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Evaluation research of the energy supply system in multi-energy complementary park based on the improved universal generating function method

Hong Li[a], Xiaodan Wang[a,*], Yajing Gao[b], Haifeng Liang[a]

[a] School of Electrical and Electronic Engineering, North China Electric Power University, Baoding 071003, China
[b] School of Electrical and Electronic Engineering, Electric Power Development Research Institute, Beijing 100053, China

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ABSTRACT

With the increasing access for distributed energy and the enlarging demand for energy utilization, considering the difference of the electric/heating/cooling energy flow in multi-energy complementary park and the uncertainty of the distributed energy output, an evaluation method of the energy supply system in multi-energy complementary park based on the improved universal generating function (UGF) method is proposed. In this method, the constraints of the startup and shutdown and the climbing of conventional energy supply units are taking into account, and a timing UGF model of each energy supply unit in multi-energy complementary park which contains the wind turbine, photovoltaic, conventional unit, micro gas turbine, gas boiler and energy storage device is established. What's more, considering the reliability, economy and electrothermal coupling characteristics of the energy supply system, an evaluation index system of the energy supply system in multi-energy complementary park is built. Finally, the correctness and feasibility of the proposed evaluation method are verified through the typical IEEE-RTS79 system. In addition, taking a multi-energy complementary park in northern China as an example, the probabilistic production simulation (PPS) and sensitivity analysis for typical scenarios to achieve the overall evaluation of the energy supply system in the multi-energy complementary park are carried out.

1. Introduction

Combined with the increasing demand for energy utilization and the exacerbation of environmental pollution, the interconnection of energy has become an inevitable trend due to the diversity of load and energy types. Whar's more, the traditional independent planning operation of the electric/heating/cooling load is not conducive to improve the overall energy efficiency of the system, and the multi-energy flow coordination planning is an effective mode for energy efficient utilization. Among them, a typical form for energy comprehensive utilization is the multi-energy complementary park [1]. In addition, the distributed energy has continuously accessed to the multi-energy complementary park due to its clean, efficient, energy saving and environmental protection features, which has a certain impact on the energy configuration of the traditional multi-energy complementary park. As the basis for the planning and operation of the multi-energy complementary park, the evaluation research of the energy supply system in multi-energy complementary park is of great significance to realize the intelligent and practical energy supply demand [2–4].

At present, for the evaluation of the energy supply system in multi-energy complementary park, the coordinated and complementary operation of the multi-energy system and the energy efficient utilization have been focused on the most scholars at home and abroad [5–10]. Among them, in Ref. [5], from the viewpoints of the energetic analysis, economic operation and environment effect, the optimization design, operation strategy and a multi-criterion evaluation of a building multi-energy complementary system in Dalian (China) are explored. In Ref. [6], through the comparision of the different categories of indexes and different thermal indexes, the evaluation effect on the multi-energy combined supply and energy cascade utilization of the regional integrated energy system are analysed. Taking the levelized energy cost, levelized CO_2 emission, utilization of renewable energy, loss of load probability as evaluation indexes, an integrated approach is presented in this study to design energy hubs combining optimization and multi-criterion evaluation in Ref. [7]. In Ref. [8], considering the conditional value at risk (CVaR) and the uncertainty of the photovoltaic

* Corresponding author.
E-mail addresses: lxy.lh@163.com (H. Li), wangxiaodan6@126.com (X. Wang), 51351706@ncepu.edu.cn (Y. Gao), hfliang@ncepu.edu.cn (H. Liang).

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Nomenclature

Subscripts and abbreviations

AC	absorption chiller
AHP	analytic hierarchy process
CE	cross-entropy
CVaR	conditional value at risk
DG	distributed generation
EC	electric chiller
EMS	energy management system
ES	electric energy storage
GB	gas-fired boiler
GRA	gray relation analysis
HS	heating energy storage
HX	heat-exchanger
MCS	monte carlo simulation
MT	micro-turbine
PCA	principal component analysis
PPS	probabilistic production simulation
PV	photovoltaic
UGF	universal generating function
UGFPPS	the probabilistic production simulation based on improved universal generating function method
WT	wind turbine

and electricity price, an optimal management system of battery energy storage in a way to maintain its operational cost at a minimum level is put forward. An optimization algorithm in which an objective function premised on economic strategies distribution limitations and the overall demand in the market structure is proposed in Ref. [9], and this method emphasizes the optimum use of electric and thermal energy distribution resources. In Ref. [10], taking the minimum operating cost as the optimization goal, a detailed optimization model is presented for planning the short-term operation of combined cooling, heating and electric energy systems, while taking into account time-varying loads, tariffs and ambient conditions.

