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Research article

Stochastic multi-objective model for optimal energy exchange optimization of networked microgrids with presence of renewable generation under risk-based strategies

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ABSTRACT

The inherent volatility and unpredictable nature of renewable generations and load demand pose considerable challenges for energy exchange optimization of microgrids (MG). To address these challenges, this paper proposes a new risk-based multi-objective energy exchange optimization for networked MGs from economic and reliability standpoints under load consumption and renewable power generation uncertainties. In so doing, three various risk-based strategies are distinguished by using conditional value at risk (CVaR) approach. The proposed model is specified as a two-distinct objective function. The first function minimizes the operation and maintenance costs, cost of power transaction between upstream network and MGs as well as power loss cost, whereas the second function minimizes the energy not supplied (ENS) value. Furthermore, the stochastic scenario-based approach is incorporated into the approach in order to handle the uncertainty. Also, Kantorovich distance scenario reduction method has been implemented to reduce the computational burden. Finally, non-dominated sorting genetic algorithm (NSGAII) is applied to minimize the objective functions simultaneously and the best solution is extracted by fuzzy satisfying method with respect to risk-based strategies. To indicate the performance of the proposed model, it is performed on the modified IEEE 33-bus distribution system and the obtained results show that the presented approach can be considered as an efficient tool for optimal energy exchange optimization of MGs.

1. Introduction

1.1. Aims and concepts

Microgrid (MG) is a group of distributed energy resources (DER) together with energy storage systems (ESS) and flexible loads with clearly defined electrical boundaries that can be operated in both islanded or grid connected modes [1]. One of the most important concerns in future distribution network is optimal energy exchange optimization of MGs. If management and control of MGs be performed optimally and efficiently, it will provide distinguished benefits and advantages for overall distribution network [2]. Therefore, reliable and economic management of MG is a crucial issue and serious challenge for distribution system corporates. The future distribution network may include of numerous MGs while their optimal management will confront to a more complex system with DER, ESS and electric vehicles as well as responsible loads [3,4].

The hierarchical structure for control of MGs can be categorized into three wide layers to facilitate powerful control which voltage/frequency stabilization using droop controllers is in primary layer [5]. Also, the voltage/frequency restoration by decentralized controllers be located in secondary layer and tertiary layer considers economic attentions such as optimal power flow between the MGs and utility grid, economic dispatch of DER units and demand side scheduling to adjust the consumption of MGs [6]. Accordingly, the main and basic subject of this paper is in tertiary layer of MGs energy management system (EMS).

1.2. Literature review

The economic and reliable management of DER units in MGs is a crucial task in terms of EMS standpoint that should be done as optimal and efficient. On the other hand, there are some uncertain parameters such as renewable power and load demand in energy exchange optimization problem that due to their stochastic behavior, the system may put at risk. Hence, it is necessary that the management of MGs be done under risk-based strategies. Some

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Nomenclature

Indices

s	Index for scenario
b	Index for branch
n	Index for node
t	Index for hour

Sets

N_S	Set of generated scenarios
N_b	Set of network lines
N_n	Set of network nodes
N_{res}	Set of isolated buses at fault times
N_{rep}	Set of isolated buses at repair times

