Availability Analysis of a Power Plant by Computer Simulation

Mehmet Savsar

Abstract—Reliability and availability of power stations are extremely important in order to achieve a required level of power generation. In particular, in the hot desert climate of Kuwait, reliable power generation is extremely important because of cooling requirements at temperatures exceeding 50-centigrade degrees. In this paper, a particular power plant, named Sabiya Power Plant, which has 8 steam turbines and 13 gas turbine stations, has been studied in detail; extensive data are collected; and availability of station units are determined. Furthermore, a simulation model is developed and used to analyze the effects of different maintenance policies on availability of these stations. The results show that significant improvements can be achieved in power plant availabilities if appropriate maintenance policies are implemented.

Keywords—Power plants, steam turbines, gas turbines, maintenance, availability, simulation.

I. INTRODUCTION

Power generation is a vital operation in all countries. Extensive reliance on power in today’s society makes it essential to have a necessary production with reliable output over time. Power stations in Gulf countries are driven by inexpensive and generously available fuel and gas. Kuwait is one of these countries where the real beginning of electricity generation started in 1934 by the establishment of Electrical National Company. Since then, several power plants with numerous steam and gas turbine units have been established in order to meet the ever-increasing demand for electricity.

A steam turbine is used in a cogeneration plant, which generates electricity as well as desalinated water in a complex process consisting of several subsystems. In general, a steam turbine cogeneration station consists of a furnace, a boiler, a turbine, a generator, a condenser, and some auxiliary units. A gas turbine station, on the other hand, consists of an air compressor, a combustion chamber, a turbine, a generator, and auxiliary units. Gas turbines are used to generate electricity only and may be of open type cycle or combined cycle. Both, steam and gas turbines include very complex machinery, which are subject to various types of failures that affect availability.

It is necessary to determine system availability for both types of stations, in order to be able to predict maximum possible electrical utility generation from these stations. Reliability and availability analysis of power plants have been considered by many researchers, and several papers have appeared in the literature. Proctor et al. [1] developed a stochastic algorithm for reliability modeling of a gas turbine standby system in Saudi Arabia. Eti, et al. [2], [3] have considered reliability analysis of a thermal power station in Nigeria and discussed related issues. Majeed and Sadeq [4] have studied availability and reliability analysis of a hydropower station in Iraq and used Markov model to study system reliability. Borges and Falcao [5] have studied the optimal distribution of electrical generation, reliability, losses, and possible improvements. Alardhi et al. [6] developed a preventive maintenance schedule for multi cogeneration power plants with production constraints by using mathematical programming. Kancev and Cepin [7] showed that testing and maintenance improve the reliability of safety systems and components in nuclear power plants, which is of special importance for standby systems. Marseguerra, and Zio [8] tried to optimize maintenance and repair policies via a combination of genetic algorithms and Monte Carlo simulation.

In this paper, we have considered availability analysis of a special power plant in Kuwait. In particular, we have selected one of the six power plants in Kuwait and collected extensive data on failures and maintenance over the past ten years. Next, we have utilized this data to determine mean time between failures and related distributions for steam and gas turbine units. Inherent and operational availabilities of the stations. Are determined based on the data collected. A simulation model is then developed to determine the effects of two different maintenance policies, namely the age-based and the block based maintenance policies, on system availability.

II. POWER STATIONS IN KUWAIT

Starting from 1934, several power stations have been established in Kuwait. While gas turbine stations have a smaller capacity and are utilized for generating electricity only, steam turbines are used in cogeneration systems with the larger capacity to generate electricity and desalinated water together. Table I shows the list of power plants, power units in each station, and the installed capacities. In this paper, only Sabiya power plant has been considered, and detailed availability analysis is performed, while other stations are left for future studies. As seen in Table I, Sabiya power plant has 8 steam and 13 gas turbines, with a total installed capacity of 4870 MW.
Table II shows different types of failures, which have frequently occurred in Sabiya steam turbines. The related mean time between failures (MTBF), failure rates ($\lambda$) and mean time to repair (MTTR) are given in the table based on historical data. Table II shows the different types of failures for the gas turbines in Sabiya Station and related MTBF, mean corrective time (Mct) and failure rates. Table IV shows the maintenance parameters, including mean time between preventive maintenance (MTBM), mean preventive time (MPMT), and related rates for steam turbine and gas turbine units. Note that two failures are combined as follows:

