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Feasibility analysis of hybrid photovoltaic/battery/fuel cell energy system for an indigenous residence in East Malaysia

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ABSTRACT

Costly and eco-destructive diesel based systems are usually used for electrifying rural areas in Malaysia. Fuel transportation is another obstacle in this regard. Moreover, unpredictable fluctuation of fuel price makes the system cost unstable. The diesel based systems can be replaced with renewable energy (RE) based systems. Thus, a feasibility analysis is necessary to assess the potentiality of RE resources. This paper analyzes the potentiality of renewable energy in Sarawak, East Malaysia. The wind speed is insufficient, but solar energy is abundant at the location. Hence, the feasibility of photovoltaic (PV), Battery and Fuel Cell (FC) based systems are investigated for the load of a village longhouse comprising 50 families located in Kapit, Sarawak. Both systems, including FC (PV/Battery/FC) and excluding FC (PV/Battery) are analyzed and compared with conventional diesel based system. The analysis focuses on net present cost (NPC) and cost of energy (COE). Other cost parameters such as installation cost, operation and maintenance cost (O & M), operating cost are also analyzed. HOMER software provided by National Renewable Energy Laboratory (NERL) is used as an analyzing tool. This paper also focuses on the operational strategy and sensitivity analysis of the hybrid system for optimal performance. The HOMER optimization results and sensitivity analysis show that the PV/Battery system is economical and environmentally friendly with total net present cost of $ 335,297 and cost of energy of 0.323 $/kWh with no emission. Thus it can be a suitable replacement of diesel based system. The FC based system has higher costs; thus despite of its benefits, it is not suggested as the best system for the situation.

1. Introduction

Electricity is a basic constituent of economic advancement and socio-economic development of a country. Fossil fuels such as oil, gas and coal are usually used for electricity generation on a large scale. However, burning fossil fuel is the reason behind environmental pollution, ozone layer depletion as well as global warming. In recent years, renewable energy sources such as solar, wind, biomass, tidal and so on have been focused by a growing environmental awareness to global warming. Small Distributed Generation (DG) plants using renewable energy (RE) sources are being developed to supply off grid and grid connected loads [1,2]. Specially, DG systems are constructed to supply electricity to remote areas where grid power is not available. Hybrid systems using renewable energy sources along with diesel generators are popular for standalone applications. However, fuel transportation is a vital issue for remote areas. The configuration of the hybrid system varies depending on the site location, capacity as well as availability of the resources. Thus, survey on the technical and economic viability is required to decide the sizing, cost and effectiveness. The context of this study is East Malaysian indigenous communities in Kapit, Sarawak where, the grid power is not present [3]. The location of the houses are remote with no proper communication for regular fuel transportation. Thus, renewable energy based hybrid systems are preferred for the location [4].

In this study, the energy resources such as solar [5] and wind [6] energy, diesel price of a selected area of east Malaysia are investigated. Other sources such as biomass, wave and tidal energy are not included in this study due to lack significant availability in the selected location. Based on the available resources, RE based distributed generation systems are analyzed. To do so, first the size and price of the system components are defined and the operating strategies are determined. The analyzed systems are PV/Battery/FC, PV/Battery and diesel based systems. Diesel based hybrid systems are not included in the analysis, because the motivation of this study is to find out a pure renewable energy based system as a replacement of diesel based system. In Fuel cell direct hydrogen is used as fuel. Hydrogen can be extracted by electrolysis of water or can be supplied externally. Here the electrolysis method is considered to avoid the transportation problem of fuel.

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Sensitivity analysis for all the configurations are also performed to elucidate the viability of each system. Finally, a comparative analysis of the RE based systems with the standalone diesel based generation unit is carried out where, cost parameters and energy parameters are focused.

2. Background study

The background study can be segregated as previous studies on renewable energy based systems and energy policy of Malaysia. They are discussed in the below sections.

