Sustainable Cities and Society 62 (2020) 102391

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Sustainable energy planning for cost minimization of autonomous hybrid microgrid using combined multi-objective optimization algorithm

Ahmed M.A. Haidar[a,b,*], Adila Fakhar[a], Andreas Helwig[b]

[a] Department of Electrical and Electronics Engineering, Universiti Malaysia Sarawak, Malaysia
[b] School of Mechanical and Electrical Engineering, University of Southern Queensland, Australia

ARTICLE INFO

Keywords:
Cost minimization
Hybrid energy systems
Multi-objective optimization
Operational analysis
Regression analysis
Rural areas electrification

ABSTRACT

With the development of scattered energy resources in the rural areas of Sarawak (Malaysia), various operational problems due to the unplanned installation of autonomous microgrids become gradually remarkable. To address this concern, the paper proposes an optimal strategy to evaluate the performance of different hybrid microgrid configurations for the Long San Village in Sarawak. A mathematical model is presented for sizing the component of the system to meet the maximum load demand under changing weather conditions and at the lowest possible cost. The developed approach simulates different microgrid models using deterministic and stochastic optimization methods to find the exact dynamic energy price of the selected optimal configuration in the context of system uncertainties. Furthermore, the operational feasibility of the system in terms of reliability and voltage security is studied in addition to economic feasibility with a comparative analysis of the environmental impact. The results show that the optimal configuration with the lowest cost of energy and net present cost can be achieved if the installed solar PV is less than 61 kW with 85 kW h of energy storage and 11 kW of hydro generation, where such system has 55,725 (kg/year) Carbon Dioxide and 330 (kg/year) Nitrogen Oxides. The findings also indicate that the dynamic energy pricing increases to 0.71 $/kWh when the power generation from renewable resources drops to zero. Further, the dynamic analysis shows that in order to reduce the voltage drop during disturbances, it is crucial to carefully install the sources in the buses connected to high energy demand.

1. Introduction

Currently, conventional energy sources generate most electricity in many countries which are based on fossil-fuel. These generating resources are continuously polluting the air and emitting greenhouse gases. There is a strong commitment by the Governments of many countries to reduce greenhouse gas emissions and global warming through the use of renewable energy resources. The main challenge here is how to facilitate the implementation of renewable generation in the rural, semi-urban and urban cities to meet the fast-growing energy demand. Achieving this will result in tackling the environmental issues and providing reliable and affordable energy to the public and the whole industry sectors, and thus, faster economic growth and improvement in social welfare as the people will get jobs in their doorsteps instead of seeking jobs in big cities. In line with the above discussion, this section is structured as follows: a brief background about renewable generation and electrification in Sarawak is outlined in the motivation subsection, followed by the state of the art in the second subsection. In the next subsection, the contributions of the paper are demonstrated. In this sense, the proposed approach is compared with the related published works in order to highlight the novelty of this paper. Finally, the scope of study with paper organization is presented in the fourth subsection.

1.1. Motivation

Renewable Energy Resources (RER) are becoming popular as an alternative option of clean and currently more environmentally friendly energy source for the electrification of rural and remote areas particularly, where the solar, wind and hydro resources are abundant. A hybrid microgrid is basically a combination of two or more RER connected with the loads that operates in a controllable entity manner. Therefore, to ensure the reliability of the system, wide control techniques are needed to intelligently manage each source in the hybrid system (Mazzeo, Baglivo, Matera, Congedo, & Oliveti, 2019; Ullah, Haidar, & Zen, 2020). In Malaysia, the interest in utilizing the hybrid microgrid based RER in an islanded mode (autonomous) is increasing exponentially, mainly in Sarawak (Hossain et al., 2018). This is due to

* Corresponding author at: Department of Electrical and Electronics Engineering, Universiti Malaysia Sarawak, Malaysia.
E-mail addresses: ahahmed@unimas.my, ahmed.haidar@usq.edu.au (A.M.A. Haidar).

https://doi.org/10.1016/j.scs.2020.102391
Received 29 December 2019; Received in revised form 9 July 2020; Accepted 10 July 2020
Available online 13 July 2020

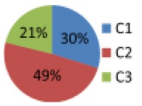
the low cost in electrifying the rural areas and simplicity in installing the hybrid microgrid compared to the high cost transmission and distribution networks from these areas into the power stations. The Sarawak Alternative Rural Electrification Scheme (SARES) was launched in 2016 to enhance the efforts towards full electricity coverage in Sarawak. The electrification scheme aims to provide continuous electricity supply to the remote communities by utilizing RER (solar and micro-hydro) in Sarawak's interior and through the advancements in alternative energy technology. In line with the SARES, there are some villages have already been connected to the main power grid in Sarawak, however, it should be noted that about 400 villages in the remote rural heartlands of Sarawak are still not connected and impossible to be connected to the main electricity grid in the near future. The reason for this is either due to the difficulty in accessing these areas or because of the distance from the center of consumption, which makes the financial returns uncertain for installations in the rural villages as these areas are far less energy-intensive. Although in some cases, the high voltage transmission lines from large hydro-power stations are passing through the remote villages, the cost of stepping down the voltage in order to supply power to these tiny communities is too expensive. Therefore, local authorities usually install small diesel generators and in some accessible remote villages where the financial viability can be ensured, generation from the hybrid energy system equipped with energy storage is also utilized.

