Sustainable Cities and Society 28 (2017) 358–366

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Performance evaluation of a stand-alone PV-wind-diesel-battery hybrid system feasible for a large resort center in South China Sea, Malaysia

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ARTICLE INFO

Article history:
Received 19 August 2016
Received in revised form 17 October 2016
Accepted 18 October 2016
Available online 21 October 2016

Keywords:
Stand-alone
HRES
Eco-tourism
HOMER
Malaysia

ABSTRACT

The tourist sectors in South China Sea, Malaysia (SCSM) completely depend on diesel generators for 24 h power supply. The emissions from diesel based power plants are environmentally risky for tourist spots. In this research article, a multi-optimal combination of stand-alone hybrid renewable energy system (HRES) for a large resort center located in SCSM has been proposed with detailed operational performance analysis. Hybrid Optimization Model for Electric Renewable (HOMER) software is used for economic and technical analysis of the system. The estimated peak and average load per day for the resort are 1185 kW and 13,048 kW respectively. The best optimized stand-alone hybrid energy system comprises of PV, wind, diesel generator, converter and battery. The optimized system resulted in net present cost (NPC) of \$17.15 million, cost of energy (COE) of \$0.279/kWh, renewable fraction (RF) of 41.6%, and CO_2 of 2,571,131 kg/year. Whereas, the diesel only system takes NPC of \$21.09 million, COE of \$0.343/kWh and CO_2 of 5,432,244 kg/year. The diesel only system has higher NPC, COE and CO_2 emission than optimized HRES. The designed and analyzed HRES model might be applicable to any tourist locations and decentralized places in SCSM and around the world having similar climate conditions.

1. Introduction

Renewable global status report shows renewable energy sources contribute 22.8% of global electricity, whereas, the remaining 77.2% comes from fossil fuels and nuclear power plant (Renewables Global Status Report, 2015). According to this report, about 1.1 billion of the world population do not have access to the electricity. However, the people of remote islands in South China Sea, Malaysia where no accessibility to the national electrical grid due to high construction cost of the transmission line, relies on the diesel generators for electricity (Basir Khan, Jidin, Pasupuleti, & Shaaya, 2015). Besides, the tourist sectors in the these islands completely depend on diesel generators for 24 h power supply (Shezan et al., 2015). But the volatile market price of diesel fuel, CO_2 emission and high operation and maintenance cost of diesel plant makes the system environmentally risky and costly (Ashourian et al., 2013; Fadaeenejad, Radzi, AbKadir, & Hizam, 2014). In addition, the diesel price is almost double in the Malaysian islands than on the mainland (Anwari, Rashid, Muhyiddin, & Ali, 2012). Therefore, standalone hybrid renewable energy system (HRES) can play the most important role to supply reliable electricity to the tourist sectors in these islands.

The islands located in South China Sea are full of renewable energy resources. In 2004–2005, eight solar hybrid system (SHS) was established by TNB in five different islands situated in South China Sea. These SHS are operated in Pulau (Pulau means Island in local language) Besar (45 kW), Pulau Pemanggil (50 kW), Pulau Sibu (100 kW), Pulau Aur (50 kW) and Pulau Tinggi (50 kW) (Borhanazad, Mekhilef, Saidur, & Boroumandjazi, 2013). In 2007, Malaysian government in collaboration with TNB implemented a hybrid renewable energy system (HRES) in Perhentian Island, which comprised of 100 kW PV array, two 100 kW wind turbine, one 100 kW diesel generator and a battery bank of 480 kWh, 240 V (DC) (Darus et al., 2009).

