American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-6, Issue-5, pp-130-133
www.ajer.org
Research Paper Open Access

Reliability Measures for Risk Mitigation of Transient Surge Pressure in Water Distribution System

Dr. Sapna Jain[1], Dr. Ajay Kumar Singhal[2],
[1]*Assistant Professor Department of mathematics, JSS academy of technical education, Noida*
[2]*Project Manager Larsen &Toubro Ltd., New Delhi*

Abstract: *In a water distribution system, pipelines are failed catastrophically as a result of surge pressure events like pipe burst or a pipeline collapse from buckling. Authors have made a mathematical model of a water distribution system with surge protection device to enable designers in mitigating risk against surge pressure [4]. In this paper an expression is deduced for system reliability and probabilistic behavior is observed over a period of time with different surge protection devices. Since the system is of non-markovian nature, the mathematical formulation of the problem is carried out by using supplementary variable technique. The model is solved by using L.T. (Laplace Transformation) technique for reliability function.*

Keywords: *Water distribution system, state transition diagram, supplementary variable technique, surge protection, reliability*

$\int : \int_0^\infty$

λ_A : Constant minor failure rate of subsystem A and subsystem C

λ_{A_1} : Constant major failure rate of subsystem A and subsystem C

λ_B : Constant failure rate of subsystem B

$\bar{S}_\phi(x) / \bar{S}_\eta(y)$: Probability density function of repairs of subsystem A & C /subsystem B in the time interval $((x, x+\Delta)/(y, y+\Delta))$ respectively.

I. Introduction

A water distribution is divided in to three units viz. pumping station (*A*), surge protection device (*B*) & water transmission main (*C*) and are connected in series.

A surge phenomenon occurs due to sudden closure of valves, power failure of pumping station, water column separation etc. and involves development of huge transient pressure in the system and will lead to sudden failure of the pipeline or equipment or a pipeline. In order to avoid surge pressure damage to piping and pipelines there are a number of alternatives available like:[1],[4]:-

The selection of surge protection device is great challenge to designers during the design process of the system based system’ s requirement and associated cost. For this purpose quantification of risk associated with various surge protection device is must and their effects on overall system’ s reliability. For the purpose of study only thee devices from above mentioned alternatives are considered for the analysis and probability of failure is assigned based on the design aptitude.[1],[4]

(i) Stronger Pipe work to Withstand Pressure Surges

Pipe work should be designed according to the damaging effects of pressure surges. This is necessary where conventional means of mitigating surge pressures may not be employed such as when handling radioactive, highly lethal fluids, where no fluid is allowed to escape. Increase in pipe wall thickness, flange rating and pipe supports should be designed to prevent environment failure. In increasing the wall thickness of the pipe in case of this reduces the internal diameter or the pipe modulus the celerity will increase and create higher surge pressures. To prevent an increase in fatigue damage devices such as variable speed drives for pumps and slow closing valves is considered. Although a more costly method of mitigating transient pressures,

once installed higher class pipe work does not require further maintenance and testing as other mitigation devices require.
Based on the technical aptitude failure rate assigned the alternative is 0.1 for reliability prediction of the system.

(ii) One Way Surge Tanks

One way surge tanks are mainly used on water transmission lines to overcome sub atmospheric pressures. They only function when the local hydraulic grade line falls below the water level in the tank. Under transient conditions the places in the pipeline where it is most likely to occur will be at significant reductions in upward slope.

They prevent a pipeline collapsing due to buckling from external pressure. The surge tank is suitable sized to fill a cavity formed by vapor column separation. The discharge pipe has to be sized to make enable the fluid to enter the pipeline. A check valve is normally fitted to the discharge pipe to prevent positive pressures overflowing the surge tank. To fill the surge tank a pipe from the main transmission line via a float valve feeds the tank. Surge tanks do not provide protection against positive pressure. more time must be allowed in the pipeline for the surge tanks to be filled again after an event.[4] Based on the design aptitude failure rate assigned the alternative is 0.2 for reliability prediction of the system.

