Feasibility Study of Standalone PV-Wind-Diesel Energy Systems for Coastal Residential Application in Pekan, Pahang

Roziah Zailan[1,*], *Siti Nurzalikha* Zaini[2], *Muhammad Ikram* Mohd Rashid[2], *Amir* Abdul Razak[1]

[1]Faculty of Engineering Technology, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300, Kuantan Pahang.
[2]Faculty of Electrical & Electronics Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang Darul Makmur

Abstract. Techno economic study is feasible to optimize the usage of renewable energy components that targeting low cost of electricity generation system. The selected case study area is coastal area in Pekan, Pahang, Malaysia. The autonomous system designed in this study is hybrid standalone PV-wind-diesel energy system to fulfil a basic power demand of 20.1 kWh/day. Such power system was designed and optimized further to meet the power demand at a minimum cost of energy using energy optimization software, Hybrid Optimization Model for Electric Renewables (HOMER). The analysis focused on the operational characteristics and economics. The standalone PV-wind-diesel energy system has total net present cost about $61, 911 with cost of energy $0.66/kWh. Apparently, the generation of electricity from both wind turbine and PV can be inflated with the diesel generator. In comparison, return of investment (ROI) value turned out lower for Feed in Tariff (FIT) as compared to self-sustained house. Payback period also longer for FIT program that makes the selling back of electricity generated to Tenaga National Berhad (TNB) is considered not favourable.

1 Introduction

An abundant resources of solar and wind could be exploited to power up the coastal housing. However, the selection of location for suitable wind turbine and solar energy harvesting need to be studied in respect to the technology options, component costs, and resource availability. The study area located in Pekan, situated on the banks of Pahang River 50km South of Kuantan and near to popular beaches such as Legenda Beach and Air Leleh Beach. In this area, potential benefit to receive strongest wind and solar at coastal area will give advantages for this project. Therefore, this paper presents a feasibility study of hybrid standalone PV-

* Corresponding author: roziahz@ump.edu.my

wind-diesel energy system for Pekan, Kuantan Pahang. The analysis was done based on typical house power demand at about 20.1 kWh/day and 1.23kW peak demand [1]. Noted that all cost conversion in this study is 1$=RM4.28 as of current rate (August 2017).

Generally, total cost for establishing such generating unit in new location with unknown harvesting energy units is unclear without proper techno economic study. Therefore, this study is beneficial to optimize the usage of renewable energy components that targeting low cost of energy production. The arrangement of wind turbine, solar panel, diesel generator and storage systems were considered. Several configurations in the simulation include size of components, capacity, lifetime and so forth. The National Renewable Energy Laboratory's (NREL) optimization tool "HOMER" was utilized to identify feasible hybrid configurations and their applicability. HOMER simulates the operation of a system by making energy balance calculations and displaying a list of configurations, sorted by net cost that can be used to compare system design [1-4].

There are various previous studies using HOMER to initiate hybrid power system in the coastal areas. Sadrul Islam *et al.* [5] was attempted to model a hybrid electricity generation system for a small community of the St Martin's Island in Bangladesh that resulted lowest COE $0.345/kWh and total net present cost (NPC) of $137,927 with a renewable fraction of 31%. A study in the same study area by Hazra *et al*. [6] also stated that the depending on diesel only is not feasible but to integrate it with hybrid energy generation system. They concluded that PV-diesel-wind-battery hybrid generation system was found most feasible and optimized. Nevertheless, Ibrahim *et al.* [1] stressed that the hybrid renewable energy system is suitable to be applied in the coastal areas if current costs of the renewable energy components could be marked down.

In Malaysia, FIT is a policy mechanism which allows users to sell back the additional electricity generated from PV system to Tenaga National Berhad (TNB) based on TNB rate. This study also attempted to look into the possibility to participate in the FIT program. For this reason, the payback period ROI were calculated for both FIT program and self-sustained house to identify which one is more reliable to be applied. Matin *et al.* [7] also calculated payback period of the proposed system using different tariff based on their country, Bangladesh after they simulated hybrid PV-wind-diesel power system in HOMER to determine number of years required to recover the cost of investment. Therefore the economic analysis section will discuss more on the paybacks period and ROI analysis between self-sustained house and FIT program.

2 Material and Methods

2.1 Energy demand and resources

Electrical load: The electrical loads for the house are classified as domestic with basics electrical load components like fluorescent lamps, ceiling fan, television, refrigerator and also washing machine [1, 6]. The hourly load consumed by the house is presented in Figure 1. Electricity demand is the rate at which electric energy is required by the load, measured in kilowatts (kW) [8]. Average power demand was estimated at about 20.1 kWh/day and peak demand of 1.23 kW.

