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Integrating gray system theory and logistic regression into case-based reasoning for safety assessment of thermal power plants

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ABSTRACT

Safety assessment of thermal power plants (TPPs) is one of the important means to guarantee the safety of production in thermal power production enterprises. Due to various technical limitations, existing assessment approaches, such as analytic hierarchy process (AHP), Monte Carlo methods, artificial neural network (ANN), etc., are unable to meet the requirements of the complex security assessment of TPPs. Currently, most of the security assessments of TPP are completed by the means of experts' evaluations. Accordingly, the assessment conclusions are greatly affected by the subjectivity of the experts. Essentially, the evaluation of power plant systems relies to a large extent on the knowledge and length of experience of the experts. Therefore in this domain case-based reasoning (CBR) is introduced for the security assessment of TPPs since this methodology models expertise through experience management. Taking the management system of TPPs as breakthrough point, this paper presents a case-based approach for the Safety assessment decision support of TPPs (SATPP). First, this paper reviews commonly used approaches for TPPs security assessment and the current general evaluation process of TPPs security assessment. Then a framework for the Management System Safety Assessment of Thermal Power Plants (MSSATPP) is constructed and an intelligent decision support system for MSSATPP (IDSS-MSSATPP) is functionally designed. IDSS-MSSATPP involves several key technologies and methods such as knowledge representation and case matching. A novel case matching method named Improved Gray CBR (IGCBR) has been developed in which a statistical approach (logistic regression) and Gray System theory are integrated. Instead of applying Gray System theory directly, it has been improved to integrate it better into CBR. In addition this paper describes an experimental prototype system of IDSS-MSSATPP (CBRsys-TPP) in which IGCBR is integrated. The experimental results based on a MSSATPP data set show that CBRsys-TPP has high accuracy and systematically good performance. Further comparative studies with several other common classification approaches also show its competitive power in terms of accuracy and the synergistic effects of the integrated components.

1. Introduction

Thermal power plants (TPPs) equip numerous industrial departments and their productive process is very complicated. In TPPs, the frequency of accidents with serious consequences is extremely high. When operating TPPs, the safety of people's lives and work conditions is a major concern. There are numerous TPPs all over the world. Taking China as an example, there are over 1200 coal-fired thermal plants. According to statistics about the national power industry of China, in 2006, the total power generated reached 2834.4 terawatt per hour (TW h) and the total installed capacity reached 622 gigawatt (GW) (Yang, Guo, & Wang, 2010). As one of the strongest nations in electric power generation, due to various limitations and causes, China produces its electric power mainly from coal (Williams, 2001). In Turkey as well, 80% of the total electricity is generated from thermal power plants (Oktay, 2009). For the purpose of reducing major and extraordinarily large accidents in TPPs and ensuring the security of electric power production, an increasing number of thermal power enterprises in China pay more attention to the security assessment issue.

Security assessment of TPPs mainly concerns three aspects: Production Equipment Systems (PES), Working Circumstance Systems (WCS), and Production Management Systems. The latter is also referred to as the Management System (MS) in current

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research. By the analysis and evaluation of these three subsystems, the TPPs establish the necessary corrective, remedial, and preventive measure, and finally realize the aim 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 evaluations for production safety are irregular, unscientific, and capricious, as well as lacking powerful knowledge support. Accordingly, there is a sizable margin of error. Along with the increasing perfection of security assessment rules and the development of information technologies, new techniques are being applied to almost all aspects of power systems to improve efficiency (Zhao, Wang, Nielsen, Li, & Hao, 2010). It is of both major significance and profound social consequences for TPPs to make their security assessment process progress toward the quantification, scientization, and automatization. MS security represents an important part of the security issue in the production of TPPs. Numerous facts show that a large part of safety accidents in TPPs occurred due to the managerial inadequateness and not for the equipment malfunctions. From the perspective of management systems Security Assessment of TPPs (SATPP), this paper investigates the whole range of security assessment in TPP production, and applies the case-based reasoning (CBR) technique to the evaluation process of SATPP. It presents a case-based decision support method named Improved Gray CBR(IGCBR) for SATPP and a framework of intelligent decision support system for SATPP (IDSS-MSSATPP).