2.1. Previous literature

Several studies have been performed in order to figure out the most convenient energy source of an alternative power generation system. Depending on the available renewable energy resources and the load demand several systems are proposed all over the world. Traditionally, Photovoltaic (PV) systems with battery backup, are used in such cases [7–10] due to its non-depletable, non-polluting nature [11]. The energy produced by PV panels solely depends on the solar irradiation, temperature and the sunshine hours [12,13]. Thus, the load during night solely depends on the battery backup which makes the battery system larger. Currently, most of the systems include diesel generator which supplies power during critical load periods [14–18]. However, diesel generators add up fuel cost to the system. Also for remote areas, fuel transportation is quite a big problem. Therefore, research is going on to establish hybrid renewable energy based system (HRES) using PV, Wind, Biomass, Hydro-power or fuel cell [19,20]. Biomass and hydropower systems require infrastructure buildup. Also, biomass needs proper supply of waste materials to produce gas. Hybrid systems can be constructed by combining PV and Wind turbine with battery backup [21–24]. PV and Wind both depend on the weather and both have uncertainties. A viable solution can be, adding a proton exchange membrane fuel cell (FC) with PV generator [20,25–31], or with wind turbine [32,33], or with both PV and wind systems [34,35]. The PEMFC converts chemical energy of hydrogen and oxygen into electrical energy through an electrochemical reaction [36]. FC can produce electricity without any harmful greenhouse gas emission if direct hydrogen is used as fuel. However, it has some emission while fossil fuel like methane or natural gas is used [37]. Moreover, FC is quiet, low maintenance needed and reliable in terms of production efficiency. Another alternative of FC is hydrogen combustion generators. However, it has several limitations, such as: it is noisy, produces pollutant gas and needs maintenance and supervision. Several researches have been carried out on fuel cell based hybrid renewable energy systems. Such as [38] includes the combination of photovoltaic (PV), battery and fuel cell either in stand-alone or grid connected mode. The integration of hybrid fuel cell, photovoltaic and battery as an electricity generation system is presented in [39]. This system is installed in five different remote regions in France therefore the method to find the optimum technical and financial combination is proposed. N. Karami constructed a simple energy management system for a grid connected PEMFC, PV panel, battery and supercapacitor system [40]. In [41], a dynamic multi-objective particle swarm optimization (DMPSO) method is used to minimize the total net present cost (NPC) of the system, unmet load, and fuel emission. The proposed method evaluates a case study including wind turbines, PV panels, diesel generators, batteries, fuel cells, electrolyzer and hydrogen tank. The analysis on initial capital, net present cost (NPC) and cost of energy for a photovoltaic-fuel cell-battery system to supply electric power in an isolated community in the Amazon region is studied in references [30]. From the study, they found that the combination of fuel cell and electrolyzer with the photovoltaic modules are costly. The study result also confirmed that the best option for storing energy from photovoltaic systems is still the use of batteries. A research conducted in [42] presents an approach for optimal operation of a grid-connected hybrid system including PV, PEMFC, electrolyzer and hydrogen storage. The produced energy is sold to the distribution grid where the system considers hourly variations in electricity price and solar irradiance. The combined heat and power application of PV/PEMFC system is assessed in ref [43], where the hybrid system is proposed for backup power system in a hospital building of Malaysia. The literatures show that, PV/FC hybrid system is a feasible alternative energy source for standalone application.

2.2. Energy policies in Malaysia

In order to assess the viability of RE based systems in Malaysia, it is necessary to know the attitude of government towards RE penetration in energy market. The major portion of electricity in Malaysia is generated by either hydropower or fossil fuel based power plants [44]. The government is now focusing on renewable energy based power generation to reduce the use of fossil fuel in this sector. To do so, the government has introduced various policies for sustainable energy development [45]. The energy policies are intended to increase the renewable energy penetration in country's energy market by facilitating technological support, solving market constraints as well as reducing related costs. In Malaysia, the Economic Planning Unit (EPU) and Implementation and Coordination Unit (ICU) supervise the energy policies. The national energy policy was first introduced in 1979 and the main focus of the policy was energy production, utilization and the environmental issues [46]. Renewable energy policies were first included in the 8th Malaysia plan [47]. In order to achieve the desired benefits of RE, the policies were improved in 9th Malaysia plan and furthermore. A brief overview of the policies are presented in below subsections.

2.2.1. Five-fuel Diversification Policy 2001

Also known as Fifth Fuel policy, the Five-fuel Diversity Policy was introduced in 2001 in the 8th Malaysia plan. By focusing the oil price hike and severe environmental degradation, the policy introduced RE as the fifth fuel with existing four energy sources (oil, coal, gas and hydro) [48]. The goal of the policy was to supply 5% of total electricity using RE; however, at the end of the tenure in 2005 only 12 MW (only 1%) electricity was supplied to the grid using the Small Renewable Energy Power Program (SREPP) whereas the total electricity generation was 500 MW[49]. As the RE growth was too slow, the government decided to continue the policy in the 9th Malaysia plan (2006-2010) [50]. Under the new plan the revised target was set to generate 350 MW electricity at the end of 2010 using RE, whereas the achieved generation was only 58.1 MW at the end of 2009 [51].

2.2.2. National Biofuel Policy 2006

In order to reduce the dependency on fossil fuel, promote palm oil as RE source and to support the Five-Fuel Diversification policy, the National Biofuel Policy was introduced in 2006. The proposition of the policy was: (1) to blend the processed palm oil with petroleum diesel at the ratio of 5% and 95% to produce biodiesel; (2) to promote biodiesel usage by funding the fuel stations to set up biodiesel pumps; (3) to include biodiesel quality standards in Standards and Industrial Research Institute of Malaysia (SIRIM); and (4) a biodiesel plant construction [52].

2.2.3. National Green Technology Policy 2009

The National Green Technology policy was launched in 2009 to stimulate the green technology and sustainable development [48]. The objectives of this policy are:

- Reducing the energy usage and increasing economic growth simultaneously.
- Facilitating green technology growth and boosting its contribution