests from maintenance centers for all jobs being done [2]. The MS problem consists of two main combinatorial optimization sub-problems, work starting date of outages, and network configuration. Conventional mathematical programming tools can be used to solve only small-scale problems. Also, the more the problem is formulated in details, the more difficult it is to obtain solutions since the number of solutions increases exponentially with the dimension of the problem. Artificial intelligence (AI) tools such as tabu search (TS) and genetic algorithms (*GA)* can provide optimal solutions of complex problems within reasonable period of time [2-4].

The paper reports on the application of AI tools, such as tabu search and genetic algorithms for the solution of the substation MS problem. Section 2 provides the problem formulation, objectives and constraints. The mathematical model is given in section 3.The solution methods are described in section 4. System testing and results are given in section 5. Section 6 includes a number of concluding remarks.

2. Problem Formulation

First, scheduling planners, in each local maintenance center (operation centers or divisions), must prepare an MS (outage work requests or work orders) for the whole system. Usually they prepare a list of maintenance and repair activities to be carried out during a specified period, considering the reconfiguration of the system to guarantee continuity of supply to customers [5]. The scheduling planners develop all the details included on the work orders that will result in a high quality job being done at minimum cost and at a time compatible with the urgency of the request. Secondly, local maintenance centers in charge of system maintenance send outage work requests to the central load-dispatching center. Upon receipt of the request, the central load-dispatching center starts to study the outage requests by conducting load flow calculations and contingency analyses. The dispatchers schedule or reschedule the tasks, considering the demand-supply balance and network constraints. If the MS is not feasible for any reason, it has to be modified by the local maintenance centers. This is achieved by shifting the dates of some maintenance activities or by exchanging some tasks with others [6]. Although we are dealing with two distinct sub-problems, they are not independent at all. To find the solution to one of them, one has to take into account the solution space of the other. Hence, it is appropriate to tackle both simultaneously as one single global optimization problem.

2.1 Problem Constraints

There are two key constraints that should be satisfied: one is the power flow constraint; the other is the constraint on work combinations. Power flow on transmission branches is limited in the case of a contingency. Constraints on work combinations are the avoidance of outage facility interference, and the requirements that some tasks cannot be done at the same time. For example, if two transmission circuits supply a substation, these circuits should not be under maintenance at the same time, to ensure continuity of supply to the customers. These forbidden work combinations are specified according to the network operations policy for a highly reliable supply of power [2, 7]. Beside the technical constraints on power flow and work combinations, it may also be necessary to satisfy administrative constraints such as a limitation of available maintenance crews, resource availability and allocation (resource constraints), interchange contracts and specific requirements from maintenance centers [2].

2.2 Objective Function

The main objective of the MS is to reduce costs by finding suitable combinations of maintenance activities. In this problem, the outages are scheduled primarily so as to maximize the work progress of tasks in the scheduling period and to minimize deviations of work dates from that requested by local maintenance centers. Both of these objectives minimize carry-over work to the next scheduling period. The objective function is defined from this criterion with some scheduling heuristics for work priority and work leveling considerations. The work priority heuristic requires that a task with higher priority be performed faster. The work leveling heuristic requires that latter accumulated tasks are preferred due to the limitation of available maintenance crews.

3. Mathematical Modeling of the Problem

The MS objective function is defined as follows: [2]

$$Min\ E = w_1{*}E_1+w_2{*}E_2+w_3{*}E_3+w_4{*}E_{4+}\ w_5{*}E_5+w_6{*}E_6+w_7{*}E_7 \qquad (4.1)$$

Subject to the following constraints:

1- Power Flow Constraint:

$PFlow_{Min(i)} \leq pflow_i \leq PFlow_{Max(i)}$

This is a non-linear constraint solved by the Gauss-Seidel iterative technique.

