Journal of Hydrology 565 (2018) 474–488

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Credibility theory based panoramic fuzzy risk analysis of hydropower station operation near the boundary

Zhiqiang Jiang[a,*], Wenjie Wu[b], Hui Qin[a], Jianzhong Zhou[a]

[a] School of Hydropower & Information Engineering, Huazhong University of Science and Technology, Wuhan 430074, China
[b] Changjiang Survey, Planning, Design and Research Co., Ltd., Wuhan 430015, China

ARTICLE INFO

This manuscript was handled by A. Bardossy, Editor-in-Chief, with the assistance of Purna Chandra Nayak, Associate Editor

Keywords:
Power generation
Runoff forecasting error
Near-boundary
Panoramic
Fuzzy risk analysis
Credibility theory

ABSTRACT

Short-term power generation operation is an important content in the hydropower station management. Because of the limitation of forecast accuracy, there is error between the forecasted runoff process and actual runoff process. When the hydropower station operation is near the water level boundaries, such as normal water level or dead water level, this error is likely to bring the risk of water abandoning or output shortage. In order to precisely evaluate the near-boundary operation risk of hydropower station caused by runoff forecasting error, a novel panoramic fuzzy risk analysis model was proposed in this paper by taking the forecasting error as a fuzzy variable. The coupling of hydrological forecasting error and the short-term operation risk of hydropower station based on credibility theory was realized, and the solving process of the model based on fuzzy simulation technology was provided in detail. Different near-boundary operation risks of hydropower station can be analyzed and evaluated by the simulation with different water level combinations in this model. The high-risk area and suggested operation area of Jinxi hydropower station in different near-boundary operation situations were clearly identified in the case study. The intuitive results of this model can provide a strong technical support for the decision-making of the dispatchers when making the power generation plans in the actual production, so that to avoid the occurrence of water abandoning or output shortage of hydropower station, and effectively improve the efficiency of water resources utilization.

1. Introduction

In the short-term power generation operation of hydropower station, the power generation plan is a very important basis for the actual production (Shayesteh et al., 2016; Li et al., 2014). It is essentially the standard of production activities for the hydropower station in the next day (Wang et al., 2013), and it has the normative effect and cannot be changed under normal circumstances (Peng et al., 2015). However, due to the accuracy limitation of runoff forecasting (Yuan et al., 2016; Lu et al., 2015), there are uncertain factors in the next day's hydropower station operation, which causes the non-matching of formulation and implementation of power generation plan existed objectively (Ji et al., 2014a; Ge et al., 2014). So, in the actual operation, the reservoir water level usually goes beyond the limited water levels because of the runoff forecasting errors, and this leads to a large number of abandoned water or output shortage.

Under the normal circumstances, due to the storage capacity and regulation of reservoir (Zmijewski and Wörman, 2016), the effect of water level deviation caused by the runoff forecasting error can be ignored (Li et al., 2015). But when the operating water level of reservoir is already near the boundary, such as close to the normal water level or the dead water level, the available reservoir storage volume that can be used to store or supply water is decreased, thus the regulation function of reservoir is greatly reduced at this moment, that may result in a large number of abandoned water or output shortage (Lu et al., 2009). Therefore, it is very necessary to carry out the risk analysis for the near-boundary operation of hydropower station based on the runoff forecasting uncertainty, and quantify the risks of hydropower station in different near-boundary operation cases, so that to provide a scientific basis and decision support for the runoff forecasting based short-term power generation operation.

The near-boundary operation of hydropower station and the corresponding control belong to the category of risk scheduling. Thus, the risk analysis is very necessary. In the risk analysis of hydropower generation operation based on runoff forecasting, the forecasting error is one of the most important risk factors (Zhang et al., 2011). At present, the research in this field has already obtained a lot of achievements, but the researches mostly focus on the random characteristics of

* Corresponding author.
E-mail address: zqjzq@hust.edu.cn (Z. Jiang).

https://doi.org/10.1016/j.jhydrol.2018.08.048
Received 26 January 2018; Received in revised form 3 August 2018; Accepted 23 August 2018
Available online 29 August 2018
0022-1694/

forecasting error, and the risk analysis methods are mainly based on probability theory and mathematical statistics (Yan et al., 2014), such as the typical probability distribution function calculation method (Mondal et al., 2012; Fares et al., 2014), the bayesian theorem based risk rate calculation method (Biondi and Luca, 2013; Chen et al., 2018) and probability combination method (Lagadec et al., 2016), etc., the research on the fuzziness of forecasting error are still rare.

Nowadays, the mathematical methods used to describe and study the objective phenomenon are generally divided into deterministic methods and uncertainty methods, and the latter mainly includes random methods and fuzzy methods. However, due to the complexity of the objective world and the constantly changes caused by perpetual motion, the random phenomena in fact is not inherently random when people use the random methods to deal with it. In addition to randomness, it also has a more general fuzzy uncertainty (Jiang et al., 2015a). As we known, the hydrological forecasting model is affected by input uncertainty, its own structure uncertainty, parameter uncertainty and many other artificial uncertainties, it is complex and difficult to be described accurately (Cheng et al., 2015; Li et al., 2018). Thus, in a runoff forecasting, the forecasting error is influenced by many objective and subjective factors (Huang et al., 2014), and its size does not have a definite limit in quantity. It not only has randomness, but also has a lot of fuzziness (Jiang et al., 2016) that the forecasted runoff value falls into a certain range as shown in Fig. 1. Therefore, the single study on the randomness of hydrological forecasting error cannot fully express the uncertainty of error, and it also cannot effectively reflect the risk of water abandoning or output shortage in the short-term hydropower station operation. So, it is necessary to carry out the risk analysis for the short-term hydropower station operation based on the fuzziness of runoff forecasting error.

