MEASUREMENT OF RELIABILITY PARAMETERS OF AMMONIA SYNTHESIS UNIT IN A FERTILIZER PLANT BY EMPLOYING BOOLEAN FUNCTION TECHNIQUE

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ABSTRACT

This paper discusses the reliability of ammonia synthesis unit. This unit consist of five subunits arranged in series and parallel configuration. For measuring reliability a mathematical model has been developed with the help of Boolean function technique. All necessary graphical illustrations are given at the end so as to explain the practical utility of the model.

Keywords: *Boolean function technique and MTTF.*

1. INTRODUCTION

During the last three decades reliability technology has been developed for use in various industries. The technology is mainly used in the development of electrical and electronics equipments. A detailed bibliography is contained in Dhillon and Singh [2]. This paper discusses an industrial problem concerned with a fertilizer plant. Although there are many units in a fertilizer plant we consider ammonia synthesis unit which is most important functionaries of a fertilizer plant.

2. DESCRIPTION OF AMMONIA SYNTHESIS UNIT

It comprises of five subunits as arranged in series:-

Subunit (A): Consists of three centrifugal compressors in series.

Subunit (B): Consists of hot heat exchanger and ammonia converter arranged in parallel.

Subunit (C): Consists two heat exchangers, one working and other is cold standby.

Subunit (D): Consists of cold condenser and ammonia separator arranged in series. Failure of any one causes the complete failure of the unit.

Subunit (E): Consists of three heat exchanger arranged in series. Failure of any are causes the compact failure of the unit.

3. ASSUMPTIONS

The associate assumptions are as follows:-

1. Initially all the equipments are good and operable.
2. The state of each component and of the whole system is either good or fail.
3. The state of all components of the system are statistically independent.
4. The failure times of all components are arbitrary.
5. Supply between any two component of the system is hundred percent reliable.
6. There is no repair facility.
7. The reliability of each component is known in advance.

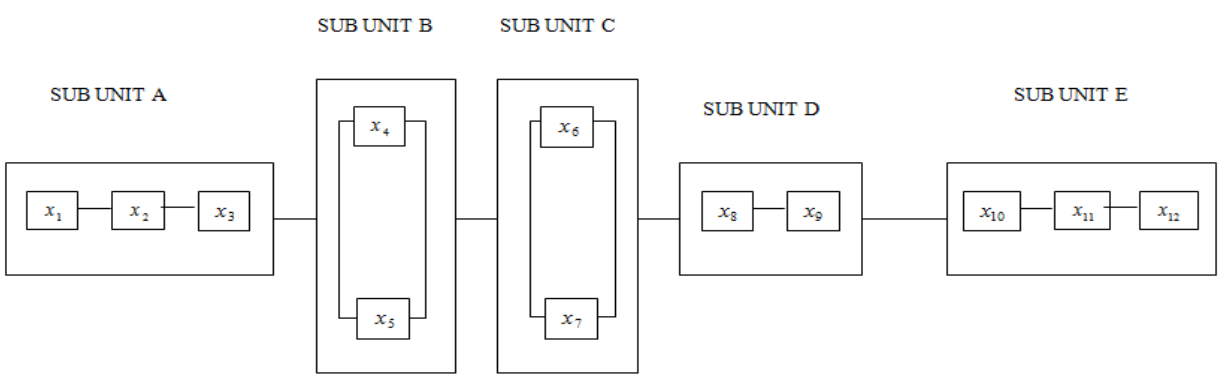

FIGURE 1 BLOCK DIAGRA

NOTATIONS

x_1, x_2, x_3	:	States of the centrifugal compressors of subunit A respectively.
x_4, x_5	:	States of heat exchanger and ammonia converter arranged in parallel of subunit B respectively.
x_6, x_7	:	States of two heat exchangers arranged in parallel of subunit C.
x_8, x_9	:	States of cold condenser and ammonia separator arranged in series of subunit D respectively.
x_{10}, x_{11}, x_{12}	:	States of three heat exchanger arranged in series of subunit E respectively.
x'	:	Negation of *x*.
$\wedge$	:	Conjunction.
x_i	:	$\begin{cases} 0, \text{ in bad state.} \\ 1 \text{ in good state, } (i\text{-}1,2,3\text{---}12) \end{cases}$
R_s	:	Reliability of the system as a whole.
R_i	:	Reliability of the component corresponding to system state x_i .
Q_i	:	Unreliability of component corresponding to system state x_i .
$R_{SW}(t)/R_{SE}(t)$	:	Reliability of the system as a whole when failures follow weibull/exponential time distribution.

