Electrical Power and Energy Systems 33 (2011) 608–614

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Probability evaluation method of equipment failure due to voltage sags considering multi-uncertain properties

Hua-Qiang Li [a,b], Xian-Yong Xiao [a,b,*], Ying Wang [a], Wu Chen [c]

[a] College of Electrical Engineering & Information Technology, Sichuan University, Chengdu 610065, China
[b] Smart Grid Key Laboratory of Sichuan Province, Chengdu 610065, China
[c] Chengdu Electric Power Bureau, Chengdu 610041, China

ARTICLE INFO

Article history:
Received 24 April 2009
Received in revised form 19 August 2010
Accepted 23 November 2010
Available online 26 January 2011

Keywords:
Voltage sag
Sensitive equipment
Failure probability
Multi-uncertainty

ABSTRACT

The existing problem with probability evaluation of sensitive equipment failure arising from voltage sags is how to measure the uncertain properties and determine the mathematical models of influencing factors. In this paper, the uncertain properties of voltage sags, voltage tolerance of sensitive equipment, and equipment operation states are explored. The intension and extension uncertainties of influencing factors are used to distinguish the mathematical properties. Stochastic and fuzzy variables are introduced to quantify these uncertainties. The corresponding models are proposed. A multi-uncertainty evaluation method of sensitive equipment failure probability is presented also. With the proposed method, the maximum entropy method is used to extract the probability distribution of voltage sag intensity while the determination principle of membership function of fuzzy safety event is applied to determine the multi-uncertainty evaluation model. As a case study, a personal computer is simulated. The results show that the proposed method is feasible and effective, and can be deployed in other fields.

1. introduction

The evaluation of sensitive equipment failure probability caused by voltage sags is one of the most important issues for the utilities and power customers [1–4]. However, there is not a clear understanding of the influencing factors, mathematical expression, and evaluation method. Current literature focuses on the voltage sag characteristics extraction, detection and classification, equipment sensitivity measurement or test and assessment methods [4–9]. The mathematical properties, namely the evaluation models and the modeling approaches, are missing. The existing probabilistic or fuzzy evaluation methods [1,3,10–13] may be effective and useful but they are difficult to be carried out in practice, because these methods, based upon subjective assumptions or experiences, may be unreliable. In order to evaluate the practical engineering, it is essential to investigate the mathematical properties, expressions, and modeling methods [14].

There are three types of evaluation methods of sensitive equipment failure events arising from voltage sags: measurement and statistics method [15–19], probability evaluation method [10,11] and fuzzy assessment method [13]. The measurement and statistic method is direct and reliable but it does not allow us to test all the sensitive equipment in practice. The probabilistic evaluation method and the fuzzy evaluation method have taken the uncertainties of equipment failure events into account. But the stochastic or fuzzy properties of uncertainties are essentially different. Therefore, we must research the uncertain properties and their expressions before evaluating the failure probability of sensitive equipment.

In fact, the uncertain properties of voltage sag characteristics, equipment voltage tolerance and possible equipment operation states under voltage sags have different characters, variations, and mathematical expressions. The existing uncertain properties consist of types such as stochastic, fuzzy, rough, random-fuzzy, fuzzy-random, and multi-uncertain, etc., among which stochastic and fuzzy properties are well known [20,21]. The former presents the uncertain intension property of uncertain events, and the latter describes the uncertain extension property [20]. For the failure event of sensitive equipment caused by voltage sags, there are two uncertain properties existing simultaneously for influencing factors. Therefore, the influencing factors can be presented by stochastic or fuzzy variables according to the uncertain properties of intension or extension. As a result, what can be established are the corresponding mathematical models as well as the evaluation model of equipment failure event.

In this paper, Section 2 investigates the uncertain properties of influencing factors. Section 3 presents the uncertain mathematical expressions of influencing factors using stochastic or fuzzy models,

* Corresponding author at: College of Electrical Engineering & Information Technology, Sichuan University, Chengdu 610065, China. Tel.: +86 28 85461856.
E-mail addresses: xiaoxianyong@scu.edu.cn, xiaoxianyong@163.com (X.-Y. Xiao).

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doi:10.1016/j.ijepes.2010.11.015