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Fuzzy logic-based user interface design for risk assessment considering human factor: A case study for high-voltage cell

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ABSTRACT

This paper presents a novel risk assessment model considering human factor based on the fuzzy logic approach. For the contribution of the literature, not only the number of people is included in the process of risk assessment, but also with the human factor as a quantitative entry in this study. A flexible and user-friendly risk assessment interface is developed using LabVIEW program, which puts at disposal different applications for the course material. Designed interface gives an opportunity to users to assess risks in a wide range of consequences containing many different combinations and options. The interface is tested for a 100-kV high-voltage cell as a case study. As a result, it is seen that the interface assesses plenty of input elements and possibilities in a short time. For this reason, the fuzzy logic approach is suggested as a suitable method for risk assessment.

1. Introduction

In the last two decades, there has been a dramatic increasing of human contribution to accident development, reaching levels of percentages of as high as 70–80%, independently of the technological domain of application. There are two main reasons for such relevant increasing, namely: (a) the very high reliability and refinement of mechanical and electronic components; and (b) the complexity of the system and the role assigned to human operator in the control loop (Cacciabue, 2000). It is now widely accepted that the majority of accidents in industry generally are in some way attributable to human as well as technical factors in the sense that actions by people caused to accidents, or people could have acted better to avert them (Jon Espen and Jan Erik, 2011).

In general, the term "human factor" is used to describe accident causality when cause is attributed to the characteristics or behavior of an individual or organization, rather than structural or mechanical failure or some environmental or other contextual factors that are outside our control. "Human errors," on the other hand, are the mistakes people make often resulting from these human factors (Elise and Sierra, 2006). Human factors may refer to various traits or "elements of the human" as individuals, which should be considered for safe and effective results from engineered systems. Or, the term may mean the applied science technology relating fundamental human sciences (like anatomy, physiology, neuro-psychology) to industrial systems (Cadick et al., 2006).

Despite the growing awareness of the significance of human factors in safety, particularly major accident safety, the focus of many sites is almost exclusively on engineering and hardware aspects, at the expense of 'people' issues (Health and Safety Executive, 2005). Careful consideration of human factors at work can reduce the number of accidents and cases of occupational ill-health. It can also pay dividends in terms of a more efficient and effective workforce (Health and Safety Executive, 2009). It is important to decide if the risks vary due to human influences. For example, there is a higher likelihood of human error between 2.00 and 5.00 am when physiology dictates that the human body should be asleep. The risks will also be influenced by how well-trained people are, whether they have had sufficient rest before starting a shift, and whether they have taken alcohol or used drugs. You may find useful information in your company's own accident reports and analyses (Health and Safety Executive, 2009).

The process of risk analysis and assessment does not include predefined definite steps. Risk assessment is an evaluation of those likelihoods and consequences. A risk assessment can either be qualitative or quantitative, although the emphasis in the system safety process typically is on qualitative risk assessment (Hardy, 2010). Risk factors and assessments are difficult to describe

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mathematically. However, if you can describe a system risk assessment qualitatively, you can use fuzzy logic. The fuzzy system can serve as a useful tool for risk analysis to consider organizational and human factors so as to enhance their study and highlight the uncertainty related to human performance variability (Kirytopoulos et al., 2014). The advantages of fuzzy logic control include the integration of human expertise, experience and knowledge into the rule base which has qualitative, descriptive and linguistic quantities (Wang and Liu, 2001). Although many studies using various methods for risk assessment are available in the literature, it is too difficult to compare them in terms of concluded risk assessments for various systems using different models. For this reason, some risk assessment standards have been developed, and are summarized in the study (Rouhiainen and Gunnerhed, 2002; Hale et al., 1990).

Statistics and probabilistic approaches are based on two qualities, frequency and severities, which are mostly, applied in risk assessment studies (Rouhiainen and Gunnerhed, 2002; Hale et al., 1990; Cuny and Lejeune, 2003; John Garrick and Robert, 2002). However, these models are subjective because availability of objective data is very rare and inadequate for risk assessment. Therefore, subjective judgment emerges as a consequence of assessment. If there are no prior data about the system or the system has been installed recently, risk can only be assessed in light of information given by the experts who are aware of the possible hazards.