There are three types of measures in fuzzy mathematics, i.e., probability measure, necessity measure and credibility measure (Lu et al., 2011). In the probability measure theory, an event with the probability measure of 1 indicates that the event is most likely to happen but does not necessarily happen, and an event with the probability measure of 0 indicates that the event is most unlikely to happen, but it doesn't mean that it doesn't happen. So, this is easy to cause the decision chaos. In comparison, the credibility theory has the self-duality, i.e., the event with the credibility measure of 1 must happen, and the event with the credibility measure of 0 must not happen (Liu and Peng, 2005). Thus, the fuzzy evaluation result based on credibility measure is more accord with people's thinking habits, and it is easy to understand and accept, and it also eliminates the decision chaos that the traditional membership degree calculation may cause. So, on the whole, it is more appropriate to use the credibility measure to study the fuzziness of forecasting error (Zeng et al., 2014).

Nowadays, fuzzy set theory has made a great progress and has been applied in many practical fields (Sun et al., 2016). In 2004, Liu successfully established the axiomatic system of credibility measure (Liu 2004), i.e., the credibility theory, which is similar to the axiomatic system of probability theory. The credibility theory is a new mathematical branch to study the quantitative law of fuzzy phenomena, and its emergence based on axiomatic approach provides a new way to explore the new fuzzy risk analysis method (Liu, 2009). At present, the fuzzy risk evaluation method based on credibility theory has been successfully applied in many fields (Jiang et al., 2015b; Davari et al., 2014), such as power system operation risk assessment (Feng et al., 2008; Hu et al., 2011), unit combination problem (Ju et al., 2016; Skulimowski, 2013), economic scheduling problem (Xin and Xiao, 2011), reliability evaluation (Zhao and Liu, 2005), power grid planning (Ernster and Srivastava, 2012), enterprise investment portfolio (Huang, 2006), capital budget issues (Huang, 2007) and the optimal allocation of water resources (Zhong et al., 2013), etc., which greatly promoted the spread and development of credibility theory. However, this theory is rarely used on the research of risk analysis of hydropower station operation based on the fuzziness of forecasting error, especially on the optimal fuzzy control of near-boundary operation of hydropower station.

Therefore, the credibility theory can be used to describe the fuzzy characteristic of runoff forecasting error and carry out the fuzzy risk analysis of hydropower station near-boundary operation. In view of this, this paper proposed a novel panoramic fuzzy risk analysis model based credibility theory, this model can not only make the fuzzy characteristic of forecasting error be effectively expressed in the short-term power generation operation of hydropower station (Sampath and Ramya, 2014), but also realize the interdisciplinary application and cross-integration of new mathematic theories and technologies in water resources management, and further develop and improve the risk control theory in the short-term power generation operation of hydropower station, which has a far-reaching theoretical significance. Particularly, in practical point of view, through the proposed model, different near-boundary operation risks can be analyzed for the hydropower station by the simulation of formulating and implementing the power generation plan with different water level combinations. So the high-risk area of hydropower station in short-term operation can be clearly identified, and the intuitive results (i.e., the risk distribution map) of the model can provide a strong technical support for the dispatchers to avoid the high-risk situations in making the power generation plan in actual production, so that to effectively avoid the occurrence of water abandoning or output shortage of hydropower station, and improve the efficiency of water resources utilization. It has a far-reaching practical application value.

The following parts of this paper are organized as follows. Section 2 is the methodologies, including a detailed formulation of short-term power generation operation model of hydropower station, a brief introduction of credibility theory, the panoramic fuzzy risk analysis

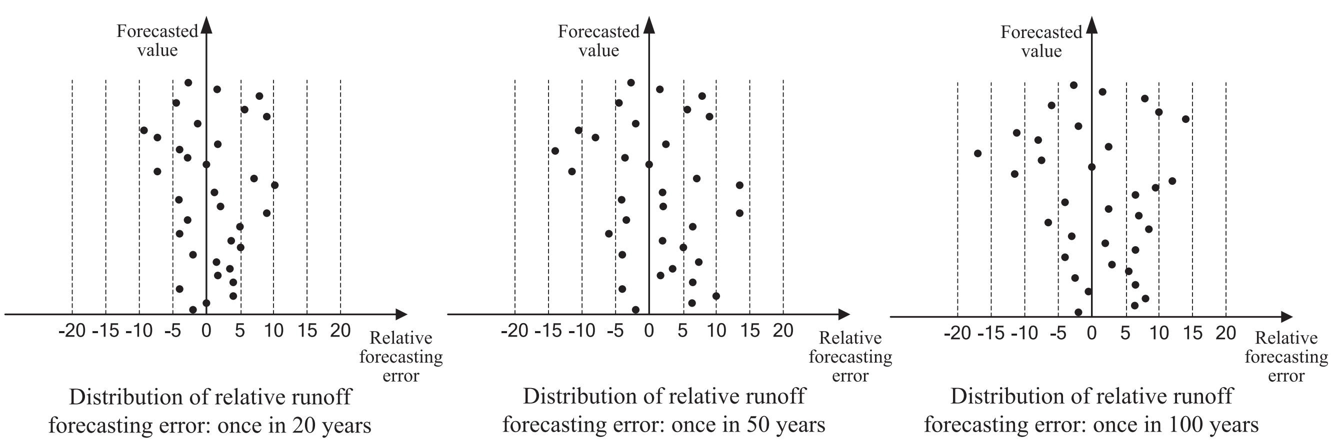

Fig. 1. Schematic diagram of fuzzy characteristic of relative runoff forecasting error.