Solar radiation and Wind resources: Hourly solar radiation data and wind speed for year 2014 were collected from Malaysian Meteorological Department (MMD) as in Table 1.

Table 1. Monthly Average Daily Radiation, Clearness Index & Wind Speed

Month	**Daily Radiation ($kWh/m^2/day$)**	**Clearness Index**	**Wind Speed (m/s)**
January	4.2	0.44	2.37
February	5.7	0.57	2.14
March	6.3	0.61	2.12
April	5.7	0.55	1.51
May	5.7	0.56	1.56
June	5.6	0.57	1.75
July	5.2	0.52	1.8
August	5.8	0.57	1.7
September	5.5	0.53	1.57
October	5.3	0.53	1.34
November	4.2	0.44	1.36
December	3.5	0.38	1.87

PV-wind-diesel power system: The schematic diagram of Photovoltaic (PV)-wind-diesel power system components are presented in Figure 1 consists of diesel generator, PV arrays, wind turbine, battery and power converters. Technical information to run the simulation using HOMER software were obtained from manufacturers of the equipment and previous studies [8-13].

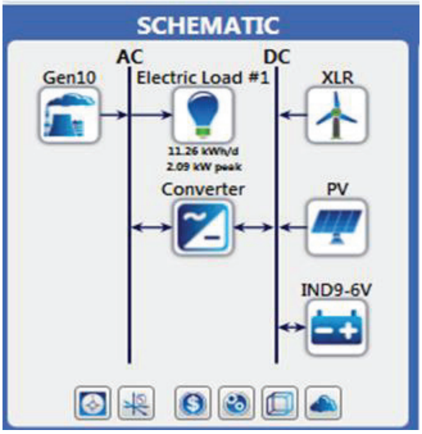

Fig 1. PV-Wind-Diesel Power System Configuration.

Table 2. Cost of Components.

Equipment	**Capacity/ Unit**	**Capital Cost ($)**	**Replacement Cost ($)**	**O&M Cost ($)**
Diesel Generator	16kW	6500	5800	0.15/h
Solar PV	5kW	11000	9500	-
Wind Turbine	1 Unit	19400	15000	75/year
Batteries (Trojan IND9-6V)	1 Unit	1325	1190	0.02/h
Converter	1kW	118	100	15/year

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3 Result And Discussion

3.1 PV-wind-diesel system simulation

For hybrid PV-wind- diesel energy system, the equipment needed to build the system were diesel generator, PV array, wind turbine, batteries and power electronic converter with specified type and quantity. The HOMER simulation tool was used to optimize the sizes of different hardware components in the PV-wind-diesel system, taking into account the technical characteristics of system operation and minimizing total net present cost of the system. The optimization results of this power system are show in Figure 2.

Architecture						Cost					System
PV (kW)	XLR	DG (kW)	S6CS25P	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)		Ren Frac (%)
		5.00	6	2.00	CC	$0.584	$54,508	$3,585	$8,686		0.0
0.250		5.00	6	2.00	CC	$0.587	$54,800	$3,564	$9,236		0.0
	1	5.00	6	5.00	CC	$0.659	$61,496	$2,586	$28,440		22
0.250	1	5.00	6	5.00	CC	$0.663	$61,911	$2,575	$28,990		23
		5.00			CC	$0.787	$73,404	$5,703	$500.00		0.0
0.250		5.00		2.00	CC	$0.800	$74,660	$5,740	$1,286		0.0
	1	5.00		2.00	CC	$0.971	$90,571	$5,510	$20,136		0.0
0.250	1	5.00		2.00	CC	$0.975	$91,007	$5,501	$20,686		0.0
	24		36	5.00	CC	$6.54	$609,997	$7,518	$513,890		100

Fig 2. The simulation results for PV-wind-diesel energy system

The least Cost of Energy (COE), $0.58 kW/h resulted from the 5 kW diesel generator alone without contribution from renewable sources. But the integration with renewable energies fell into fourth least COE as $0.66 kW/h, resulted from the combination of 5 kW diesel generator, 0.25 kW of PV array, 1 unit of wind turbine, 6 unit of batteries and 5 kW converter. The strategy taken in this simulation is to ensure the power generator provide enough power to meet the demand. The renewable energy sources in collaboration with the diesel generator were evaluated to determine the feasibility of the system.

