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Models of probability of failure on demand for safety instrumented system using atmospheric elements

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ABSTRACT

Safety instrumented system (SIS) is an essential device to protect the industries from dangerous situations. Reliability of SIS is measured by the analysis of probability of failure on demand (PFD) which is an integral part in quantitative risk and safety assessment to determine the risk and safety integrity level. PFD varies from location to location due to atmospheric effects. In this paper, new mathematical models are proposed to compute the failure probability of the equipment due to corrosion considering three atmospheric factors: temperature, humidity and wind speed. The models are solved by least squares methods using standard data to identify the parameters involved in the models. Finally, comparison between the two proposed models is made to select the better model for computing the failure probability. The models provide good correlation with reference data. These models can be used to compute the PFD at any geographical location.

1. Introduction

Safety instrumented system (SIS) is very important for detecting hazardous events and preventing them from forming accidents. For this reason, SIS is used in many industrial sectors. The reliability analysis of SIS is performed by analyzing the probability of failure on demand of its components. Determination of failure probability is very important to incorporate preventive and protective safeguards: preventive to reduce undesirable events and protective to reduce the undesirable consequences (American Institute of Chemical Engineers, 1994, 2001; Ouache et al., 2014). Many methods have been proposed to determine the level of risk and the safety integrity level (SIL) (Qinqin et al., 2014; Pinto, 2014), such as checklist analysis, preliminary hazard analysis (Ozog, 1985), "What-if" analysis, hazard and operability study (Dunjó et al., 2010; Mohammadfam et al., 2012; Bendixen and O'Neill, 1984), failure modes and effects analysis, Bowtie analysis (Khakzad et al., 2012; Ferdous et al., 2012; Mokhtari et al., 2011), fault tree analysis, event tree analysis (Ouache and Adham, 2014a, 2014b), cause–consequence analysis, human reliability analysis and layer of protection analysis (Summers, 2003) which are classified under qualitative, semi-quantitative and quantitative approaches.

Quantitative risk and safety analysis is an effective approach used to estimate the risk and SIL in industry in order to prioritize the risks and to find a way to reduce them to acceptable level (Arunraj and Maiti, 2009; American Institute of Chemical Engineers, 1989a; Fu et al., 2014). However, quantitative risk and safety approach still faces the problem of uncertainty that refers mainly to the uncertainty of failure probability (Markowski et al., 2009; Khakzad et al., 2012, 2013; Pasman and Rogers, 2013). The failure data of the equipment in the most references are provided without referring to the circumstances, where the data collection must consider the factors which can influence the failure rates (American Institute of Chemical Engineers, 1989b). Therefore, the analysis of the factors that can affect failure probability is the key element to deal with uncertainty. Furthermore, the failure probability of equipment depends on the circumstances of the equipment operation (Ouache et al., 2015). The identical system and the same circumstances should be used for data collection. Three general types of causes for failure probability have to be taken into account: (i) external events e.g., earthquakes, tornadoes, floods and sabotage; (ii) equipment failures e.g., corrosion, vibration and defects; (iii) human failures e.g., maintenance error, operational error and critical response error due to inappropriate actions (American Institute of Chemical Engineers, 2001).

The scope of this paper is to investigate the effects of environmental related factors on the failure probability of the equipment

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and to develop mathematical models to compute the failure probability for given atmospheric factors at a location around the world. Construction of a mathematical model is based on the basic physical laws and empirical considerations of a real problem. The mathematical model may not always have an analytical solution and is very often hard to obtain the solution by hand computation. Therefore we employ a computer to achieve the solution by numerical methods. If the model can sufficiently represent the real problem, the numerical methods can be used to solve the model on the computer which generally provides a practical solution to the problem (Kabir, 2007). Increasing computer memory and speed year by year significantly reduces the required time of numerical model and improves the accuracy in computation. Numerical models are massively used in industry for analysis, prediction, product design etc. Many impossible, dangerous or expensive experiments such as explosions, accidents are replaced by simulation of the corresponding models.

In this paper, two mathematical models are proposed to compute the failure probability of equipment due to corrosion at any geographical location by taking into consideration three external factors: temperature, humidity and wind speed. The external factors have the influences on the corrosion of the equipment where the equipment under investigation is of the same operation time, design and material. Least squares method is employed to identify the parameters involved in the model. Finally, comparison between the two proposed models is made to obtain the better model for computing the failure probability.

