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A hybrid harmony search algorithm with differential evolution for day-ahead scheduling problem of a microgrid with consideration of power flow constraints

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HIGHLIGHTS

- A day-ahead scheduling model for the optimal operation in microgrids is proposed.
- Power flow constraints are introduced to consider the transmission network.
- A hybrid harmony search algorithm with DE is proposed to solve the model.
- Some improvements to the hybrid algorithm are present to enhance searching ability.
- IEEE test systems are considered to verify the proposed model and algorithm.

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ABSTRACT

With constructions of demonstrative microgrids, the realistic optimal economic dispatch and energy management system are required eagerly. However, most current works usually give some simplifications on the modeling of microgrids. This paper presents an optimal day-ahead scheduling model for a microgrid system with photovoltaic cells, wind turbine units, diesel generators and battery storage systems. The power flow constraints are introduced into the scheduling model in order to show some necessary properties in the low voltage distribution network of microgrids. Besides a hybrid harmony search algorithm with differential evolution (HSDE) approach to the optimization problem is proposed. Some improvements such as the dynamic *F* and *CR*, the improved mutation, the additional competition and the discrete difference operation have been integrated into the proposed algorithm in order to obtain the competitive results efficiently. The numerical results for several test microgrids adopting the IEEE 9-bus, IEEE 39-bus and IEEE 57-bus systems to represent their transmission networks are employed to show the effectiveness and validity of the proposed model and algorithm. Not only the normal operation mode but also some typical fault modes are used to verify the proposed approach and the simulations show the competitiveness of the HSDE algorithm.

1. Introduction

The energy crisis has emerged in recent years and the environmental contamination has reached a high level due to the excessive exploitation and use of fossil energy. Because of the benefits of renewable energy for environmental protection, society begins to pay much attention to the development and utilization of renewable power sources. The renewable energy generating systems have been used extensively in remote areas for the last few decades in order to cover electricity needs [1]. However, the interconnections of distributed renewable units will bring great challenges to the operation of power systems. The microgrid, as a friendly approach to this challenge, has attracted more and more attentions nowadays. It is a set of components including low-voltage distribution networks, distributed generation units, energy storage systems and controllable loads [2] and it could operate in two modes: either be connected to the larger national grid or isolated from it [3].

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Nomenclature

Parameters and constants

T	total scheduling periods
N_1	total number of wind-solar-battery generators
N_2	total number of diesel
C_1	generating cost
C_2	additional maintenance costs when the units are starting up
C_3	additional maintenance costs when the units are closing down
a_j, b_j, c_j	unit cost coefficients
n	number of network nodes
V_i^{ideal}	expected voltage magnitudes of node i
δV_i	allowed maximum voltage offset of node i
v_t	actual wind speed at time interval t
v_c	cut-in speed of wind turbine
v_f	cut-out speed of wind turbine
v_r	rated wind speed of wind turbine
P_r	rated power of wind turbine
η	power conversion efficiency of photovoltaic cell
Y_{PV}	rated capacity of photovoltaic cell
$I_T(t)$	radiation that photovoltaic cell accept at time interval t
I_s	standard test condition
P_{bat-t}	charging (or discharging) power at time interval $t + \Delta t$
C_{bat}	nominal capacity of battery
Δt	time interval
$P_i^{\min}$, $P_i^{\max}$	output power lower and upper bounds of unit i
$SOC_{\min}$, $SOC_{\max}$	minimum and maximum state of charge of the battery
$P_{ij}^{\min}$,$P_{ij}^{\max}$	minimum and maximum of power flow between node i and node j
$V_i^{\min}$, $V_i^{\max}$	minimum and maximum limits of voltage at node i
R_j^u, R_j^d	ramp-up and ramp-down limits of a diesel generator j
L_u	increased load rate caused by load forecasting inaccuracy
W_u	reductive wind power generation caused by wind power forecasting inaccuracy
PV_u	reductive photovoltaic power generation caused by photovoltaic power forecasting inaccuracy
$P_{im,t}$	maximum output of diesel generator i at time interval t
G_{ij}, B_{ij}	conductance and susceptance between node i and node j

Variables

$x_j(j,t)$	output power of a renewable energy generator j at time interval t
$P_{j,t}$	output power of a diesel generator j at time interval t
ΔV	penalty term of voltage offset
V_i	voltage magnitudes of node i
P_{WT}	output power of wind turbine
P_{PV}	output power of photovoltaic cell
SOC_t	state of charge at time interval t
F_j	fuel cost
P_{ij}	apparent power between node i and node j
SU_t	aggregate spinning reserve that all diesel generators can increase at time interval t
SU_{it}	spinning reserve that diesel generator i can increase at time interval t
P_{lt}, P_{wat}, P_{pvat}	load forecasted, wind power generation planned and photovoltaic power generation planned
P_{Gi}	total output at node i
P_{Di}	load at node i
δ_i, δ_j	voltage phase at node i and node j

Acronyms

PEM	proton exchange membrane
FCPP	fuel cell power plants
DER	Distributed Energy Resource
GA	genetic algorithm
PSO	particle swarm optimization
DE	differential evolution
HS	harmony search
HSA	harmony search algorithm
SOC	state of charge
HSDE	hybrid differential evolution with harmony search
HM	harmony memory
HMS	harmony memory size
AIADE	hybrid artificial immune algorithm with DE
GADE	hybrid genetic algorithm with DE
PSODE	hybrid particle swarm optimization with DE
MDE	modified DE

Microgrids have been considered as the alternative way to supply energy demands of future power grids in a reliable and efficient way. However, most of the researches are still in the stage of laboratory or small scale application demonstration at present. For autonomous islanded microgrids, there are at least two problems in the operational aspect should be solved before the mass production run. One is the control problem [4–9], and the other is the energy management problem [10–18]. Generally, the day-ahead scheduling [19] and the real-time scheduling [11,20–23] are two of the most important tasks in the energy management problem of micrgrids. The focus of this paper aims at the former one.

There are two issues for the optimal day-ahead scheduling: one is the accurately modeling and the other is the efficient solving. The optimization problems for scheduling in microgrids are usually formulated as linear programming problems [24], mixed-integer linear programming problems [25–28], mixed-integer quadratic programming problems [29], etc. The programming models in literature are usually different with different involved microgrids. For supplying power, potable water and hydrogen as the transportation fuel in remote areas, Ref. [30] presented a viable solution through poly-generation microgrids. Tidal power generators and fuel cells were introduced into an independent microgrid to locally produce energy for local consumption [31,32]. However, only Ref. [32] considered the power losses of inverters/converters. The study of Ref. [33] focused on the short term scheduling problem of multiple PEM (proton exchange membrane) fuel cell power plants (FCPPs) connected in parallel to supply electric and thermal energy to a microgrid community, while in Ref. [34], the optimal operation of a wind turbine, a solar unit, a fuel cell and a storage battery was studied separately. However, these two researches only involved simple microgrid systems: one only involved several parallel PEM fuel cells and the other involved several power sources but only with one unit. Ref. [35] proposed a multi-agent system scheduling for an islanded power system with distributed resources, which consists of integrated microgrids and lumped loads. The main focus of Ref. [36] was to incorporate originality in ideas to evaluate how different optimal output sets of DER-mix could share an electrical tracking demand among micro-turbines and diesel generators of various sizes economically. The formulated models mentioned above neglected the transmission network but it is unreasonable for the ratio value of R/X in low voltage network is high. To establish an accurate scheduling or operational model, some practical operation conditions in microgrids should be considered in the formulation of the optimization prob-