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Multi-objective hydro-thermal-wind coordination scheduling integrated with large-scale electric vehicles using IMOPSO

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ABSTRACT

Since the intermittency and volatility of wind power has restricted its penetration into power grid, coordination scheduling of flexible resources and wind energy becomes a promising technique for promoting wind power utilization. Hence, this paper integrates large-scale electric vehicles (EVs) with wind power generation to formulate multi-objective hydro-thermal-wind with EVs scheduling (MOHTWES) problem. And what's more, an improved multi-objective particle swarm optimization (IMOPSO) algorithm is proposed for solving the above problem with various constraints. By introducing a unique dual population evolution mechanism and a hierarchical elitism preserving strategy based on crowding entropy, IMOPSO can achieve excellent and well-distributed Pareto optimal solutions in objective space. Furthermore, a set of constraint handling strategies are utilized to guarantee that the solutions obtained are in feasible region. Finally, a daily scheduling problem of hydro-thermal system is used to verify the performance of IMOPSO, the numerical results of which shows the Pareto optimal solutions obtained by IMOPSO have greater advantages than the comparison algorithms. Furthermore, it can be concluded from the simulation results for MOHTWES problem that, smart scheduling of EVs integrated with wind energy can promote wind power utilization and reduce the generation cost and emission simultaneously.

1. Introduction

Wind energy has been treated as a clean green energy resource and experienced rapid development worldwide in the past decades [1]. But the intermittency and volatility of wind power restricts its large-scale integration into electric grid [2]. In this regard, the incorporation of flexible resources and wind energy has been studied to facilitate wind power penetration into grid.

In Ref. [3], demand side management (DSM) has been implemented by means of a unit commitment problem with high wind penetration. For handling system load balance constraints considering wind uncertainty, pumped storage units were dispatched to accommodate wind power generation in Ref. [4]. In Ref. [5], energy storage system (ESS) and DSM have been considered simultaneously in the multi-objective dispatch model incorporating wind power. And the characteristics and operation strategies of present EES technologies in relation to wind power integrated system have been summarized in Ref. [6].

Besides, large amount of electric vehicles (EVs) with vehicle-to-grid (V2G) capability can be used as loads and energy sources, the intelligent scheduling of which is a promising technique under smart grid environment [7]. Ref. [8] has analyzed the requirements and feasibility for integrating large-scale EVs into the existing power grid when performing V2G ancillary services. There is no doubt that participation of EVs into grid will play an important role in power system operation. On one hand, the charging periods of EVs can be negotiated between users and system operators. In this way, EVs are scheduled to charge from the grid during valley load periods [9], which is regarded as a special mode of DSM. On the other hand, EVs with V2G capability can be considered as ESS for allowing bidirectional power flow between the batteries and the grid. Consequently, EVs can absorb the surplus wind energy and promote wind power utilization [10].

In this context, some studies have focused on the coordination scheduling of EV fleet and wind energy. Ref. [11] developed a practical model considering the uncertainty of wind power sources and EVs to assess the contribution of V2G systems from the point of

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Nomenclature

i	thermal unit index
j	wind power plant index
m	hydro power plant index
l	electric vehicle fleet index u upstream reservoir index
t	time interval index
N_g	the number of thermal units
N_w	the number of wind power plants
N_h	the number of hydro power plants
N_u	the number of upstream reservoirs
N_e	the number of EV in the fleet
T	the number of time intervals
$P_{D,t}$	system load demand at hour t
$P_{i,t}$	generation power of thermal unit i at hour t
$P_{i,\min}$	minimum power output of thermal unit i
$P_{i,\max}$	maximum power output of thermal unit i
$P^w_{j,t}$	generation power of wind power plant j at hour t
$P^h_{m,t}$	generation power of hydro plant m at hour t
$P^h_{m,\min}$	minimum power output of hydro plant m
$P^h_{m,\max}$	maximum power output of hydro plant m
$P^d_{1,t}$	discharging power of EV fleet at hour t
$P^c_{1,t}$	charging power of EV fleet at hour t
$E_{n,t}$	charging/discharging power of the nth EV at hour t
$E^{dr}_{n,t}$	driving power of the nth EV at hour t
$SOC_{n,t}$	state of charge of the nth EV at hour t
BC	battery capacity of EV
S	the random variable of wind speed
W	the random variable of wind power
c	scale factor at a given location
k	shape factor at a given location s wind speed
s_R	rated wind speed s_{in} cut-in wind speed
s_{out}	cut-out wind speed
w	wind power output
$w_{R,j}$	rated wind power output of wind plant j
$V_{m,t}$	storage volume of reservoir m at hour t
$V_{m,\text{begin}}$	initial storage volume of reservoir m
$V_{m,\text{end}}$	final storage volume of reservoir m
$V_{m,\min}$	minimum storage volume of reservoir m
$V_{m,\max}$	maximum storage volume of reservoir m
$Q_{m,t}$	water discharge of hydro plant m at hour t
$Q_{m,\min}$	minimum water discharge of hydro plant m
$Q_{m,\max}$	maximum water discharge of hydro plant m
$I_{m,t}$	water inflow of reservoir m at hour t
$S_{m,t}$	water spillage of hydro plant m at hour t
$\tau_{u,m}$	water transport delay from reservoir u to reservoir m
$E_{d,\max}$	maximum discharging power of EV
$E_{c,\max}$	maximum charging power of EV
$SOC_{\min}$	minimum limit of state of charge of EV
$SOC_{\max}$	maximum limit of state of charge of EV
SOC_{ini}	initial state of charge of EV

