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Statistical approach for analyzing the transient reliability of boiler system using CAS Mathematica

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ABSTRACT: The focal point of this manuscript is to address the reliability analysis of Boiler unit in the Thermal power plant driven from coal. It is made up of six subunits laid out in series and parallel manner, alongwith some standby units. The system under consideration is modelled in transient state aided by Markov birth-death process and CAS Mathematica is deployed to solve the resulting complicated system of probabilistic equations arising out of 8 working states.

KEYWORDS: Transient reliability, Boiler system, Markov process

1. INTRODUCTION

Power sector is one of the major role criteria to measure the country's socio-economic broadening. Over the years we have seen a tremendous hike in demand for thermal power generation and coal has emerged as an utmost vital and extensively used fuel for the purpose. The foremost basic principle used in generating Thermal Power is the conversion of heat energy arising out of steam power into electricity, by flowing the steam through generator activated turbines. These steam turbines require high pressure and high temperature entering steam. High energy being absorbed by the turbine results in dropped pressure and temperature at the exit. In order to increase the capacity of plant, different stages of steam turbines are employed such as high pressure turbine, intermediate pressure turbine and low pressure turbines. However, to increase the efficiency and minimise the wastage of resources, we device a model to reuse the resulting low pressure and low temperature steam by restoring its original vitals and then repeat the process. To restore high pressure, first convert the steam into liquid and elevate its pressure with the help of condenser heat exchangers. However temperature is increased with the aid of "water tube boiler" steered by burning pulverized coal. Initially the feed water will pass through an economizer, encapsulate energy from the flue gas and later transform into steam. The pure steam is separated at a steam drum. Finally, the resulting steam in its original state with high pressure and high temperature can be fed back into the steam turbine and the cycle can be repeated over and over again for continuous power production. However, we add super heater to extend the efficiency of a plant as we know that the higher the temperature of the steam the more efficient the cycle resulting high power output, of course taking into account the cut-off temperature that a turbine material can withhold. The heart of the plant undoubtedly lies in the Boiler unit, consummating this whole cycle. We focus in analyzing the transient state reliability of the Boiler unit system in the Thermal power plant (Jagtap, Bewoor, and Kumar, 2020), in which availability of boiler-furnace system is optimized in a steady state, using particle swarm optimization method. However, in this paper we have obtained a Markov model and studied the reliability of the above mentioned system in a time-dependent transient state. Further, worked upon by utilizing CAS Mathematica for the purpose due to its supreme proficiency in probability and statistics adaptivity that happens to be absolutely imperative to study reliability with precision.

2. METHODOLOGY

2.1 THE SYSTEM UNIT

The system is made up of six subsystems laid in series:

I. Subsystem A: It consists of one "boiler drum" unit whose failure leads to system failure.

II. Subsystem B: It consists of one "boiler tubing" unit whose failure leads to system failure.

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III. Subsystem C It consists of one "fuel firing system" unit whose failure leads to system failure.

IV. Subsystem D: It consists of one "Superheater" unit whose failure results to the system working in reduced capacity.

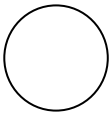
V. Subsystem E: It consists of one "Economizer" unit whose failure results to the system working in reduced capacity.

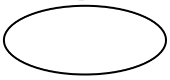
VI. Subsystem F: It consists of one "Reheater" unit whose failure results to the system working in reduced capacity.

2.2 ASSUMPTIONS AND NOTATIONS

Assumptions used in the system (Jagtap, Bewoor, and Kumar, 2020) "Notations for depicting diversified states of its subunits are as under:

- **A, B, C, D, E, F:** Represents full capacity states of all six subsystems respectively.
- **a, b, c, d, e, f:** Represents the failed states of A, B, C, D, E and F respectively.
- **$\bar{D}$, $\bar{E}$, $\bar{F}$:** Represents the reduced state of D, E and F respectively.
- **$a_1, a_2, a_3, a_4, a_5, a_6$:** Mean failure rate in A, B, C, D, E and F respectively
- **$b_1, b_2, b_3, b_4, b_5, b_6$:** Mean repair rate in A, B, C, D, E and F respectively
- **$P_i(t)$:** Probability of the system unit working in i^{th} state at any time t.
- ▯ /▯▯: Derivative w.r.t time."


