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Original Research Article

Strategy for developing energy systems for remote communities: Insights to best practices and sustainability

D.O. Akinyele *, R.K. Rayudu

Smart Power & Renewable Energy Systems Group, School of Engineering and Computer Science, Victoria University of Wellington, PO BOX 600, Wellington 6140, New Zealand

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ABSTRACT

Energy planners and policymakers have identified off-grid energy systems as an option for electrifying remote communities around the globe. Such systems could be fueled by either non-renewable or renewable energy resources, but because of the issue of climate change and the compelling need for environmental sustainability, the global community is strongly advocating the use of eco-friendly energy technologies. Renewable energy technologies are therefore deployed for clean energy production, especially in places where there are vast renewable energy resources. However, while there is high optimism about such technologies, there is a lack of knowledge and understanding of the strategies necessary to successfully develop them for off-grid communities. This invariably leads to poor, unreliable and unsustainable systems. This paper introduces enabling strategies for developing energy systems in remote communities, with the aim of achieving sustainability. The planning approaches attempt to integrate the necessary processes and stakeholders during the pre-design, detailed design, implementation and post-implementation stages, with reference to global engineering standards. We present a user-centered approach and also introduce design safety and load growth factors into the energy supply system sizing model for achieving reliable systems. Two different remote communities in Nigeria are used to test the proposed design approaches. The results demonstrate how the issue of a lack of knowledge could be addressed, thus, providing useful approaches for achieving widespread deployment of distributed energy generation projects for isolated communities around the world.

Introduction

The provision of clean energy is currently identified as one of the important programmes that are being pursued by many nations in the world [1–12]; such an agendum continues to increase the adoption, utilization and popularity of renewable energy – both for on-grid and off-grid applications. The declaration of the years 2014 to 2024 as the decade of Sustainable Energy for All (SE4All) [12] by the UN, is also considered as one of the factors that continually draw the attention of many electricity suppliers, independent power producers, governments and policymakers, and industrialists around the world, towards the uptake of renewable energy technologies. The application of the diesel-powered off-grid electricity systems is associated with relatively high life cycle costs, apart from the systems' adverse environmental impact. This, in addition to the concern of climate change and the need to ensure environmental sustainability are also part of the key factors that supports the deployment of clean energy systems, compared to the conventional energy option.

It is currently reported that about 1.3 billion people in the world remain without access to modern energy services [3–12]; half of these people live in sub-Saharan Africa. Renewable energy projects are currently being considered in many parts of this region to address the energy shortage problem, e.g. distributed solar PV, wind, hydro, biomass generation system, depending on the available renewable energy resources in the countries within the region [13].

However, while there is a high optimism about renewable electricity generation to improve the poor energy situation, there is a lack of knowledge and understanding of the appropriate strategies that are necessary to realize successful energy systems in this region. The absence of such strategies invariably leads to poor, unreliable and unsustainable energy systems, which is a major setback for deploying renewable energy technologies.

In this study, we use Nigeria as an example of countries, within the African region, where there are increased failure rates of renewable energy systems, especially the solar photovoltaic systems. A lot of PV-based street lighting and water pumping systems

* Corresponding author. Tel.: +64 223891364.
E-mail addresses: daniel.akinyele@ecs.vuw.ac.nz, akin_dan@yahoo.com (D.O. Akinyele).

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Nomenclature

A_d	days of autonomy
$A.T.L$	DPPP output after deducting temperature losses (kW or kWh)
$A.T.T.L$	DPPP output after deducting the total losses (kW or kWh)
B_s (min)	minimum battery capacity (kWh)
B_s (max)	rated battery capacity (kWh)
B_s	actual battery capacity (kWh)
DoD	depth of discharge (%)
D_{rf}	derating factor
D_{sf}	design safety factor
D	load demand (kWh)
E_{pr}	energy produced by the PV system (kWh)
E_{df}	energy difference (kWh)
G_a	solar irradiance of the site (W/m^2)
G_{STC}	solar irradiance at STC (1 kW/m^2)
LOE	loss of energy
L_{gf}	load growth factor
$MDoD$	maximum depth of discharge (%)
$NOCT$	nominal operating cell temperature (°C)
$O.\ L$	other losses (kW or kWh)
P_r	rated capacity of the DPPP without losses (kW)
P_o	output of the DPPP after deducting losses (kW)
P_{mp}	rated module power (W)
S_{irr}	solar insolation (kWh/m^2/day)
T_c	cell temperature (°C)
$T_{c,STC}$	cell temperature at STC (°C)
T_a	ambient temperature (°C)
V_s	battery system voltage (V)
η_{STC}	efficiency of DPPP at STC (%)
η_{act}	actual DPPP efficiency (%)
η_{rtp}	round trip efficiency (%)
α_p	temperature coefficient of power (%/°C)
x	number of PV modules