4. FORMULATION OF MATHEMATICAL MODEL

The successful operation of the system in terms of logical matrix are expressed as:

$$F(x_1, x_2, x_3 ------ x_{12}) = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 & x_6 & x_8 & x_9 & x_{10} & x_{11} & x_{12} \\ x_1 & x_2 & x_3 & x_4 & x_7 & x_8 & x_9 & x_{10} & x_{11} & x_{12} \\ x_1 & x_2 & x_3 & x_5 & x_6 & x_8 & x_9 & x_{10} & x_{11} & x_{12} \\ x_1 & x_2 & x_3 & x_5 & x_7 & x_8 & x_9 & x_{10} & x_{11} & x_{12} \end{bmatrix} \quad \text{...(1.1.1)}$$

SOLUTION OF THE MODEL

By the application of algebra of logic equation (1.1.1.) may be written as:

$$F(x_1, x_2, x_3 ------ x_{12}) = [x_1 \quad x_2 \quad x_3 \quad x_8 \quad x_9 \quad x_{10} \quad x_{11} \quad x_{12} \wedge f(x_4 x_5 x_6 x_7)] \quad \text{...(1.1.2)}$$

Where

$$f(x_4 x_5 x_6 x_7) = \begin{bmatrix} x_4 & x_6 \\ x_4 & x_7 \\ x_5 & x_6 \\ x_5 & x_7 \end{bmatrix} \quad \text{...(1.1.3)}$$

Substituting the following eqn (1.1.3)

$$P_1 = [x_4 \quad x_6] \quad \text{...(1.1.4)}$$

$$P_2 = [x_4 \quad x_7] \quad \text{...(1.1.5)}$$

$$P_3 = [x_5 \quad x_6] \quad \text{...(1.1.6)}$$

$$P_4 = [x_5 \quad x_7] \quad \text{...(1.1.7)}$$

We obtain

$$f(x_4x_5x_6x_7)=\begin{bmatrix}P_1\\P_2\\P_3\\P_4\end{bmatrix} \quad \ldots(1.1.8)$$

Using orthogonalization algorithm eqn (1.1.8) may be written as

$$f(x_4x_5x_6x_7)=\begin{bmatrix}P_1 & & & \\ P_1' & P_2 & & \\ P_1' & P_2' & P_3 & \\ P_1' & P_2' & P_3' & P_4\end{bmatrix} \quad \ldots(1.1.9)$$

Now using algebra of logic, we have

$$P_1=\begin{bmatrix}x_4 & x_6\end{bmatrix}$$

$$P_1'=\begin{bmatrix}x_4' & \\ x_4 & x'_6\end{bmatrix}$$

$$\therefore \quad P_1'P_2=\begin{bmatrix}x_4' & \\ x_4 & x'_6\end{bmatrix}\wedge\begin{bmatrix}x_4 & x_7\end{bmatrix}$$

$$=\begin{bmatrix}x_4 & x'_6 & x_7\end{bmatrix} \quad \ldots(1.1.10)$$

Similarly we obtain the following

$$P_1'P_2'P_3=\begin{bmatrix}x_4' & x_5 & x_6 & \\ x_4 & x_5 & x_6 & x'_7\end{bmatrix} \quad \ldots(1.1.11)$$

and

$$P_1'P_2'P_3'P_4=\begin{bmatrix}x_4' & x_5 & x_6 & x_7\end{bmatrix} \quad \ldots(1.1.12)$$

Using eqn (1.1.10) through (1.1.12), eqn (1.1.8) gives

$$f(x_4x_5x_6x_7)=\begin{bmatrix}x_4 & x_6 & & \\ x_4 & x_6' & x_7 & \\ x_4 & x_5 & x_6 & x_7' \\ x_4' & x_5 & x_6 & \\ x_4' & x_5 & x_6 & x_7\end{bmatrix} \quad \ldots(1.1.13)$$

Using eqn (1.1.13) in (1.1.2) we obtain

$$F(x_1,x_2,x_3 ------ x_{12})=\begin{bmatrix}x_1 & x_2 & x_3 & x_4 & x_6 & x_8 & x_9 & x_{10} & x_{11} & x_{12} & & \\ x_1 & x_2 & x_3 & x_4 & x_6' & x_7 & x_8 & x_9 & x_{10} & x_{11} & x_{12} & \\ x_1 & x_2 & x_3 & x_4 & x_5 & x_6 & x_7' & x_8 & x_9 & x_{10} & x_{11} & x_{12} \\ x_1 & x_2 & x_3 & x_4' & x_5 & x_6 & x_8 & x_9 & x_{10} & x_{11} & x_{12} & \\ x_1 & x_2 & x_3 & x_4' & x_5 & x_6 & x_7 & x_8 & x_9 & x_{10} & x_{11} & x_{12}\end{bmatrix}$$