2- Forbidden Work Combinations: (FWC)

$$\sum_{t=1}^{T} \sum_{i \in FC}^{n} \sum_{j \in FC}^{n} u_i y_{it} u_j y_{jt} = 0$$

Where:

- Number of carry-over tasks (E_1):

$$E_1 = n - \sum_{i=1}^{n} u_i$$

- Work date deviation from requested date (E_2):

$$E_2 = \sum_{i=1}^{n} u_i \left| x_i - x_{0i} \right|$$

- Work priority (E_3):

$$E_3 = \sum_{i=1}^{n} u_i p_i$$

- Variance of number of daily tasks (E_4):

$$E_4 = \sum_{t=1}^{T} \sum_{i=1}^{n} u_i y_{it}^{\ 2}$$

E5 = number of overloaded facilities

$$E_6 = \sum_{i=1}^{m} \left| \frac{pflow_i}{PFlow_i} \right|$$

E_7 = number of switched facilities

Where:

$PFlow_{Min(i)}$, $PFlow_{Max(i)}$	lower and upper limits of power flow on branch *i*,
$pflow_i$	power flow of branch *i*,
w_j	weight of each component,
n	number of tasks in scheduling period *T*,
$u_i = 1$	if scheduled when constraints are satisfied, otherwise = 0,
x_i, x_{0i}	scheduled and requested starting date of task *i*,
p_i	priority number of task *i*, smaller is higher.
	priority is determined by type of work, voltage level, etc.
$y_{it} = 1$	if facility for task *i* is outed at *t*, otherwise = 0,
FC	combination of forbidden task *i* and *j*,
$PFlow_i$	operational power flow limit of branch *i*,
m	number of overloaded facilities,
T	scheduling period.

The load flow problem is solved by the use of the Gauss-Seidel method. The line flows (power flows) are calculated using the final bus voltage after convergence takes place. The line flow from bus *i* to bus *n* am given by equation [4.2]

$$Pflow_{in} - jQflow_{in} = V_i^{*}(V_i - V_n)Y_{in} + V_i^{*}V_i\left(\frac{Y_{in}^{/}}{2}\right) \qquad (4.2)$$

Where

$Pflow_{in}$	real power flow from bus *i* to bus *n*,
$Qflow_{in}$	reactive power flow from bus *i* to bus *n*,
$Y_{in}^{/}/2$	line charging of line *i-n*.
P_i	real power of bus *i*,
Q_i	reactive power of bus *i*,
V_i^*	voltage magnitude of bus *i* (* means conjugate),
Y_{in}	element *(i , n)* of bus admittance matrix *(Y_{Bus})*,
V_n	voltage magnitude of bus *n*,
N	total number of buses in the network.

4. Solution Algorithms

Combinatorial optimization problems can be solved by exact or by approximate methods. In exact methods, all the feasible solutions are evaluated and the best one is selected as the optimal solution. However, exact methods are impractical when a real-life problem is to be solved. This is due to the large number of feasible solutions to be evaluated. This paper reports on the application of the genetic algorithm (GA), and the tabu search (TS) methods for the solution of the substation MS problem. The methods are well documented in the literature and will not be reviewed here [8-12].

4.1 Application of the TS Method to the Substation MS Problem

The TS solution method has been implemented to the MS problem. First, the basic network, including power flow values, is constructed, and no overload condition is maintained. The automatic scheduling arranges the tasks so as to satisfy all the constraints. This problem consists of date scheduling and network configuration, both of which are combinatorial optimization problems [2]. The basic steps in *TS* method are as follows [39]:

Step 1: Set initial solution (assumed to be the best solution). Tabu list is empty since no moves have been generated.

Step 2: Enumerate candidates (moves) which consist of the present solution’s neighborhood, except for tabu moves. These moves must be in the neighborhood space solution.

Step 3: Move to the best candidate. Add the new move attribute to tabu list and discard the old moves attributes from the tabu list if the tabu list exceeds the specified length (tabu list size).

Step 4: Repeat Steps 2 and 3 until the termination condition (stopping criteria) is satisfied.

4.2 Application of the GA Method to the Substation MS Problem

The basic steps in the GA method for the MS of outages are as follows:

Sept 1: Generate random population (individuals).

Step 2: Evaluate fitness of current population.

Step 3: Select chromosomes, based on fitness, for reproduction.

Step 4: Perform GA operators such as crossover and mutation to give a new improved population.

Step 5: Repeat steps 2 to 4 until the termination condition (stopping criteria) is satisfied.

4.2.1 Problem Representation

As stated above, a chromosome is a proposed schedule in which each gene represents the start date of a task (x_i). This means that each chromosome (string of genes) represents a possible solution, with each sub-string (gene) representing the starting date of a task. The algorithm starts from an initial population generated randomly.

