Energy xxx (2015) 1–18

Contents lists available at ScienceDirect

Energy

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

# Optimal combination of solar, wind, micro-hydro and diesel systems based on actual seasonal load profiles for a resort island in the South China Sea

M. Reyasudin Basir Khan [a, *], Razali Jidin [a], Jagadeesh Pasupuleti [b], Sharifah Azwa Shaaya [a]

[a] Centre for Automation and Embedded Computing System (CAECS), College of Engineering, Universiti Tenaga Nasional, Jalan IKRAM – UNITEN, 43000 Kajang, Selangor, Malaysia
[b] Centre for Power System Simulation (CPSS), College of Engineering, Universiti Tenaga Nasional, Jalan IKRAM – UNITEN, 43000 Kajang, Selangor, Malaysia

ARTICLE INFO

*Article history:*
Received 14 March 2014
Received in revised form
12 December 2014
Accepted 30 December 2014
Available online xxx

*Keywords:*
Tioman
HOMER
Solar
Wind
Micro-hydro
South China Sea

ABSTRACT

This paper proposes multiple optimal combinations of hybrid renewable energy systems for a resort island based on actual generation-side energy auditing, assessment of seasonal renewable energy resources availability versus load profiles, and techno-economic analyses. The resort island selected is Tioman, as it represents the typical energy requirements of many resort islands in the South China Sea. The island relies mainly on diesel fuel for electricity generation. However, diesel is subjected to high and volatile market prices, high operation and maintenance costs, and poses environmental risks. Therefore, to mitigate diesel fuel dependency, an optimal combination of hybrid renewable energy systems is proposed. The project starts with an actual generation-side auditing including the distribution of loads, seasonal load profiles, and types of loads as well as an analysis of local development planning. Subsequently, surveys of available renewable resource potentials such as solar, wind, and hydro were conducted that involved collection and analysis of meteorological data. Furthermore, reconnaissance study for hydro potentials has been based on topographic maps and hydrological studies. Finally, HOMER (Hybrid Optimization Model for Electric Renewable) software was used to perform techno-economic analyses for the hybrid system. Results of the analyses include the optimal system configurations, cost of hybrid system, fuel saving, and $CO_2$ emission reduction.



## 1. Introduction

### 1.1. Renewable energy status

The Renewable Energy Network for the 21st Century (REN21) Global Status Report 2013 showed that fossil fuels currently contribute 78.2% of the world energy consumption, while 19% comes from renewable resources and the remaining comes from nuclear energy [1]. The report indicates that RE (renewable energy) progresses robustly in all end user sectors, its capacity continuously growing, while globally its price continues to decrease. In order to reduce fossil fuel dependency, governments and private sectors worldwide are pursuing research and supporting the development of sustainable energy.

### 1.2. The current energy situation of islands in the South China Sea

Most populated islands in the South China Sea rely on fossil fuels for energy. The volatility of diesel fuel prices, possible risk of fuel spills, high operation and maintenance costs and environmental pollution are exposed by the communities for power generation in this area. Mass tourism had a big impact to the energy and environmental conditions of the islands such as excessive usage of energy, degradation of natural landscapes, contamination of

*Abbreviation:* BOS, balance of systems; COE, cost of energy; $CO_2$, carbon dioxide; DSMM, Department of Survey and Mapping Malaysia; FIM, first inter-monsoon; MMD, Malaysian Meteorological Department; NASA POWER, NASA Prediction of Worldwide Energy Resource; NEM, northeast monsoon; NPC, net present cost; NREL, National Renewable Energy Laboratory; RE, renewable energy; REN21, Renewable Energy Network for the 21st Century; RM, Ringgit Malaysia; SIM, second inter-monsoon; SREP, Small Renewable Energy Program; SWM, southwest monsoon; TNB, Tenaga Nasional Berhad; TNBES, Tenaga Nasional Berhad Energy Services; TNBR, Tenaga Nasional Berhad Research; WECS, wind energy conversion system.

* Corresponding author. Tel.: +60 3 8921 2020; fax: +60 3 8928 7166.
*E-mail addresses:* Reyasudin@uniten.edu.my, reyasudin@gmail.com (M.R. Basir Khan), Razali@uniten.edu.my (R. Jidin), Jagadeesh@uniten.edu.my (J. Pasupuleti), Shazwa@uniten.edu.my (S.A. Shaaya).

http://dx.doi.org/10.1016/j.energy.2014.12.072
0360-5442/

seawater and causing harm to the marine life, which makes it difficult for the island to achieve sustainability. There is poor electricity supply in the islands which the main part of the islands is supplied by local diesel generation and some of the dwellings in rural areas have lack electricity supply. Electricity supply from diesel generators is expensive and releases high amounts of greenhouse gasses. Moreover, the majority of the islands have poor grid connections.

