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A case-based knowledge system for safety evaluation decision making of thermal power plants

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ABSTRACT

Safety assessment of thermal power plants (TPP) is an important means to ensure the safety of production in thermal power production enterprises. Modern information technology can play an important role in TPP safety assessment. The evaluation of power plant systems relies, to a large extent, on the knowledge and experience of the experts undertaking the task. Case-based reasoning (CBR) is introduced for the safety assessment of TPP since it models expertise through experience management. This paper provides a case-based approach for the Management System safety assessment decision making of TPP (MSSATPP). We introduce a case matching method named CBR-Grey, which integrates the Delphi approach and grey system theory. Based on this method, we implement a prototype of case-based knowledge system (CBR-SYS-TPP) for the evaluation decision making of the panel of experts. Our experimental results based on a real-world TPP safety assessment data set show that CBRSYS-TPP has high accuracy and systematically good performance.

1. Introduction

Industrial production, especially in the area of power generation, oil and gas, aviation, mining, and nuclear plants, often has significant safety implications on the safety of people's life and property, thus is attracting increasing attention from industry practitioners as well as researchers [1]. As an essential industrial component, thermal power plants (TPP) equip many industrial departments and their production process is very complicated. When operating TPP, the safety of people's lives and work conditions is a major concern. There are numerous TPP all over the world. Taking China as an example, there are over 1200 coal-fired thermal plants. In 2006, the total power generated in China by TPP reached 2834.4 terawatt per hour (TWh) and the total installed capacity reached 622 gigawatts (GW) [2]. As one of the nations with most electric power generation, China produces its electric power mainly from coal [3]. Another country that relies heavily on TPP for power generation is Turkey, where 80% of the total electricity is generated from TPP [4]. Safety assessment of TPP mainly concerns three aspects: Production Equipment Systems (PES), Working Circumstance Systems (WCS), and Production Management Systems. The third is also referred to as the Management System (MS) in current research. Through analyzing and evaluating these three subsystems, TPP can establish necessary corrective, remedial, and preventive measures, and realize the goal of controlling the accidents in advance.

As one of modern management ladders, safety assessment is a powerful tool for automatically diagnosing safety issues. However, numerous existing evaluations for production safety are irregular, unscientific, and capricious.

Because of the lack of powerful information and knowledge support for panel of experts during their decision making process of evaluation, the current used approach of direct expert evaluation is too subjective. Accordingly, there is a sizable margin of error. Hence, it is necessary to reduce its subjectivity. Along with the perfection of safety assessment rules and the development of information technologies, new techniques are being applied to almost all aspects of power systems to improve efficiency [5]. It is of both scientific and social significance for TPP to improve their safety assessment process toward better quantification, scientization, and automatization. MS safety represents an important aspect of the

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safety issue in the production of TPP. Numerous facts show that a large part of safety accidents in TPP occurred due to the managerial inadequateness and not for the equipment malfunctions.

From the perspective of Management Systems Safety Assessment of TPPs (MSSATPP), this paper investigates the whole range of safety assessment in TPPs' production, and applies the case-based reasoning (CBR) technique to the evaluation decision making process of MSSATPP. It presents a case-based decision support method named improved grey CBR (IGCBR) for MSSATPP and a framework of knowledge system for intelligent decision making (IDSS-MSSATPP).

This paper is organized in six sections. Section 2 is literature review regarding the evaluation on the power system and case retrieval methods in knowledge-based decision making, as well as the motivation of this study. Section 3 describes TPP safety evaluation process, introduces the evaluation indexes and defines four statistics for performance evaluation in the later experiments. Section 4 deals with problem's domain knowledge acquisition methodology mainly focusing on the weight determination method based on Delphi method and the retrieval algorithm based grey system theory. Also, the data set for experiments is introduced in this section. Section 5 introduces the system implementation and relevant experiments. And the main results are presented and brief discussion is also given. Section 6 concludes the paper and briefly introduced the trial application in a large-scale thermal power plant.

2. Literature review

2.1. The evaluation on the power system

Common evaluation issues concerning the power industry have been reported in the literature. In view of the special importance of production safety for TPP, it is important to study scientific approaches that fit the characteristic features of the production and management of TPP for safety assessment. However, few research studies focus on the safety assessment of TPP in production – the inside safety itself. Most of the literature focuses on the operational performance [6], energetic and exergetic performance analyses [7], the selection of an optimum power plant [8], air quality impact [9,10], and ecological efficiency [11]. Second, as far as content assessment is concerned, few studies concern safety evaluation of management work.