(iii) Relief Valves

Relief valves are in a variety of designs. A simple conventional spring loaded relief valve is not likely to operate sufficiently fast to relieve a pressure wave as it passes the relief valve nozzle. *To be effective against shock waves a pressure relief valve is placed as close as practicable to the main pipe which is being protected. If a valve is located on a branch pipe the shock wave will have to pass the branch by a distance of about twice the branch \length before the reflected wave from the relief valve gets back to the pipe junction as a reduced pressure waves*. Specialized relief valves have been designed for use in the water industry. They are termed a Neyrpic valve. They are direct acting valve designed to operate in milliseconds. It is a simple spring-loaded disc with no guides that requires maintenance to ensure that the valve operates. Based on the practical experiences failure rate assigned the alternative is 0.3 for reliability prediction of the system.

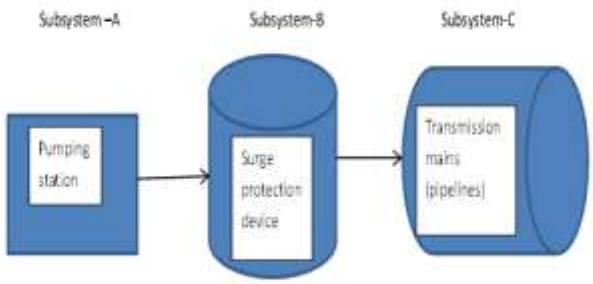

Fig.1 :Block Diagram of a Water Distribution system

Formulation Of Mathematical Model:

The model under consideration is exhibited in fig. 1. The flow of states of the system under consideration has been depicted in a state transition diagram [5] which is a logical representation of all possible state' s probabilities encountered during the failure analysis of water distribution system against transient surge pressure.[1],[4] These probabilities are mutually exclusive and provide the complete Markovian characteristic [3] of the water distribution process. Therefore using continuity arguments and elementary probability considerations, one obtains the difference differential equations for the stochastic process [6,7,8], which is discrete in space and continuous in time. These difference differential equations are solved by Laplace Transform Technique [6,9,10,11] by using initial and boundary conditions obtained by state transition diagram and then the Laplace Transform of operational availability by using laplace transform technique. When repair rates follow exponential time distribution i.e. setting $\bar{S}_{\varphi}(s) = \frac{\varphi}{s+\phi}$ in equation of operational availability [6], one obtains the Laplace transform of the operational availability of the distribution system as below:

$$\bar{P}_{up}(s) = operational\ Availability = \left[1 + \frac{2\lambda_A}{(s+\lambda_{A_1}+\lambda_A+\lambda_B)} + M\right] * \frac{1}{D(s)} \quad ..(1)$$

$$M = \frac{2\lambda^2_A}{(s+\lambda_{A_1}+\lambda_A+\lambda_B)(s+2\lambda_{A_1}+\lambda_B)}$$

Where

D(s)= $s + 2\lambda_A + \lambda_B + X\overline{S_\varphi(s)} + Y\overline{S_\eta(s)}$ $X = \lambda_B + \frac{2\lambda_A\lambda_B\overline{S_\varphi(s)}}{(s+\lambda_{A_1}+\lambda_A+\lambda_B)}$ +N

where

$$N = \frac{2\lambda_B\overline{\overline{S_\phi(s)}^2}\lambda_A^2}{(s+\lambda_{A_1}+\lambda_A+\lambda_B)(s+2\lambda_{A_1}+\lambda_B)}$$

$$Y = \frac{4\lambda_{A_1}\lambda^2_A}{(s+\lambda_{A_1}+\lambda_A+\lambda_B)(s+2\lambda_{A_1}+\lambda_B)} + \frac{2\lambda_A\lambda_{A_1}}{(s+\lambda_{A_1}+\lambda_A+\lambda_B)}$$

Now we obtain the Laplace transform of the reliability on substituting all repairs as zero in the L.T. of operational availability of the system [equation 1] and then taking its inverse Laplace transform we get an expression of reliability function[8] as below:

$$R(t) = e^{-(2\lambda_A+\lambda_B)t} - \frac{2\lambda_A\lambda_{A_1}}{\lambda_A-\lambda_{A_1}}e^{-(\lambda_{A_1}+\lambda_A+\lambda_B)t} +$$

$$\frac{2\lambda^2{}_A\lambda}{(\lambda_A-\lambda_{A_1})^2}e^{-(2\lambda_{A_1}+\lambda_B)t} + \frac{\lambda_A(2\lambda_{A_1}-\lambda_A)}{(\lambda_A-\lambda_{A_1})^2}e^{-(2\lambda_{A_1}+\lambda_B)t} \quad \ldots(2)$$