Finally, the probability of the successful operation (i.e. reliability) of the system is given by

$$R_s=P_r\{F(x_1,x_2,------x_{12})\}$$

$$R_s=R_1R_2R_3R_8R_9R_{10}R_{11}R_{12}[R_4R_6+R_4Q_6R_7+R_4R_5R_6Q_7$$
$$Q_4R_5R_6+Q_4R_5R_6R_7] \quad \ldots(1.1.14)$$

$$R_s=R_1R_2R_3R_8R_9R_{10}R_{11}R_{12}[R_4R_6+R_4(1-R_6)R_7+R_4R_5R_6(1-R_7)$$
$$+(1-R_4)R_5R_6+(1-R_4)R_5R_6R_7]$$

$$R_s=R_1R_2R_3R_8R_9R_{10}R_{11}R_{12}[R_4R_6+R_4R_7+R_5R_6+R_5R_6R_7-R_4R_6R_7$$
$$-2R_4R_5R_6R_7] \quad \ldots(1.1.15)$$

5. PARTICULAR CASES

Case 1:- If reliability of each component of the complex system is R, eqn (1.1.15) yields

$$R_s = R^{10}\left[3-2R^2\right] \quad \ldots(1.1.16)$$

Case 2:- When failure rates follow Weibull distribution

Let failure rates of state x_i is λ_i where *(i=1,2,2---12)*

Then from eq^n (1.1.16) reliability of system at an instant *t* becomes

$$\begin{aligned}R_s(t) &= e^{-(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_6+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12})t^\alpha}\\ &+ e^{-(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_7+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12})t^\alpha}\\ &+ e^{-(\lambda_1+\lambda_2+\lambda_3+\lambda_5+\lambda_6+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12})t^\alpha}\\ &+ e^{-(\lambda_1+\lambda_2+\lambda_3+\lambda_5+\lambda_6+\lambda_7+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12})t^\alpha}\\ &- e^{-(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_6+\lambda_7+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12})t^\alpha}\\ &- 2.e^{-(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5+\lambda_6+\lambda_7+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12})t^\alpha}\end{aligned} \quad \ldots(1.1.17)$$

Where α is positive parameter.

Case 3:- When failure rates follow exponential distribution

Exponential distribution is a particular case of Weibull distribution for $\alpha = 1$, the reliability of the system in this case at an instant *'t'* is given by

$$\begin{aligned}R_s(t) &= e^{-(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_6+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12})t}\\ &+ e^{-(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_7+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12})t}\\ &+ e^{-(\lambda_1+\lambda_2+\lambda_3+\lambda_5+\lambda_6+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12})t}\\ &+ e^{-(\lambda_1+\lambda_2+\lambda_3+\lambda_5+\lambda_6+\lambda_7+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12})t}\\ &- e^{-(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_6+\lambda_7+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12})t}\\ &- 2.e^{-(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5+\lambda_6+\lambda_7+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12})t}\end{aligned} \quad \ldots(1.1.18)$$

And, the expression for MTTF in this case is

$$\begin{aligned}MTTF &= \int_0^\infty R_s(t).dt\\ &= \frac{1}{\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_6+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12}}\\ &+ \frac{1}{\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_7+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12}}\\ &+ \frac{1}{\lambda_1+\lambda_2+\lambda_3+\lambda_5+\lambda_6+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12}}\\ &+ \frac{1}{\lambda_1+\lambda_2+\lambda_3+\lambda_5+\lambda_6+\lambda_7+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12}}\\ &- \frac{1}{\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_6+\lambda_7+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12}}\\ &- 2.\frac{1}{\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5+\lambda_6+\lambda_7+\lambda_8+\lambda_9+\lambda_{10}+\lambda_{11}+\lambda_{12}}\end{aligned} \quad \ldots(1.1.19)$$

6. NUMERICAL COMPUTATION FOR RELIABILITY & MTTF

(A) Setting all $\lambda_i = \lambda = 0.001, \alpha = 2$ in eqn (1.1.17) and (1.1.18) one may obtain the table-1& figure 2

(B) Setting all $\lambda_i = \lambda$ = 0.01 to 0.10 in eqn -(1.19) one may obtain the table 2 and fig. 3.

