Sustainable Energy Technologies and Assessments 23 (2017) 48–56

Contents lists available at ScienceDirect

Sustainable Energy Technologies and Assessments

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

Original article

Techno-economic analysis of a hybrid system to power a mine in an off-grid area in Ghana

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ARTICLE INFO

Keywords:
Renewable energy
Mining
Hybrid energy system
HOMER
Fuel cell
Ghana

ABSTRACT

In spite of the abundance of renewable energy and its potential application to mining industries, Ghana has not seen much investment in this area. The provision of electricity for mining activities in Ghana is cost intensive, especially in remote areas that are not connected to utility-grids. In this study, a technical and economic analysis of a hybrid electric power system for an off-grid mine company was conducted. Three different hybrid systems, together with a "Generator only" system as base case were analysed using HOMER software, to select the optimum energy system. The selected system consists of 50 MW of Solar PV, 15 MW of fuel cell system, 600 batteries, 20.5 MW of converter and 20 MW of diesel generator. The system produces 152.99 GWh of electric energy annually. The PV array produces 44%, the fuel cell produces 40% and the diesel produces 14%. At the current cost of system components, and based on assumptions adopted in this study, the optimal system yields a cost of energy of US$0.25/kW and a least cost of energy of US$0.22/kWh, at a diesel price of US$0.80/litre and 30% reduction in both PV module and fuel cell system costs.

Introduction

There is much demand for electricity in Ghana due to its growing economy, increase in per capita consumption of electricity by the addition of new consumers to the national grid, and the increase in modernisation. Sustainable economic growth of any developing country mainly depends on the supply of electricity infrastructure. To fulfil this ever-growing demand of energy sustainably, there is a need to exploit the renewable energy (RE) potential of the country. The industrial sector, of which the mining sector is part, consumes the highest amount of electricity, as opposed to residential and non-residential sectors in Ghana [1]. For instance, in 2014, the industrial sector consumed 5055 GWh (which represent 49.6%) out of 10 182 GWh consumed by all sectors, which are residential, non-residential, industrial and street lighting [2].

Mining is an energy-demanding industry, and energy is a critical concern for its effective operation and profitability. Analysis reveals that in 2009, the major gold mines consumed about 13% of Ghana's electricity; this translated into about 317,000 tCO_2 emissions (using a 2006–2008 weighted average grid emissions factor of 265 tCO_2/GWh) [3]. It was also estimated that in 2008, the major gold mining companies used about 9% of the country's diesel fuel consumption that year [3]. If little or non-carbon electricity sources are to replace the current electricity sources, emissions would be reduced significantly.

Mining sites are, usually, sited in locations with substantial amount of ore deposits. These locations are mostly remote and isolated from suitable energy infrastructure. Mining companies often resort to off-grid energy systems for operation. Remote mines operating independently from the electrical grid usually rely on diesel generation as a preferred energy systems option because of their relatively cheaper upfront investment cost, notwithstanding the negative implications of using these energy systems. Examples of negative impact of these systems are noise pollution, emission of pollutants, and high maintenance and operating costs (mainly from increasing cost of fuel).

Therefore, mining industries are continually finding interest in renewable energy technologies (RETs) because most often than not, some RETs are more cost competitive than traditional energy solutions, especially in isolated off-grid locations, where miners often have to transport fuel over very long distances. The more isolated the mine, the more likely alternative energy sources are required [4]. A study conducted by CRMPS and THEnergy reveals that typical cost savings from solar photovoltaic range from 25% to 30%. In highly remote areas with escalated fuel prices, the reductions can go beyond 70% [5].

EYGM Limited [4] explained that renewable energy (RE) sources could help mining companies achieve energy security, minimise exposure to energy price fluctuations and increase energy price

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http://dx.doi.org/10.1016/j.seta.2017.09.001
Received 25 April 2016; Received in revised form 2 June 2017; Accepted 1 September 2017
2213-1388/

prediction. The role renewable energy resources will play in mining is not as far-off or futuristic as one may suppose. The debate for big investments in RE exceeds sustainability and social responsibility, and it is now a strong economic reason for mining companies [4]. With cost and operational efficiencies forming the backbone of mining businesses, innovative hybrid system solutions can provide RE as an alternative source of fuel, reducing fuel consumption, whilst providing reliable and affordable electricity. These systems could hypothetically save over three (3) million litres of fuel yearly [6,7].

The major drawback of these clean sources of energy is that, the initial investment can be extremely high. However, the costs of RETs like solar PV have been dwindling over the years due to technology advancement [8]. There is an increasing demand for these energy technologies. These technological innovations have led to annual declines in RE costs, and companies can take control of their energy requirements using on-site RE generation, efficiency technologies and micro-grids. This creates significant prospects for cost savings and operational optimisation [3].

Hybrid systems combine one RE source and a conventional source or more renewable forms of power with or without a conventional energy source to provide a particular energy service or energy requirement that works as a standalone system or tied to the grid. These systems may or may not include energy storage and backup components [9]. Several studies have been conducted on the application of hybrid energy systems around the world in such sectors as homes, small and large hotels, school buildings, remote villages, and other commercial buildings [10,11]. However, per the authors' knowledge, very little has been done on hybrid energy systems in Ghana and can be found in the open literature [12], and particularly, for the mining sector.