4.2.2 Elimination of Power Flow Overload

If the schedule obtained has overloads, random switching of standby lines is performed to resolve the overload problem. The best configuration is selected from the neighbor solutions for each search step even if the objective function to be minimized, for overload mitigation, becomes worse than before. If there are no overloaded branches, the iteration is terminated. The network configuration is thus determined.

5. Numerical Results

The algorithms described in section 4 are used to solve the MS problem.

5.1 5-Bus System

This section will demonstrate the solution obtained for the 5-bus system using the proposed TS algorithm. Although the system is small, it was used to validate the proposed TS algorithm before applying it to the 24-bus system.

5.1.1 System Description

The 5-bus system, as shown in Figure 1, has generation on buses 1 and 2, which supplies the other buses. The line data of this system, the per unit values of the transmission line impedances and line charging admittances are given in [13].

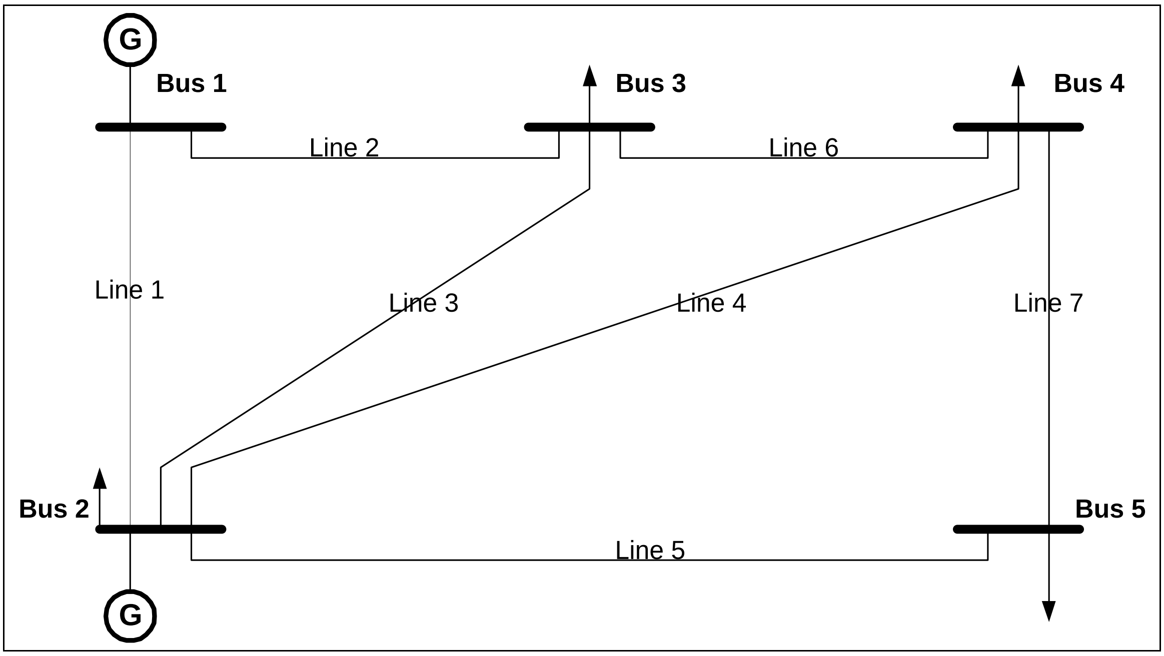

Figure 1: The 5-Bus System

5.1.2 Automatic Scheduling and Results

Six MS cases were studies and investigated. These schedules were chosen based on possible outages of the system with the help of human expert maintenance schedulers, because such data could not be found in the literature. The MS were obtained subject to the following conditions:

- Each schedule has a maximum of six different maintenance tasks (considered as a high number of tasks for such a small system).
- No standby lines are available in this system.
- The initial configuration of the system has no overloaded branch/facility.
- Priority of maintenance outage tasks is given by maintenance schedulers in the initial requested schedule obtained from maintenance centers.
- Branch outage priority depends on the type of work involved. Higher priority in the schedule would preferably be scheduled in the given initial schedule. Priority starts from 1 (highest) to 6 (lowest).
- The duration of each outage depends on the work involved. The duration of each outage is given by the initial requested maintenance schedule.
- The required manpower depends on the type of work involved in the outage. In this work, manpower is assumed to be available and enough to execute the work.
- The starting date is the starting date of executing the maintenance outage work.

