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A feasibility study of hybrid wind power systems for remote communities

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ABSTRACT

Global warming, climate change and the recent global financial crisis have emphasised the need for reducing carbon emissions whilst also ensuring economic feasibility. This study addresses this topic by investigating the technical and economic feasibility of replacing diesel power generation with hybrid wind power systems in remote communities. For this purpose, the economic, technical and environmental characteristics of eight different hybrid wind power systems were established and compared in respect to their performance in the isolated community of French Island (Victoria, Australia). The results obtained in this study demonstrated the economic and environmental superiority of the hybrid wind–diesel–battery system over all other systems studied in this project. This system was found to have the lowest net present cost and cost per kWh among the modelled systems. Furthermore, the results clearly indicated that hybrid wind power systems are, in general, a feasible and preferable alternative to diesel power generation on the French Island. The research methodology and procedure that were developed in this project can be used to investigate and identify the most viable hybrid power system for other remote communities based on their specific environmental, social and economic circumstances.

1. Introduction

Climate change and global warming is one of the most critical issues facing the world today. Furthermore, with the world's knowledge of, and exposure to, the recent global financial crisis, prudent investment is also of the utmost importance. Consequently, it is necessary to endeavour to limit greenhouse gas emissions wherever possible whilst remaining competitive in a financial sense. This endeavour is aided by the constant advancement of technology, especially in terms of renewable energy. Renewable energy technology, when combined with advancements in energy storage design, provides an excellent opportunity for carbon emission reduction through the integration of more than one energy resource in a hybrid power generation system.

In line with this philosophy, this project was initiated in order to investigate the use of hybrid wind power systems as an alternative to diesel generators for the supply of electricity to isolated communities. By definition, isolated communities are difficult to access and thus it is not possible to extend the electricity grid to accommodate them (Nfah and Ngundam, 2008). It is estimated that almost two billion people worldwide have no direct access to electrical networks, as noted in Kaldellis and Kavadias (2007) with reference to Jenson (2000). Hence, their electric power demands need to be met by either stand-alone generation systems or through expensive grid extensions (Kaldellis and Kavadias, 2007). For this reason, many rural consumers employ diesel generation due to its low initial cost, easy maintenance and simple operation, as reported by Drouilhet (2008) and Kaldellis and Kavadias (2007). However, expensive operational costs are a hindering factor over the life cycle of these systems (Drouilhet, 2008). Therefore, the implementation of hybrid power systems is a possible solution to this problem (Shi et al., 2007). As fuel costs rise and environmental concerns increase, hybrid wind power systems, with their reduced fuel consumption, become more practical for remote communities (Drouilhet, 2008). Indeed, hybrid power systems are often recommended as a "promising solution to electrifying the isolated locations far from the electrical distribution network" (Shi et al., 2007).

Hybrid power systems involve the integration of two or more resources, one of which is generally renewable, in order to form a power supply (Hongxing et al., 2009). These systems can be comprised of different combinations of components such as diesel generators, wind turbines, photo-voltaic systems, hydro turbines and various energy storage devices (Taylor, n.d.). Renewable energy sources, especially wind and solar, are inherently stochastic in nature and thus are unreliable power sources by themselves (Hongxing et al., 2009). The benefit of hybrid power systems is that combining power sources can partially rectify this shortcoming (Hongxing et al., 2009). Generally, to ensure a reliable power supply, a diesel generator is combined with the renewable energy resource. This combination allows the diesel generator to supply power when the renewable energy source is unavailable. A literature review undertaken during the course of this project demonstrated that a significant amount of research is devoted to

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the design optimisation and modelling of hybrid systems as reported by Hongxing et al. (2009) and Shi et al. (2007). However, the published literature appears to contain little information on the economic analysis of hybrid wind power systems throughout their life span. Furthermore, few researchers have compared the performance of various hybrid power systems at a common location (Nfah and Ngundam, 2008).

Motivated by reducing global carbon emissions and addressing the shortcomings of previous research into this topic, the aims of this study are two-fold: one aim is to establish and accentuate the economic, technical and environmental characteristics of several different hybrid wind power systems, and to compare their performance in relation to their application in the remote community of French Island in Victoria, Australia. The second aim is to provide a clear and concise blueprint for assessing the feasibility of using hybrid wind power systems in any isolated community. In order to achieve these aims, the research methodology is described before the calculation procedure used in this study is illustrated. The results of this investigation then follow, whereby discussion and appropriate concluding remarks are provided.

2. Research methodology

2.1. Types of hybrid wind power systems investigated in this study

The first stage of this feasibility study involved the identification of various hybrid wind power systems. These systems were then investigated, evaluated, compared and contrasted throughout the study. The selection process required a compilation of all hybrid wind power systems that had a testing history, which were commercially available and were applicable to any location. Also crucial to the project was the evaluation of several energy storage options. This is due to the intermittent nature of wind energy generation.

