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A complete off-grid PV-Diesel-Battery Hybrid Energy System with feasibility analysis, system modeling and Optimization

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Abstract

The electrification process of the remote areas and decentralized areas are being a vital fact for the improvement of its agricultural and industrial issues such as the southern region of Malaysia. Renewable energy resources can be used extensively to support and fulfill the demand of expected loads of these areas. This article presents an analysis of a complete off-grid PV-Diesel-Battery Hybrid renewable energy model with a backup of a 5kW generator. The main objective of the present analysis is to visualize the optimum volume of systems capable of fulfilling the requirements of 38 kWh/d primary load in coupled with 5 kW peak for 37 households for a decentralized area of the said region. The lowest cost of energy (COE) is nearing USD 0.895/kWh and Net Present Cost (NPC) is USD 158,206. The decrement of the CO_2 emissions also can be identified from the simulation results by using that most feasible renewable energy system.

Keywords: *Renewable Energy, Photovoltaic, HOMER, Optimization, Hybrid Model.*

Nomenclature	**Subscripts**
A Net Area of solar module (m²)	Gen-1 Generator 1
E Electrical energy (kWh)	Gen-2 Generator 2
H yearly standard global solar radiation	PV photovoltaic
*r*Solar module ratio (%)	NREL National Renewable Energy Laboratory
v Wind speed (m/s)	HOMER Hybrid Optimization Model for Electric Renewable

1. Introduction

The development along with technological advancement of a country is completely dependent on the energy stored by that country. Fossil fuels are still the main resources of energy to handle the energy demand of the world[1]. But, the problem has been arising during last few decades for having not only the negative impacts of fossil fuel on environment but also the shortage of it.Therefore, some serious efforts should be taken to find out some alternatives before ending the resources of the fossil fuels where renewable energy draws the most attention to the current researchers of the world [2]. The renewable energy resources vary with other conventional fossil fuel resources in such a way that they have some characteristics like renewability, inexhaustibility, naturally replenished and sometimes cost-effective.The main resources of renewable energy are solar (PV and thermal), wind, hydropower, biomass, tidal, wave and geothermal etc. This study has chosen the PV as one of the energy resource components of the proposed hybrid system suitable for off-grid residential power supply[3].It is a common phenomenon in tourist sector that the stand-alone diesel generators are usually used to supply the electricity rather than grid connections.
Therefore, the study only concerns the energy supply by RES installation which can be categorized into following two groups:

i. Hybrid Renewable Energy system: This type of system consists of a RES system with conventional fossil fuel systems (especially with diesel generators). For example, PV hybrids, WECS hybrids and small to large scale PV/WECS hybrids etc[4].

ii. Autonomous Controlled system: It is a complete independent system which produces the energy by stand-alone and/or with a combination of other renewable energy technology such as photovoltaic (PV) only, wind energy conversion system (WECS) only and combined PV-WECS.

Therefore, the energy consumption phenomenon of tourist sectors cannot be represented by the studies of energy efficiency of industrial and domestic sectors. The literature shows very few (only two) case studies for the feasibility of RES in tourist accommodation. For this analysis, HOMER has been used for simulation and therefore estimation of various output parameters by providing some input parameters for a specific area such as the southern region of Malaysia Hence the current study focuses on the following points below:

i. To discuss the feasibility of the proposed system considering the efficient power distribution and proper maintenance of RES.

ii. To estimate the most economically feasible technology for RES and compare it with other technologies. Here, the comparison is made considering the NPC and COE for various RES.

For the last few years the visiting rate of Malaysia has been increased rapidly. Another great demand for the household activities has been increased dramatically [5]. The increasing power consumption, increasing energy generation costs, bad weather and climate conditions have increased the interest in the renewable energy system. The low carbon emissions are one of the reasons for increasing demand of renewable energy system[6].