This is very important since it is used to define the period of the outage.

- ♦ The scheduling period (T) is assumed to be one week - seven (7) days.
- ♦ Resources (spare parts) are assumed to be available without any delay.
- ♦ The maintenance duration given to any equipment is enough to complete the maintenance work.

There are two schedules. The first one represents the initial schedule requested by the local maintenance center. Also, it shows the following when running the TS program:

- the proposed (requested) starting date of each task,
- the priority of each task,
- any existing FWC problem,
- any existing overload and in which day(s),

The second schedule is the final output of the program after running TS no. 1. It shows the following:

- the starting date of each task (final),
- any existing FWC problem,
- any existing overload and in which day(s),
- the objective function of the maintenance outage schedule,

The proposed TS approach was tested on different cases to verify its effectiveness. In moving a task on the schedule, weighting factors in the objective function were specified as $w_1 > w_2 > w_3 > w_4$. This means a preference order of E_1, E_2, E_3 *and* E_4. Throughout the application of TS on the 5-bus system, the TS parameters were as given in Table 1. The representation of the word "line" in the schedules, tables and text does not necessarily mean outage of a line. It may mean an outage of bus(es), circuit breaker(s) or transformer(s).

Table 1: Parameters of the TS Program for the 5-Bus System

TS Parameters	Starting Date Movement
TS List Size	7
Total Iteration	500

The initial maintenance schedule for case no. 1 is given in Table 2. This is considered as the initial requested schedule by local maintenance centers or departments. It has five maintenance tasks.

Task 1 proposes to maintain the line between bus 2 and 3 (line 3) on day 1 (starting date of task no. 1 = day 1 and duration of task no. 1 = 1 day). Task 2 proposes to maintain line 5 on days 2 and 3 (starting date of task 2 = day 2 and duration of task 2 = 2 days). Task 3 will take line 7 on days 3 and 4. Task 4 will take line 1 on days 5 and 6 and task 5 will take line 4 on day 7. The program will generate the base configuration of the system, based on the system input data. This is to make sure that the base configuration has no overload branch or facility. Also, it will save the given schedule as "the initial requested schedule" and will check for both constraints (FWC and Overload). As stated above, here only the FWC constraint is considered. Table 2 shows that the maintenance schedule at day 3 has an FWC between tasks 2 and 3 (between lines 5 and 7), since taking out line 5 and 7 at the same time will separate bus 5 out of the system. Also, it shows that at days 5 and 6, an overload exists in the system. Running the TS program will solve this problem by moving the starting date of task 2 from day 2 to day 1 and without changing task 3 because the priority of task 3 is higher than task 2. The encountered moves to reach the final solution are given in Table 3. Table 3 gives a close view of the program procedure until the final solution is reached. It is important to note that move no. 2 has a lower objective value but it has a FWC. Move no. 1 has no FWC, which becomes the best solution. An FWC may be obvious in small systems but in real systems it is not that easy to observe. Table 4 is the solution of MS case no. 1.

Table 2: Initial Requested Maintenance Schedule for the 5-Bus System - Case no. 1

Tasks	Priority	Days						
		1	2	3	4	5	6	7
1	1	Line 3						
2	3		Line 5	Line 5				
3	2			Line 7	Line 7			
4	4					Line 1	Line 1	
5	5							Line 4
FWC				(5,7)				
Overload						Yes	Yes	

Table 3: Encountered Moves of Task no. 2 for Case no. 1

Move #	New Starting Date	Any FWC	Objective Function	
1	1	No	0.278	Best
2	3	Yes	0.178	
3	4	Yes	0.378	
4	5	No	0.478	
5	6	No	0.578	

