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Flexible hybrid renewable energy system design for a typical remote village located in tropical climate

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Energy management and sustainable resources are regarded as major concerns when designing hybrid energy systems. Finding an efficient framework that combines reliable design and satisfies continuous operation at minimal cost at all conditions is essential for both customers and investors. In this regard, this paper details the adoption of a creative approach using HOMER software to come up with a flexible design of a hybrid system that includes conventional and renewable energy sources. This study involves a comprehensive survey in this field, detailed techno-economic assessments, analyses of operational performance, and the evaluation of environmental aspects pertaining to the aforementioned system. It investigates all conditions that influence the system for both off-grid and on-grid connections by examining it over a typical remote Malaysian village. A sensitivity analysis was also conducted at all stages to verify the optimum design among all changes of different sell-back, power purchase, fuel prices, load growth, and other variables. Also, this study was proceeded to determine and examine the technical, economical and environmental aspects of the system. The results showed that the optimum system for both off-grid and on-grid connections consists of 300 kWp of photovoltaic (PV) modules, two diesel generators rated at 100 kW and 50 kW, a 150 kW converter and 330 kWh battery banks. The total Net Present Cost (NPC) and Cost of Energy (COE) fell within (1500000.0–2450000.0 $) and (0.151–0.233 $/kWh), respectively, for different renewable energy fraction (RF) values of (23–55.43%) and CO_2 emissions of (245284.0–570643.0 kg/Yr). Moreover, the results indicated the importance of considering all parameters prior to the implementation of any hybrid system in order to realize the proposed objectives. The study demonstrates the high capability of the proposed flexible design in meeting the loads, support continuous operation, and reduce the harmful emissions towards the environment over all conditions for both off-grid and on-grid connections.

1. Introduction

Finding sustainable and reliable sources of energy represents a perennial challenge in the current and past decade. Meanwhile, renewable energy resources play an important role in providing clean, reliable, and sustainable energy (Lau et al., 2010). The positive environmental impact of renewable energy resources makes it favored for use as an energy source in power generation (Adaramola, 2015). On the other hand, fossil fuel suffers from several adverse effects brought about by its transportation, storage, and prices. It is also harmful effects towards the environment (Shezan et al., 2016). Besides, Its ubiquity and extensive usage have also resulted in its shortage and increased prices over time (Ong et al., 2011). While dispersed populations located far away from the national grid makes the connection to the power grid technically inefficient and economically impossible (Shaahid and Elhadidy, 2007). The aforementioned problems can be mitigated using an alternative solution involving a hybrid system made up of more than one source of energy (Rajkumar et al., 2011). Fig. 1, shows a simplified block diagram of a typical hybrid system.

Nevertheless, using standalone renewable energy sources is considered unreliable due to the random nature of renewable energy resources and the associated high costs (Phuangpornpitak and Kumar, 2007). Specifying the most suitable configuration requires deep analysis of the availability of natural resources at the proposed

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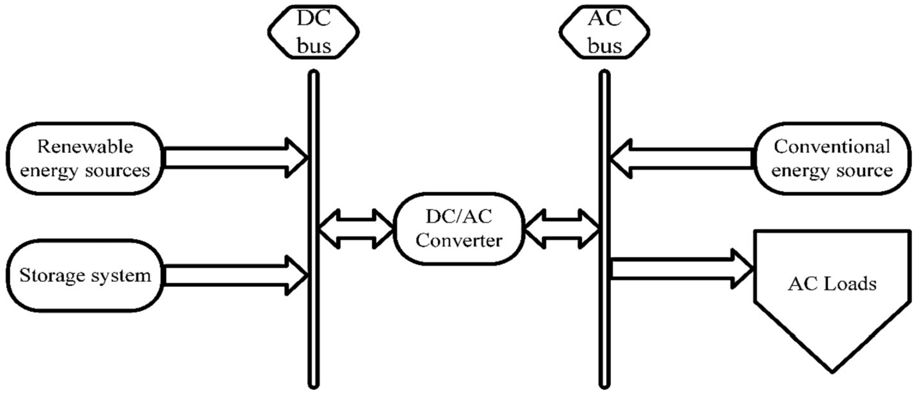

Fig. 1. Simplified block diagram of the typical hybrid system.

location. Using a suitable Load Management (LM) system is especially important from a management standpoint, as it helps reduce peak power loads (Amini et al., 2013). The reported results confirmed the effectiveness of using LM system for large distribution networks with minimum error calculations.