2. Safety instrumented system

Safety instrumented system (SIS) is employed to prevent the industries from dangerous situations. SIS plays an important role as a protective layer around industrial process systems where different names are given to SIS, such as emergency shutdown system, safety shutdown system and safety interlock (Hokstad, 2014; Andy Ingrey et al., 2007; Instrument Society of America, 2012). SIS consists of various elements: sensor, input isolator block (analogue input), logic system, analogue output isolator block (analogue output) and actuator (control valve) as shown in Fig. 1. Sensors and actuators installed in different locations are exposed to different factors, such as chemical, physical and atmospheric elements which can affect the probability of failure on demand for these components. Statistics mentioned that the highest percentage of probability of failure on demand is assigned to actuator as 40% followed by sensor as 25%, control system as 15% and interface modules as 10%, as depicted in Fig. 1. The two last components have less failure probability which refer to the protected environment (protected control room). Fig. 1 also presents the components of the SIS with percentages of probability of failure on demand for each component.

3. Probability of failure on demand

Probability of failure on demand is the likelihood of a system failure that can be computed by the total number of failures divided by the total period of time. Different sources are available to obtain failure probability, such as center of chemical process safety (CCPS) (American Institute of Chemical Engineers, 1989b), institute of electrical and electronics engineers standard (IEEE 500) (The Institute of Electrical and Electronics Engineer, 1986), offshore reliability data (OREDA) (OREDA, 2002; Stein Hauge, 2010), PDS data handbook (DS – Norwegian acronym for "reliability of computer based safety systems") (Stein Hauge, 2010), RNNP reports (Norway's petroleum activity) (Petroleum Safety Authority, 2010), Exida safety equipment reliability handbooks and FARADIP (FAilure RAte Data In Perspective) database (Hauge et al., 2010). Data of failure probability are statistically reliable but they do not consider the specific features and the conditions of the case under study (Reyes, 2008).

Failure probability should be measured by experienced persons with proper knowledge of the equipment, the operation and safety issues (Lundteigen and Rausand, 2008). Furthermore, failure probability analysis has to take the following factors into consideration: (i) characteristics of the equipment, (ii) internal fluid of equipment, (iii) external circumstances of equipment. Using the reliable references such as CCPS, IEEE 500 and OREDA can help to deal with uncertainty in failure probability (Center for Chemical Process Safety, 2000; Markowski et al., 2009; Khakzad et al., 2012, 2013).

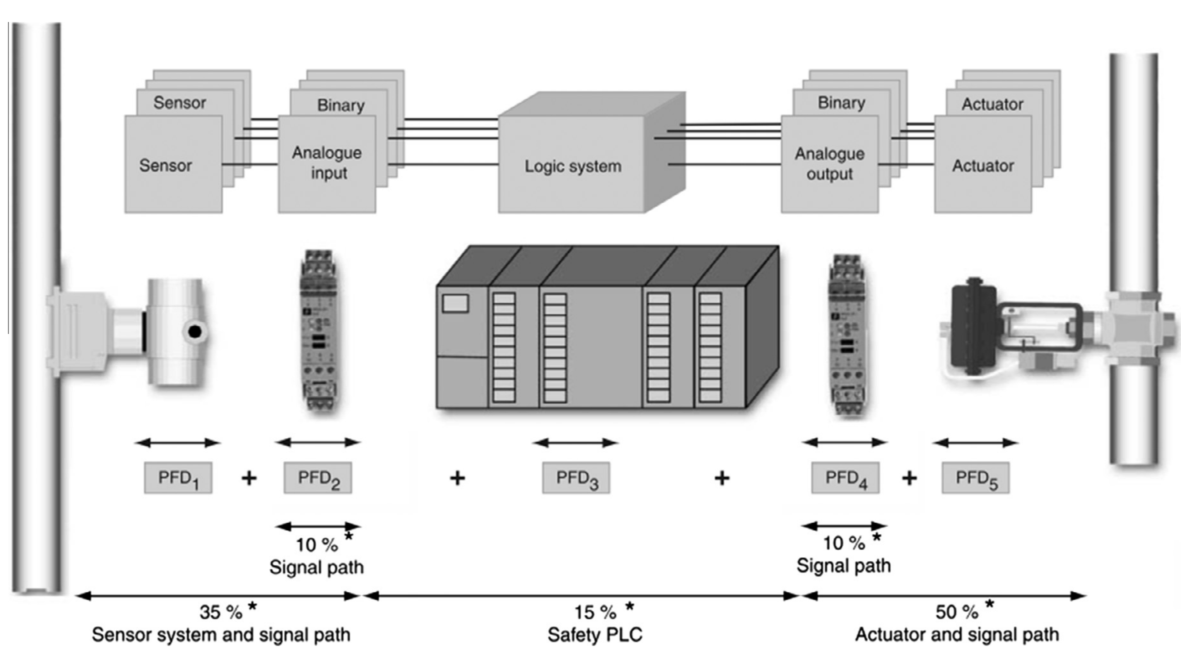

Fig. 1. Components of safety instrumented system with PFD.