Table 1 demonstrates the status of the microgrid connected system in different locations of Sarawak. Three categories are summarized in this table: grid-connected (C1), possible access to the grid but currently is not connected (C2) and access is not possible to the main power grid (C3). Following the first table, the ratios of the rural areas that currently need electrification are illustrated in Table 2 (Khengwee et al., 2017; Shiun, 2016). Indeed, connecting the rural areas to power grid cannot be achieved without building substations and transmission systems. As this approach is not feasible from the economical point of view and due to the availability of massive exploitable potential of solar and hydro resources in Sarawak, hybrid microgrid design can be the best candidate in reducing the huge investment for rural electrification, avoiding the environmental impact and improving the sustainability of renewable energy systems, and thus fulfilling the energy demand. In fact, the lack of in-depth consideration for enabling planning and study the operating condition of the installed systems is the main reason for failing the application of microgrid in the rural areas of Sarawak, as this may require research efforts and strategies for the implementation of sustainable hybrid systems in the remote communities. This implies that the qualified practitioners or contractors will need to have additional training and experience in the installation of off-grid microgrids in rural areas. Referring to Tables 1 and 2, it is indicated that most of the rural areas in Sarawak (Malaysia), particularly the remotest villages in the jungles are lacking centralized electricity. Developing these areas is a daunting task and huge investment is needed as it is difficult at the moment connecting them to the main power grid. Connecting different types of RER with the loads to form a microgrid requires setting up a methodology to accurately represent the parameters of the optimal configuration, which generally depends on the main activities of the local communities and the location of the RER. Therefore, it is crucial to measure the system response during normal and abnormal conditions.

1.2. Literature survey

In the literature, several research works were carried out to study the optimal design of microgrids in grid-connected and islanded modes with various combinations of RER and energy storage. A variety of techno-economic feasibility studies of hybrid energy systems proposed in the existing literature can be divided in terms of optimization techniques into two categories, deterministic (traditional) and stochastic. In simple words, in the deterministic approach, the behaviors of RER (solar irradiance and wind speed) including load demand remain constant over the period of historical datasets. In this sense, the parameters of the system are represented by mathematical expression utilizing large entry data at the given pre-determined inputs without a physical model. On the other hand, the stochastic method considers the random behaviors of the system, where uncertainties of RER are formulated using appropriate models to estimate the output, here, the obtained value can be near or exactly as the projected value. Different strategies have been presented to design and optimize the hybrid microgrid systems using traditional algorithms. For instance, in the study (Nazira, Laksono, Waldi, Ekaputra, & Coveriaa, 2015), a microgrid design was proposed to utilize the local renewable energy (micro-hydro and solar PV) for the on-grid area. The authors concluded that the lowest cost is achieved with a microgrid model having the highest micro-hydro power capacity (152 kW). Even though this study considered an operational analysis, the behavior of the model was not evaluated during abnormal conditions. A similar study for the electrification of rural villages in Nigeria was carried out in Olatomiwa (2016) to determine the optimal configuration of the hybrid system. In this work, the researcher modelled solar PV and diesel generator with battery and simulated the model using the hybrid optimization model for electric renewable (HOMER) software. In this same context, Ajayi, Ohijeagbon, Mercy, and Ameh (2016) conducted an economic feasibility analysis of hybrid energy system and viability assessment of wind and solar resources for 6 sites in North-East, Nigeria. Performance evaluation of a stand-alone hybrid renewable energy system has been presented in Hossain, Mekhilef, and Olatomiwa (2017) to supply a large resort center in south China sea, Malaysia. In this study, HOMER was used for economic and technical analysis with an estimated peak load of 1185 kW and an average load of 544 kW during the day, to provide helpful insights to the policymakers in the development of grid-connected hybrid renewable systems. The concentrated solar power system was used with PV system and thermal storage as an energy source in isolated microgrids in Puertecitos, Mexico (Aguilar-Jiménez et al., 2018). From the economic analysis, the researcher revealed that the hybridization of the systems incorporating thermal storage allows manageability and complementarity and thus, reduction in the levelized cost of energy. A techno-economic analysis was conducted in (Al-Ghussain, Ahmed, & Haneef, 2018) for a hybrid PV-wind system integrated with Lithium-Ion

Table 1
Current need for electrification in Sarawak.

Electrification in rural areas	Category 1 (grid connected)	Category 2 (possible access to the grid)	Category 3 (not possible access to the grid)	Each in percentage %
Villages	556	916	397	
Households	9567	17,603	11,321