2. Methodology

2.1 Location analysis and Data Resources

The daily solar radiation data have been collected for every month of the year 2009 from the Malaysian meteorological department for the Southern region of Malaysia. An estimation of solar insulation on horizontal surface has been done by using well known Angstrom Correlation and the sunshine hour data of Southern region, Malaysian Meteorological Department, the nearest meteorological station from Selangor, Malaysia[7]. Fig. 1 shows the geographical position of Southern Region (Lat.: 2° 44' N, Long.: 101° 42' E). To calculate wind resources data, Malaysian Meteorological Department has measured wind speed for the year 2009 by maintaining the height of 30 m upwards from the ground surface level. The result was not up to the expectation level that is why just the wind and solar resource and average temperature data have been considered to discover the most efficient hybrid renewable energy system. HOMER runs few to thousands hours to simulate the best suitable energy system considering the optimum power supply and load demand.

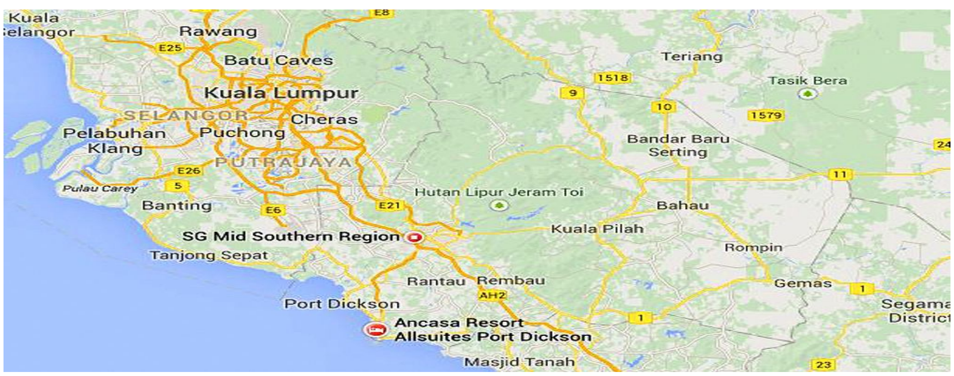


Fig. 1: Southern Region of Malaysia [8].

2.2Hybrid Renewable Energy System Components

2.2.1 Solar Energy (Photovoltaic) System

Monthly average global radiation data has been taken from Malaysian Meteorological Department[9]. From the longitude and latitude data of the considered area can be calculated the clearness index through HOMER renewable energy software. The synthesized 2304 hourly values for a year can be created by HOMER renewable energy software through the utilization of the Graham algorithm. The solar radiation is elevated in April, February, March, August, September and October has been represented inFig. 2. USD 50 /kW have been considered as the rate of PV component counting the mechanism for Malaysia. The life span of the system has been preferred as 2 decades.

There are 3 types of module has been considered for PV modules such as 3 kW, 4 kW and 5 kW. Table 1shows the factors of PV module related with the simulation.

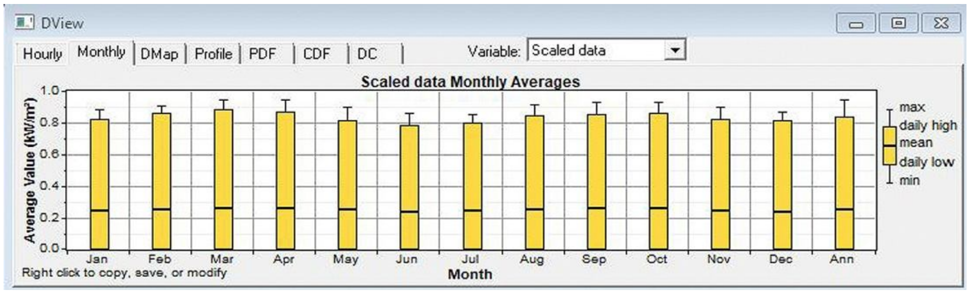


Fig. 2: Monthly average solar radiation data in a specific year.

Table 1: Photovoltaic array expense assumption and procedural factors.

Factors	Value
Net Cost	50 $/kW
Substitution Cost	40 $/kW
Maintenance and Operation Cost	5 $/kW
life span	20 Years
Derating factor	80 %
Tracking System	No Tracking System

2.2.2 Specification of Diesel Generator module

The fuel used in HOMER is modeled by a linear curve characterized by a slope and intercept at no load. **Table 2** shows the assumptions of cost for a diesel generator and the other factor related with power generation and range of capacity. Fig.3 shows the cost curve generated by the diesel prices in terms of cost analysis.