The purpose of this study is to investigate the potential of historical knowledge based on cases to complement the deficiency of experts' personal experience and of knowledge for TPP safety evaluation. It specifically investigates a framework of intelligent decision support system for TPP security assessment and a novel case retrieval method named IGCBR combining logistic regression and Gray System theory for knowledge acquisition from a case base. The framework includes the knowledge support process in TPP safety evaluation, evaluation indexes, and the functional structure of an intelligent decision support system for SATPP. After experimenting with the system, results suggest that the case-based knowledge system is able to provide powerful decision support for the team members during the SATPP. Also, results show that the proposed retrieval method yields high accuracy and synergetic effects for knowledge acquisition in case-based SATPP. Subsequent comparative experiments further verify its predominance.

In the next section we introduce the study background including the SATPP evaluation process and the motivations of the study. The third section reviews common approaches used for security assessment in previous literature, as well as the technical features and the applications of case-based reasoning, especially the applications of CBR in the area of evaluation. In the fourth section, we develop a framework of case-based IDSS-MSSATPP: a case-based technical assessment process, evaluation indexes, and the functional design of IDSS-MSSATPP. The fifth section presents our research methodologies, including case knowledge representation, a novel retrieval algorithm based on Gray System theory, a weight determination method from the perspective of statistics, the experimental design, the data set, and our implemented experimental tools. In the sixth section, the key results of our research are presented. In the seventh section we present discussions and add our interpretation to the current work. The eighth section sets forth the conclusion and the implications. Finally, in the last section, the limitations are discussed and future work is suggested.

2. Background

Power plant safety evaluations are performed by panels of experts through investigation, discussion, and negotiation. This process is explained in this section, as well as the motivations for building the IDSS-MSSATPP system.

2.1. Power plant safety evaluation process

Security assessment is one of the important measures and safeguards for enforcing the electric security basis in TPP production and for guaranteeing safe, stable, and economical TPP operation. As an important part of the whole security assessment work of TPPs, MSSATPP is an all-around examination and evaluation of the safety management work in the production of TPPs. Two different parts are involved in the security assessment of TPPs: inside evaluation and outside foreign expert evaluation, respectively. The former is operated by a thermal power plant itself. Power companies organize expert groups with relevant personnel to evaluate their safety status, identify issues, and then propose revision suggestions according to the evaluation index, standard, or criterion. The latter is generally organized by the electric power company responsible for a group of TPPs. To do so, the electric power companies organize audits in which relevant experts complete their evaluation work. To prepare for the actual audits performed by the electric power companies, most of the electric power incorporations currently complete their internal thermal power plants safety evaluation work through external experts' evaluation. The complete evaluation steps are approximately as follows:

- Step 1: organize an experts' group to conduct the assessment. The experts can come from a technical layer, a management layer of the electric power companies, the institutes of the electric power, or universities or government departments related to electric power.
- Step 2: determine the weights associated with the evaluation index or the total score of each index by DELPHI (Kayacan, Ulutas, & Kaynak, 2010).
- Step 3: organize the experts' visit to the thermal power plants and their scoring through the fact-finding inspection.
- Step 4: gather the score, conduct group discussions, and finally make decisions. Usually, the evaluation can end in one of two ways: qualified with minor correction and remedy, or unqualified with major correction and remedy.[1]

One detail deserves to be paid attention to here: the conclusion is not obtained simply by the direct addition of the scores from the experts. The real decision making process is that the experts' group draws the final conclusions through discussion and consultation. The rule of "who gets a high score, who passes" is not necessarily clear-cut. This process is understandable because evaluating the security on basis of the scores only is not reasonable. Different thermal power plants are evaluated by different experts' groups, and the scoring measures of experts may be different due to their diverse characters, moods, and knowledge background. Therefore, electric power enterprises come to conclusions through comprehensive group evaluation. In this practice, historical or antecedent cases are very valuable for the decision making process of these experts.

2.2. Motivations

Several limitations of in the evaluation process described above can be highlighted as follows.

First, the evaluation approach presents too much subjectivity. It

[1] This kind of division is not very strict. There is also an exception. A minority of the electric power enterprises only score and do not draw the specific conclusions: qualified or unqualified. However generally, there are only two outcomes: major correction and remedy or not.