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Availability Analysis of a Power Plant by Computer Simulation

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***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.

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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.

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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 (λ) and mean time to repair (MTTR) are given in the table based on historical data. Table II shows the two 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
POWER STATIONS IN KUWAIT

Station Name	Number of Steam Turbines	Installed Capacity (MW)	Number of Gas Turbines	Installed Capacity (MW)
Shuwaikh	0		6	42
Shuaiba	6	120	4	108
Doha East	7	150	6	18
Doha West	8	300	5	30
Al Zor South	8	300	19	124
Sabiya	8	300	13	190

$$\text{Combined MTBF}= 1/(\lambda 1+\lambda 2) \quad (1)$$

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

$$\text{Combined MTTR}=(\lambda 1*\text{MTTR1}+\lambda 2*\text{MTTR2})/(\lambda 1+\lambda 2) \quad (2)$$

TABLE II
DIFFERENT FAILURE AND REPAIR RATES FOR STEAM TURBINES

Types of Failures	MTBF (Hours)	Failure Rate/ 1000 hours. (λ)	MTTR (Hours) (Mct)	Repair Rate/ Hour (μ)
Emergency	79000	1.2658E-05	232	0.00431
Tripping	11500	8.6957E-05	131	0.00763
Combined Failures	10038.7	0.0000996	143.8	0.0069541

TABLE III
DIFFERENT FAILURE AND REPAIR RATES FOR GAS TURBINES

Types of Failures	MTBF (Hours)	Failure Rate/ 1000 hours. (λ)	MTTR (Hours) (Mct)	Repair Rate/ Hour (μ)
Emergency	1130	0.000885	24.7	0.040486
Tripping	3160	0.000317	38.3	0.026111
Combined Failures	832.4	0.001201	28.3	0.035336

TABLE IV
MAINTENANCE PARAMETERS FOR STEAM AND GAS TURBINES

Types of Turbines	MTBM (Hours)	Maintenance Rate/ 1000 hours. (π)	MPMT (Hours) (Mpt)	PM Rate/ Hour (β)
Steam	6192	0.0001615	881	0.0011351
Gas	5544	0.0001804	1205	0.0008299

III. AVAILABILITY CALCULATIONS

In order to determine availability measures, it is necessary to combine MTBF for corrective maintenance and MTBM for preventive maintenance and come up with a combined MTBMc. Also, related repairs must be combined by using appropriate rates as weights. The following equations are utilized to combine these maintenance and repair times to obtain overall combined mean time between all maintenance and mean time to perform a maintenance (MT) for both corrective and preventive actions:

$$\text{MTBMc}=1/(1/\text{MTBF}+1/\text{MTBM}) =1/(\lambda+\pi) \quad (3)$$

$$\text{MT}=(\lambda*\text{Mct} + \pi*\text{Mpt})/(\lambda+\pi) \quad (4)$$

MTBMc calculations are done by using combined MTBF, combined failure rates, MTBM, and maintenance rates from Tables II and III for steam and gas turbines. Furthermore, MT calculations are made using the combined Mct values from Tables II and III and Mpt values from Table IV for the steam and gas turbines separately. Table V shows the calculated combined MTBMc and mean maintenance time (MT) values for each type of turbine. There are three types of availabilities in a system with related formulas as given below:

$$\text{Inherent Availability, Ai} = \text{MTBF}/(\text{MTBF}+\text{Mct}) \quad (5)$$

$$\text{Achieved Availability, Aa} = \text{MTBMc}/(\text{MTBMc}+\text{M}) \quad (6)$$

$$\text{Operational Availability, Ao} = \text{MTBMc}/(\text{MTBMc}+\text{MDT}) \quad (7)$$

where MDT=MT+logistic and administrative delays. Assuming such delays are negligible, system availabilities are calculated and presented in Table V for steam and gas turbines.

TABLE V
COMBINED OVERALL MEAN TIME BETWEEN MAINTENANCE

Types of Turbines	MTBMc: Combined (Hours)	Combined down time (MDT)	Inherent Availability (Ai)	Operational Availability (Ao)
Steam	3829.75	599.77	0.986	0.865
Gas	723.70	181.89	0.967	0.799

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

Open Science Index, Energy and Power Engineering Vol:9, No:4, 2015 waset.org/Publication/10005396

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.

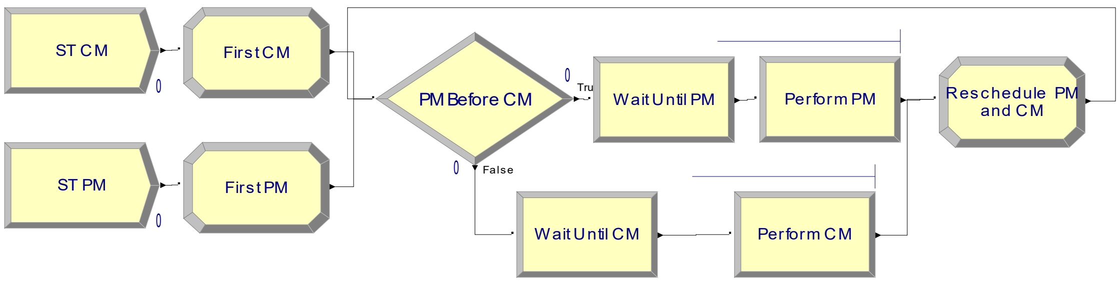

Fig. 1 Snapshot of simulation model for ABP

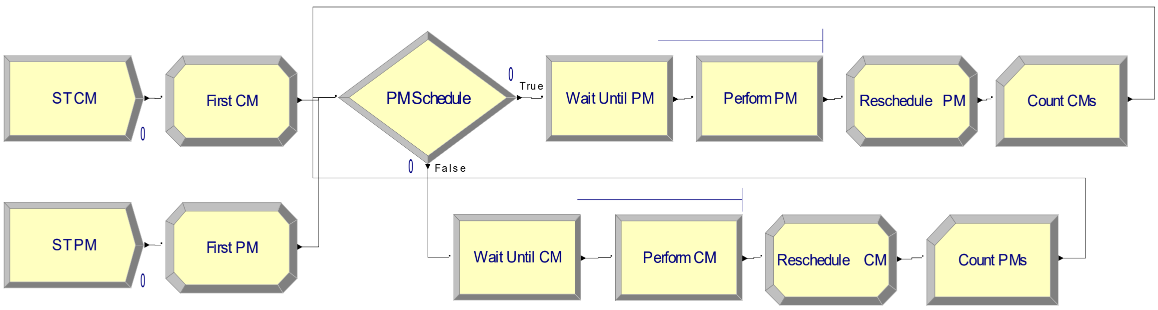

Fig. 2 Snapshot of simulation model for BBP

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.

TABLE VI
STEAM AND GAS TURBINE AVAILABILITIES UNDER DIFFERENT MAINTENANCE POLICIES

Types of Turbines	Ao ABP	Ao- ABP Confidence Limits	Ao BBP	Ao- BBP Confidence Limits
Steam	**0.886**	(0.876, 0.896)	**0.8588**	(0.839, 0.879)
Gas	**0.931**	(0.930, 0.932)	**0.7872**	(0.7772,0.7972)

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 se stations. In this paper, we have taken a particular power station, which

Open Science Index, Energy and Power Engineering Vol:9, No:4, 2015 waset.org/Publication/10005396

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*(300)*0.886=2126.4 MW for the steam turbines, and 13*(190)*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.

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