Table 2: Procedural parameters with Cost conjecture for Diesel Generators.

Factors	Value
Net Cost	120 $/kW
Substitution Cost	100 $/kW
Maintenance and Operation expense	0.014 (5 kW) $/kW
Lifetime	900000 Minutes (15,000 Hours)
Least Load quotient	30 %
Fuel Curve Slope	0.441/h/kW $_{output}$
Fuel Curve Intercept	0.062/h/kW $_{rated}$
Fuel Cost	0.8 $/liter

Fig. 3: Cost Curve of Diesel Generator.

2.2.3 Battery Module

In that off-grid hybrid renewable energy system, the Hoppecke 6OPzS 300 storage batteries have been utilized.There are six stipulations such as effectiveness, life time, rectifier effectiveness, rectifier aptitude;

substitution and net cost have been shown in Table 3. Fig.4shows the cost curve indicated the cost analysis for the battery module.

Table 3: Procedural Parameters with Cost Assumptions for Battery.

Parameters	Value
Lifetime	1 decade
effectiveness	95 %
Rectifier aptitude	90 %
Rectifier effectiveness	89 %
principal Cost	90 $/kW
substitution Cost	70 $/kW

2.2.5 Converter Specification

The converter is one kind of device that can convert electrical power from ac to dc in a process called rectification and from dc to ac in a process called inversion. There are two types of converters such as rotary (rectifier or inverter) and solid-state can be sampled by Homer renewable energy software. The verdict variable refers to the converter size that delegate to the inverter capacity; by inverting dc power with the device can generate the utmost amount of ac power. We used a 3 kW Converter for our hybrid System. The life time is 20 years and the efficiency for inverter and rectifier as follows 90 % and 85 % respectively. The cost analysis with converter has been represented by the cost curve mentioned by Fig. 5.

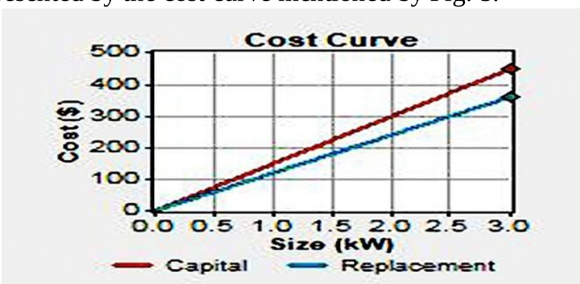


Fig.5: Cost Curve of Converter.

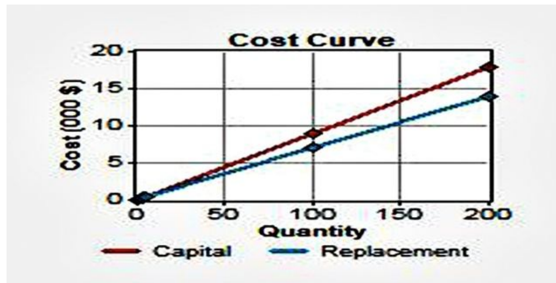


Fig. 4: Cost curve for Battery Module

3. A Developed off-grid Hybrid Renewable Energy System

Solar energy (Photovoltaic) and Battery module have been used with a diesel generator and a converter module in this analysis. An extra generator has been used as a back-up energy producer. An electrical primary load demand, renewable energy resources such as solar resource and other mechanisms as like as PV (photovoltaic) array, battery storage, and converters constitute an off-grid hybrid renewable energy system. Fig. 6 shows the model of a complete hybrid renewable energy system.

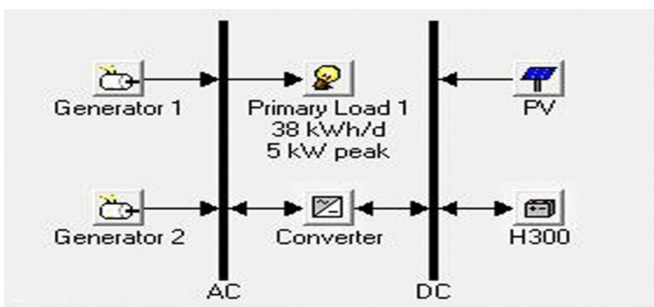


Fig.6: Complete Block Diagram of a PV-Diesel Hybrid Energy System.