Techno-economic viability of off-grid HRES for remote villages and islands has been reported by many authors (Ajayi, Ohijeagbon, Mercy, & Ameh, 2016; Charfi, Atieh, & Chaabene, 2016; Demiroren

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http://dx.doi.org/10.1016/j.scs.2016.10.008
2210-6707/

& Yilmaz, 2010; Diaf, Belhamel, Haddadi, & Louche, 2008; Himri, Boudghene Stambouli, Draoui, & Himri, 2008; Ismail, Moghavvemi, & Mahlia, 2013; Nandi & Ghosh, 2010; Rahman, Khan, Ullah, Zhang, & Kumar, 2016; Shaahid & El-Amin, 2009; Shaahid, Al-Hadhrami, & Rahman, 2014), whereas, the study on HRES for hotels and tourist locations are limited (Aagreh & Al-Ghzawi, 2013; Dalton, Lockington, & Baldock, 2008; Dalton, Lockington, & Baldock, 2009a; Dalton, Lockington, & Baldock, 2009b; Güler, Akdağ, & Dinçsoy, 2013; Shezan et al., 2015).Thus, more research can be conducted to understand feasibility and performance of HRES for the tourist locations.

The Tioman Island is located in the South China Sea along the east coast of Peninsular Malaysia with the geographic location of 2° 47′ 47″ N, 104° 10′ 24″ E (Muda et al., 2011). The island consists of thirteen villages, private and government offices, schools, commercial buildings, mosques, police stations, resort and hotels, hospitals and an airport. TNB supplies electricity to this island with 8.9 MW diesel power plant at Tekek village and a 500 kW mini hydro plant at Juara village through 11 KV distribution line. However, TNB is unable to supply electricity to very big resort and hotels like Berjaya Tioman Resort (Basir Khan et al., 2015).Therefore, this study aim to investigate the feasibility and performance of an off-grid HRES for a large resort located in Tioman Island for load demand of 13,048 kWh/day. HOMER (Hybrid Optimization Model for Electric Renewable), developed by the U.S. National Renewable Energy Laboratory (NREL), is employed for design and performance evaluation of the HRES (Lambert, Gilman, & Lilienthal, 2006).

Moreover, there are more than twelve small islands in South China Sea surrounding Pulau Tioman named; Pulau Aur, Pemanggil, Sibu, Babi Besar, Tinggi, Rawa, Harimau, Dayang, Tengah, Tulai and Pulau Seri Buat that have more or less same climate conditions as Tioman Island (NASA surface meteorology and solar energy data base, 2016). The monthly average solar radiation (kWh/m^2/day) and wind speed (m/s) for these islands are presented in Table A1 while, monthly average ambient temperature (°C) and clearness index are presented in Table A2. Thus, this analysis can represent any of the off-grid hybrid RE system for large resort center located in these islands. In the first part of this paper, site description with load estimation and resource assessment are conducted whereas, in the second part, model design and its techno-economic parameters is described. Third, the performance of proposed model is analyzed. Finally, uncertainty of the model is investigated with HOMER software.

2. Methodology

2.1. Site description and load estimation

The Berjaya Tioman Resort (BTR), a big chalet style hotel and resort located in Tioman Island, was selected in this study. Geographical location of this resort is 2° 48′ 30″ N, 104° 8′ 29″ E, as shown in Fig. 1.

The resort is powered by diesel generators installed at the resort, but hourly load data was not available at the resort. Thus, hourly load profile of one year for the resort was estimated. The list of electrical appliances employed and their power rating is shown in Table 1, while the estimated load profile for one year is shown in Fig. 2 for different seasons. All the electrical appliances and its numbers are computed based on the available information from the resort (Berjaya Tioman Resort, 2015). The electrical load in this resort varies seasonally due to variation in tourist presence. The duration of northeast monsoon (NEM), the first inter-monsoon (FIM), the southwest monsoon (SWM), and the second inter-monsoon (SIM) are November-February, March-April, May-August, and September-October respectively that control the climate and weather in Tioman Island (Basir Khan et al., 2015). In NEM season, high wind speed and heavy rainfall affects the tourism business significantly. Consequently, the load profile of this resort is high

Fig. 1. Location of BTR in Tioman Island [Source: Google map and then edited].