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Risk assessment of wind turbines: Transition from pure mechanistic paradigm to modern complexity paradigm

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ABSTRACT

Many technological systems that are composed of technical parts embedded in human, organizational, and environmental contexts can be categorized as complex systems. They have various interactions and a nonlinear relationship between their components. They are also open to their environment and make exchanges with it.

Almost all traditional risk assessment techniques, such as Failure Modes and Effect Analysis (FMEA), Hazard and Operability Analysis (HAZOP), Fault Tree Analysis (FTA), and Probabilistic Risk Analysis (PRA) rely on a chain of linear cause and effect analysis. These techniques also have some limitations in terms of incorporating efficient links between risk models and human and organizational factors for studying modern complex technological systems.

This paper generally reviews existing approaches of risk assessment for complex technological and specifically studies risk assessment of wind turbines. Then it proposes an integrated risk assessment framework for complex technological systems through a Bayesian network considering various system levels and their interaction using a cause and effect approach.

Since wind turbines are instances of complex power generating systems consisting of several structural, electrical, and mechanical components interacting with human resource and organizational factors within natural, political, economic, and social environments, the proposed model is applied to assess risk and reliability in a wind turbine. Different scenarios of reliability analyses were investigated, which illustrated that Bayesian networks are effective for the reliability assessment of the chosen system and very useful for understanding the system behavior.

Contents

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1. Introduction

Continuing population growth and effort for improving the standards of living have led to an increasing energy demand all over the world. Energy needs are met by conventional energy sources which are based on fossil fuel resources. Even though the conventional energy sources have largely contributed to the economic development, there is essential need for increasing the use of renewable energy sources in the energy balance of each country. Renewable energy sources have experienced remarkable development during the first decade of the 21st century and investments in this field have increased by more than tenfold during eight years from 2004 to 2011 [1,2].

Wind turbines are a renewable source of energy expected to play an increasingly important role in providing electricity due to the increase in their capacities and number of grid-connected wind turbines [3]. Furthermore, wind power is estimated to be the fastest growing renewable energy resource and wind power penetration in power systems increases at a significant rate [4]. High penetration rate of wind power into power systems at present and in near future will have several impacts on their planning and operation. One of these impacts is the effect of wind power on the reliability and safety of power systems. A wind turbine is a complex power generating system consisting of several structural, electrical, and mechanical components interacting with human resource and organizational factors within natural, political, economic, and social environments. Its efficiency and availability depend largely on its reliability and safety level. So, wind turbine reliability is a significant factor in ensuring the success of a wind power system.

Technological systems such as wind turbines are composed of technical parts embedded in human, organizational, and environmental contexts. They have various interactions and a nonlinear relationship between their components. They are also open to their environment and make exchanges with it. In such a system, small changes can cause complex and great consequences in the behavior of the overall system. Systemic nature of technology embedded in social, cultural, environmental, and economic networks is accompanied by the driving forces such as demography, environmental changes, socioeconomic changes, connectedness, and mobility [5] results in reshaping risks in technological systems. It makes most of traditional risk assessment approaches and tools inefficient in terms of coping with modern complex technological systems' risks.

Traditional risk assessment and modeling approaches are architected based on the Newtonian paradigm and reductionism. This paradigm is based on the belief that systems are composed of independent elements and can be easily understood by breaking down to their smallest elements and describing interaction manner of their elements [6]. In other words, following Newtonian paradigm of analysis, traditional risk assessment methods are incapable of modeling interactions among elements of complex systems. Almost all traditional risk assessment techniques, such as Failure Modes and Effect Analysis (FMEA), Hazard and Operability Analysis (HAZOP), Fault Tree Analysis (FTA), and Probabilistic Risk Analysis (PRA) rely on a chain of linear cause and effect analysis. These techniques also have some limitations in terms of incorporating an efficient link between risk models and human and organizational factors in order to study modern complex technological systems.

In the present study, to ultimately analyze the current state of risk assessment in wind turbine, the literature of risk assessment in technological systems and specifically, wind turbines is reviewed. Furthermore, the research stream of modeling risk in complex technological systems is investigated. Then, considering strength and weakness of existing approaches, a Bayesian network model is developed to analyze risk and reliability of a wind turbine.

This paper is organized as follows: Section 2 reviews risk assessment trend and main paradigms for complex technological systems. It also investigates risk assessment literature in wind turbines in terms of approaches, models and features. Section 3 describes a Bayesian network to model risk and reliability in complex technological systems. Section 4 introduces the Bayesian network application for risk and reliability analysis of wind turbines and discusses the results of Bayesian network model implementation. Finally, Section 5 presents the conclusions.

2. Literatue review

2.1. Risk assessment approaches: reviewing the trend

Reviewing risk assessment literature, we can recognize three distinct paradigms (Fig. 1): (1) *Technical factor* focused, (2) *Human factor* focused, and (3) *Safety/ Organizational factor* focused paradigms. The technical approach focuses on methods for finding ways to prevent failure of structures and technical parts. Probabilistic Risk Assessment (PRA), Fault Tree Analysis (FTA), Failure Mode and Effect Analysis (FMEA), and Hazard and Operability Analysis (HAZOP) are some examples of such methods which are developed and applied to identify and manage risks in this paradigm.

The first paradigm has been evolved by inserting the missing part of common risk assessment methods, namely human factor, and resulted in the development of different generations of human reliability models such as Human Reliability Assessment (HRA), Cognitive Reliability and Error Analysis Method (CREAM), and Human Cognitive Reliability Correlation (HCR) to cover both technical and human factors in risk assessment. To cover the human aspect of risk assessment models, many HRA methods have been developed. The first generation of HRA methods, such as Technique for Human Error Rate Prediction (THERP) [7], was developed to predict the probability of human error in performing procedural tasks, or mainly Error of Omission (EOO), and the probability of doing something that was unplanned or unintended or Errors of Commission (EOC) [8]. All HRA methods are based on the assumption that performance is affected by conditions, which is traditionally described as Performance Shaping Factors (PSFs). In first-generation HRA methods, PSFs are used directly to modify human error probability and there is little justification for it in terms of an underlying performance model. HRA models of the second generation are increasingly becoming cognition based and

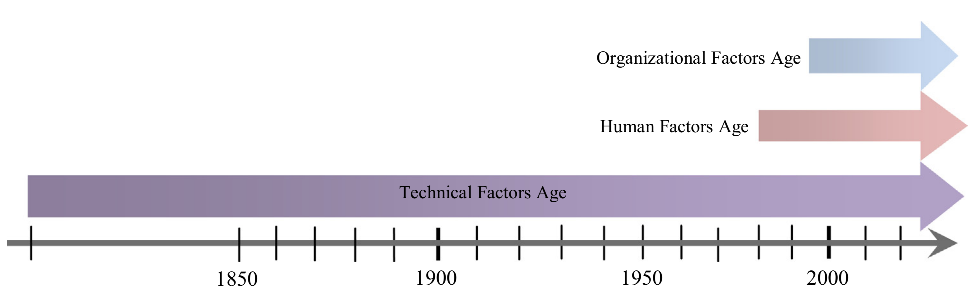

Fig. 1. Trends in risk research and studies.