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A novel general approach to evaluating the reliability of gas turbine system

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ABSTRACT

In this paper, a new methodology named as vague lambda–tau, is proposed for reliability analysis of the repairable systems based on a trapezoidal vague set with different left and right heights. In this methodology, the trapezoidal vague set with different left and right heights is coupled with the conventional lambda–tau method to evaluate the vague expressions for OR-transition of the Petri Nets model. The qualitative and quantitative analysis of gas turbine system has been discussed in this work. In qualitative analysis, the Petri Net model is obtained from its equivalent Fault Tree and in quantitative analysis, the reliability parameters are evaluated using the vague lambda–tau methodology. The system reliability can be analyzed in a more flexible and intelligent manner by using the proposed approach.

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1. Introduction

For fast technological innovation, the developments of new products are becoming much complicated not only due to their system functioning but also because of their system components. Therefore, reliability analysis is an important field of academic research and practice. In the beginning, the idea of reliability of a system or a machine or a person was based on theoretical discussions. Later on, a mathematical shape was given to the concept of reliability of a system. The mathematical development of reliability gave thrust to many ideas in the field of electrical, mechanical and electronics engineering and allied industries. In order to render the system as safe as possible, a number of analysis techniques have been developed: Failure Mode Analysis, Event Tree Analysis, Markov Models and FTA. FTA is a powerful diagnostic technique and is widely used for demonstrating the root causes of undesired events in system failure. The concept of the FTA was developed by the Bell telephone laboratory in 1961 and it is widely used in many fields.

Traditionally, the reliability of a system's behavior is fully characterized in the context of probability measures. The outcome probability of the top event is certain and precise, as long as, the data of the basic events are from reliable information. However, in a real system, the information is inaccurate and supposed to have linguistic representation. The estimation of the precise value of the probabilities becomes very difficult in many applications. Therefore, in order to handle the insufficient information, the fuzzy methodology (Zadeh, 1965) is used to evaluate the system reliability. Determining the reliability of various systems using the fuzzy set theory and the fuzzy arithmetic can be found in the literature (Singer, 1990; Cai et al., 1991a, 1991b; Cheng and Mon, 1993; Chen, 1994; Verma et al., 2002; Huang et al., 2004).

The Fuzzy set theory has been shown to be a useful tool to handle the situations in which the data are imprecise. In real life problems, there may be hesitation or uncertainty regarding the belongings of an object to a set or not. In the fuzzy set theory, there is no means to incorporate such hesitation or uncertainty. For this, vague set (Gau and Buehrer, 1993) has been used. Chen (2003) presented the arithmetic operations between vague sets and also proposed a new method for analyzing the fuzzy system reliability based on vague sets. Kumar et al. (2005) presented a fuzzy reliability analysis of a marine power plant using the vague set theory, where the reliability of the components of the system is represented by trapezoidal vague sets defined on the universe of discourse [0, 1]. Shu et al. (2006) proposed an algorithm to evaluate the fault interval of the system components using vague FTA and applied this method to the failure analysis problem of Printed Circuit Board Assembly (PCBA). Taheri and Zarei (2011) investigated the Bayesian system reliability assessment in a vague environment.

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The FTA approach assumes that the causes of events are random and statistically independent. But certain common causes can lead to correlations in event probabilities which violate the independence assumptions and could exaggerate the likelihood of an event fault. State space based approaches like the Markov models overcome this limitation, but it requires the solution to be computed over a set of equations that increases exponentially with the number of components. To overcome these limitations, Petri Nets can be conveniently used since it allows us to describe large state spaces by a restricted number of model primitives (places, transitions and tokens). Unlike the Fault Tree, the use of Petri Nets also allows efficient simultaneous generation of minimal cut and path sets. Hura and Atwood (1988) proposed the use of Petri Nets to represent Fault Trees. Kumar and Aggarwal (1993) used both Petri Nets and Fault Tree methods for software reliability analysis. Petri Nets can also be used to directly simulate the Fault Trees. Liu and Chiou (1997) described such a method and proposed an algorithm for generating minimal cut sets of the translated trees. Knezevic and Odoom (2001) developed a new methodology which uses Petri Nets instead of the Fault Tree methodology and solves for reliability indices utilizing the fuzzy lambda–tau method. Prediction of failure in an industrial system by the use of Fuzzy Petri Net (FPN) was presented by Sharma et al. (2008). Chen et al. (2012) presented a new method for fuzzy risk analysis based on the proposed new fuzzy ranking method for ranking generalized fuzzy numbers with different left and right heights.