have failed or not working properly in so many communities in the country. One of the reasons for this is that many of the installations have been done without proper consideration for the site characteristics. For instance, solar PV systems are being designed based only on the irradiance data for the dry season, without considering the seasonal variation of the solar energy resources. We also found that attention is mostly paid to the design, cost and installation aspects of the off-grid electrification projects, without adequate considerations for their long-term viability.

The vast majority of the renewable energy systems in the country suffer from technical problems because they are not designed according to standards, i.e. the best practices are compromised because of the high initial capital cost of the renewable energy systems. As such, one or more key components of sustainability are being ignored, which invariably results in poor performance or failure or unreliable systems. For instance, out of the estimated 3500 MW small hydropower potential in the country, only 64.2 MW has been exploited, as reported by Energy Commission of Nigeria [14]. The widespread application of solar electricity technologies could help to diversify the country's energy mix.

The concept of a community-based energy system is new in the country, and it can only thrive through a sound framework that integrates the social, technical, environmental, financial, and institutional and policy aspects [15]. Therefore, conscious research efforts are needed to create well-planned approaches for the development and management of such schemes, which can aid the better understanding and planning of renewable energy technologies.

In addition, most recent scholarly publications in the aspect of energy development for remote communities are also found to majorly concentrate on the technical – modeling and simulation and the economical considerations, as reported in [16–40]. Kolhe et al. in [16] presented a research on the techno-economic sizing of off-grid hybrid electricity system for rural application in Sri Lanka, based on PV/wind/battery/diesel systems. The paper seeks to develop an energy system for the rural community, with optimum cost. The author in [17] discussed the feasibility study and sensitivity analysis of a stand-alone photovoltaic–diesel–battery hybrid energy system in the north of Algeria. The central aim of the research is the investigation of the techno-economical feasibility of hybrid energy generation.

The efficient energy control strategies for a standalone renewable/fuel cell hybrid power source has also been presented [18], with the discussion of four energy control strategies for a standalone energy system. The evaluation of the value of batteries in small-scale electricity systems is discussed in [19], using an improved energy systems model. The research presents the Energy System Model (ESM), based on an engineering-economic approach of developing a microgrid system. A polygeneration energy container is presented in [20], which focuses on the design and testing of energy services for remote developing communities.

A study on the joint energy management system of electric supply and demand in houses and buildings has also been discussed [21]; it focuses on the development of a framework that offers optimal solutions based on energy generation and consumption patterns. An SOC-based battery management system for small power grids is discussed in [22], concentrating on the investigation of battery energy management control for on-grid and off-grid small-scale electricity systems. The scholarly work in [23] discusses the coordinated V-f and P-Q control of solar photovoltaic generators with MPPT and battery storage system. The study focuses on the control of the voltage and frequency of an islanded microgrid electricity system.

The authors in [24] discussed techno-economic analysis of solar photovoltaic power plant for garment zone of Jaipur city. The paper in [25] focuses on the off-grid rural electrification experiences in South Asia. It concentrates on the status and best practices, which includes technology selection, business approach, policies and management. A study has also been presented on the optimal sizing of a PV/wind/diesel system with battery storage for off-grid electrification, using Rafsanjan, Iran as a case study [26]. Wind resource assessment for decentralized power generation is discussed in [27], using a complex hilly terrain in the western Himalayan region as a case study.

Optimum sizing of PV panel, battery capacity and insulation thickness for a photovoltaic operated domestic refrigerator is presented in [28]. The major point of the research is the design of a stand-alone energy system for operating a refrigerator. A heuristic method to design autonomous village electrification projects with renewable energies has also been discussed [29], which centers on the design and configurations of distributed wind-solar systems. The research in [30] gives attention to the decentralized demand–supply matching using community microgrids and consumer demand response. The paper maintains a position that energy demand–supply matching is very crucial for decision making in developing countries. A paper has also been presented on the assessment of decentralized hybrid PV solar–diesel power system for applications in the Northern part of Nigeria [31]. The study focuses on the simulation and cost analyses of a hybrid energy