Deciding on the load is one of the most important steps in the design of the proposed hybrid systems. In this study, a hypothetical model community of 37 families in 37 households, each comprising of 4 family members, is considered. The household in the rural area is simple and does not require large quantities of electrical energy for lighting and electrical appliances due to not being connected with the national grid network. A rural household generally uses electrical energy for lighting, cooling and entertaining[10].There are 2 fans (Star standard ceiling fan, 50 W), 4 energy savings bulbs (Philips tornado bulb, 20 W each), 1 television (Sony bravia, 50 W), 2 table lamps (Emen 69076, 5 W) and 1 refrigerator (160 W) have been calculated for each family and considered for the load demand analysis. The primary load or energy consumption pattern usually varies over 24h and over different months of the year. Fig. 7 and 8 shows two load profiles on a day of Northeast Monsoon (January) and Southeast Monsoon

(July). HOMER simulates the operation of a system by making energy balance calculations for each of the 8760h in a year.Load demand data had been amalgamated through the specifica
tion of emblematic daily load demand profile data and after that some parameters has been added. Therefore, about 38kWh primary loads can be handled per day along with a scale of yearly 5kW peak load.

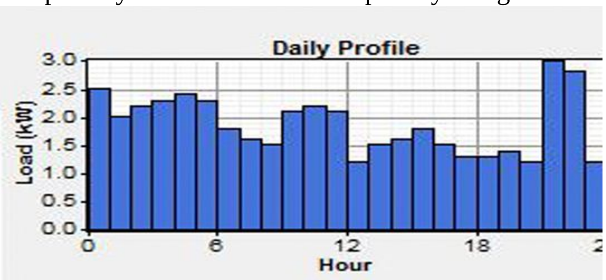


Fig.7: Daily load profile of a particular day of Northeast monsoon (January).

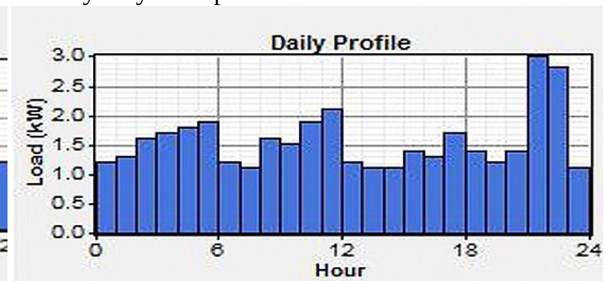
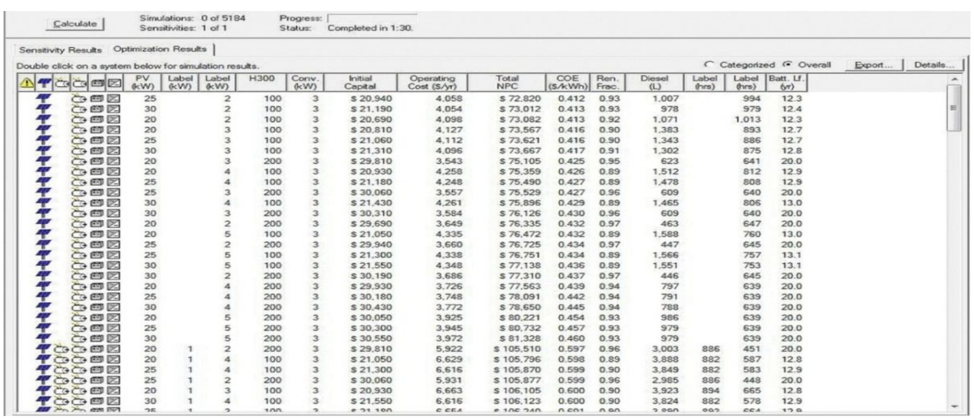


Fig.8: Daily load profile of a particular day of southwest monsoon (July).