Table 4: Final Schedule of Case no. 1 Obtained by the TS Program

<table>
<tr><th rowspan="2">Tasks</th><th rowspan="2">Priority</th><th colspan="7">Days</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th></tr>
<tr><td>1</td><td>1</td><td>Line 3</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td>3</td><td colspan="2">Line 5</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td>2</td><td></td><td></td><td colspan="2">Line 7</td><td></td><td></td><td></td></tr>
<tr><td>4</td><td>4</td><td></td><td></td><td></td><td></td><td colspan="2">Line 1</td><td></td></tr>
<tr><td>5</td><td>5</td><td></td><td></td><td></td><td></td><td></td><td></td><td>Line 4</td></tr>
<tr><td colspan="2">FWC</td><td colspan="7"></td></tr>
<tr><td colspan="2">Overload</td><td></td><td></td><td></td><td></td><td colspan="2">Yes</td><td></td></tr>
<tr><td colspan="9">Objective Function of TS no. 1 = 0.278</td></tr>
</table>

Similar schedules were produced for the remaining MS cases.

5.2 24-Bus System

This section will demonstrate the solution obtained for the 24-bus system using the proposed TS and GA methods.

5.2.1 System Description

The 24-Bus system is shown in Figure 2. The system data is given in [13].

5.2.2 Automatic Scheduling and Results – Tabu Search

For the 24-bus system, the maintenance schedules were obtained subject to the following conditions:

- Each schedule has a maximum of ten different maintenance tasks.
- Dotted lines, as shown in the Figure 4, represent standby lines in the system.
- The initial configuration of the system has no overloaded branch/facility.
- Priority of maintenance outage tasks is given by maintenance schedulers in the initial requested schedule obtained from maintenance centers.
- Branch outage priority depends on the type of work involved. Higher priority in the schedule would preferably be scheduled in the given initial schedule. Priority starts from 1 (highest) to 10 (lowest).
- The duration of each outage depends on the work involved. The duration of each outage is given by the initial requested maintenance schedule.
- The required manpower depends on the type of work involved in the outage. In this work, manpower is assumed to be available and enough to execute the work (no shortage of manpower).
- The starting date is the starting date of executing the maintenance outage work. This is very important, since it is used to define the period of the outage.
- The scheduling period (T) is assumed to be one week - seven (7) days.
- Resources (spare parts) are assumed to be available without any delay.
- The maintenance duration given to any equipment is enough to complete the maintenance work.

Throughout the application of TS on the 24-bus system, the TS parameters are as given in Table 5.

Table 5: Parameters of TS Program for the 24-Bus System

TS Parameters	Starting Date Movements	Switching of Standby Lines
TS List Size	7	7
Total Iteration	500	100