Table 1

S.No.	t Time	$R_{SE}(t)$ $\alpha = 1$ Exponential Distribution	$R_{SW}(t)$ Weibull Distribution
1	0	1.00000	1.00000
2	1	0.99396	0.99396
3	2	0.98790	0.97590
4	3	0.98184	0.94620
5	4	0.97596	0.90514
6	5	0.97000	0.85371
7	6	0.963907	0.79319
8	7	0.958000	0.72537
9	8	0.95200	0.652059
10	9	0.94620	0.57563

Table 2

S.No.	λ	MTTF
1	0.01	13.33
2	0.02	6.60
3	0.03	4.44
4	0.04	3.33
5	0.05	2.66
6	0.06	2.22
7	0.07	1.90
8	0.08	1.67
9	0.09	1.48
10	0.10	1.33

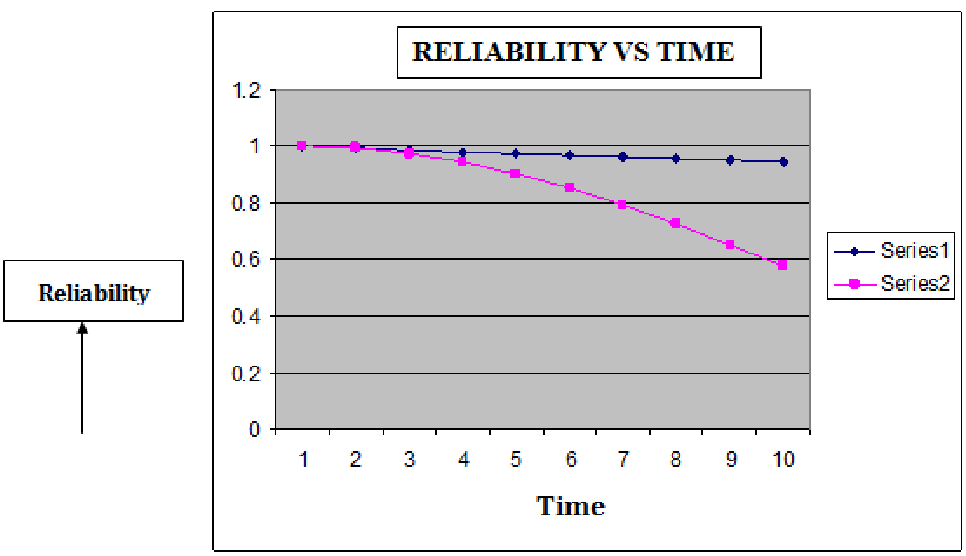

Fig-2

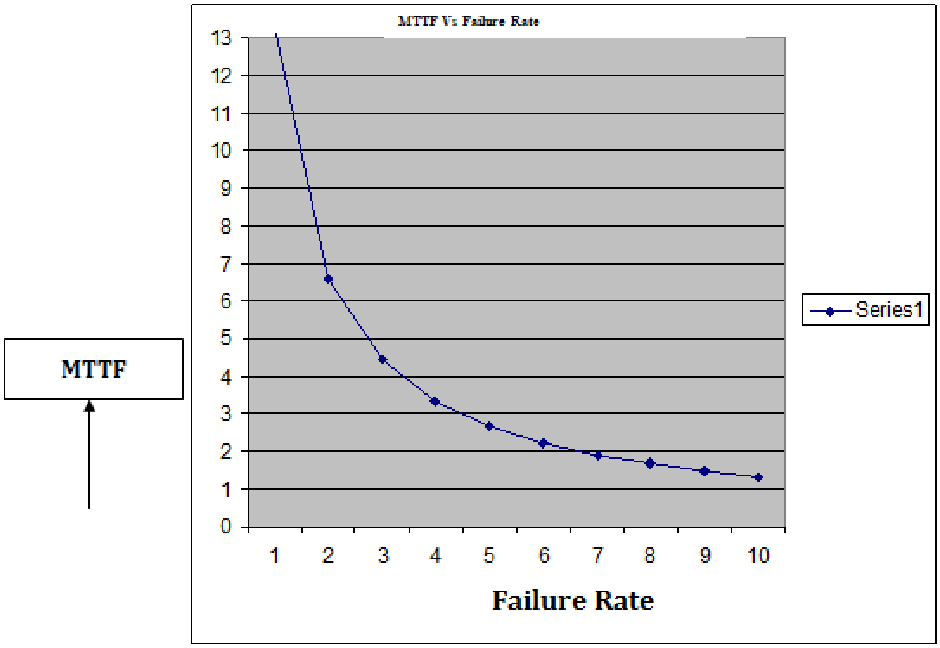

Fig-3

7. INTERPRETATION OF THE RESULTS

Table 1 and fig 2 shows that reliability function $R_{SW}(t)$ decreases catastrophically in the beginning but thereafter it decreases constantly. The value of $R_{SE}(t)$ remains better as compared of $R_{SW}(t)$.

Table 2 and figure 3 shows that the values of MTTF with increase in failure rate. A critical examination of fig 3, yields that the value of MTTF decreases rapidly as we make increase in the value of failure rate λ but thereafter it decreases in constant manner.

8. REFERENCES

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