With the help of these expressions in the Operational availability, reliability we have illustrated the graphs fig (2) predicting the system' s behavior over a period of time.The effect of using surge proction device on system reliability is studied for three cases;-

Case(1) When surge protection measure is Stronger Pipe work to Withstand Pressure Surges having a failure rate λ_B =` and λ_A =.1.

Case(2) When surge protection device is **one way surge tank** having a failure rate λ_B =.2 and λ_A =.1.

Case(3) When surge protection device is **Relief valve**s having a failure rate λ_B =.3 and λ_A =.1.

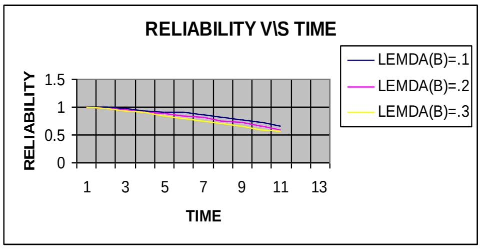

Fig.2Reliability v/s Time

II. Conclusions

The study of the above curve leads to many conclusions. It indicates that selection of surge protection device has serious impact on overall reliability of the system and invites due attention during the design stage. Designer can carry out techno-economical evaluation and will be able to find optimal solution based on system requirements for surge protection and cost viability. This curve also depicts the percentage of equipments which should be available after *t* years of operation. When *t* approaches infinity, the probability of survival approaches zero, therefore any equipment, which is available for use after an extended period of time, is the direct result of maintainability or the ability to repair or maintain.

References

[1]. Calabro S.R. (1962), Reliability Principles and Practices, McGraw Hill, Book Company, Inc. New York.Cambridge, England.
[2]. Cox, D.R. (1955); the Analysis of Non Marcovian Stochastic Process by Inclusion Of Supplementary Variable; Proc. Camb. Philsoc, Vol 51, PP 433-441.
[3]. Gullick, R.W. et al, 2004. Occurrence of transient. Low and Negative Pressure in distribution System.

[4]. Jour. AWWA, 96:11:52.
[5]. H. Gupta And J. Sharma (1981); State Transition Matrix And Transition Diagram Of K-Out-Of-N: G System With Spares, IEEE Transactions On Reliability, R-30(4): PP395-397.
[6]. Jain Sapna(2004), Reliability Estimation Of Various Complex Systems Under Mixed Redundancy, Thesis Submitted To C.C.S. University,Meerut,India
[7]. Kuo Way, Zuo Ming J. (2003); Optimal Reliability Modeling, John Willey & Sons, Inc., USA.
[8]. Lee Bain and Max Engelhard (1991); Statistical Analysis Of Reliability And Life Data Models, Marcel Dekker.
[9]. Medhi, J. (1982), Stochastic Processes, Willey Eastern Limited, New Delhi, India.
[10]. Shooman, M.L. (1968); Probabilistic Reliability: An Engineering Approach, McGraw Hill, New York.
[11]. Wider D.V. (1946), The Laplace Transforms, Printiceton University Press,Princeton,New Jersey
[12]. Ivo Pothof,Bryan Karney(2009)" Guidelines for transient analysis in water transmission and distribution systems"
[13]. Boulos, P.F.; Wodd, D.J.; & Funk .E. 1990. A Comparison of Numerical and Exact solution for Pressure Surge analysis. Proc. 6th international BHRA conf. On pressure surge (A.R.D. Thorley, editor).
[14]. H.M. Ramos,a. Borga(2016) " Surge effects in pressure systems for different pipe materials" chapter in advance resources and hydraulic engineering
[15]. Thesis " Modeling Of Hydraulic Transients In Closed Conduits" byAli EL-Turki, Department of Civil and Environmental engineering Colorado State University,USA