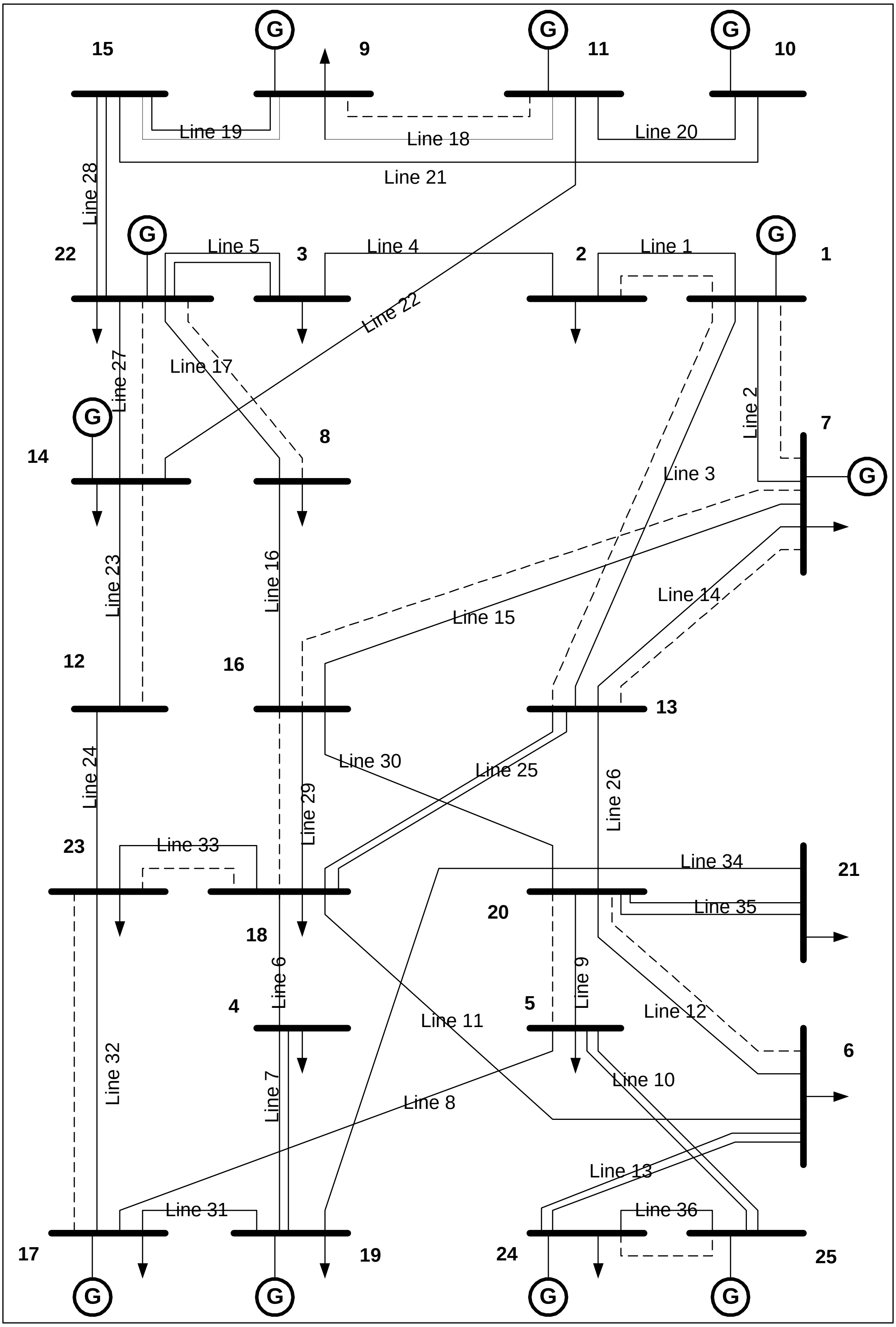

Figure 2: The 24-Bus System

Maintenance Scheduling Case No. 1:

The proposed maintenance schedule for case no. 1, given in Table 6, is considered as the initial requested schedule by local maintenance centers. It has ten (10) maintenance tasks. The schedule proposes to maintain line 6 on days 1 and 2, line 14 on days 1, 2 and 3, line 7 on days 2, 3, 4 and 5, line 9 on days 5, 6 and 7 and so on. The program will generate the base configuration of the system. Also, it will save the given schedule as "the initial requested schedule" and will check for both constraints (FWC and overload). Table 6 shows that the schedule at day 2 has a FWC between tasks 1 and 3 (between lines 6 and 7), since taking out line 6 and 7 at the same time will isolate bus 4 from the system. Also, it shows that the schedule has overloaded lines for all days. Running the TS program will satisfy the two constraints in two steps. A change of starting dates is the first step. Task no. 3 has higher priority than task no. 1 which will enforce the program to move task no. 1 to resolve the FWC problem. Table 7 gives the output of TS no. 1. The second step is the switching stage, which will remove the overloading in the schedule. The switched standby lines and their order are given in Table 8. This is the final solution.

Table 6: Initial Requested Maintenance Schedule for the 24-Bus System

- Case no. 1

<table>
<tr><th rowspan="2">Tasks</th><th rowspan="2">Priority</th><th colspan="7">Days</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th></tr>
<tr><td>1</td><td>3</td><td colspan="2">Line 6</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td>2</td><td colspan="3">Line 14</td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td>1</td><td></td><td colspan="4">Line 7</td><td></td><td></td></tr>
<tr><td>4</td><td>4</td><td></td><td></td><td></td><td></td><td colspan="3">Line 9</td></tr>
<tr><td>5</td><td>5</td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Line 27</td></tr>
<tr><td>6</td><td>6</td><td></td><td></td><td colspan="3">Line 34</td><td></td><td></td></tr>
<tr><td>7</td><td>7</td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Line 18</td></tr>
<tr><td>8</td><td>8</td><td></td><td></td><td></td><td></td><td colspan="3">Line 36</td></tr>
<tr><td>9</td><td>9</td><td colspan="4">Line 16</td><td></td><td></td><td></td></tr>
<tr><td>10</td><td>10</td><td></td><td></td><td colspan="2">Line 31</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">FWC</td><td></td><td>(6,7)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Overload</td><td colspan="7">Yes</td></tr>
</table>

