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

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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-
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.
The economic analysis section will discuss more on the paybacks period and ROI analysis to determine the number of years required to recover the cost of investment. Therefore, the payback period of the proposed system using different tariff based on their country, between self-sustained house and FIT program. This study also attempted to look into the possibility to participate in the FIT program. For electricity generated from PV system to Tenaga National Berhad (TNB) based on TNB rate, components could be marked down. This study is beneficial to optimize the usage of renewable energy components that targeting low COE $0.345/kWh and total net present cost (NPC) of $137,927 with a renewable fraction of 31%. A study in the same study area by Hazra et al. concluded that PV-diesel-wind-battery hybrid generation system was found most feasible compared to diesel only which is not feasible but to integrate it with hybrid energy generation system. They also stressed that the hybrid renewable energy system is suitable to be applied in the coastal areas if current costs of the renewable energy are optimized. Nevertheless, Ibrahim et al. also calculated that all cost conversion in this study is 1$=RM4.28 as of current rate (August 2017).

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

| Month    | Daily Radiation (kWh/m²/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].

![Schematic Diagram](image)

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      |
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 shown in Figure 2.

![Fig 2. The simulation results for PV-wind-diesel energy system](image)

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 5,658 kWh/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](table)

| 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  |
energy system in the next study. The trend of monthly electricity production can be referred
neglected. Several amount of excess energy can be suggested to cater for PV-wind hydrogen
respectively. Besides that, it is clear that approximately 8.7% of energy (873.5 kWh/yr) was
system. The optimization results of this power system are show in Figure 2.

All values related to the electricity production and load served by the system are

for the proposed system. Thus, the selling back of electricity generated to Tenaga National Berhad
sustained house. Thus, the selling back of electricity generated to Tenaga National Berhad

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=$28,990 |
| Annualize income= Total production x HOMER COE | Annualize income= Total production x TNB tariff rate ($) |
| 10,046kWh/yr x $0.66/kWh | 10,046 kWh/yr x $ 0.16/kWh |
| = $6894.4/yr | = $1643.04/yr |
| Payback period = 4.2 years | Payback period = 17.64 years |
| ROI= Annualize income/ Total capital cost | ROI= Annualize income/ Total capital cost |
| = $6894.4/ $28,990 | = $1643.04/ $28,990 |
| = 0.24 per annum (24%) | = 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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