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Economic analysis of PV/diesel hybrid power systems in different climatic zones of South Africa

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ABSTRACT

Recently hybrid power systems (HPSs) consisting of integrated operation of two or more different types of energy sources and storage devices are being deployed for rural electrification or electrification of remote areas in many countries across the world. This is seen as a cost effective solution in contrast to extending the utility grid in remote areas. The types of upcoming renewable and low-carbon generation technologies are being preferred for such systems depending on their availability and economic viability in these countries. Moreover, HPSs are also being preferred in order to improve the overall energy efficiency of the system and to get a judicious generation mix which would minimise the operating cost of the system. Rural communities in South Africa endure poor access to electricity mostly due to the lack of grid connected power lines. It is therefore the ideal place to conduct a study on the economic feasibility of introducing HPSs for typical residential loads for the rural community in South Africa. This paper reports on the investigating economic feasibility of a PV/diesel HPS in various climatic zones within South Africa.

1. Introduction

A study done by the United Nations Environment Program (UNEP), indicated that an estimated 1.7–2.0 billion people around the world have got no access to grid based electricity services, the majority of which live in underdeveloped rural areas [1,2]. In order to realise sustainable human development, electricity has been identified to be a key measure in achieving this goal [3,21]. There are many factors contributing to the poor distribution of electrical resources, such as harsh terrain and the isolation of many rural villages. However, the ultimate reason for the poor distribution comes down to economic investment. It is too costly to install large grid connected power lines over vast distances to supply electricity to a small number of people [4]. This is one of the main reasons for the vast amount of research currently being done into standalone renewable energy sources (RESs) and hybrid power systems (HPSs) which combine two or more different types of renewable and low-carbon generators (e.g., photovoltaic, microturbines, diesel generators, wind turbines, fuel cells, etc.) with storage devices. The main object of combining a diesel generator with any of these renewable sources is to ensure minimum diesel fuel consumption, thus minimising operating costs and carbon footprint of the system [22].

It has been widely discussed in research literature that preference towards renewable and low-carbon generation technologies have stemmed from the problems faced by conventional fossil-fuel based power generation. One major reason is the depletion of fossil fuel reserves (i.e. coal and oil) and enormous growth in global population and hence energy demand [1,5]. Solar power generation through photovoltaic (PV) arrays, is arguably the most eco-friendly, emission free and sustainable source of energy known to man [23]. This is due to the fact that the suns energy is inexhaustible and un-intrusive, and as a result is slowly becoming an increasingly favourable source of energy for countries with a daily average of solar radiation levels in the range of 3–6 kW h/m^2 [6].

Another major issue with the burning of fossil fuels for energy purposes is the emission of green house gasses (GHGs). On the contrary, renewable energy sources are virtually emission free and consequently help the fight against global warming by reducing the amount of carbon dioxide being released into the atmosphere [7,24]. Scientists predict global warming could have drastic effects on the world's weather patterns and climate. In light of this, in the December of 1997 the Kyoto Protocol was developed in which 160 nations signed an agreement in order to cut/reduce carbon emissions through carbon taxes and the Clean Development Mechanism (CDM) [6]. This agreement has been one of the backbone catalysts in promoting empirical research and development into renewable energy sources such as solar and wind [8].

However appealing the incorporation of PV systems for large scale energy production may seem, especially for rural areas, such

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projects require large capital investments and exhibit high costs of production. Studies predict that not before the year 2020 will the widespread adoption of PV systems play a major role in energy production without significant breakthroughs in technology [9]. Currently, the most advanced solar panels can convert about 22% of the suns spectral rays into electricity, but still a lot of research effort and money are being invested into making solar panel technology more efficient [6].

Nonetheless, PV system is finding a role in many rural and small scale power applications [6] and HPSs where it is combined with other more stable forms of generation such as microturbines and diesel generators along with storage devices. Emerging Markets (EMs) such as Indonesia, Mexico, Saudi Arabia, China and India are excellent examples of how rural electrification can be achieved. Studies within these EM's confirm that it is becoming more viable to incorporate RES systems and HPSs into everyday life [4,11]. Popular uses include water pumping for communities and irrigation, water heating, lighting, power for telecommunication towers and billboard illumination [1].

South Africa, like many of the EM's mentioned above, also has a complex cultural, political and economic environment and is faced with a similar set of energy related issues. Rural communities endured poor access to electricity for decades, much of which is due to the lack of funding and the introduction of grid connected power lines. The paper therefore reports on investigating the economic feasibility of introducing PV/diesel HPS in different climatic zones within South Africa for residential type customers in remote rural, urban and semi-urban areas.