Constants

C_{gas}^{MT}	Price of natural gas for MT units
K_{th}^{MT}	Price of sold power of MT units
k	Maximum power correction for air temperature
η	Efficiency of the MT units
∂, ϱ and γ	Coefficients of MT units
K_{om}	Operation and maintenance coefficients of DER units
P_{rate}	Rated power of WT units
P^D	Load demand
$£_s$	Probability of scenario s
$£_s^D$	Probability of load demand at scenario s
$£_s^{PV}$	Probability of PV generation at scenario s
$£_s^{WT}$	Probability of WT generation at scenario s
G_{ING}	Incident irradiance
G_{STC}	Irradiance at standard test condition
P_{STC}	Rated power of PV unit
υ	Wind speed [m/s]
V_r	Rated wind speed [m/s]
V_{ci}	Cut-in speed of WT units [m/s]
V_{co}	Cut-out speed of WT units [m/s]
T_c, T_r	PV Cell and reference temperatures, respectively
c	Scale index of Rayleigh PDF
τ,ω	Parameters of Beta PDF
λ	Failure rate of lines
σ, ξ	Standard deviation and shape parameter of Beta PDF
ψ	Mean value of Normal PDF
η_{ch}, η_{dis}	Efficiency of charge/discharge of ESS units
μ	Membership function of fuzzy set theory
β	Risk aversion parameter
C_{int}	Cost of interruption [$/kW]
C_{loss}	Cost of power loss [$/kW]
W_S	Sold electricity price [$/kW]
W_B	Bought electricity price [$/kW]
M	Number of non-dominated solutions
R_b	Resistance of network lines
L_b	Length of network lines
$U_{s,t}^{Up}$, $U_{s,t}^{Dn}$	Minimum up/down time of DER units
$RU_{s,t}$, $RD_{s,t}$	Ramp up/down power of DER units

Variables

P^{WT}	Power generation of WT units [kW]
P^{PV}	Power generation of PV units [kW]
P^{MT}	Power generation of MT units [kW]
P^{ch}, P^{dis}	Charging and Discharging of ESS units
$P_{t,s}^S$	Sold power at scenario s and hour t
$P_{t,s}^B$	Bought power at scenario s and hour t
P_b, Q_b	Active and reactive powers in line b
P^{loss}, Q^{loss}	Active and reactive powers losses
V_n	Voltage of node n
I_b	Current of line b
$\phi_{t,s}^{ch}$, $\phi_{t,s}^{dis}$	Binary variables for charging/discharging modes
P_{res}	Restored Loads at fault conditions
P_{rep}	Not restored Loads at fault conditions
T_{res}	Time of fault and switching
T_{rep}	Time of repair after fault

Functions

VaR_α	Value at risk in the confidence level α
$CVaR_\alpha$	Conditional VaR in the confidence level α
ENS	Energy not supply
SOC	State of charge for ESS units
OMC	Operation and maintenance cost
F^{tot}	Total objective function
F_{Ex}	Expected value of objective function
Z	Multi objective function

references [7–10] already investigated the risk analysis where the risk-based approaches represent a preferred solution to restrain the cost of undesirable events due to uncertain parameters. The risk-based approach centralizes on the decision about the acceptable level of risk as risk seeking or risk aversion in decision making framework while the conventional EMS methods focus only on the value of the solutions.

Some literature has been studied the MGs energy management problem from different perspectives. Ref. [11] presented a new scenario-based model for optimal management of renewable based MGs considering operation cost under uncertainty in PV power generation by stochastic programming. Palma [12] proposed a new rolling horizon algorithm for management of MGs based on MINLP formulation considering demand response program. Study in [13] presented a stochastic non-linear approach for energy optimization scheduling of MGs based on resiliency improvement in islanded mode by using priority list. Ref. [14] proposed a bi-level optimization method for EMS of linked MGs to maximize the profit of system which the proposed method is converted into a single-level model by Karush-Kuhn-Tucker (KKT) condition. An optimal power scheduling strategy considering renewable distributed generation based on resilience enhancement for interconnected MGs is presented in [15] using multi-interval estimation with considering the stochastic behavior of solar, wind, and demand. In [16] a bi-level model based on multi agent systems is proposed to DER management in the multi MGs network considering power exchange to participate in power market using naive auction algorithm. An optimal decentralized observable Markov decision model is proposed in [17] for optimal control of linked MGs based on dynamic programming algorithm to minimize the operation cost of MGs and improve the efficiency of DERs units. In [18] a multi-objective approach is proposed for optimal operation of MGs based on electric vehicle scheduling with considering operation and maintenance cost under uncertainties in load and generation using discrete benders decomposition programming. Ref. [19] presented a cost based approach for optimal power flow in the multi MG system with incorporating distribution-interline power flow controller.