### 1.3. RE potential for resort islands in the South China Sea

Resort islands in the South China Sea have the potential to develop many renewable energy systems such as hydro, wind and solar. The island's geographical condition such as its hilly landscape and numerous stream flows from highland areas permits the development of hydropower system [2]. The high average annual rainfall of the islands also contributes to the potential installation of hydropower stations. The average solar radiation per month is about 400–600 MJ/m$^2$, which is capable for the establishment of small and large-scale solar power [3]. Meanwhile, the NEM (Northeast monsoon) season creates an opportunity for development of small-scale wind power for many islands in the South China Sea [4]. There has been some renewable energy project implemented in several islands such as the installation of solar hybrid systems in Besar Island, Pemanggil Island, Sibu Island, Aur Island and Tinggi Island in the year 2004 and 2005 [5]. In addition, renewable energy system research was conducted by the UKM (Universiti Kebangsaan Malaysia) at several islands in the South China Sea located alongside the east coast of peninsular Malaysia. The research reported promising results on the installation of hybrid solar energy in Kapas Island in Terengganu and 150 kW wind turbines in Layang Layang Island [6]. In an effort to develop sustainable energy in Malaysia, the government expanded SREP (Small Renewable Energy Program) from the renewable energy policy to support small renewable energy connection to the island grid. In order to attain the policy objective, the government embarked on a hybrid renewable energy project on Perhentian Island, Terengganu in collaboration with the Terengganu state government and TNBES (TNB Energy Services) in 2007 [6]. The project comprises the installation of two 100 kW wind turbine units, 100 kW PV array, one 100 kW diesel generator unit and a 240 Volt DC 480 kWh battery bank [7].

The renewable energy assessment for Tioman Island had been previously assessed by several researchers. M. H. Ashourian et al. proposed an optimal combination of solar energy and wind energy for Juara village only [8]. Meanwhile, Chik M. N. et al. perform sustainability indicators to determine sustainability degree for solar, wind and hydro resources in Tioman Island [9]. Both of the studies did not consider seasonal RE resource variations, the island's electrical infrastructure, or the actual load profile. This paper will provide a detailed analysis of assessment and an optimal combination of solar, wind and micro-hydro based on seasonal RE variation and the actual load profile.

### 1.4. Seasonal variation in Malaysia and islands in the South China Sea

The surface climate of Malaysia and many islands in the South China Sea is subjected to two monsoon seasons and two transitional periods namely the inter-monsoon seasons. The two monsoon seasons are the SWM (southwest monsoon) and NWM (northeast monsoon). The SWM season can be characterized by southwesterly wind; it usually begins in May and typically lasts up to three or four months [10]. On the other hand, the NEM season is subjected to northeasterly winds; it usually occurs in November and ends in February or March of the next year [10]. The two inter-monsoon periods happen between the southwest and northeast monsoon seasons. These generally take place in March to April, which is the FIM (first inter-monsoon), and from September to October, namely the SIM (second inter-monsoon) [11,12].

### 1.5. Tioman Island

Tioman Island is among one of resort islands located in the South China Sea within the east coast of Peninsular Malaysia. It is located at 2°47′47″N latitude and 104°10′24″E longitude. The island is situated 32 km from the east coast of Peninsular Malaysia and covers an approximate area of 135 km$^2$ [13]. The location of Tioman Island is showed in Fig. 1. The island features rocky hills and a mountainous background, which constitutes to the obstruction of land movement, thus limiting the habitable area. Being located in east coast of Peninsular Malaysia makes the island highly affected by the NEM season, thus producing a seasonal tourism industry [14].

The island's coastline is surrounded by eleven major villages, which are Teluk Salang, Penuba, Air Batang, Tekek, Lalang, Paya, Genting, Nipah, Mukut, Asah and Juara. The largest village in Tioman Island is Tekek and it is the town centre of the island. It has police station, school, clinic, resort and hotels, government and private offices and an airstrip. There are different types of tourist facilities clustered around the villages in Tioman Island such as beach resorts, mini-resorts and village chalets [14]. Tourism is the dominant economic sector in the island [13].

## 2. Energy audit

### 2.1. Electricity infrastructure

Tioman Island's electricity is operated and managed by TNB (Tenaga Nasional Berhad), the largest utility company in Malaysia. The electricity on the island is supplied by one diesel plant at Tekek village, a mini-hydro plant located at Juara village and small diesel engines distributed in a few locations. The electricity is distributed through 11 kV distribution networks throughout the island as shown in Fig. 2.

The study of electricity networks in the island shows that the diesel plant in Tekek village is the main 24-hour power supply for the island, while the mini-hydro plant mostly serves electricity for Juara village only. The distributed diesel generators act as a power backup during peak load demand when the main diesel generators have output constraints.

#### 2.1.1. Diesel plant

The main power station in Tioman Island is the diesel power plant located in Tekek village. The plants are equipped with a main office, a jetty, small distribution workshop, six diesel engines, and two fuel storage tanks.

The diesel plant comprises two diesel engines, each with rated capacity of 2.5 MW, one 2.4 MW diesel engine, and three diesel engines with rated capacity of 500 kW each that have been installed in 1990 and 1995 respectively. At the time of audit, only one 2.5 MW and three 500 kW of the generator sets were in working condition. One of 2.5 MW diesel engine was operating as a base station, with its output supplemented by the three 500 kW diesel sets. The total diesel generation for Tioman Island for the years 2009, 2010 and 2011 was 9,600,580 kWh, 8,983,200 kWh and 9,500,600 kWh respectively.

Please cite this article in press as: Basir Khan MR, et al., Optimal combination of solar, wind, micro-hydro and diesel systems based on actual seasonal load profiles for a resort island in the South China Sea, Energy (2015), http://dx.doi.org/10.1016/j.energy.2014.12.072