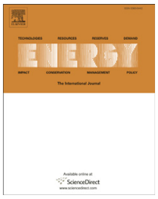
Energy 161 (2018) 425–434

Contents lists available at ScienceDirect

Energy

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



Use of a second-order reliability method to estimate the failure probability of an integrated energy system

Xueqian Fu [a], [*], Gengyin Li [b], Huaizhi Wang [c]

[a] College of Information and Electrical Engineering, China Agricultural University, China
[b] The State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources (North China Electric Power University), China
[c] College of Mechatronics and Control Engineering, Shenzhen University, China

ARTICLE INFO

Article history:
Received 5 January 2018
Received in revised form
29 May 2018
Accepted 23 July 2018
Available online 24 July 2018

Keywords:
Failure probability
Gas deliverability
Integrated energy system
Multi-Carrier systems

ABSTRACT

A shortage of gas supply renders gas expensive and may even cause power outages. Estimation of the failure probability of gas supply is an essential component of an integrated energy system. To ensure that failure probability estimation is relevant to an actual project, energy network constraints should be fully considered in calculations. Here, this paper develops a second-order reliability estimation method to cope with the nonlinearity caused by network constraints. Under conditions of integrated energy supply, correlations exist between the extremes of wind power, the heat loads, and failure of the natural gas supply. This paper illustrates the proposed method by comparing the results to those of other methods. The proposed method is efficient in terms of both accuracy and computational time. Compared to a mixed algorithm, which required 1101.1 s to simulate tens of thousands of samples, the proposed method takes 3.5 s to obtain a failure probability. Also, the proposed method improves accuracy by at least 10-fold compared to that of a first-order reliability method.

© 2018 Elsevier Ltd. All rights reserved.

1. Introduction

The use of renewable energy sources reduces pollution. Intermittently renewable energy sources have attracted a great deal of interest, associated with challenges when operating integrated energy systems (IESs). The unpredictability of intermittently renewable energy sources renders IES planning and operation difficult, which is a major problem. When estimating the failure probability of an IES, both uncertainty modelling and a theory of multiple energy carriers (MECs) must be invoked. Dependencies among the different random variables are of vital importance in terms of uncertainty modelling. Da et al. presented a practical, probabilistic load flow method using the dependencies of different input nodal powers to balance active power in electrical systems [1]. Usaola developed an approximation method based on statistical moments and the Cornish-Fisher expansion to estimate the probabilistic load flow considering the intermittent characteristics (i.e., the capriciousness) of wind power (WP) [2]. When modelling intermittent WP, the joint probability distribution of the marginal distributions of wind speed and active WP can be expressed using a normal copula function [3]. Yu et al. described a Monte Carlo method based on Latin hypercube sampling and the Cholesky decomposition [4]. The Monte Carlo method of Ref. [5] effectively estimated the reliability of a power system that receives energy from both intermittent and (correlated) renewable energy sources. Chen et al. developed a mixed algorithm, adding the Nataf transformation to the Monte Carlo method [6]. The mixed algorithm can be used to model uncertainty in an IES, which has many random (although correlated) loads and renewable energy sources.

Consider the MECs of an IES. An energy hub is considered to be a unit featuring MECs. As early as 2007, the definition of an energy hub was developed in Ref. [7] and used in Switzerland to afford technical, economic, and environmental benefits. Competition between MECs must be considered when planning expansion of local IESs to minimise investment, operation difficulties, and emissions [8]. Energy reliability and availability are affected by MEC interdependence. Koeppel et al. showed that energy supply reliability could be improved using certain optimal conversions of MECs [9]. Novel formulations of the energy hub were presented in Ref. [10]; both applicability and accuracy were addressed using mixed-integer linear programming, which balances the energy loads and

---

[*] Corresponding author. Present address: College of Information and Electrical Engineering, China Agricultural University, 17 Qinghua Donglu, Beijing 100083, People's Republic of China.

E-mail address: fuxueqian@cau.edu.cn (X. Fu).

https://doi.org/10.1016/j.energy.2018.07.153
0360-5442/© 2018 Elsevier Ltd. All rights reserved.

supplies among MECs. The interdependencies of MECs, in terms of both sources and loads, were considered in Ref. [11]; the experimental results revealed that modelling of load dependencies and resource limitations ensured that MEC models satisfied practical demands. A multi-agent system was developed in Ref. [12] to optimise the operations of MECs within an energy hub; the results make it clear that energy hubs can participate in energy-related markets, affording significant cost reductions. Similarly, Ref. [13] presented a particle (swarm) optimisation algorithm featuring time-varying acceleration coefficients to optimise the operation of energy hubs of MECs in IESs; such hubs featured both electrical and natural gas systems. The IESs operated more economically than independently operated systems. Reference [14] sought to minimise economic and environmental costs; MEC operation was optimised via dynamic parameter adjustments to the IESs of several energy hubs. In addition to optimising MEC operations, energy network constraints have also attracted attention. Martinez-Mares et al. presented a unified analysis of gas and power flow in networks featuring both electricity and natural gas, and found that the Newton-Raphson formulation correctly and effectively computed gas and power flow [15]. Nastasi et al. presented a novel research method using hydrogen to save primary energy by linking heat and electricity networks in a transition mode [16].