Notable efforts to diversify energy sources, and to increase the utilisation of RE resources have been increasing around the world [13]. Literature deliberate on different combinations of RE systems together with conventional diesel generation, with or without storage, and the evaluation of their technical and financial viability [13–15]. These literatures have found out that the combination of RETs with diesel generation result in lower cost of energy, increased reliability and reduced emissions of greenhouse gases (GHG), as well as lower cost of energy production as compared to systems consisting of only one energy source [16].

Adaramola et al. [12] presented an economic analysis of the viability of a PV/wind/diesel hybrid system in an isolated location of southern Ghana. An optimal system of 80 kW PV array, 100 kW wind turbine, 100 kW diesel generator, a 60 kW converter and 60 units of battery produced the mix of electricity to meet the load. It has been observed that the PV/wind/genset hybrid was the most economically feasible solution based on the net present cost (NPC) and levelised cost of energy (LCOE).

Mohammed et al. [17] reported the design of an optimal standalone hybrid PV/Fuel cell (FC) power system, without battery storage, to supply the electric load demand of the city of Brest, France. The HOMER-based optimisation study, using the total NPC clearly shown that the proposed hybrid power system, and, in particular, the FCs are a viable alternative to diesel generators as a non-polluting reliable energy source with a reduced total cost of maintenance. It has also was shown that a FC generator could efficiently complement a fluctuating renewable source such as solar energy to satisfy growing loads [17].

Balachander and Vijayakumar [18] also demonstrated with their cost-benefit analysis of FC–Solar PV hybrid system application for smart grid distributed generation system that hydrogen storage fuel system is economically less compared with battery storage system. This study further explored the significance of minimising the excess energy from the hybrid system to cut down the LCOE for hybrid RE system. The results revealed that the minimum cost combination leads to 89% of total electricity produced by PV and remaining 11% by FC.

Three different hybrid power system configurations and diesel generator system for producing electric power in rural areas of Bangladesh have also been analysed [19]. The foremost aim was to determine the optimal size of systems that could meet the daily load demand of 50 households for three remote sites. The results showed that a hybrid system consisting of 6 kW PV, 10 kW diesel generating set, with battery storage was the most economically feasible, and by using the system, CO_2 emissions could be decreased by 38% over the diesel only system.

Salehin et al. [20] also designed an optimum hybrid system made up of solar PV and diesel generator. The purpose was to discover the optimum hybrid system based on available resources for a location in Bangladesh. The evaluation of electricity production, techno-economic analysis and CO_2 emissions analysis for the system was undertaken for the selected location. When the PV/diesel generator/battery system was compared with a system of diesel generator only, it was found out that addition of PV with diesel generators was appropriate and had a minor effect on the environmental.

The prospect of utilising hybrid standalone energy system for electricity generation in rural and semi-urban areas in the Northern part of Nigeria using HOMER software has been reported by Adaramola et al. [21]. The study suggests that a PV/Generator/Battery hybrid system is the most economically viable option for the selected locations, and other similar locations. Additionally, the simulation results indicate that the LCOE for the optimum hybrid system was below the cost of using diesel generator only. Reduced GHG emissions were also reported.

Many areas in Ghana have no access to electricity from the utility grid. There is a challenge to supply electricity because of two reasons. First, there is not enough power generation to fulfil the current power demand [1]. More so, even if there is enough power generation, extension of the grid to off-grid areas may be very challenging due to their geographical locations, and may not prove economical. ARE [22] reported that due to the usually, long distances between the existing grid and the off-grid areas, the costs of electrifying these areas through grid extension are very high, and, therefore, hybrid RE systems, in most cases offer a cheaper and less polluting option. Furthermore, the increased reliability of these systems and the best use of local resources favours this solution. Hence, hybrid RE systems prove to be the possible means of providing electricity for off-grid sites.

Regardless of the scale of operation, a mine could benefit from RE as a strategy to gain a measure of energy independence, not only from an unreliable grid, but also from the carbon – based fuels traditionally used on site. There are many renewable power projects that have proved successful in meeting the electrical load of a factory [6].

However, there is limited cases in Ghana, particularly, cases from the mining sector to demonstrate the technical feasibility and potential economic gains that could be realised from the application of a hybrid system in that context. Establishing the technical and economic feasibility of developing a hybrid system to provide electric power for mining activities will inform relevant stakeholders about options to reduce the load demand on Ghana's national grid, and make the excess power available to those with less capability to generate their own electricity. From an environmental perspective, options to reduce emissions, noise pollution and the mine's overall carbon footprint. This will also set the pace for projects of similar nature to be developed to serve the mining and other industries. Consequently, the overall objective of this study is to perform a technical and economic feasibility study employing hybrid RE system to power an off grid mine in Ghana.

To achieve the overall general objective of this study, the following specific objectives were also formulated: (i) determine the load profile of a selected mine and size an appropriate power plant; (ii) determine which option is both technically and economically feasible, if any; and (iii) analyse the sensitivity of the hybrid power system. The scope of this work is limited to the development of a framework to aid the planning, technical and economic analysis of an off-grid hybrid renewable energy system. The work, however, does not include the