Profit Evaluation of Urea Plant where HPD and LPD Share Load upon the Failure of Gas Separator

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ABSTRACT
The present study relating to the profit evaluation of three dissimilar units of the Urea Plant System. In this paper we have considered the decomposition section of Urea Plant having High Pressure Decomposer (HPD), Low Pressure Decomposer (LPD) & Gas Separator where on the failure of Gas Separator HPD & LPD shares the load of system but will produce less amount of Urea as compared to case when all units are operating. Functioning of all the units ensures the system functioning for high production of Urea but if gas separator fails, system operates only with two units HPD & LPD which produce less amount of Urea. In case of failure of Gas Separator, system goes to halt state where temperature and pressure of HPD & LPD have increased with the help of control valve and conversion of Urea is decreased here. In case of failure of any one among HPD & LPD, system does not work. Various measures like MTSF, Steady State Availability & Profit evaluation of the system has been computed graphically using the theory of Semi Markov Processes and Regenerative point technique.

KEYWORDS: Standby systems; dissimilar units; Semi Markov Processes.

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INTRODUCTION:

Reliability ensures the efficient and continuous operation of the system without any disturbances. Most of the industries are demanding to increase the reliability of their system, to meet the increasing demand of the society so the proper functioning of all units is the necessity of any industry. In the literature of reliability lots of work relating to standby units, system comprising three units\(^1\)\(^-\)\(^2\) and dissimilar units\(^3\)\(^-\)\(^4\) have already been done under various conditions.

Goyal et al. analysed the concept of reduced capacity due to shortage of raw material regardless of the number of operable units\(^5\). Malhotra et al. discussed the concept of load sharing depending upon demand of production\(^6\). This idea has been extended in the present paper where on the failure of Gas Separator HPD & LPD shares the load of system but will produce less amount of Urea as compared to case when all units are operating. In this paper sincere effort has been made on sharing the load by the HPD and LPD to meet the daily requirement of Urea instead of shut down of plant upon the failure of the Gas Separator which can be seen in Urea Plant of National Fertiliser Limited. Urea is a nitrogenous fertilizer being used all over the world & its utilization increasing day by day. In the agricultural sector, Urea is extensively used as a fertilizer and animal feed preservative.

In the present system there are three dissimilar units High Pressure Decomposer (HPD), Low Pressure Decomposer (LPD) & the Gas Separator. Out of which functioning of all the units ensures the system functioning for high production of Urea but if Gas Separator fails system operate only with two units HPD & LPD which produces less amount of Urea. In case of failure of Gas Separator, system goes to halt state where temperature and pressure of HPD & LPD have increased with the help of control valve and conversion of Urea is decreased here. In case of failure of any one among HPD & LPD system does not work. There is only single repairman for the system and only one failure occurs at a time. Priority of repair is given to recent failed unit. Failure time distribution is exponential for each unit and the distributions of repair times are arbitrary. Various measures like MTSF, steady state availability, busy period of repair man, expected no visits by the repairman & Profit analysis of the system has been computed graphically using the theory of Semi Markov Processes and Regenerative point technique.

MODEL DESCRIPTION:

Various states of the system are shown in the state transition diagram in fig.1. All the states \(S_0\), \(S_1\), \(S_2\), \(S_3\), \(S_4\), \(S_5\), \(S_6\) and \(S_7\) are regenerative states. Here states \(S_0\), \(S_4\) and \(S_7\) are operative states, \(S_1\), \(S_2\), \(S_5\) and \(S_6\) are failed states & \(S_3\) is halt state.
NOTATIONS:

\( \lambda_1 \): Constant failure rate of unit 1.

\( \lambda_2 \): Constant failure rate of unit 2.

\( \lambda_3 \): Constant failure rate of unit 3.

\( \beta \): Operating rate of control valve.

\( \alpha \): Repair rate of unit 1, 2 and 3.

\( S_i \): States of the system with number \( i \), \( i=1, 2, 3 \ldots 7 \).

\( O_i, O_{II}, O_{III} \): Unit 1, 2 & 3 is in operating state.

\( f_{r_1}, f_{r_{II}}, f_{r_{III}} \): Unit 1, 2, 3 under repair.
Unit 3rd is under repair from the previous state.

Unit 3rd is waiting for repair.

$G(t), g(t)$: cdf and pdf of repair time of all units.

