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Dispatching strategies for coordinating environmental awareness and risk perception in wind power integrated system

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A B S T R A C T

Wind power plays a significant role in economic and environmental operation of electric power system. Meanwhile, the variability and uncertainty characteristics of wind power generation bring technical and economical challenges for power system operation. In order to harmonize the relationship between environmental protection and risk management in power dispatching, this paper presents a stochastic dynamic economic emission dispatch model combining risk perception with environmental awareness of decision-makers by following the principle of chance-constrained programming. In this power dispatching model, the description of wind power uncertainty is derived from the probability statistic character of wind speed. Constraints-handling techniques as a heuristic strategy are embedded into non-dominated sorting genetic algorithm-II. In addition, more information is digested from the Pareto optimum solution set by cluster analysis and fuzzy set theory. The simulation results eventually demonstrate that the increase of the share of wind power output will bring higher risk, though it is beneficial for economic cost and environmental protection. Since different risk perception and environmental awareness can possibly lead to diverse non-dominated solutions, decision-makers may choose an appropriate dispatching strategy according to their specific risk perception and environmental awareness.

1. Introduction

As one of the most widely used scheduling methods in electrical power system, ED (economic dispatch) has received abroad attention and research for a long time. For it schedules the load demand that is supposed to be constant during a given interval of time, among the online generators economically while meeting various requirements containing the generators' static behavior [1]. DED (dynamic economic dispatch) is an extension of ED, which allocates the online generator outputs with the predicted load demands over a certain period of time. DED considers the ramp rate limits of generators between time intervals, which are often overlooked in the ED problem [2]. Therefore, DED operates the electric power system more economically [3]. Meanwhile, with the enhancement of people's environmental awareness, the ED problem is changed into a multi-objective optimization problem, called the EED (economic emission dispatch) problem [4]. As a research direction of the EED problem, DEED (dynamic economic emission dispatch) can simultaneously minimize fuel cost and emission issues over a short-term time span [5]. Comparing with EED and DED, DEED is a more practical solution for the optimal power flow dispatching problem considering both emissions and the ramp rate limits [6].

With the development of economy and the progress of society, the consumption of fossil fuels increases significantly [7]. Owing to the environmental pollution, there are some large-scale industries which have negative domestic and cross-border effects on the ecological balance, like the electrical power industry [8]. Reducing emissions of gaseous pollutants (such as NO_x (nitrogen oxides), SO_x (sulphur oxides) and CO_x (carbon oxides)) is one of the most pressing issues facing the electrical power industry [9]. To achieve that goal, in consideration of some obvious advantages: renewable, clean and low-cost, wind power has been widely infiltrated into the power system for reducing the total electrical energy costs and air pollutant emissions of power generation [10]. Obviously, as far as

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Nomenclature

Variables

$T_{i,t}$ the scheduled power output of the i th thermal power generator during time interval t
W_t the wind power output during time interval t
$P_{D,t}$ the load demand of power system during time interval t
$P_{L,t}$ the transmission line losses during time interval t
W available wind power
V wind speed

Parameters

M the number of thermal power generators
T the quantity of time intervals
a_i, b_i, d_i, e_i and f_i cost coefficients for the i th thermal power generator
α_i, γ_i, λ_i, δ_i and τ_i emission coefficients for the i th thermal power generator
$T_i^{\min}$ the minimum power generation limit for the i th thermal power generator
$T_i^{\max}$ the maximum power generation limit for the i th thermal power generator
B_{ij}, B_{i0} and B_{00} transmission network power loss B-coefficients
T_{60} the fixed length of each time interval
η_1, η_2 the confidence level
UR_i the ramp up rate limits for the i th thermal power
DR_i the ramp down rate limits for the i th thermal power
α the ratio of load demand forecasting error
β_u the ratio of forecasting error for overestimating wind power output
θ the weighting factor
k,ζ the shape parameter
c,β the scale parameter
v_i the cut-in wind speed
v_r the rated wind speed

List of abbreviations

ED economic dispatch
DED dynamic economic dispatch
EED economic emission dispatch
DEED dynamic economic emission dispatch
SMP stochastic mathematical programming
CCP chance-constrained programming
NSGA-II nondominated sorting genetic algorithm-II
MOEA multi-objective evolutionary algorithms
NO_x nitrogen oxides
SO_x sulphur oxides
CO_x carbon oxides
PSRR positive spinning reserve requirements
NSRR negative spinning reserve requirements
PDF probability density functions
CDF cumulative distribution function
GW Gamma-Weibull

the integration usage of wind power is concerned, diverse environmental awareness of decision-makers may lead to different power dispatching strategy. Meanwhile, unlike thermal power generation, the uncertainties of wind power may bring more risks of dispatching and pose new challenges for power system operation [11]. Correspondingly, the deterministic DEED models for thermal power system applications are unable to describe the uncertainties in power dispatching [12].

Under the background, SMP (stochastic mathematical programming) is an effective tool for obtaining optimal decision making under uncertainty, many researchers have begun to formulate suitable power dispatching models based on SMP. A model is developed to include wind power uncertainty in the ED problem, besides the classic economic dispatch factors, factors accounting for both overestimation and underestimation of available wind power are considered [13]. A model for EED problem related with wind power penetration is proposed, and it considers operational cost and security factors as opposite objectives which should be minimized simultaneously [14]. A model is presented to solve the DEED problem incorporating uncertainties in the process of power generation, and the constraints of both reliability and efficiency are especially considered to restrain the disturbances of uncertainties [15]. However, these models using probability methods may not clearly depict the risk level arising from wind power uncertainty. Furthermore, the risk perception of decision-makers cannot be directly reflected during the decision process.

To solve these problems, CCP (chance-constrained programming) developed by Charnes and Cooper, is a commonly used SMP method to describe the risk level of uncertainties in optimization problems. It was designed to get the optimal solution while allowing for constraint violation with random variables under certain prescribed confidence levels [16]. Contrast with deterministic linear programming, CCP permits violation of constraints to some extent, that is, a method of analyzing decision risks from different constraints must be identified. Due to these advantages, CCP models have been successfully used in power dispatching under uncertainty. For example, a novel unit commitment model is proposed considering demand response and electric vehicles, which can promote the exploitation of wind power [17]. An approach is presented for long-term reactive power investment planning and operation using a multiperiod mixed-integer stochastic convex model, where load uncertainty is also included [18]. A multiobjective stochastic framework based on CCP is developed to handle combined heat and power economic load dispatch considering various kinds of stochastic characteristics [19]. Similarly, on the basis of the principle of CCP, the risk level caused by wind power uncertainty can also be depicted in the DEED problem.

Large-scale wind power grid integration is often referred as a double-edged sword at existing performance level. Specifically, it may save energy consumption and reduce environmental pollution owing to lower cost and fewer emissions of wind power generation. On the other hand, it may have adverse effect on the safety of power system as a result of wind power's characteristics such as randomness, intermittence and uncontrollability. When decision-makers face such contradiction, harmonizing the relationship between environmental protect and risk management is the foundation of power dispatching in wind power integrated system. To achieve this, it is therefore meaningful to investigate how to allocate the power reasonably for electric power system by considering the environmental awareness and risk perception of decision-makers. Therefore, the purpose of this study is to formulate a DEED model and decision-making method to control the risks for wind power uncertainty, and to depict the recognition level of environmental protect. With these model and method, this study tries to find out how the environmental awareness and risk perception affect the optimal solution of the DEED problem, and how to get an effective and scientific strategy combining environmental awareness with risk perception.