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Decision-making between a grid extension and a rural renewable off-grid system with hydrogen generation

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ABSTRACT

Most populations in rural Africa have no access to electricity, in this study, a comparative analysis between grid extension and the implementation of renewable off-grid hybrid power system is carried out. The objective of the study is to determine the best feasible option. Napier, a farming village in the Western Cape province of South Africa was selected as the site for the comparative analysis and HOMER PRO software was used to develop an optimal system using the wind and solar resources of the selected site. The load profile considered in the analysis includes lighting, cooking and hot water demands. The best feasible option is determined based on the Net Present Cost of each feasible scenario. Sensitivity analysis on the current cost and the projected cost of hydrogen storage w conducted to observe the impact of the cost of hydrogen storage on the renewable off-grid system cost of energy.

Introduction

The power system industry in many countries is built around large power plants that use fossil fuels or nuclear energy as their primary source of energy. Generally, these power plants are situated far away from urban agglomerations and involve the construction of transmission and distribution networks that are required to transport power to consumers in metropolitan areas. The solutions to the power system industry also need to consider rural communities, which in most cases are situated far from metropolitan cities and have no access to electricity. In 2016, the World Energy Outlook revealed that an estimated population of 1.2 billion did not have access to electricity; many people suffer from poor power supply quality and the majority are based in rural sub-Saharan Africa and developing Asian countries [1].

Supplying electricity to these areas seems to be a difficult task because, on the one hand, these populations are remote, dispersed and characterised by a low electrical energy consumption while, on the other hand, most of the inhabitants of these areas are very poor and unable to pay the electricity bills [2]. Therefore, enlarging the power grid to meet the load requirements of these remote areas has shown to be economically and sometimes even technically unfeasible. However, the use of off-grid systems in such cases has proven to be an alternative; the electricity can be supplied from an individual source or a combination of renewable sources for instance

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Nomenclature

AFC	Alkaline fuel cell
A_w	Total swept area
β_T	Photovoltaic temperature coefficient
CC	Cycle charging
COE	Cost of Energy
DMFC	Direct methanol fuel cell
eff_w	Efficiency of the wind turbine
FC	Fuel cell
H2	Hydrogen
G_t	Radiant power incident
I	Electrolyser current
γ	Polytrophic coefficient
LED	Light Emitting Diode
LF	Load Following
MCFC	Molten carbonate fuel cell
NASA	US National Aeronautics and Space Administration
N_C	Number of cells in series
NPC	Net Present Cost
η_C	Compressor efficiency
η_F	Faraday efficiency
η_{PV}	Power reduction factor
O&M	Operation and Maintenance
P_1	Inlet pressure
P_2	Outlet pressure
PAFC	Phosphoric acid fuel cell
PEM	Polymer electrolyte membrane
PEMFC	Polymer electrolyte membrane fuel cell or polymer electrolyte membrane fuel cell
$P_{e,w}$	Power of the wind turbine generator
P_{comp}	power required for the compression
PMU	Power Management Unit
PV	Photovoltaic
P_{PV}	Output power of a photovoltaic panel
$P_{PV-rated}$	Nominal power of the photovoltaic panel
P_w	output power of a wind generator
P_{rated}	Rated power
P_{tank}	Pressure of hydrogen in the tank
$\dot{q}_{H2}$	Rate of hydrogen or mass flow rate of hydrogen
R	Gas constant
SOFC	Solid oxide fuel cell
T	Compressor inlet temperature
T_C	Temperature of the photovoltaic panel
$T_{C,STC}$	Cell temperature under standard test conditions
TV	Television
V	Rated speed
V_{act}	Activation voltage
V_{conc}	Concentration voltage
V_{cut-in}	Cut-in wind speed
$V_{cut-off}$	Cut-off speed
V_{FC}	Fuel cell output voltage
V_{ohmic}	Ohmic voltage
V_{tank}	Volume of the tank
n_{tank}	Number of moles of gas in the tank
WASA	Wind Atlas for South Africa

wind generators, photovoltaic panels, micro hydro, fuel cells, etc. or from non-renewable diesel generators. In countries such as Russia, the electricity supply in remote areas is based on diesel generators. These systems inflict important economic and social charges on population, which include the environmental effects of greenhouse, black carbon and oil spills [3]. As a result, renewable off-grid power systems are getting more attention and their use is becoming more widespread. Many publications with regards to these technologies for rural or remote areas applications have been reported in the literature.

Okoye et al. [4] proposed the use of solar chimney power plants for rural communities with poor or no access to the grid electricity. A site-specific hourly meteorological data was considered in the feasibility assessment of the plant in seven chosen regions of Nigeria. The results revealed that a solar chimney power plant with a collector diameter of 600 m and a height of 150 m would be able to generate 154–181 kW depending upon the daily weather conditions. McCarty et al. [5] compared six different energy technologies including improved biomass-fired cookstoves, advanced biomass-fired cookstoves, communal biomass-fired cookstoves, Liquefied Petroleum Gas cookstoves, solar water heaters and community-charged solar fluorescent lighting for a village in Mali. The results uncovered that no individual technology could optimally resolve all the environmental, health, social and economic objectives at the same time. An integrated strategy that considers the user trend to the fuels and devices that are most convenient and affordable for each task was discovered to lead to the most important impacts in all areas.

Komatsu et al. [6] analysed the characteristics of solar home systems in Bangladesh. An attempt to determine the factors that affect users' satisfaction so as to promote the expansion of the coverage of solar systems. The research evaluates the determinant factors of user satisfaction and households' judgement of the benefits of solar home systems. Carrasco et al. [7] recommended a tool for the design of electrification systems for rural areas based on photovoltaic panels using the Moroccan photovoltaic electrification plan as a reference. The tool derives from a mathematical model consisting of a set of decision variables such as location, transport etc., to meet various constraints with the objective function of minimising the cost. Rinalde et al. [8] proposed an experimental development of two prototypes of thermoelectric generators for the electrification of rural isolated homes. The recommended thermoelectric generators make use of the residual heat thrown away by the firewood home stove.

Bernal-Agustin et al. [9] applied Pareto-based Evolutionary Algorithm to design an optimal isolated hybrid PV-wind-diesel hybrid energy system with the objective functions of reducing the total cost and the pollution. Based on two daily load profiles assumed to be unchanged throughout the year, the research proposed practical low costs and pollution design solutions. Adeoti et al. [10] evaluated the electrical loads requirement of a rural house in Nigeria for PV-based homes design. It was revealed that each household necessitated an approximated annual energy of 850.8 kWh to meet the lighting and basic home appliances energy requirement. It was as well acknowledged the fact that the design of PV-based homes will