All values related to the electricity production and load served by the system are summarized in Table 3. The results of the simulation showed that the PV-wind-diesel hybrid system had a total annual electrical energy production of 10,046 kWh/yr. The electricity generation came mostly from diesel generator with 56.32% at about 5,658kWh/yr while wind turbine and PV-array generated energy at 42.82% (4,301 kWh/yr) and 0.87% (87 kWh/yr), respectively. Besides that, it is clear that approximately 8.7% of energy (873.5 kWh/yr) was neglected. Several amount of excess energy can be suggested to cater for PV-wind hydrogen energy system in the next study. The trend of monthly electricity production can be referred to Figure 3.

Table 3. Operational Characteristics of the PV-Wind-Diesel System

Annual Electricity Production	**kWh/year**	**%**
PV-array	87	0.87
Diesel generator	5,658	56.32
Wind Turbine	4,301	42.82
Total production	**10,046**	**100.00**
Annual electrical load served		
AC primary load served	7,300	100
Total	7,300	100
Other		
Excess electricity	873.5	8.7

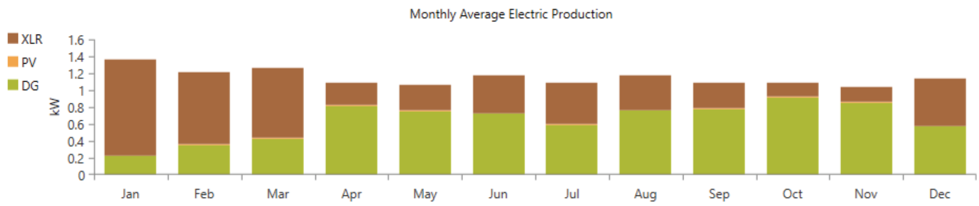

Fig 3. Monthly Electricity Production Trend of the PV-Wind-Diesel System

Through the economic analysis, the most expensive annualized cost is contributed from wind turbine at $1,518 followed by batteries ($622), converter ($46), PV ($43) and diesel generator ($39). Total annualized cost for overall system is $4,843. HOMER uses the total net present cost (NPC) to represent the life-cycle cost of a system (Figure 8). The highest NPC came out from the BWC Excel-R wind turbine $19,400, followed by batteries $7,950, converter $590, PV panel $550 and diesel generator $500. Total NPC is $61,911. F

From this study, diesel generator apparently contributed highest portion of electricity while wind speed is highly potential in three months, January, February and March. The contribution from solar is very minimal. Apparently, fully dependent on the consumption of diesel fuel was reduced with integration of those renewable resources. All in all, capital cost, total Net Present Value (NPC) and COE of the systems were recorded as $28,990, $61,911 and $0.66/kWh respectively. From the analysis, COE is considered high until price reduction be made to respective devices involved in such system.

3.2 Self-Sustained House and FIT Program Analysis

On the other hands, economic analysis was done to complete this study by introduced other alternative in order to promote FIT that currently stirred by government through SEDA Malaysia. Therefore, both payback period and ROI were calculated to determine which one is favourable option between self-sustained house and FIT program. Table 4 provide detail summary of both option. Noted that the cost of electricity for installation above 4kW and up to (and including) 24kW is $2.90/kWh as of January 2017 [14]. Payback period was calculated to identify specific duration to recover the cost of investment of the system. Meanwhile, the return on investment (ROI) expresses the benefit to the investor resulting from an investment of some resources. A high ROI means the investment is worthy for the investment cost. As a performance measure, ROI used to evaluate the efficiency of an investment [15]. In comparison, ROI value for FIT program is lower as compared to the self-sustained house. Thus, the selling back of electricity generated to Tenaga National Berhad (TNB) is not recommended for the proposed system.

Table 4. Comparison between Self-Sustained House and FIT Program

SELF-SUSTAINED HOUSE	**FIT PROGRAM**
Total capital cost= $28,990	Total capital cost= $28,990
Annualize income = Total production x HOMER COE = 10,046kWh/yr x $0.66/kWh = $6894.4/yr	Annualize income = Total production x TNB tariff rate ($) = 10,046 kWh/yr x $ 0.16/kWh = $1643.04/yr
Payback period = 4.2 years	Payback period =17.64 years
ROI= Annualize income/ Total capital cost = $6894.4/ $28,990 = 0.24 per annum (24%)	ROI= Annualize income/ Total capital cost = $1643.04/ $28,990 = 0.06 per annum (6%)

4 Conclusion

At the end of HOMER simulation, standalone PV-wind-diesel energy system presented total net present cost about $61,911 that capable to generate electricity at cost of energy $0.66/kWh. From the economic analysis, it has resulted that ROI for FIT program is lower than self-sustained house. Payback period also longer for FIT program that makes the selling back of electricity generated to Tenaga National Berhad (TNB) is not favourable. This study may be extended to involve the integration of other renewable resources system and environmental aspect for an extensive coastal area in the future.

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