Table 7: Schedule of Case no. 1 Obtained by TS no. 1 Program

<table>
<tr><th rowspan="2">Tasks</th><th rowspan="2">Priority</th><th colspan="7">Days</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th></tr>
<tr><td>1</td><td>3</td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Line 6</td></tr>
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<tr><td colspan="2">FWC</td><td colspan="7"></td></tr>
<tr><td colspan="2">Overload</td><td></td><td colspan="6">Yes</td></tr>
<tr><td colspan="9">Objective Function of TS no. 1 = 1.113</td></tr>
</table>

Table 8: Final Schedule of Case no. 1 Obtained by the TS Program

<table>
<tr><th rowspan="2">Tasks</th><th rowspan="2">Priority</th><th colspan="7">Days</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th></tr>
<tr><td>1</td><td>3</td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Line 6</td></tr>
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<tr><td colspan="2">FWC</td><td colspan="7"></td></tr>
<tr><td rowspan="3">Standby Lines Stages</td><td>1</td><td>-</td><td>6</td><td>6</td><td>-</td><td>15,4</td><td>9,11,4</td><td>9,11,4</td></tr>
<tr><td>2</td><td>-</td><td>4</td><td>4</td><td>4</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>3</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td colspan="2">Overload</td><td colspan="7"></td></tr>
<tr><td colspan="9">Final Objective Function of TS Program= 1.686</td></tr>
</table>

5.2.3 Automatic Scheduling and Results – Genetic Algorithms

In the following, six MS cases will be presented and described. These maintenance schedules were chosen based on possible outages of the 24-Bus system with the help of human expert maintenance schedulers because such data could not be found in the literature.

There are two schedules. The first one represents the initial maintenance outage schedule requested by local maintenance centers. The table also shows the following:

- the proposed starting (requested) date of each task,
- any existing FWC problem and between which tasks and in which day(s),
- any existing overload and in which day(s).

The second table is the output after running the GA program, which represents the final solution of the given MS case. It shows the following:

- the starting date of each task (final),
- any existing FWC problem and between which tasks and in which day(s),
- the switched standby lines numbers and stages,
- any existing overload and in which day(s),
- the final objective functions for the maintenance outage schedule.

In moving a task on the schedule, weighting factors in the objective function were specified as $w_1 > w_2 > w_3 > w_4$.

Throughout the application of the GA on the 24-bus system, the GA parameters are as given in Table 9.

Table 9: Parameters of GA Program for the 25-Bus System

GA Parameter	Value
Chromosome Size	10
Population Size	100
Crossover Rate	0.65
Mutation Rate	0.30
Total Iteration	500

Maintenance Scheduling Case No. 1:

The proposed maintenance schedule for case no. 1 is already given in Table 6. It is considered as the initial requested schedule by local maintenance centers. It has ten (10) maintenance tasks. According to the program flowchart of GA given in Fig.2, the program will generate the base configuration of the system, based on the system input data, to make sure that the base configuration has no overloaded branch or facility. The GA program will first generate the initial population, which represents possible solutions (schedules) to the problem. Then the individuals will be evaluated according to the fitness function and so on in order to reach to the final solution, which is given in Table 10. Table 10 shows also the switched standby lines and their order.