Others explored uncertainty modelling of IES multi-carrier energy systems. A novel method (based on a chance-constrained programming model) that employed a support vector machine and adaptive control technology was developed in Ref. [17] to solve the nonlinear programming problem associated with intermittent, highly uncertain photovoltaic sources of certain distribution networks. The impact of (capricious) weather on intermittent and (correlated) renewable energy sources and heating loads was investigated in Ref. [18]. To advance the discipline of uncertainty, Ref. [19] used an information entropy approach to quantify the uncertainties of intercorrelated power sources and heating loads. To improve analyses of IESs affected by weather, Ref. [20] presented a typical scenario-generation algorithm for an IES using the Wasserstein distance metric. Thus, IES reliability analysis has advanced, but work continues, as does research on both methodological aspects and concrete applications [21]. This paper further explores the failure probability issue of the gas supply for an IES in Ref. [21], and improves the estimation method presented in Ref. [21]. The same IES model as presented in Ref. [20] is used in simulations in the current paper to ensure the research continuity of the IES.

The novel contributions can be summarised as follows. (1) From a practical viewpoint, it is essential to consider the failure probability of gas supplies in IESs suffering from gas shortages in northern China. (2) To the best of our knowledge, this is the first paper to consider energy network constraints; this renders the failure problem very complex, requiring nonlinear computation. (3) This paper uses a second-order reliability method (SORM) to resolve the complex nonlinear computation of gas supply failure probabilities; this paper achieves a good balance between the accuracy of the results and computation time.

The paper is organised as follows. First, the problem is described to emphasise the practical engineering significance afforded by estimates of gas supply failure probabilities. Second, the SORM is introduced. Third, failure probabilities are calculated using different models. Finally, practical use of the scenario is discussed, followed by the conclusions.

2. The problem

2.1. Engineering problem

Natural gas is an important energy source for IESs. However, natural gas shortages have affected energy supplies in both China and the United States, as discussed below. By the end of 2014, China had built 17 gas storage tanks, with reserves of 4.3 billion cubic metres, accounting for only 2.3% of all natural gas consumption. The National Development and Reform Commission (NDRC) of China lowered the natural gas price to non-residents by 0.7 CNY (Chinese Yuan) per cubic metre on November 20, 2015, creating great uncertainty in downstream market demand and concern about winter warmth. In 2015, the China Daily website claimed that the natural gas supply to northern China had encountered a temporary shortage, and the authorities developed an emergency plan to limit the indoor temperatures of public buildings and suspend supply to factories to ensure residential heating. The China National Petroleum Corporation experienced difficulties when unloading imported liquefied natural gas from ships, causing a temporary shortage of natural gas, according to the Beijing Municipal Commission of the City Administration and Environment. With the coming of winter in 2017, the situation has become increasingly severe. Beijing and Qingdao have both raised the price of natural gas by over 10%. From November 15, 2017 to March 15, 2018, the natural gas price to commercial and industrial customers in Beijing has risen by 9.71%, or approximately 0.184 CNY per cubic metre. As gas demand continues to be strong, the gas supply-and-demand situation has become increasingly serious.

In February 2014, frigid weather across the United States and Canada caused a natural gas shortage at power plants in southern California, affecting residential power supply. As early as February 2011, natural gas shortages affected the southwestern United States. A total of 1.3 million customers were without power at any one time, and over 4 million were ultimately affected. In terms of gas, over 50,000 business and residential customers lost supply over the same period [22]. Such failures simultaneously jeopardise the security of both the power grid and the gas system, as shown in Fig. 1.

2.2. Problem formula

As described above, the specific engineering problem addressed by this paper concerns accurate estimation of the impact of uncertainty on the reliability of the gas supply to an integrated energy system. As per the actual energy project, it can be assumed that uncertainty in the IES derives from intermittent wind power, load fluctuations, and variations in gas deliverability. To estimate the failure probability of the gas supply to the IES, a limit state function, i.e. the problem formula, is used to show how random variables, i.e. uncertainties, affect the gas supply balance,

$$g(X) = X_{n+1} - X_{load} = X_{n+1} - F(X_1, X_2, ..., X_n), \qquad (1)$$

where $X = [X_1, X_2, ..., X_n, X_{n+1}]$ represents random variables in the IES, $[X_1, X_2, ..., X_n]$ are random heating loads and wind speeds, X_{n+1} is the variation in gas deliverability for the IES, X_{load} is the entire gas consumption by the IES, and $F(\cdot)$ is a gas consumption function

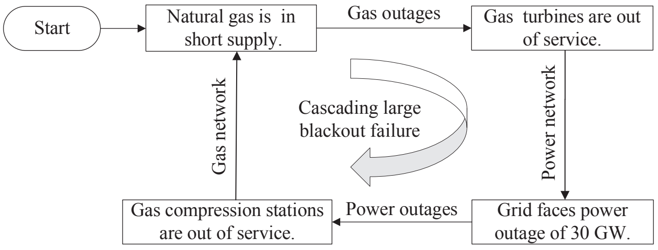


Fig. 1. Evolution patterns of blackout events in southwestern USA.

Download English Version:

https://daneshyari.com/en/article/8070864

Download Persian Version:

https://daneshyari.com/article/8070864

Daneshyari.com