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A hybrid energy management and battery size optimization for standalone microgrids: A case study for Flinders Island, Australia

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ABSTRACT

Microgrids are increasingly being used as a platform to integrate distributed generation such as renewable energy sources and (RESs) conventional sources in both grid-connected and isolated power systems. Due to the inherent intermittent nature of RESs, energy storage systems (ESSs) that can absorb fluctuations have become inevitable. Nevertheless, large capacities of ESSs increase the initial cost while small capacities lead to instabilities and increase in the cost of conventional fuels. Therefore, finding the optimal size of the ESS for a given application is essential for the reliable, efficient and economical operation of a microgrid. Once the battery size is decided, maintaining its energy at appropriate levels is essential to ensure stable and safe operation of the microgrid. This paper presents a novel expert fuzzy system - grey wolf optimization (FL-GWO) based intelligent meta-heuristic method for battery sizing and energy management. The proposed energy management operation is carried out by a Grey Wolf Optimiser (GWO) that is helped to set the membership functions and rules of the fuzzy logic expert system. The unit commitment (UC) issue, which is essential for the proper operation of the isolated microgrid, has been additionally considered in this paper. To verify the performance of the proposed method, results are compared with the rules-based method and traditional GWO algorithm. It has been proven from the results that the FL-GWO has a significant convergence property and capability to minimize the Levelized Cost Of Electricity (LCOE) by 14.13% and 24.15% compared with conventional GWO algorithm and rules-based method, respectively. The weather conditions for different climates is used to verify the performance of the intelligent energy management method under different operating scenarios. The results show that the intelligent online multi-objective energy management strategy is capable of managing a smooth power flow with the same optimal configuration in the isolated microgrid, minimising the fossil fuel utilisation and reducing the CO_2 emission level.

1. Introduction

Alternative energy sources such as wind, biomass, solar, hydro have are increasingly being used especially in rural areas and remote islands owing to their availability, scalability, reliability, higher power quality, higher flexibility, less cost and less ecological impacts [1–3]. However, with the high penetration of these DGs into the power grid, their inherent drawbacks such as intermittency and resultant power quality issues become prominent. Microgrids have recently emerged as a platform to solve these issues locally and thereby achieve reliable supply of electrical power [4–8].

Microgrids are small networks that work as a cluster of loads and micro-sources operating as a single controllable network that produces and distribute power in remote areas such as villages, industrial complexes or even in remote islands [9,10]. Microgrids have the ability to be grid-connected, where the system is able to connect to the conventional upstream grid or it can be a standalone system when there is no possibility of connecting to a power grid. Microgrid has many advantages over the conventional power system as they are scalable, do not require large capital investments, generally less ecological problems compared to traditional generation systems and can be customised to suit community needs [9,11,12].

However, the constraints of the power generated by renewable sources bring significant challenges to the microgrid especially on the

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Nomenclature

Abbreviations

BES	Battery energy storage
BESS	Battery energy storage system
CO_2	Carbon dioxide
DG	Distributed generation
dg	Diesel generator
ED	Economic Dispatch
ESS	Energy Storage System
FL	Fuzzy logic
IR	Interest rate
LCOE	Levelized cost of electricity
MG	Microgrid
NOA	Number of agents
O&M	Operation and Maintenance
OR	Operating reserve
PV	Photovoltaic
RES	Renewable energy source
SOC	State of charge
T	Operation time horizon
TCT	Tidal current turbine
UC	Unit Commitment

Constants

OM_{dg}, OM_{PV}, OM_{WT}, OM_{TCT}	Fixed operation and maintenance cost of the diesel generator, photovoltaic, wind turbine and tidal current turbine, respectively
$OM_{sources}$	Fixed operation and maintenance cost of the distributed generators
SDC_{dg}	Shut-down cost of diesel generator
SUD_{dg}	Start-up cost of diesel generator

Variables

C_{BES}	Battery capacity
C_{BES}	Battery capacity
Dmnd	Load demand
D_P	Diesel price
D_P	Diesel price
E_{CO2}	CO_2 emission
P_{dg}, P_{PV}, P_{WT}, P_{TCT}, P_{BES}	Electrical power of diesel generator, solar, wind turbine, tidal current turbine and battery energy storage, respectively
P_{diff}	Difference of power between the generations and demands
$SOC_{Battery}$	State of charge of the battery

stability and power quality. Therefore, energy storage has been identified as a promising solution to overcome those issues and enhance the system security and flexibility [13]. During the high availability periods, ESSs can be utilised to store the surplus of power and release stored energy when there is a power shortage in the grid. In addition, due to the real-time pricing of the electrical market, the ESS can take the advantage of participating in the market by purchasing the energy from the upstream grid during the off-peak hours and sell it back to the upstream grid during the peak demand hours. Furthermore, storage devices in microgrids could provide ancillary services to the grid as well to enhance the power quality [14–16].

Microgrids with DGs and ESSs form are a complex system that requires an intelligent optimization to operate at best possible conditions. The two significant aspects that should be taken into account in these optimization exercises are UC and ED [17]. The UC problem involves determining the start-up and shut-down schedules of the generator units to satisfy the load demands, which is a complex optimization problem with both integer and continuous variables. Once the UC problem is solved, the ED problem starts searching for the optimal power outputs from the local generation sources or utility grid based on the microgrids structures.

Therefore, there is a strong need for more intelligent technologies to deal with the optimal scheduling operations of DGs and ESS sizing in microgrids by considering UC and ED. Artificial intelligent technologies are broadly used in power system optimization due to their robustness and their ability to deal with complex problems. In contrast, traditional techniques are not capable of solving optimization problems in the hybrid power systems mainly due to incomplete information as well as the multiple conflicts in the objectives. In such environments, artificial intelligence techniques such as neural networks, fuzzy logic and bio-inspired algorithms can be used due to their inherent nonlinear mapping, simplicity and powerful search capability [18].

Consequently, a significant challenge appeared in designing the microgrid that related to select the optimum size of the ESS and optimum energy management scheduling. The conventional generation scheduling schemes typically rely on the accuracy of the demand forecastings methods used, which is hard to apply for microgrids due to the small-scale demands and intermittencies of the renewable energy resources. On top of that, real-time pricing of diesel fuel for remote microgrids is another uncertainty dimension to the scheduling problem. Therefore, due to aforementioned challenges leave the issue open to design robust and cost-effective solutions for microgrids based on selecting the optimum ESSs size and optimum energy management scheme.

1.1. Related work

This section presents a review of the relevant optimization approaches reported in the literature and discusses state-of-the-art optimization methods that deal with optimal scheduling operations of DGs and ESS sizing in MGs. Many scientific works have been proposed by researchers to deal with the energy management problems [17,19–28] in microgrids. Muhammad Khalid et al. [29] proposed a dynamic programming for controlling the setting up of the battery energy storage system with the aim of reducing the overall cost of purchasing power from different energy producers including the renewable energy generations within the microgrid. Zhengmao Li and Yan Xu [30] have presented a mixed integer programming approach to coordinate the energy dispatch for controllable generation units such as (fuel cell, electric boiler, heater and power plant and electric chiller), as well as uncontrollable generation units like renewable sources. The proposed study aims to cut down the microgrid operation costs and enhance the dispatch flexibility in supplying power, heat and cooling in the day-ahead energy market.

In [31] the optimal discharging scheme of the ESSs problem in microgrids was studied by applying hyper heuristic algorithms. The study used the evolutionary algorithm as a global approach for reducing buying the power from the utility grid. Quanyuan Jiang et al. [32] used double layer coordinated control method for managing the energy in