4. Simulation, Optimization Results and Discussion:

An optimal hybrid renewable energy system can be designed by HOMER renewable energy software through large number of hourly simulations again and again. Various values for wind speed, solar radiation, diesel cost and least renewable fraction have been contemplated to conduct simulations and these values assuring much more suppleness in the analysis. Fig. 9shows Simulation outcomes in considering an off-grid hybrid pv-diesel-wind-battery hybrid energy model with an highest capacity shortage of 0.03%.USD has been considered as the currency for all costs related with that hybrid system. Fig. 10 shows the details calculation, simulation results and cost analysis with System architecture, NPC, COE, Operating cost, Electrical energy produced by wind turbine, PV, and diesel generator system, unmet load, excess electricity, capacity shortage and renewable fraction of the most monetarily practicable hybrid energy system relevant for the preferred area in both simple case and best case. In the same time, with a base NPC of USD 158,206 and base COE of USD 0.895/kWh, an off-grid hybrid PV, diesel generator and battery hybrid system is efficiently more feasible and this is observed by the sensitivity analysis in the most economically feasible case.Fig. 11 shows the electrical energy generated with practicability from the off-grid hybrid PV-diesel-wind-battery system. A hybrid energy system can be considered as a most feasible renewable energy system constituted of 5 kW PV module, a diesel generation with a divisional power of 5 kW (utilizing 5 kW) and 100 storage batteries in cementation to 3 kW converters and rectifiers.



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Sensitivity Results | Optimization Results

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PV (kW)	Label (kW)	Label (kW)	H300	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)	Label (hrs)	Batt. Lf. (yr)
25		2	100	3	$ 20,940	4,058	$ 72,820	0.412	0.93	1,007		994	12.3
30		2	100	3	$ 21,190	4,054	$ 73,012	0.413	0.93	978		979	12.4
20		2	100	3	$ 20,690	4,098	$ 73,082	0.413	0.92	1,071		1,013	12.3
20		3	100	3	$ 20,810	4,127	$ 73,567	0.416	0.90	1,383		893	12.7
25		3	100	3	$ 21,060	4,112	$ 73,621	0.416	0.90	1,343		886	12.7
30		3	100	3	$ 21,310	4,096	$ 73,667	0.417	0.91	1,302		875	12.8
20		3	200	3	$ 29,810	3,543	$ 75,105	0.425	0.95	623		641	20.0
20		4	100	3	$ 20,930	4,258	$ 75,359	0.426	0.89	1,512		812	12.9
25		4	100	3	$ 21,180	4,248	$ 75,490	0.427	0.89	1,478		808	12.9
25		3	200	3	$ 30,060	3,557	$ 75,529	0.427	0.96	609		640	20.0
30		4	100	3	$ 21,430	4,261	$ 75,896	0.429	0.89	1,465		806	13.0
30		3	200	3	$ 30,310	3,584	$ 76,126	0.430	0.96	609		640	20.0
20		2	200	3	$ 29,690	3,649	$ 76,335	0.432	0.97	463		647	20.0
20		5	100	3	$ 21,050	4,335	$ 76,472	0.432	0.89	1,588		760	13.0
25		2	200	3	$ 29,940	3,660	$ 76,725	0.434	0.97	447		645	20.0
25		5	100	3	$ 21,300	4,338	$ 76,751	0.434	0.89	1,566		757	13.1
30		5	100	3	$ 21,550	4,348	$ 77,138	0.436	0.89	1,551		753	13.1
30		2	200	3	$ 30,190	3,686	$ 77,310	0.437	0.97	446		645	20.0
20		4	200	3	$ 29,930	3,726	$ 77,563	0.439	0.94	797		639	20.0
25		4	200	3	$ 30,180	3,748	$ 78,091	0.442	0.94	791		639	20.0
30		4	200	3	$ 30,430	3,772	$ 78,650	0.445	0.94	788		639	20.0
20		5	200	3	$ 30,050	3,925	$ 80,221	0.454	0.93	986		639	20.0
25		5	200	3	$ 30,300	3,945	$ 80,732	0.457	0.93	979		639	20.0
30		5	200	3	$ 30,550	3,972	$ 81,328	0.460	0.93	979		639	20.0
20	1	2	200	3	$ 29,810	5,922	$ 105,510	0.597	0.96	3,003	886	451	20.0
20	1	4	100	3	$ 21,050	6,629	$ 105,796	0.598	0.89	3,888	882	587	12.8
25	1	4	100	3	$ 21,300	6,616	$ 105,870	0.599	0.90	3,849	882	583	12.9
25	1	2	200	3	$ 30,060	5,931	$ 105,877	0.599	0.96	2,985	886	448	20.0
20	1	3	100	3	$ 20,930	6,663	$ 106,105	0.600	0.90	3,923	894	665	12.8
30	1	4	100	3	$ 21,550	6,616	$ 106,123	0.600	0.90	3,824	882	578	12.9