The feasibility of employing hybrid renewable energy systems for electrifying remote locations was widely investigated in different parts of the world (Hurtado et al., 2015; Ataei et al., 2015; Izadyar et al., 2016). In (Hurtado et al., 2015), the hybrid system was designed and built in a laboratory, where it includes Photovoltaic (PV) and biomass energy resources, in addition to a battery storage system. This system operated for a long period of time and was duly tested in order to determine its operational behavior. The stability of the generated energy reaches 98% and it was deemed to be efficient to supply remote areas. Similarly, in (Ataei et al., 2015), the authors examined the feasibility of a hybrid wind/PV/diesel generator system. Three different scenarios working under different conditions were investigated. The results confirmed the high capability of the hybrid system over standalone diesel generator system in reducing the total Net Present Cost (NPC) and Cost of Energy (COE) of the system. It also indicated that the application of a maximum limit on the produced harmful emissions would result in increasing the total cost of the system, but would simultaneously reduce the dependence on the diesel generators. Correspondingly, the authors in (Izadyar et al., 2016) demonstrated the significant potential of using hybrid systems in Malaysia. They reported that Langkawi island is the most suitable location for a hybrid wind/solar system, followed by Tioman island. Hybrid systems assess the continuous supply of the loads, which help enhance the reliability and efficiency of the proposed sites. Similarly, The techno-economic feasibility for on-grid connection was assessed in (Nacer et al., 2016). The results indicated that introducing RE hybrid system to the grid would enhance the reliability of the national grid at peak load period and reduce its harmful emissions.

The current technological developments would reduce the photovoltaic (PV) price, which would significantly support the development of new projects (Adaramola and Vågnes, 2015). Several studies discussed the feed-in tariff (FIT) policies related to hybrid renewable energy systems. The results indicated that finding suitable FIT strategies and appropriate governmental subsidies would promote the establishment hybrid renewable energy systems around the world (Wong et al., 2015; Chua et al., 2011; Mekhilef et al., 2012). A summary of the most common metrics of standalone and hybrid systems are tabulated in Table 1.

Many researchers developed new approaches towards the optimization of hybrid renewable energy systems. Numerous methods were proposed, such as using mathematical models (Kaabeche and Ibtiouen, 2014; Caballero et al., 2013), simulation software (Fathima and Palanisamy, 2015; Fadaee and Radzi, 2012), control models (Dreidy et al., 2017) and artificial intelligence (Behzadi and Niasati, 2015; García-Triviño et al., 2014). A review of the usage of different approaches in off-grid and on-grid systems is presented in (Erdinc and Uzunoglu, 2012). In this study, a systematic review has been established, which includes a detailed analysis of the commercial sizing software tools, optimization techniques, and the promising future techniques. It posits that the optimal sizing significantly improves techno-economic performance as well as promote the widespread use of environmentally friendly resources. In addition, it also outlines the advantages of including more than one source of energy (hybrid systems) compared to using one source of energy in the provision of more economical, and reliable energy supply.

Satisfying high reliability, overcoming standalone system's deficiencies, and reducing the dependence on fossil fuels are the main reasons for selecting a suitable optimization tool. For example, HOMER software was used to examine the potential of using PV and wind turbines to meet load demands of onshore locations in Temajuk, Indonesia (Hiendro et al., 2013). The results indicate that HOMER software offers optimal sizing and reports a comprehensive techno-economic analysis. More optimized studies using different methods are found in (Wang et al., 2015; Alsayed et al., 2013; Kazem et al., 2013). Table 2, summarizes optimization techniques commonly used in finding the optimal system.

1.1. Literature review over off/on grid connections

There are some studies that are particularly informative, discussing different off-grid and on-grid topologies and detailed as follows:

1.1.1. Off-grid systems (standalone system)

Standalone hybrid renewable energy systems have been widely developed all around the world for different purposes. A study in Iran involved finding the optimal design for a hybrid PV-wind-fuel cell system (Maleki et al., 2016). The general aim of this study was to minimize the life-cycle cost at maximum allowable losses of power supply probability. The results confirmed that the most cost-effective system among all the configurations is the PV-wind-fuel cell, where it is the most cost-effective system in supplying electrical energy at the proposed location. Similarly, MATLAB Simulink was used to develop an optimum standalone system. The authors implemented an illustrated techno-economic analysis to determine the optimal solution. The optimum system was determined to be PV-wind combination system. This study specified that all capital,