**TRANSITION PROBABILITIES:**

The non-zero elements $p_{ij}$, are given by

$$p_{01} = \frac{\lambda_1}{\lambda_1 + \lambda_2 + \lambda_3}, \quad p_{02} = \frac{\lambda_2}{\lambda_1 + \lambda_2 + \lambda_3},$$  
$$p_{03} = \frac{\lambda_3}{\lambda_1 + \lambda_2 + \lambda_3}; p_{10} = 1,$$

$$p_{20} = 1, \quad p_{34} = 1,$$

$$p_{40} = g^*(\lambda_1 + \lambda_2), p_{475} = \frac{\lambda_2}{\lambda_1 + \lambda_2} [1 - g^*(\lambda_1 + \lambda_2)],$$
$$p_{476} = \frac{\lambda_1}{\lambda_1 + \lambda_2} [1 - g^*(\lambda_1 + \lambda_2)], p_{57} = 1$$

$$p_{67} = 1, p_{70} = g^*(\lambda_1 + \lambda_2),$$

$$p_{75} = \frac{\lambda_2}{\lambda_1 + \lambda_2} [1 - g^*(\lambda_1 + \lambda_2)], p_{76} = \frac{\lambda_1}{\lambda_1 + \lambda_2} [1 - g^*(\lambda_1 + \lambda_2)]$$

It can be verified by these transition probabilities that

$$p_{01} + p_{02} + p_{03} = 1, p_{10} = 1,$$

$$p_{20} = 1, \quad p_{34} = 1,$$

$$p_{40} + p_{475} + p_{476} = 1, p_{57} = 1,$$

$$p_{67} = 1, \quad p_{70} + p_{75} + p_{76} = 1$$

Mean sojourn times $\mu_i$ in the state $S_i$ are

$$\mu_0 = \frac{1}{\lambda_1 + \lambda_2 + \lambda_3}, \quad \mu_1 = -g''(0),$$

$$\mu_2 = -g''(0), \mu_3 = \frac{1}{\bar{r}},$$

$$\mu_4 = \frac{1}{\lambda_1 + \lambda_2} [1 - g^*(\lambda_1 + \lambda_2)], \mu_5 = -g''(0),$$
\[
\mu_6 = -g^r(0), \mu_7 = \frac{1}{\lambda_1 + \lambda_2} [1 - g^r(\lambda_1 + \lambda_2)]
\]

The unconditional mean time taken by the system to transit for any regenerative state ‘j’ when it (time) is counted from the epoch of entrance in to state ‘i’ is mathematically stated as

\[
m_{ij} = \int_0^\infty t dQ_{ij}(t) = -q^r_{ij}(0)
\]

\[
m_{01} + m_{02} + m_{03} = \mu_0, m_{10} = \mu_1,
\]

\[
m_{20} = \mu_2, m_{34} = \mu_3,
\]

\[
m_{40} + m_{475} + m_{476} = \int_0^\infty t g(t) dt, m_{57} = \mu_5,
\]

\[
m_{67} = \mu_6, m_{70} + m_{75} + m_{76} = \mu_7
\]

where, \( \int_0^\infty t g(t) dt = K_1(say) \)

**MEAN TIME TO SYSTEM FAILURE:**

Mean time to system failure (MTSF) of the system is determined by considering failed state as absorbing state when system starts from initial state \( S_0 \) is

\[
\text{MTSF}\equiv T_0 = \lim_{s\to 0} \frac{1-\phi^*_0(s)}{s}
\]

Using L’ Hospital Rule & putting the value of \( \phi^*_0(s) \), we have

\[
T_0 = \frac{N}{D}
\]

where \( N = \mu_0 & D = 1 \)

**AVAILABILITY ANALYSIS:**

Using the theory of regenerative processes, the availability \( A_0 \) of the system is given by

\[
A_0 = \lim_{s\to 0} \left(sA_0^*(s)\right) = \frac{N_1}{D_1}
\]

where

\[
N_1 = \mu_0 p_{70} + \mu_4 p_{03} p_{70} + \mu_7 p_{03} (1 - p_{40})
\]

\[
D_1 = \mu_0 p_{70} + \mu_1 p_{01} p_{70} + \mu_2 p_{02} p_{70} + \mu_5 p_{03} p_{70} + K_1 p_{03} p_{70} + p_{03} (1 - p_{40}) \{ \mu_5 p_{75} + \mu_6 p_{76} + \mu_7 \} \]
BUSY PERIOD ANALYSIS OF A REPAIRMAN:

Busy period analysis of a repairman is given by

\[ B_0 = \frac{N_2}{D_1} \]

where

\[ N_2 = p_{70}(K_1p_{01} + K_1p_{02} + K_2p_{03}) + (K_4p_{75} + K_4p_{76} + \mu_7)(p_{34}p_{03}(p_{47} + p_{57})) \]

& \( D_1 \) is already specified.

EXPECTED NUMBER OF VISITS OF REPAIRMAN:

Expected no. of visits of repairman is given by

\[ V_0 = \frac{N_3}{D_1} \]

where

\[ N_3 = p_{70}(p_{01} + p_{02} + p_{03}) = p_{70} \]

& \( D_1 \) is already specified.