On the other hand, in the fuzzy logic method, qualitative and quantitative risk methodologies are combined and the structure becomes more flexible. Thus, the risk rate can be stated by both numerical values as in the qualitative risk analysis and definitions as in the quantitative risk analysis in the fuzzy logic approach. By this means, the risk rate can be determined using many inputs such as possibility of the hazard, frequency of the exposure, and degrees of possible harm. In addition, it can easily be applied to any complicated system by means of changing the rule base. The fuzzy logic method can also incorporate expert human judgment to define those variables and their relationships. Thus, it can be closer to reality and can be site specific as compared to some of the other methods. For this reason, the fuzzy logic is getting increasingly popular for risk assessment nowadays. Various applications have been carried out recently. Sii et al. (2001) have developed a security model related to marine environment and marine security systems using the fuzzy logic approach. The developed model gives out more effective results compared to previous risk models. Nieto-Morote and Ruz-Vila, 2011 have presented risk assessment based on the theory of fuzzy set indicating that fuzzy logic is used as an effective analyzing tool in the case of excessive amounts of risky situations in the analytic hierarchy process (AHP). A fuzzy logic-based risk assessment tool has been developed to assess the risk of river-based hydroelectric power plant projects by Kucukali (2011). Fuzzy logic methodology enables multi-criterion decision analysis and provides an easy and understandable way to analyze the possible risks that emerge in the projects. Bajpai et al. (2010) developed a method in which two linguistic fuzzy scales are used at the base of trapezoidal fuzzy numbers in the modification of the early developed security risk factor table (SRFT) model by using the concept of fuzzy logic. This method was tested at a refinery and compared to formerly used methods so that it could be explained. Cho et al. (2002) emphasize that conventional risk assessments involve ambiguities. In order to get rid of these ambiguities, a new method is suggested to assess risks more securely by using fuzzy concepts. Cho et al. present new forms of fuzzy membership curves as well. Markowski et al. (2011) have indicated that workers happen to be a potentially risk group in an explosive environment and their safety and health conditions are based on regulations published by ANSI/AIHA in the United States and ATEX in the European Union. They emphasize that risk assessment is a must for ATEX but is not so for ANSI/AIHA, and state that in order to assess the risks, the assessment must come into existence in a semi-quantitative explosion layer of protection analysis (ExLOPA) that was implemented for the purpose of developing a standard method that did not earlier exist. Hu et al. (2007) developed a methodology named formal safety assessment (FSA) in order to increase marine security. Quantitative risk assessment and a comprehensive modeling of possible risk, along with the extent of frequency and severity especially in the navigation of seagoing vessel, were accomplished by analyses as a result of FSA approach as well. Hadjimichael (2009) not only developed a risk modeling methodology capable of stating the risk factors by using fuzzy expert systems named, The Flight Operations Risk Assessment System (FORAS), but also estimated cumulative effects of possible dangers in single-flight operations by using a quantitative relative risk index defined by the FORAS risk model. Li et al. (2008) developed a new risk assessment method that could assess the possible risk at a power system by determining the outage of power system components using a hybrid model consisting of fuzzy clumps and Monte Carlo simulation. Elsayed (2009) accomplished a multiple-attribute risk assessment by using a fuzzy inference system based on the usage of fuzzy clumps, rule base, and fuzzy inference engine. The suggested method was designed for seagoing vessel-operating modes as open sea and/or port input/output transit and was tested at a terminal during the loading–unloading process of a natural gas-loaded seagoing vessel. Lavasani et al. (2011) assessed the risk of hazards using a basic risk item (BRI) composed of fuzzy numbers because of the emphasized reason that obtained data cause uncertainty in risk assessment owing to complex and incomprehensible hazard mechanisms. In this study, a flexible and applicable risk assessment interface is developed using the fuzzy logic method involving the human factor. While in the classic methods the human factor is generally added to risk assessment as a multiplier, in the suggested approach, behavior attributes, as well as the number of persons, are also considered. Thus, elements originating from human behaviors that are likely to affect the possibilities of occurrence of dangers to an important degree are evaluated via the fuzzy logic approach.

2. Model description

Inelastic conventional methods are not suitable for dialectics due to the fact that an object either belongs to a clump or not, which means that the underlying logic is 1 or 0 and which can be stated by certain expressions as open-closed or hot–cold. Fuzzy logic is a mathematical method of processing uncertain and vague data. By using the basic properties and operations defined for fuzzy sets, any compound rule structure may be decomposed and reduced to a number of simple canonical rules (Ross, 2004; Morari et al., 2010).

In this study, the rules of fuzzy logic risk assessment are designated by availing the PILZ method; however, the boundary conditions are designated by taking advantage of the smooth passing of fuzzy logic unlike PILZ method that reduces the number of rule base.

Two main assessment units constituted as hazard and human factors include three inputs each that are likelihood (LO), frequency of exposure (FE), degree of possible harm (DPH), and fatigue and attention deficit (F/AD), stress (S), technical competence (CW/II), respectively, as seen in Fig. 1. Interim values are carried out with the fuzzy logic-based interface by reason of the fact that the number of linguistic labels belonging to inputs of the two main assessment units was reduced compared to conventional methods as variable gaps increased.

Membership functions of the inputs are seen in Fig. 2. Sharp transitions between the linguistic inputs labels are eliminated as