In addition, for the optimization evaluation method of the multi-energy complementary system, in Ref. [11], through the communication, analysis, game and decision of the multi-agent, the system reliability evaluation is carried out with the dynamic process simulation of time series monte carlo method. In Ref. [12], an optimization method based on the gravitational search algorithm is carried out to solve such problem in a microgrids including different types of distributed generation (DG) units with particular attention to the energy storage and demand response. A multi-criteria evaluation model has been developed by combining the improved gray relation analysis (GRA) approach and the analytic hierarchy process (AHP) method in Ref. [13], which compares the influences of climate conditions and building types on the introduction of the building combined thermal and electric energy systems in China and Japan. An algorithm for energy management system (EMS) based on the multi-layer ant colony optimization is presented in Ref. [14] to solve the energy scheduling problem. In Ref. [15], an EMS algorithm based on the mixed-integer nonlinear programming is put forward for microgrids to improve its reliability and efficiency as well as to reduce its total cost of energy. In Ref. [16], the dynamic weight function, two dimension penalty function, catastrophe decision theory and self-organizing feature map network are applied to evaluate the multi-energy complementary system.

Based on the above evaluation researches, most of them are evaluated from the aspects of renewable energy access and multi-energy flow coordination and complementary operation of the energy supply system. The evaluation indexes include the energy utilization rate, energy saving rate, economic cost and so on, and most of the evaluation methods are intelligent solving algorithm. Namely, taking the evaluation indexes as the objectives, the optimization for the energy allocation and operation strategy of the multi-energy complementarity system can be achieved. However, the existing research is seldom involved the random outage failure and the uncertainty of each energy supply unit in multi-energy complementary system, and the evaluation of the operating modes and energy supply characteristics of each energy supply unit in multi-energy coupling system is also lack. Therefore, drawing lessons from the probabilistic production simulation (PPS) of the power system and from the perspective of the energy supply device of the multi-energy complementary park, the operation mode analysis, production cost calculation and reliability evaluation can be carried out by considering the random outage failure and the uncertainty of electric/heating/ cooling load output of each energy supply unit. Then the key indexes of the power generation cost, reliability and pollutant discharge of each energy supply unit can be obtained, and the output dispatch scheduling plan of each energy supply unit in multi-energy complementary park can be realized.

At the current research stage, the PPS methods proposed by scholars at home and abroad mainly include the block method, semi invariant method, piecewise linear approximation method, equivalent electric quantity function method and so on [17,18]. Considering the uncertainty of wind power and photovoltaic (PV) and load fluctuation, the main methods in common use include the monte carlo simulation (MCS) [19,20] and analytical method [21–24]. The monte carlo simulation method can be divided into the sequential MCS method and non sequential MCS method, and the analytic method includes the sequence operation theory method and universal generating function (UGF) method. Among them, for the traditional PPS methods, in Ref. [17], the concept of considering the power and electricity constraints at the same time for the reliability evaluation of the power generation system is proposed, and the selection of the reliability index of the power generation system is discussed. A PPS method of the power system based on the timing load curve is established in Ref. [18], and the random outage failure of generator set is reflected in the change of the power supply capability in this method. For the PPS with distributed energy, in Ref. [19], considering the sequential MCS and the cross-entropy (CE) method, a new method to evaluate the system generating capacity reliability indexes with the consideration of time-varying power sources and loads is proposed. A timing PPS method of the power system with the wind power and energy storage is put forward under the operation scheduling strategy which corresponds to the loading sequence and the charging and discharging conditions of each unit in Ref. [20].

What's more, as a kind of analytic method, the UGF method has been applied in the PPS process due to its features with simple principle, convenient calculation and so on. For the researches of the UGF method, in Ref. [21], the state distribution of power system based on the extensive-form structure is described, and taking wind power as an example, the PPS including clean energy is discussed. Through making the whole power system equivalent to a multi-state system, a PPS method of power system based on the UGF method is proposed in Ref. [22]. Considering the existence of the time-varying characteristics of wind power and load in power system, a novel PPS approach considering wind speed correlation is carried out based on the UGF method in Ref. [23]. In Ref. [24], combined with the principal component analysis (PCA) method and the hierarchical clustering method, a PPS method based on the UGF method is put forward.

Therefore, based on the aforementioned discussions, for the evaluation methods from the perspective of the energy supply device in multi-energy complementary park, most of them are carried out at the power system, less involved in the overall evaluation of the electric/heating/cooling multi-energy flow system. What's more, there are still a