In terms of evaluation approaches, few approaches are actually able to solve the problems of providing powerful and helpful expert information support for experts' decision making and the reuse of domain knowledge. Until now, rare contributions have been made to the assessment approaches for management safety of thermal power plants. In previous literature, a small amount of prior articles use decision trees [12], structure-preserving energy functions [13], pattern recognition, and fuzzy estimation [14]. In recent years, new methods such as fuzzy decision trees [15], Bayes' classifiers [16], Monte Carlo methods [17], probability methods [18], perturbation methods [19] and Bayesian networks [20] are used for the assessment of probabilistic safety, equipment liability, voltage safety of power transmission system, and construction project safety management. Besides, various artificial neural networks (ANNs) [21,22] are also used to resolve the above problems. Modern ANNs are non-linear statistical data modeling tools and used to model complex relationships between inputs and outputs or to find patterns in data. They process information using a connectionist approach to computation and have become one of the most commonly used approaches for the evaluation regarding the power system. However, few of these research literatures are related to the assessment of management work during TPPs production.

2.2. Case retrieval

In this section, we will review case retrieval methods in knowledge-based decision making. We firstly review the knowledge-based decision making, including case-based reasoning and its applications. In real world, a number of knowledge-based systems are developed for the support of various decisions making. One of typical cases is the knowledge based decision support system (KBDSS) developed by Padma [23]. This systems acquires and quantifies the work-related risks on musculoskeletal disorder specifically, shoulder and neck pain (SNP) that is a prevalent pain complaint within the working environment. Its objective involves knowledge acquisition performed through literature analysis, traditional and concept mapping interviews with neurology, orthopaedic, psychology and physiotherapy experts to identify risk factors that include mechanical, physical and psychosocial categories. In KBDSS, the weight determination of ranking the relative factor importance has accomplished using analytic hierarchy processing (AHP) analysis. As one of important knowledge-based reasoning techniques, CBR can provide an information service and decision support for the whole process of decision making, including knowledge organization, knowledge acquisition, automotive revision and knowledge reuse. Part of its advantage lies in that it can capture expert knowledge, provide methods for knowledge management, and give suggestions for fast problem-solving. Different from ANNs and decision trees, it can address the problem of over fitting. Combined with other intelligent reasoning techniques (such as rule-based reasoning) [24], CBR has been applied widely to health care, engineering design, classification, prediction, recommendation, technologies optimization, organizational behaviour science, social learning, and numerous other fields, while a great many successful application instances have also been achieved [25–29]. In the field of evaluation research, there are also many articles concerning CBR, such as the CBR applications to software cost estimation [30], software effort estimation [31], risk assessment in audit judgment [32], risk analysis for electronic commerce [33], web break sensitivity evaluation in a paper machine [34], safety risk analysis in information safety systems [35], safety evaluation of process configuration [36], and so forth.

The following review is regarding the case retrieval methods. The fundamental idea in CBR is problem solving based on the retrieval of similar cases. Definitely, case retrieval is a key stage in case-based knowledge reasoning. And the global efficiency of CBR systems is greatly determined by their retrieval algorithms. The objective of case retrieval is to identify cases with greatest similarity to the problems described as quickly as possible. In the research area of CBR, researchers have developed various retrieval techniques for different study issues. The most commonly used one is k-nearest neighbour (k-NN) based on Euclidean distance. Euclidean distance metric has the merit that it allows knowledge to be brought to bear on the assessment of similarity. The feature set can be chosen to reflect the important features in the domain. While this metric handles continuous attributes reasonably well, it does a poor job with discrete attributes. Nonmatching discrete attributes contribute maximally to the distance while matching attributes don't contribute at all. Besides k-NN method, various other retrieval techniques, from Fish and Shrink [37] to more sophisticated methods such as mix neural networks [38], genetic algorithms [39], and fuzzy ant colony systems or fuzzy logic [40,41] have been developed. Another key technique to improve accuracy in CBR retrieval is the attribute weighting technology. Attributes with weights of zero are effectively ignored during similarity computation, whereas attributes with high weights have the most impact in determining similarity. There are many approaches to weighting including experience of the expert, analytic hierarchy