Fig. 9: Simulation Results of a complete PV-Diesel-Battery Hybrid Renewable Energy System

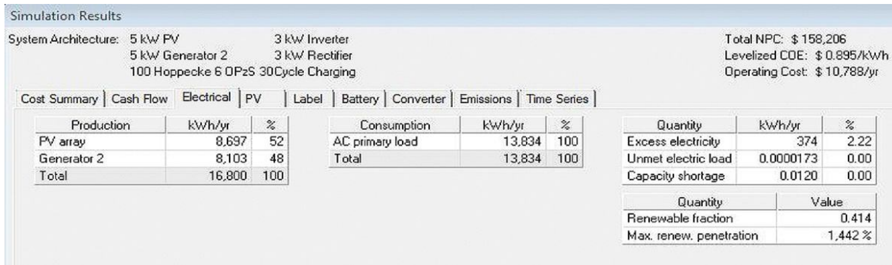

Fig. 10: Simulation Results with the power generation, NPC and COE.

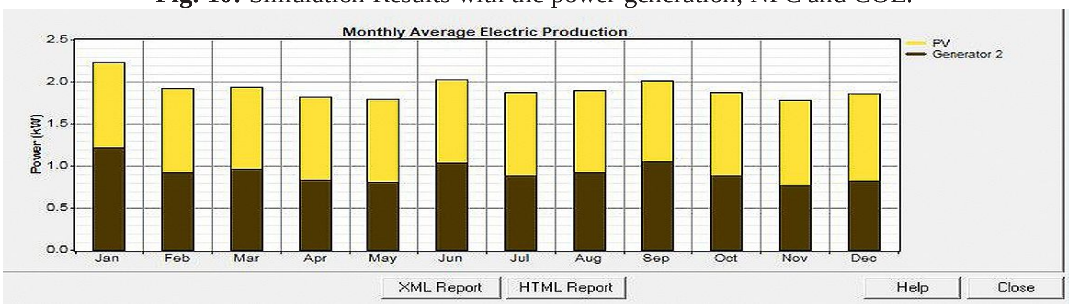

Fig.11: Power generation with generator 2 coupled with PV module.

5. Conclusion

With the consideration of the demand of huge amount of electrical power a complete hybrid PV-diesel-battery renewable energy model has been developed. This hybrid energy system will be applicable especially for decentralized and remote areas.Since, diesel based power generation system completely depends on fossil fuel which is too expensive, therefore, only diesel generator cannot be feasible to supply the electrical power to the remote areas. The simulation reveals that the selected location has a huge potentiality of solar radiation about 8.025–17.370 kWh/ m^2/day which exhibits a promising feasibility to develop a PV-Diesel Generator-Battery hybrid energy system. For the economic feasibility analysis of the proposed system, it is found that for 37 decentralized off-grid households would be composed of 5 kW PV array together with a 5 kW diesel generator and 100 numbers of batteries of which each has a nominal voltage of 12 and capacity of 300 Ah. The investigation of the best results shows that the COE of the optimized system is USD 0.895/kWh and the NPC of the optimized system is USD 158,206. By establishing this energy system would lead to reduction in emissions of GHG and CO_2. In the near future we will try to introduce some more convenient renewable energy model and proper control system for the hybrid energy system for the different area of the world.

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