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Probabilistic optimal scheduling of networked microgrids considering time-based demand response programs under uncertainty

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HIGHLIGHTS

- A novel EMS is introduced to cope with demerits of prevailing EMSs.
- A new networked MGs structure is proposed to facilitate the MGs optimal scheduling.
- Time-based DRPs are exploited to mitigate the costs of consumers and MGs owners.
- PSO algorithm is used to optimize the cost of MGs under uncertain parameters.
- The efficiency of PSO can be revealed after comparing with a stochastic optimization.

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ABSTRACT

Networked microgrids (NMGs) are beneficial and economical for both microgrids' owners and consumers as this structure could potentially play a significant role in energy efficiency, power system reliability and sustainability. Renewable energy sources (RESs) and sharp fluctuations in load consumption impose new challenges in solving operational problems in smart distribution grids. As a result, deterministic methods are not able to provide a precise analysis of microgrids operation and planning. Therefore, stochastic algorithms are used as powerful tools in ensuring reliable solutions especially in operation problems. In this paper, daily optimal scheduling problem of NMGs considering intermittent behavior in generation and load is investigated in a proposed energy management system (EMS). Two demand response programs (DRPs) based on time of use (TOU) and real time pricing (RTP) are integrated into the optimal scheduling model and the developed model is solved using a metaheuristic algorithm under uncertainties of RESs and loads. The numerical simulations show the effectiveness of the proposed model through comparison with solution from stochastic optimization.

1. Introduction

A microgrid (MG) is a group of interconnected loads and renewable energy sources (RESs) within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. An MG can connect/disconnect to/from the grid in order to operate in both grid-connected or islanded mode [1,2]. In a microgrid, economic load dispatch plays a crucial role in minimizing total operation cost under physical constraints [3,4]. One of the important challenges in MG management is creating the balance between loads and generations of MG and import/export power in order to meet demand-supply balance in any given time [5]. In [6], authors have studied the energy consumption scheduling of connected multi-MGs considering demand uncertainty. The operation of distribution network operator (DNO) and networked microgrids (NMGs) in grid-connected mode are coordinated without considering uncertainties in the side of DGs and loads [7].

MG optimal scheduling problem has been analyzed considering multi-MGs in recent researches, in which the available MGs not only are connected to each other but also have an interaction with DNO. In [8], a day-ahead optimization problem is solved using a robust min-max-min cost considering economic aspects of smart distribution grids. To achieve optimal solutions, a decomposition algorithm based on dual cutting planes in a mixed-integer linear programming (MILP) format along with demand response programs are exerted. In [9], a hybrid differential evolution with harmony search approach is developed to address the complication of mixed integer nonlinear programming in minimizing the total

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Nomenclature

Indices/sets

$\{i, j, t\} \in T$	indices for time
$\{m, n\} \in MG$	indices for microgrids
l	index for loads
u	index for generation units
OM	index for operation and maintenance cost
g	index for generated power
BAT	index for battery packs
CH	index for the amount of battery charge
DCH	index for the amount of battery discharge
$sell$	index for sold power
pur	index for purchased power
k	index for pollutants
w, z	indices for particles in PSO

Parameters and constants

$E(i,i)$	self elasticity
$E(i,j)$	cross elasticity between ith and jth hour
λ	cost coefficient
C_{nl}	natural gas price
L	natural gas low-hot value kW h/m^3
UR	ramp up rate
DR	ramp down rate
ϵ_{rec}	heat recovery factor
η_e^t	electrical efficiency of MT at hour t
η_b	boiler efficiency
$P_{BAT,CAP}$	capacity of battery kW
P_{BAT}^{loss}	power loss of battery kW
Υ	price coefficient of different pollutants
r_1, r_2	random functions in the range [0,1]
W	inertia weight factor
c_1, c_2	acceleration coefficients of PSO
N	number of variables

Variables

C_{l0}	initial electricity price before DRP [\$/kW h]
P_{l0}	initial demand value before DRP [kW h]
$P_{l,new}$	consumption power after DRP [kW h]
$C_{l,new}$	electricity energy price after DRP [\$/kW h]
ΔP_l	difference between demands before and after DRPs
S	customer's benefit
B	costumer's income
C	energy cost in different modes
P	RES output power [kW]
η	efficiency of generation units
u	commitment status of generators
SOC	state of charge of batteries
$C_{pur,mn}$	cost of purchased power by MG-m from MG-n [\$/h]
$C_{sell,mn}$	cost of sold power by MG-m to MG-n [\$/h]
$P_{pur,mn}$	purchased power by MG-m from MG-n [kW]
$P_{sell,mn}$	sold power by MG-m to MG-n [kW]
$P_{tran,m}$	the amount of transactive power of MG-m [kW]
OF	objective function
$Cost_{op}$	operation cost [\$/h]
$Cost_{em}$	emission cost [\$/h]
ρ	emission factor of pollutants
x	vector of uncertain input variables
Y	vector of uncertain output variables
χ	position vector of particles in PSO
ϕ	velocity vector of particles in PSO
P_{best}	best previous position of particles in PSO
g_{best}	best particle among all P_{best} in PSO

Acronyms

NMG	Networked Microgrid
RES	Renewable Energy Source
EMS	Energy Management System
DR	Demand Response
DRP	Demand Response Program
TOU	Time of Use
RTP	Real Time Pricing
PSO	Particle Swarm Optimization
DNO	Distribution Network Operator
MG	Microgrid
MGCC	Microgrid Central Controller
WT	Wind Turbine
PV	Photovoltaic panel
MT	Micro Turbine
FC	Fuel Cell
CHP	Combined Heat and Power
PDF	Probability Distribution Function
DG	Distributed Generation
MCS	Monte Carlo Simulation

value of operation cost of the smart microgrid system assigning the power flow constraints. Nowadays, plug-in hybrid electric vehicles (PHEVs) and storage devices are key elements within the microgrids which make them very reliable and resilient small scale energy zones. In this regard, Kamankesh et al. [10] introduce a robust symbiotic organisms search algorithm to analyze the optimal operation of the MG considering different charging behaviors of PHEVs and various charging patterns in the MG under uncertain nature of the studied network. One of the remarkable benefits of microgrids has to do with the resilience improvement of the network through mitigating the possible interruptions during natural disasters. In [11], the optimal scheduling of a resiliency-oriented microgrid is investigated in a centralized management system. A procedure based on distributed dynamic programming algorithm is assumed in solving optimal daily scheduling of microgrids as a knapsack problem [12]. Cardoso et al. [13] investigate the optimal planning of batteries using stochastic linear programming under uncertainty in fuel cell outages. From another point of view, networked MGs play a crucial role in providing powerful and reliable operation for future smart distribution grids [14] where both MG owners and customers benefit from reliable and economical power delivery. In [15], a decentralized Markov decision process is introduced in NMGs environment to minimize the operation costs of MGs under an optimal control framework. In [16] various entities can take part in power market considering multi-agent systems for the energy management of DGs in multiple MGs. A transformative architecture for the optimal operation and self-healing of autonomous networked MGs is studied in [17] and during generation deficiency in one MG, the framework is entered into the self-healing mode. In [18], the authors focus on a three-stage algorithm based on coalitional game strategy in multiple MGs network with multi-agent system to solve the economic power transaction problem. Studies in [19,20] have introduced the Multi-MGs concept and solved optimal power dispatch problem in that environment considering market operation under load and generation uncertainties.

Among the important aspects of the microgrids, the economic analysis of MGs has taken specific consideration among the