: Full capacity state.


: Reduced capacity state.


: Failed state.

3. SYSTEM MODELLING

Mathematical model of Boiler System is constructed and discussed (Jagtap, Bewoor, and Kumar, 2020). The system of obtained probabilistic differential equations is solved along with the initial conditions,

$$\left[\frac{d}{dt}+\sum_{i=1}^{6} a_i\right]P_0(t) = b_1P_{41}(t)+b_2P_{42}(t)+b_3P_{43}(t) + b_4P_1(t)+b_5P_2(t) + b_6P_3(t). \quad (1)$$

$$\left[\frac{d}{dt}+\sum_{i=1}^{6} a_i + b_4\right]P_1(t) = b_1P_{19}(t)+b_2P_{20}(t)+b_3P_{21}(t) + b_4P_{22}(t)+b_5P_6(t)+b_6P_4(t) + a_4P_0(t). \quad (2)$$

$$\left[\frac{d}{dt}+\sum_{i=1}^{6} a_i + b_5\right]P_2(t) = b_1P_{28}(t)+b_2P_{29}(t)+b_3P_{30}(t) + b_4P_6(t)+b_5P_{31}(t)+b_6P_5(t) + a_5P_0(t). \quad (3)$$

$$\left[\frac{d}{dt}+\sum_{i=1}^{6} a_i + b_6\right]P_3(t) = b_1P_{37}(t)+b_2P_{38}(t)+b_3P_{39}(t) + b_4P_4(t)+b_5P_5(t)+b_6P_{40}(t) + a_6P_0(t). \quad (4)$$

$$\left[\frac{d}{dt}+\sum_{i=1}^{6} a_i + b_4 + b_6\right]P_4(t) = b_1P_{14}(t)+b_2P_{15}(t)+b_3P_{16}(t) + b_4P_{17}(t)+b_5P_7(t)+b_6P_{18}(t) + a_4P_3(t)+a_6P_1(t) \quad (5)$$

$$\left[\frac{d}{dt}+\sum_{i=1}^{6} a_i + b_5 + b_6\right]P_5(t) = b_1P_{32}(t)+b_2P_{33}(t)+b_3P_{34}(t) + b_4P_7(t)+b_5P_{35}(t)+b_6P_{36}(t) + a_5P_3(t)+a_6P_2(t). \quad (6)$$

$$\left[\frac{d}{dt}+\sum_{i=1}^{6} a_i + b_4 + b_5\right]P_6(t) = b_1P_{23}(t)+b_2P_{24}(t)+b_3P_{25}(t) + b_4P_{26}(t)+b_5P_{27}(t)+b_6P_7(t) + a_4P_2(t)+a_5P_1(t) \quad (7)$$

$$\left[\frac{d}{dt}+\sum_{i=1}^{6} a_i + b_4 + b_5 + b_6\right]P_7(t) = b_1P_8(t)+b_2P_9(t)+b_3P_{10}(t)+b_4P_{11}(t) + b_5P_{12}(t)+b_6P_{13}+a_4P_5(t) + a_5 P_4(t)+aP_6(t). \quad (8)$$

$$\left[\frac{d}{dt}+b_m\right]P_i(t) = a_mP_j(t) \quad (9)$$

m = 1: i = 8, j = 7; i = 14, j = 4; i = 19, j = 1; i = 23, j = 6; i = 28, j = 2 ; i = 32, j = 5 ; i = 37, j = 3 ; i = 41, j = 0

m = 2: i = 9, j = 7; i = 15, j = 4; i = 20, j = 1 ; i = 24, j = 6; i = 29, j = 2 ; i = 33 , j = 5 ; i = 38, j = 3 ; i = 42, j = 0.

m = 3: i = 10, j = 7; i = 16, j = 4 ; i = 21, j = 1 ; i = 25, j = 6; i = 30, j = 2 ; i = 34, j = 5 ; i = 39, j = 3 ; i = 43, j = 0.