economic and reliability. Ref. [12] modeled a distribution system composed of wind units, diesel units, photovoltaic units and plug-in hybrid EVs parking lots, and the test results demonstrated an improvement in the operation conditions of the system. In Ref. [13], demand response and EVs were considered simultaneously for a wind-thermal scheduling problem to promote wind power utilization. In the above studies, only minimizing generation cost was considered as the operation objective. However, with global environment deterioration, government has paid increasing attention to the management of pollution emission. In Ref. [14], the coordinated scheduling of plug-in electric vehicle fleets connected to grid were considered as a type of dispatchable demand response and energy storage resource to reduce the fuel cost and CO_2 emission, yet the simulations were performed for a power system composed of 10 thermal units and 3 EV fleets, without the consideration of wind power.

Consequently, it is crucial to study the economic and emission dispatch (EED) problem [15], which is a multi-objective optimization problem with equality and inequality constraints. Ref. [16] proposed a non-dominated sorting gravitational search algorithm with chaotic mutation (NSGSA-CM) to solve multi-objective hydro-thermal scheduling problem. Numerical results indicated that the proposed NSGSA-CM had a more superior performance than previous algorithms, yet the renewable energy is not considered. For solving multi-objective hydro-thermal-wind scheduling (MOHTWS) problem, Ref. [17] proposed an extended NSGA-III with the reference-point based selection mechanism to enhance the distribution of Pareto solutions, while Ref. [18] developed a composite ranking index combined with ant lion optimization technique to find the best solution. In Ref. [17,18], wind power cost was calculated by overestimation cost and underestimation cost, which was strongly dependent on the values of the reserve and penalty cost coefficients with wind energy conversion system [19].

In the current study, different kinds of flexible resources such as DSM [3,5,14], pumped storage units [4], ESS [5,6] and EVs [7–10] have been accompanied with wind energy to facilitate its high penetration into grid. Refs. [11–13] have only studied cost minimization problem considering the incorporation of EVs with wind energy. Ref. [14] has proposed a hierarchically coordinated operation framework for bidirectional dispatch of the EV fleet without wind power integration. Refs. [17,18] have studied the economic and emission dispatch (EED) problem for the hydro-thermal-wind scheduling system, yet they didn't consider effective strategies to promote wind power utilization.

From the above literature, there is no study considering the coordinated dispatch of large-scale EVs and wind energy with the conventional hydrothermal scheduling problem, measuring the effect of large-scale EVs integration on both generation cost and emission as well as mitigating wind power variability and uncertainty.

As a result, the purpose of this study is to formulate a multi-objective hydro-thermal-wind with EVs coordination scheduling (MOHTWECS) model, the schematic outline of which is shown in Fig. 1. As shown in Fig. 1, the coordination scheduling system contains three conventional thermal plants, four cascade hydro power plants, two wind power stations and large-scale EV fleet, by which the effectiveness of smart scheduling of large-scale EVs to facilitate the wind power utilization and reduce cost and emission can be investigated.

For the coordinated optimal operation of EVs in the transmission system and distribution system, Ref. [20] has proposed a hierarchical operation framework, which facilitates independent system operators (ISOs), distribution system operators, and individual households to integrate EVs into existing transmission, distribution and home area networks, respectively. And a novel bilayer optimization scheme of transmission and distribution system has been proposed to solve the temporal and spatial scheduling problem of EVs with wind power integration in Ref. [21].

In this study, we focus on the ISO's EV operation module in the proposed hierarchical framework in Ref. [20]. As a type of special