There are several different energy storage technologies and configurations that hybrid systems can utilize. Detailed description of many (electrical, mechanical and chemical) energy storage options that can be considered for use in hybrid power plants is available in the published literature, e.g., Zafirakis (2010), to which interested readers should refer. According to Zafirakis (2010, p. 63) for a power plant of the size considered in this paper, possible storage systems include superconducting magnetic energy storage (SMES), compressed air energy storage (CAES), fuel cell and hydrogen storage (FC-HS) and flow batteries depending on the required discharge time. Pumped hydro storage (PHS), flywheels, super-capacitors and thermal energy storage (TES) are other options that could be investigated. In terms of suitability of energy storage for a large wind farm (200 MW), Hessami and Bowly (2010) have reported that the best storage medium is CAES followed by PHS and then TES in terms of the economic feasibility of adding energy storage to an existing wind farm. However, for the purpose of this paper, in order to cover a wide range of energy storage types, it was decided to focus on CAES, batteries and hydrogen storage. A brief description of these storage systems is provided below.

A common method is to store excess electrical energy in a series of batteries. This allows for the simple and highly efficient transfer of power to the community when the power supply is insufficient. However, standard batteries store energy in the DC form, so a limiting factor is the requirement of a generally expensive converter/inverter to produce AC power for the community (Ibrahim et al., 2007).

Another energy storage system is compressed air energy storage (CAES), which works using the excess renewable power to run a compressor to compress air which is then stored in a reservoir. When the wind power produced is less than what is required, the compressed air is used to supercharge the diesel engine, making it more efficient (Ibrahim et al., 2007). The supercharging process works by raising the intake air density of the engine to increase the specific power. The result is more power generated by the system, with lower fuel consumption. Another example of CAES is the compression and storage of air for later discharge to a gas turbine power generation system, as described in Hessami and Rocha (2008).

A third energy storage alternative is the hydrogen storage system, which uses the surplus electricity in an electrolyser to produce hydrogen, which is then stored in a pressurised vessel (Hessami and Waters, 2008). When required, the stored hydrogen can be converted to electricity via a fuel cell or an internal combustion engine; the option of transporting hydrogen for off-site use is also considered.

Whilst it would have been ideal to investigate and assess the feasibility of every known form of hybrid wind power system for a certain location, this was impractical from a time and resource perspective. Therefore, the systems that were selected for investigation in this study are those listed in Table 1. Other forms of renewable energy such as tidal power, bio-fuel and geothermal energy were disregarded from the selection process due to commercial unavailability, poor testing history or location specific availability. Furthermore, the wind/diesel/energy storage and wind/solar/diesel/energy storage combinations are by far the most prevalent hybrid power systems available in the market. For reasons of illustration, a schematic diagram of the HWDBPS is provided in Fig. 1, which shows that the available wind power is either used in the community or stored in the batteries. If the wind power or power from batteries is not sufficient, the diesel generators are employed to meet the power demand of the community.

2.2. Site selection

The second stage of this study involved the selection of a specific isolated community upon which to base the modelling process, data profile and equipment sizing. Using a specific location ensured uniform conditions for the comparison of the performance of these systems. The selected remote community was to act as a case study for other communities in a similar isolation. Furthermore, the chosen community was required to be appropriate for the placement of a hybrid wind power system. French Island (Victoria, Australia) was chosen as it satisfied the criteria of non-connection to the electrical grid, being a small and centralised community, having moderate wind and solar radiation conditions, having information on community living requirements and having a reliable water supply. Obviously, for other remote communities, the site selection stage of the process may be unnecessary as they are acting in the interest of their own community.

French Island is located in the middle of Western Port Bay in Victoria, Australia, and is accessible only by ferry. It is an unincorporated territory with no local government, which means that the community manages its own affairs and the few public facilities that are available (FICA, 2009). The island is not connected to the main

Table 1
The hybrid wind power systems modelled in this study.

System description	Abbreviation
Diesel power system	DPS
Hybrid wind–diesel power system	HWDPS
Hybrid wind–diesel–battery power system	HWDBPS
Hybrid wind–diesel–hydrogen power system	HWDHPS
Hybrid wind–diesel–compressed-air power system	HWDCaPS
Hybrid wind–solar–diesel power system	HWSDPS
Hybrid wind–solar–diesel–battery power system	HWSDBPS
Hybrid wind–solar–diesel–hydrogen power system	HWSDHPS
Hybrid wind–solar–diesel–compressed air power system	HWSDCaPS