Table 10: Final Schedule of Case no. 1 Obtained by the GA Program

<table>
<tr><th rowspan="2">Tasks</th><th rowspan="2">Priority</th><th colspan="7">Days</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th></tr>
<tr><td>1</td><td>3</td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Line 6</td></tr>
<tr><td>2</td><td>2</td><td></td><td></td><td></td><td></td><td colspan="3">Line 14</td></tr>
<tr><td>3</td><td>1</td><td></td><td colspan="4">Line 7</td><td></td><td></td></tr>
<tr><td>4</td><td>4</td><td></td><td></td><td></td><td colspan="3">Line 9</td><td></td></tr>
<tr><td>5</td><td>5</td><td></td><td></td><td></td><td colspan="2">Line 27</td><td></td><td></td></tr>
<tr><td>6</td><td>6</td><td colspan="3">Line 34</td><td></td><td></td><td></td><td></td></tr>
<tr><td>7</td><td>7</td><td></td><td></td><td colspan="2">Line 18</td><td></td><td></td><td></td></tr>
<tr><td>8</td><td>8</td><td></td><td colspan="3">Line 36</td><td></td><td></td><td></td></tr>
<tr><td>9</td><td>9</td><td></td><td></td><td colspan="4">Line 16</td><td></td></tr>
<tr><td>10</td><td>10</td><td></td><td></td><td></td><td></td><td colspan="2">Line 31</td><td></td></tr>
<tr><td colspan="2">FWC</td><td colspan="7"></td></tr>
<tr><td rowspan="3">Standby Lines Stages</td><td>1</td><td>-</td><td>15</td><td>-</td><td>-</td><td>-</td><td>-</td><td>6</td></tr>
<tr><td>2</td><td>-</td><td>-</td><td>12</td><td>1</td><td>1</td><td>-</td><td>-</td></tr>
<tr><td>3</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>1,2</td><td>-</td></tr>
<tr><td colspan="2">Overload</td><td colspan="7"></td></tr>
<tr><td colspan="9">Final Objective Function = 7.9910</td></tr>
</table>

5.3 Comparison between the Results Obtained by Tabu Search and Genetic Algorithms

The results obtained both from the application of the TS or GA as given in pervious sections of this section shows that these tools are practical for the MS problem. The results obtained by TS were faster and better than the GA as explained in Table 12. This is due to the fact that the GA starts from an initial random solution which slows the convergence. The GA depends largely on the initialization, which controls the performance of the program and the final solution. Also, the GA will need more time to evaluate the fitness function for every individual in the population. Table 11 shows the date deviations between the requested and the obtained schedules. Generally, the scheduling problem can be solved by many artificial intelligence techniques but the results show that the TS performed well against other algorithms [14].

5.4 Comparison with Published Results

The TS method used in this work was used in a similar study conducted by [2]. The constraints considered were the forbidden work combinations and power flow constraints. The test systems used by this work, however, are different to the one used by [2]. The authors used a portion of the Kansai Electric Company, Japan. The obvious difference is in the way of reconfiguration and switching in the network, since the one used by [2] did not consider the number of switched lines. The results of both were promising showing that this new developed method for automatic scheduling of maintenance outage tasks using a TS is a practical MS optimization tool. Since March 1998, the developed system [2] has been made practical at the KEPCO central load dispatching center. Also GA was used to improve the system performance of outage scheduling of maintenance tasks in a distribution system [15]. The objective function was in terms of cost functions (manpower cost and system cost). The constraints considered were supply continuity and system security, load pattern and outage window. The proposed GA approach was tested on a model network and on an outage plan arranged manually by the planning engineer. The results gave a better arrangement than the original in a fast and efficient way. The difference between this proposed method and the one proposed in this work is that [15] did not consider the switching to resolve the overloaded branches. Also, it did not consider the starting date requested by the initial maintenance schedule.

Table 11: Requested Date Deviation for TS and GA Methods

		TS	GA
Requested Date Deviation	MS Case no. 1	1	9
	MS Case no. 2	1	6
	MS Case no. 3	1	5
	MS Case no. 4	0	3
	MS Case no. 5	2	3
	MS Case no. 6	3	7
For 24-Bus System			

6. Conclusions

An optimization model has been studied and applied for the purpose of scheduling maintenance outages in transmission and distribution systems. A feature of this model is the ease in which constraints can be formulated. Heuristic techniques were used to solve the MS optimization problem. The TS and GA methods were applied to reconfigure networks and to reschedule the starting dates of the work. The developed scheduling methods were applied to 5-Bus and 24-Bus test systems for maintenance outage schedules. In this paper, the search strategy has been implemented for scheduling maintenance outages for substations systems. The objective was mainly to maximize the work progress of tasks in the scheduling period which minimize the carry-over work to the next scheduling period and minimize deviations of the work date from that requested by local maintenance centers

7. Acknowledgements

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