**TABLE I**

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Number of Steam Turbines</th>
<th>Installed Capacity (MW)</th>
<th>Number of Gas Turbines</th>
<th>Installed Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuwaikh</td>
<td>0</td>
<td>6</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>Shuaiba</td>
<td>6</td>
<td>120</td>
<td>4</td>
<td>108</td>
</tr>
<tr>
<td>Doha East</td>
<td>7</td>
<td>156</td>
<td>6</td>
<td>18</td>
</tr>
<tr>
<td>Doha West</td>
<td>8</td>
<td>300</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>Al Zor South</td>
<td>8</td>
<td>300</td>
<td>19</td>
<td>124</td>
</tr>
<tr>
<td>Sabiya</td>
<td>8</td>
<td>300</td>
<td>13</td>
<td>190</td>
</tr>
</tbody>
</table>

Combined MTBF = $1/(\lambda_1+\lambda_2)$  \hspace{1cm} (1)

Similarly, two MTTR for different types of failures are combined by using weighted average as follows:

Combined MTTR = $(\lambda_1 \times \text{MTTR}_1 + \lambda_2 \times \text{MTTR}_2)/(\lambda_1+\lambda_2)$  \hspace{1cm} (2)

**TABLE II**

<table>
<thead>
<tr>
<th>Types of Failures</th>
<th>MTBF (Hours)</th>
<th>Failure Rate/1000 hours ($\lambda$)</th>
<th>MTR (Hours)</th>
<th>Repair Rate/ Hour ($\mu$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency</td>
<td>79000</td>
<td>1.2658E-05</td>
<td>232</td>
<td>0.00431</td>
</tr>
<tr>
<td>Tripping</td>
<td>11500</td>
<td>8.6957E-05</td>
<td>131</td>
<td>0.00763</td>
</tr>
<tr>
<td>Combined Failures</td>
<td>100387.7</td>
<td>0.0000996</td>
<td>143.8</td>
<td>0.0069541</td>
</tr>
</tbody>
</table>

**TABLE III**

<table>
<thead>
<tr>
<th>Types of Failures</th>
<th>MTBF (Hours)</th>
<th>Failure Rate/1000 hours ($\lambda$)</th>
<th>MTR (Hours)</th>
<th>Repair Rate/ Hour ($\mu$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency</td>
<td>1130</td>
<td>0.000885</td>
<td>24.7</td>
<td>0.040486</td>
</tr>
<tr>
<td>Tripping</td>
<td>3160</td>
<td>0.000317</td>
<td>38.3</td>
<td>0.026111</td>
</tr>
<tr>
<td>Combined Failures</td>
<td>832.4</td>
<td>0.001201</td>
<td>28.3</td>
<td>0.035336</td>
</tr>
</tbody>
</table>

**TABLE IV**

<table>
<thead>
<tr>
<th>Types of Turbines</th>
<th>MTBM Maintenance Rate/1000 hours ($\pi$)</th>
<th>MPMT (Hours)</th>
<th>PM Rate/ Hour ($\beta$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam</td>
<td>6192</td>
<td>0.0001615</td>
<td>881</td>
</tr>
<tr>
<td>Gas</td>
<td>5544</td>
<td>0.0001804</td>
<td>1205</td>
</tr>
</tbody>
</table>

**TABLE V**

<table>
<thead>
<tr>
<th>Types of Turbines</th>
<th>MTBMc Combined Mean Time Between Maintenance</th>
<th>Inherent Availability</th>
<th>Operational Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam</td>
<td>3829.75</td>
<td>0.986</td>
<td>0.865</td>
</tr>
<tr>
<td>Gas</td>
<td>723.70</td>
<td>0.967</td>
<td>0.799</td>
</tr>
</tbody>
</table>

As it can be seen from Table V, inherent availabilities are high, such as 0.986 for steam turbines and 0.967 for gas turbines. However, operational availabilities, which are real availabilities in the operational environment, are low such as 0.865 for steam turbines and 0.799 for gas turbines. This is due to the performance of maintenance, which are essential for keeping the system operational. Exclusion of maintenance may result in frequent failures, which in turn could result in extended down times and very low availabilities. In order to increase operational availabilities, Mpt and Mct, should be reduced by employing more repair personnel.