Bearing in mind the great importance of the gas turbine for plant operation, its reliability and other parameters like availability, mean time between failures, expected number of failures, etc., should be carefully evaluated in order to anticipate the technical and economical performance of the plant. In these types of problems, it rarely occurs that degree of acceptance, degree of rejection and degree of hesitation will be the same corresponding to different values of reliability. Therefore, in this paper, a new methodology named as vague lambda–tau is proposed for reliability analysis of the repairable systems based on a trapezoidal vague set with different left heights and right heights. In this methodology, the trapezoidal vague set with different left heights and right heights is coupled with a conventional lambda–tau method to evaluate the vague expressions for OR-transition of the Petri Nets model. This paper involves the qualitative and quantitative analysis of gas turbine system. In qualitative analysis, the Petri Net model is obtained from its equivalent Fault Tree and in quantitative analysis, the reliability parameters such as the *expected number of failures* (ENOF), *mean time between failures* (MTBF), *availability* ($\tilde{A}_T$), and *reliability* ($\tilde{R}_T$) are evaluated using the vague lambda–tau methodology.

The rest of the paper is organized as follows: In Section 2, the introduction to the Petri Net theory and conversion from FTA to a Petri Net model is presented, while the lambda–tau methodology for determining reliability of repairable systems is presented in Section 3. Section 4 introduces the basic definition and operations of the trapezoidal vague set with different left and right heights and Section 5 proposes a new approach of vague reliability and presents an algorithm to find out the vague reliability of a system. In order to illustrate the proposed approach, an example of a gas turbine system has been considered. Also, some comparisons with the existing approaches are discussed in Section 6. Finally Section 7 makes conclusions.

2. Petri Nets theory

Petri Nets are general purpose graphical and mathematical tools for describing the relations between conditions and events. Owing to the variety of logical relations that can be represented with Petri Net, it is a powerful tool for modeling system. It can be used not only for simulation, reliability analysis and failure monitoring, but also for dynamic behavior observation. This greatly helps fault tracing and failure state analysis. It has been subjected to a lot of mathematical work in the literature (Hura and Atwood, 1988; Liu and Chiou, 1997; Knezevic and Odoom, 2001; Sharma et al., 2008). In the field of reliability modeling, Petri Nets are easy to implement and more effective than the traditional FTA. Similar to the Fault Tree model, graphical models based on the Petri Net model can be constructed to represent the cause and effect relationship among events. Fig. 1 is the AND/OR logic gate operations of the Petri Net model corresponding to the Fault Tree AND/OR logic gates. Fig. 2 is a Fault Tree example in which events A–E are basic causes of event 0. The logical relations between the events are described as well. The

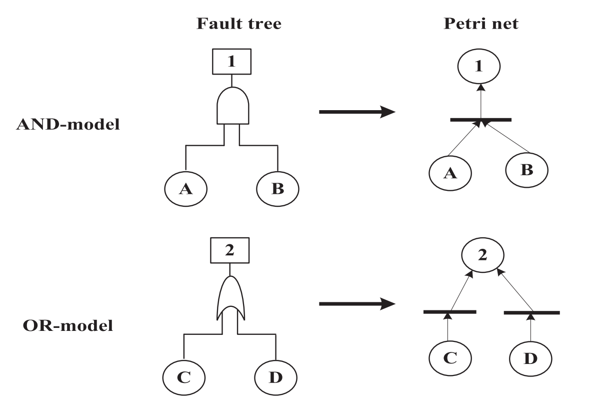

Fig. 1. Basic Fault Tree logic gates and their representation in the Petri Net model.

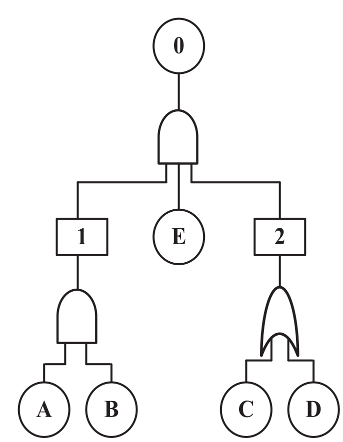

Fig. 2. The Fault Tree model.

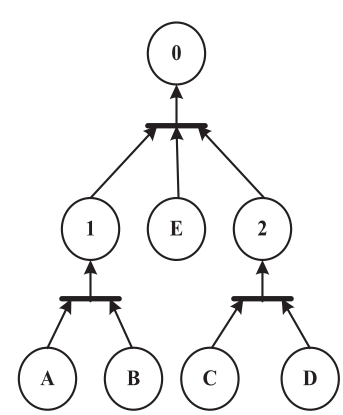

Fig. 3. The Petri Net transformation of Fig. 2.

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