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Multi-microgrids approach for design and operation of future distribution networks based on novel technical indices

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HIGHLIGHTS

- Proposing the MMGs-based approach for optimal operation of ADNs.
- Comparing the results with conventional method in different scenarios.
- Considering novel technical indices for quality evaluation of ADNs operation modes.
- Using a powerful multi-objective optimization method known as NSGA-II.
- Modeling the intermittent nature of RESs, loads, and energy prices by considering their PDFs.

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ABSTRACT

Clustering the large scale active distribution networks (ADNs) into a set of smaller microgrids (MGs) or multi-microgrids (MMGs)-based operation of ADNs can have several benefits for the utility, electric power consumers, and distributed generation (DG) owners such as easier control strategy, distributed control among MGs, load routing and transfer among MGs and reliability enhancement. This research proposes a novel program for optimal operation of ADNs based on the MMGs approach. Initially, the operation of ADNs was carried out by integrated management of all distributed energy resources (DERs) using probabilistic forward-backward load flow using Monte Carlo simulation (MCS) algorithm. In this stage, energy storage devices (ESDs) as one of the significant components of MG are sized and sited in ADN. In the second stage, the operation quality is scrutinized accurately by testing the possibility of MG construction in the modified ADN based on various technical criteria such as adequacy, efficiency, voltage profile, and reliability. This issue has not been addressed in the previous researches. Finally, the results of the proposed model are compared with conventional operation method in different scenarios by implementation on IEEE 33-bus ADN and an actual Portuguese distribution network using a powerful multi-objective optimization tool known as non-dominated genetic algorithm-II (NSGA-II).

1. Introduction

Distributed generations (DGs) are not taken into consideration in the design of existing distribution systems, hence exploitation of these resources (which their penetration level continually increases) can result in the appearance of unwanted conditions in some parameters such as power quality, reliability, efficiency, safety, among others. As a result, novel efficient management in the operation of the active distribution networks (ADNs) will be required. In the final report of Electric Power Research Institute (EPRI) about technical and economic aspects of microgrid (MG) compared with traditional power system from cost, efficiency, reliability, and ancillary services viewpoints, it has been recommended over the superiority of MG in several aspects [1]. In this manner, using the MG concept for taking the advantages of renewable-based DGs and efficient utilization of ADNs would be a suitable approach which is the scope of this research. A typical MG is presented in Fig. 1. In this model, elastic or responsive loads and energy storage devices (ESDs) play a significant role. In fact, two main advantages are provided in MG for flexible management of load and system operation. The first refers to the passing of the load from its passive state to an active one and increasing its capability to participate in demand side management (DSM) programs. The second advantage is the fast development of ESDs for load and generation balancing [2]. This research takes the effect of ESDs into consideration.

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Nomenclature

Acronyms
ADN active distribution network
CHP combined heat and power
DER distributed energy resource
DG distributed generation
DNO distribution network operator
ESD energy storage device
EMM energy management module
GA genetic algorithm
GSEMS global smart energy management system
LSEMS local smart energy management system
NSGA II non-dominated sorting GA II
MCS Monte-Carlo simulation
MG microgrid
MGCC microgrid central controller
MMG multi-microgrid
NSGA non-dominated genetic algorithm
RES renewable energy resource
PCM protection management module
PDF probability density function
PV photovoltaic generator
SOC state of the charge
WT wind turbine

Indices and sets
t, N_t index and set for total number of time ranges in the simulation
c, N_{MC} index and set for total number of MCS algorithm execution
i, j, N_b, N_c index and set for total number of busses and customers
n, $N_{\mu G}$ index and set for total number of constructed MGs
r, N_{RES} index and set for total number of RESs
e, N_{ES} index and set for total number of ESDs
N_L total number of network lines

Parameters
E_{ES_min} minimum storable energy in ESD
E_{ES_max} maximum storable energy in ESD
V_{min} minimum bus voltage amplitude
V_{max} maximum bus voltage amplitude
Y_{ij} line admittance
T_c PV cell temperature
λ annual failure rate
Q_L reactive power of load
E_{ES} stored energy in ESD
U annual interruption duration
P_r rated active power of wind turbine
P_{STC} active power of PV module at standard test conditions
S_{STC} solar irradiance at standard test conditions
P_{ch/dis_max} maximum charge/discharge power rate of ESD
v_{ci} cut-in speed of wind turbine
v_r rated speed of wind turbine
c scale index
S solar irradiance
h_t time segment (here two hours)
k_{MPT} maximum power temperature coefficient

Variables
B_{UG} price of active power received from upstream network
P_{UG} active power received from upstream network
Q_{UG} reactive power received from upstream network
P_{RES} active power of RES
V bus voltage amplitude
Q_{RES} reactive power of RES
P_{Loss} active power losses
$\overline{P}_L$ average value of load demand
$\overline{P}_{Loss}$ average value of active power losses
$\rho_{\mu G}$ power matching percent of load and generation in MG
P_{pv} active power of PV module
T_a ambient temperature
SAIFI system average interruption failure index
CAIDI customer average interruption duration index
SAIDI system average interruption duration index
R_index_{opt} optimum predefined amount for reliability index
R_index_{self} reliability index for each MG without consideration of upstream MGs
$R\_index_{UP\mu G}$ reliability index of upstream MGs

2. Literature review

Up to now, only a few studies have been proposed about the operation methods of ADNs, and most of the studies have focused on the operation of MGs in which the properties of all distributed energy resources (DERs) (i.e. DGs and ESDs) such as location, type, and capacity are given as input data. For instance, Ref. [3] proposes a stochastic model for optimal MG operation considering uncertainties related to load, generation and market prices based on multi-objective optimization framework. Also, in [4] the model predictive control is developed for reducing the running costs of an experimental MG. Optimal MG scheduling has been done by Jaramillo and Weidlich [5] aiming at the reduction of peak power received from the upstream network. In this work, more focus has been given to hydrogen storage system which is made up of an alkaline electrolyzer, hydrogen cylinder bundles and a fuel cell for energy storage. The subject of energy management in MG has been observed by Kuznetsova et al. [6] where they have developed an integrated framework for agent-based modeling. The given approach demands an increase in system performance in terms of reliability indices. In [7], optimal energy management regimes in a practical MG are determined. Meanwhile, the sensitivity analyses of storage capacity and energy demand are carried out. Optimal planning and operation of aggregated DERs considering their interaction with market prices in presence of aggregators has been proposed in [8]. Morvaj et al. [9] have combined the distribution grid constraints and building energy use with the optimal design and operation of DERs as an optimization framework. Finally, an approach for optimal operation of DERs containing RESs and ESDs for diesel-free remote communities has been presented in [10].

Among the published researches on operation methods of ADNs, Ref. [11] has proceeded to the operation of future distribution networks under MMGs concept and has considered the economic management of this MGs with probabilistic modeling of load and generation by probability density functions (PDFs). The subject of ESDs and their mode of operation have not been treated in this research. In [12], the authors have carried out similar research considering environmental costs and comparing certain heuristic methods of simulation. In [13], the coordinated energy management in subsidiary MGs connected to the main ADN has been followed with the calculation of generation cost (particularly