m = 4: i = 11, j = 7; i = 17, j = 4 ; i = 22, j = 1; i = 26, j = 6.

m = 5: i = 12, j = 7; i = 27, j = 6 ; i = 31, j = 2; i = 35, j = 5

m = 6: i = 13, j = 7; i = 18, j = 4 ; i = 36, j = 5 ; i = 40, j = 3

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with the initial conditions,

$$P_i(t) = \begin{cases} 1 \text{ for } i = 0 \\ 0 \text{ for } i \neq 0 \end{cases} \qquad (10)$$

The given system is solved under real conditions. The resulting mathematical model is solved using CAS Mathematica and the values of working states P_0, P_1, P_2, P_3, P_4, P_5, P_6 and P_7 at a time t , are obtained reliability is calculated as as follows:

$R_1(t) = P_0(t) + P_1(t) + P_2(t) + P_3(t) + P_4(t) + P_5(t) + P_6(t) + P_7(t)$

4. PERFORMANCE ANALYSIS OF THE SYSTEM

We analyse the reliability with fluctuation in values of failure and repair rates.

a) Variational study:

We analyse the reliability of the system for various values of repair rates as: $b1 = 0.003$,

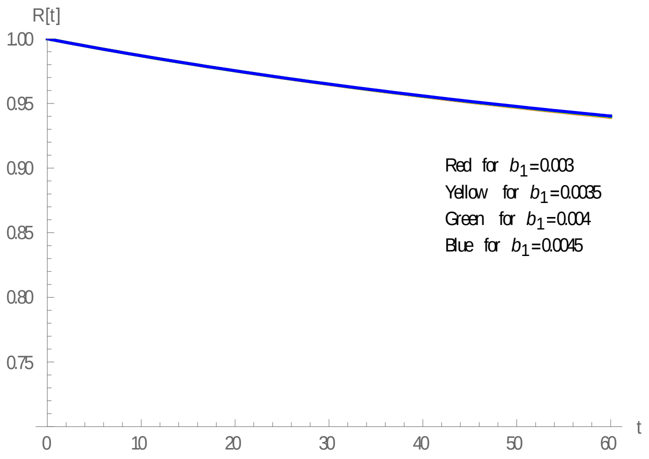
$0.0035, 0.004$ & 0.0045 and other values of failure and repair rates as: $a_1 = 0.0004$; $a_2 = 0.0005$; $a_3 = 0.0005$; $a_4 = 0.0004$; $a_5 = 0.0006$; $a_6 = 0.0004$, ; $b_2 = 0.02$; $b_3 = 0.01$;

$b_4 = 0.005$; $b_5 = 0.005$; $b_6 = 0.004$;are kept constant.

Table 1: Variation of Probability of subsystem A with respect to its repair rate with passage of time

t	$b_1 = 0.003$	$b_1 = .0035$	$b_1 = 0.004$	$b_1 = .0045$
6	0.991904	0.991908	0.991911	0.991915
12	0.984379	0.984393	0.984407	0.984421
18	0.97737	0.977401	0.977432	0.977462
24	0.970831	0.970885	0.970938	0.97099
30	0.964718	0.9648	0.964881	0.964962
36	0.958992	0.959109	0.959223	0.959337
42	0.95362	0.953776	0.953929	0.95408
48	0.948571	0.948771	0.948967	0.94916
54	0.943816	0.944065	0.944308	0.944548
60	0.939332	0.939633	0.939928	0.940218

b). Graphical Analysis



5. CONCLUSIONS

A study, analysing the transient reliability of boiler unit in a thermal power plant has been carried out. While performing the variational study for the boiler drum, it took cognizance of the fact that an average reliability of the system can be over 96% if we take the failure rates and repair rates in a prescribed combination. However optimum reliability reached is more than 99% and it decreases as time increases and increases with increase in repair rates. Similar analysis has been carried out for other subunits as well, concluding that the model capable of generating the average reliability exceeding 97% in transient state. Also, CAS Mathematica acted as crest in acquainting us with accurate results, that proves to be highly advantageous for the company management.

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