South Africa's electricity production capacity is currently estimated at 44,000 mW. This value leaves a reserve margin of about 8–10%. Due to certain economic events occurring in South Africa such as the 2010 soccer world cup and the natural need for growth through the development of infrastructure, this reserve margin has slowly been seen to be on the decrease due to the large increase in the building sector in order to meet such demands. However, the rapid increase in demand has not sufficiently been met by the increase in power output capacity. In order to realise a sustainable future, these two factors need to almost follow a linear relationship to ensure a balance is always maintained. Over the past couple of years this type of relationship has not been the case, and as a result local load shedding or power outages has become a common occurrence to ensure the load on the grid never exceeds the power producing capacity of the nation. The affect that load shedding has on local businesses and infrastructure can often prove to be crippling as electricity is often key to the regular operation and functionality of many of these facilities. Therefore the need for power "security" with regards to a guaranteed supply at a reasonable cost is therefore becoming a very topical area of research within South Africa. For many years the purchase cost of electricity has been relatively inexpensive and was therefore never taken into consideration when designing systems with regards to the generation, distribution and the end use of energy. Recently Eskom has also included a 25% increase on the purchase cost of electricity per year for the next 3 years. As a result people are starting to rethink the way in which they use electricity, due to the fact that the cost of energy is becoming a greater variable in ones annual budget along with a greater emphasis on social responsibility in minimising ones impact on the environment. This paper therefore aims at becoming one of the initial building blocks in exploring the possibilities in using alternative power sources within South Africa to empower people to become independent power producers and thus ensuring ones relative power supply "security". The outcomes of the simulations will hopefully aid in selecting the ideal location within South Africa to install a completely off grid hybrid power supply system with the correct sizing ratios of the diesel generator to the PV solar array depending on the current cost of fuel and solar irradiation experienced in certain areas defined by their climatic zones.

The paper is organised into nine sections including Introduction. Section 2 gives an energy resource analysis of South Africa while Section 3 discusses the drivers for renewable energy in South Africa and also justifies the context of the work done by the authors. Section 4 describes the hybrid power system (HPS) configuration considered for study. Section 5 discusses modelling the HPS for economic feasibility analysis. Section 6 lists the data input required for modelling along with assumptions regarding component sizing and pricing. Section 7 gives the feasibility evaluation while Section 8 and Section 9 deal with the results, discussions and recommendations.

2. Energy resource analyses of South Africa

South Africa is a mineral rich country with enormous reserves in low grade coal. Research conducted by the Department of Minerals and Energy (DME) indicated that the 68% of electricity produced comes from coal powered plants. Other energy supplying resources within South Africa include crude oil (19%), natural gasses (2%), nuclear power plants (3%), hydro power plants (0.1%) and renewable energy sources (8%) [10]. Thus in order to offset the major carbon footprint imprinted by the burning of coal, more research on renewable energy deployment in South Africa is required. An extract from a report conducted by the DME stated; "With the setting of renewable energy targets and with carbon trading under the Kyoto Protocol, the role of renewable energy is expected to expand" [10].

On the other hand different energy consumption sectors within South Africa include industry (36.2%), commerce (6.7%), residential (17.9%), mining (7.00%), agriculture (2.9%), transport (25.7%), non-specified (0.70%) and non-energy use (2.9%). This relatively high demand for energy, especially in the residential sector, again acts as a driver for conducting more research on renewable energy generation sources into the residential sector is also required. Another extract from the report conducted by the DME supported the fact that PV systems could be a viable renewable energy source; "South Africa's abundant sunshine is only beginning to be tapped in more remote areas for electricity generation for domestic and institutional applications" [10].

3. Driver for renewable energy in South Africa

South Africa is attempting to ensure that it continuously meets its energy demand. The national electric utility of South Africa, has recently instigated the construction of three new power plants and the extension of a number of existing power plants. This is expected to increase the country's net power producing capability. The three new power plants, which are nearing completion, include the Medupi plant, the Kusile plant and Ingula plant. Both the Medupi and the Kusile plants will be coal powered plants while the Ingula plant is based on a pumped storage scheme. Curbing energy shortage is therefore the main driver of renewable energy for South Africa. Furthermore, as already highlighted, South Africa's carbon footprint is already at considerable levels coming as the 14th CO_2 emitter in the world rankings. This is due to intensive dependence on coal for power generation. This serves as the second major driver for the country to not only enhance generation capacity but also to improve the energy mix by resorting to cleaner generation technologies. As mentioned previously, South Africa already experiences a major carbon footprint due to its extensive use of coal for power generation. The addition of two new coal powered plants will further increase South Africa's net emissions and have a major impact on the environment through increased green-