**IV. EFFECTS OF MAINTENANCE POLICIES ON POWER STATION AVAILABILITIES**

Maintenance procedures and policies can have significant effects on system availabilities. In order to analyze the effects of maintenance policies on Sabiya Power Station availability for both steam and gas turbines, we have developed a simulation model based on ARENA [9] software. As it is known from general practice, there are two types of equipment stoppages in the most general sense. The first type is the stoppage due to random failures, which require a corrective maintenance (CM) or repair actions. The second type is the
stoppage due to preventive maintenance (PM), which require
time to perform PM. The corrective time is denoted as MCt,
while the preventive time is denoted as Mpt. As a result of
these two stoppages, there are two general types of
maintenance, called maintenance policies. The first policy is
called age-based maintenance (ABM) policy, in which case,
whenever the equipment is stopped for either CM or PM,
whichever comes first, the next maintenance for CM or PM is
rescheduled from the time the repair is completed. Effectively,
it is assumed that the equipment is renewed and starts as fresh.
The second policy is called block based maintenance (BBM)
policy, in which case, each stoppage is independent of the
others and if a failure occurs and a repair is completed, the
following PM is not rescheduled; it is performed at the
scheduled time even if it is shortly after the failure.

The simulation model is run for each maintenance policy
for each type of system, steam turbines and gas turbines, in
order to observe the system availability under different
operational conditions. Fig. 1 shows a snapshot of the
simulation model for the ABP and Fig. 2 shows a snapshot for
BBP. In the simulation model, failures and maintenance are
generated based on the random times and the necessary repairs
are done based on the selected policy. As it can be seen in the
model of Fig. 1, in ABP, the next failure or maintenance is
rescheduled after any failure or maintenance is performed.
However, in the BBP, the next failure or maintenance is
rescheduled after occurrence the respective failure or the
maintenance operation and the completion of the necessary
repair or maintenance action. The difference is in the
rescheduling of the next CM or PM. Using the data collected
for each type of turbine unit in the power station, we have
simulated the steam turbines and gas turbines separately and
determined the effect of different policies on system
availabilities. The simulation was run for a period of 10 years,
assuming 24 hours of operation per day. Each case was
replicated 30 times in order to determine 95% confidence
limits on availability values estimated. Table VI shows the
simulation results for each case.

As it can be seen from the results in Table VI, power station
availability is significantly increased when maintenance policy
is changed from blocked based policy to age-based policy. For
example, for the case of steam turbines, the availability is
increased from 85.88% to 88.60%, while in the case of gas
turbines, it is increased from 78.72% to 93.1%. This very high
increase in the gas turbines is because gas turbines fail more
frequently and each time a failure occurs, the following PM is
eliminated by combining with the failure. The next PM is
rescheduled from the time repair is completed. Effectively, the
majority of the times the PM are combined with the CM since
MTBF is much smaller than MTBM.

V. CONCLUSIONS
One of the major problems faced in the operation of power
plants is a determination of turbine unit availability under
different operational conditions and maintenance policies.
This is essential in order to estimate the expected maximum
possible electrical utility output from the station. In this
paper, we have taken a particular power station, which

<table>
<thead>
<tr>
<th>Types of Turbines</th>
<th>Ao ABP</th>
<th>Ao-ABP Confidence Limits</th>
<th>Ao BBP</th>
<th>Ao- BBP Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam</td>
<td>0.886</td>
<td>(0.876, 0.896)</td>
<td>0.8588</td>
<td>(0.839, 0.879)</td>
</tr>
<tr>
<td>Gas</td>
<td>0.931</td>
<td>(0.930, 0.932)</td>
<td>0.7872</td>
<td>(0.7772, 0.7972)</td>
</tr>
</tbody>
</table>
consisted of 8 steam turbine units and 13 gas turbine units. Data was collected from historical records, and various failure, and maintenance related parameters were estimated. Next, a simulation model was developed, and the power station availabilities were determined assuming system was operated under different maintenance policies. It was found that ABP resulted in higher availabilities than BBP. Assuming that the system was operated with ABP, the operational capacity for utility electrical generation could be calculated by multiplying the availability with the installed capacity. For example, operational capacity would be $8 \times (300) \times 0.886 = 2126.4$ MW for the steam turbines, and $13 \times (190) \times 0.0.931 = 2299.57$ MW for the gas turbines. Modeling and analysis procedures and the results presented in this paper are expected to be a useful guide for operational engineers and maintenance managers in power plants for further analysis and improvements of systems.

REFERENCES


Mehmet Savsar is a professor of Industrial Engineering at College of Engineering & Petroleum at Kuwait University. He has over 160 publications in international journals and conference proceedings. He is on the editorial board of several journals and conferences. He is a senior member of the IIE and a member of INFORMS.

Dr. Savsar holds a Ph.D. degree from the Industrial Engineering Department of the Pennsylvania State University, USA. Prior to joining Kuwait University, he worked in USA, Turkey, and Saudi Arabia as a researcher and faculty member in various universities. His main research areas are quality, reliability, maintenance, simulation, and facility location analysis.