PROFIT ANALYSIS:

The expected total profit acquired to the system is given by

\[ P = C_0A_0 - C_1B_0 - C_2V_0 \]

where

\[ C_0 = \text{Revenue per unit up time of the system.} \]
\[ C_1 = \text{Cost per unit up-time for which the repairman is busy.} \]
\[ C_2 = \text{Cost per visit of a repairman.} \]

GRAPHICAL REPRESENTATION AND CONCLUSION:

The following particular cases are considered for graphical representation. Let us suppose that \( g(t) = \alpha e^{-\alpha t} \). Therefore, we have

\[ p_{01} = \frac{\lambda_1}{\lambda_1 + \lambda_2 + \lambda_3}, \quad p_{02} = \frac{\lambda_2}{\lambda_1 + \lambda_2 + \lambda_3}. \]
\[ p_{03} = \frac{\lambda_3}{\lambda_1 + \lambda_2 + \lambda_3}, \quad p_{10} = 1, \]

\[ p_{20} = 1, \quad p_{34} = 1, \]

\[ p_{40} = \frac{\alpha}{\lambda_1 + \lambda_2 + \alpha}, \quad p_{47^5} = \frac{\lambda_2}{\lambda_1 + \lambda_2 + \alpha}, \]

\[ p_{47^6} = \frac{\lambda_1}{\lambda_1 + \lambda_2 + \alpha}, \quad p_{57} = 1 \]

\[ p_{67} = 1, \quad p_{70} = \frac{\alpha}{\lambda_1 + \lambda_2 + \alpha}, \]

\[ p_{75} = \frac{\lambda_2}{\lambda_1 + \lambda_2 + \alpha}, \quad p_{76} = \frac{\lambda_1}{\lambda_1 + \lambda_2 + \alpha} \]

\[ \mu_0 = \frac{1}{\lambda_1 + \lambda_2 + \lambda_3}, \quad \mu_1 = \frac{1}{\alpha} = K_1, \]

\[ \mu_2 = \frac{1}{\alpha} = K_1, \quad \mu_3 = \frac{1}{\beta} = K_2, \]

\[ \mu_4 = \frac{1}{\lambda_1 + \lambda_2 + \alpha}, \quad \mu_5 = \frac{1}{\alpha} = K_1, \]

\[ \mu_6 = \frac{1}{\alpha} = K_1, \quad \mu_7 = \frac{1}{\lambda_1 + \lambda_2 + \alpha} \]
As shown in fig. 2 the behaviour of MTSF w.r.t. rate of failure of Gas Separator ($\lambda_3$) for the different values of the rate of failure of HPD ($\lambda_1$). It clear from the figure that MTSF gets decreased with increase in values of rate of failure of Gas Separator ($\lambda_3$). Also MTSF decreases as failure rate of HPD ($\lambda_1$) increases.
As shown in fig. 3 nature of profit w.r.t to rate of failure of Gas Separator ($\lambda_3$) for the different values of rate of failure of HPD ($\lambda_1$). As the failure rate of Gas Separator ($\lambda_3$) increases, the profit of the system decreases. Also, on the increase in the failure rate of HPD ($\lambda_1$), profit decreases.

![PROFIT VS COST PER UNIT UP TIME OF THE SYSTEM($C_0$) FOR THE DIFFERENT VALUES OF FAILURE RATE OF GAS SEPARATOR($\lambda_3$)](image)

Figure 4. Profit vs cost per unit up time of the system for the different values of failure rate of gas separator

As shown in fig.4 behaviour of profit w.r.t. cost per unit up time of the system ($C_0$) for the different values of failure rate of Gas Separator ($\lambda_3$). As the values of $C_0$ increases profit of the system also increases. The conclusion drawn from the graph is given below:

1. For $\lambda_3 = 0.0006$ profit is positive or zero or negative according as $C_0 >$ or $= or < 1718.7346$. It would not be helpful if the cost per unit up-time of the system is less than 1718.7346.
2. For $\lambda_3 = 0.006$ profit is positive or zero or negative according as $C_0 >$ or $= or < 2430.90$. It would not be helpful if the cost per unit up-time of the system is less than 2430.90.
3. For $\lambda_3 = 0.06$ profit is positive or zero or negative according as $C_0 >$ or $= or < 2837.856$. It would not be helpful if the cost per unit up-time of the system is less than 2837.856.

**CONCLUSION:**

The paper analyses the Profit evaluation of the Urea Plant. In our study conclusions have been drawn on the basis of a particular case. However, our model can be used by anyone using such system and can draw the conclusion in the same manner by putting those values of parameters in the general expressions obtained by us for the model, which exist for his/her system.
REFERENCES:


