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Techno-Economic Analysis of Grid-Connected PV System for a Location in Perlis, Malaysia

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ABSTRACT

Hybrid Renewable Energy System (HRES) is a system that comprises of multiple renewable generations with backup generation such as diesel generator or battery system. Currently, most of the remote areas depends on diesel generator for energy. However, diesel releases high amount of CO2. Moreover, diesel prices also are high and fluctuates according to the global market price. Hence, techno-economic analysis of a HRES system of grid-connected photovoltaic (PV) were conducted using Hybrid Optimization of Multiple Energy Resources) software (HOMER. The analyses include inputs such as load demands and renewable resources. The results include Net Present Cost, capital investment, renewable energy fraction, Cost of Energy and CO2 emissions. Multiple configurations will be assessed that suited best for the selected location.

1. INTRODUCTION

1.1 Hybrid Renewable Energy System (HRES)

Hybrid Renewable Energy System (HRES) has been used widely in remote areas where there are high demands of renewable energy. HRES involves in combining two or more renewable energy sources with the aim of providing higher efficiency of energy output [1-3]. The combination of energy resources provides an output result of almost 100% efficiency, in the case of supplying to higher output loads. HRES system are well – defined of their standardized set of frameworks to implement an effective and resourceful energy harvesting system. Some of the common configurations used in the HRES includes in;-

I. PV, Wind or Diesel Generators HRES
II. PV, Wind, Fuel Cell HRES
III. Wind or Battery HRES
IV. Biomass, Wind, Diesel Generators HRES
V. PV, Wind, Biomass, Fuel Cell HRES [4]

There must be a critical storage technology to ensure that there is continuous supply of power to the load. There are many types of energy storage system that can be used in a HRES such as compressed air energy storage, hydrogen fuel cells, flywheels, supercapacitors, superconducting magnetic energy storage (SMES) and batteries. Figure 1 below illustrates a standard HRES.

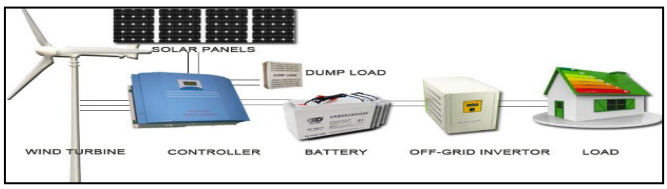

Fig. 1. HRES block diagram [4]

1.2 Hybrid Optimization of Multiple Energy Resources (HOMER)

HOMER is an online tool of advanced system optimization with design analysis and project specification. HOMER also

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works as a design tool for independent power systems and decision making where it simulates the operation of a hybrid system. HOMER can be used in optimizing the economics of small and off – grid power system in a chosen location [5].

It provides in a detailed grid and rate modelling as well as an reliable grid connection. In the economic perspective, the complete cost structure and economic analysis will serve as an output with many options..

2. METHODOLOGY

The chosen area for the design and testing of the HRES system with HOMER software was Kampung Sena, Perlis. The selection of this place was because there were large differences in temperature readings during cold and hot seasons. The hot seasons are between January to September while the cold seasons spans from October to December. Besides that, Kampung Sena accommodated a large build – up area which contributed to an easy and systematic approach in development of the system.

One of the main issues identified in Kampung Sena was that the solar power that has stifled its use was that energy production only took placed during the presence of sunlight [5-6]. As a solution, a battery storage facility was used to store the excess solar energy and enables a back – up power to be supplied during a power failure. The proposed HRES is shown in Figure 2 below. The primary energy contributor to the HRES was solar panels and electricity from the main power grid whereas battery were utilized as storage systems and served as a backup during a power failure. The system was connected in a closed loop with the main power grid lines at Kampung Sena.

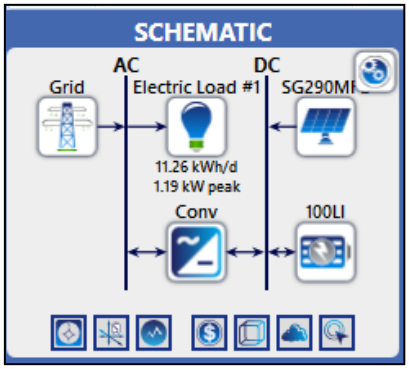


Fig. 2. The proposed system diagram

The load profile was obtained by calculating the electricity consumed by the residence in Kampung Sena over a period of one year. The operational hours for the residential area were 24 hours a day and 7 days in a week. The load used at Kampung Sena was attached at the residential's load section. The load consumption profile from January to September is shown in Table 1 while the load consumption profile from October to December is shown in Table 2.

Table 1. Load consumption profile from January to September in Kampung Sena

Hours	Load Power (Watt, W)
0	86035
1	86035
2	86035
3	86035
4	86035
5	86035
6	60385
7	60385
8	60385
9	121035
10	121035
11	121035
12	84135
13	84135
14	84135
15	104055
16	104055
17	86675
18	106315
19	106315
20	106315
21	141875
22	125565
23	86035

Table 2. Load consumption profile from October to December in Kampung Sena

Hours	Load Power (Watt, W)
0	49275
1	49275
2	49275
3	49275
4	49275
5	49275
6	69505
7	69505
8	69505
9	120475
10	120475
11	120475
12	73975
13	73975
14	73975
15	73975
16	73975
17	73975
18	93615
19	93615
20	93615
21	93615
22	93615
23	49275

In terms of maintenance and performance, Figure 3 shows the proposed HRES had a project lifespan of 25 years with the nominal discount rate for Malaysians as 3.29% and the expected inflation rate as 3.80%.

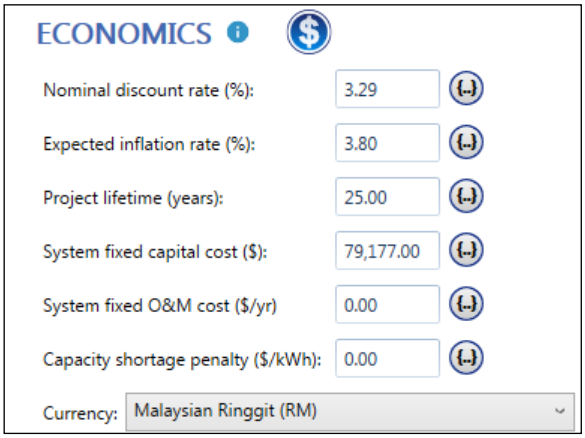


Fig. 3. Lifetime operation of HRES

2.1 *Photovoltaic (PV) panels*

The PV panels used in Kampung Sena was Peimar SG290MFB which had a rated capacity of 1 kW with initial and replacement cost of RM 640 per panel. The lifetime of these PV panels ranges from 10 – 25 years. The monthly averaged solar Global Horizontal Irradiance (GHI) data is shown in Table 3 below while the graphical tabulation of GHI data can be seen in Figure 4. In Table 4, the monthly averaged temperature data is illustrated with a graphical tabulation shown in the Figure 5.

Table 3. Monthly averaged solar irradiance [9]

Month	Clearness Index	Daily Radiation (kWh/m²/day)
Jan	0.563	5.260
Feb	0.592	5.860
Mar	0.561	5.810
Apr	0.541	5.650
May	0.497	5.060
Jun	0.484	4.820
Jul	0.483	4.840
Aug	0.457	4.690
Sep	0.450	4.650
Oct	0.438	4.370
Nov	0.449	4.230
Dec	0.485	4.420

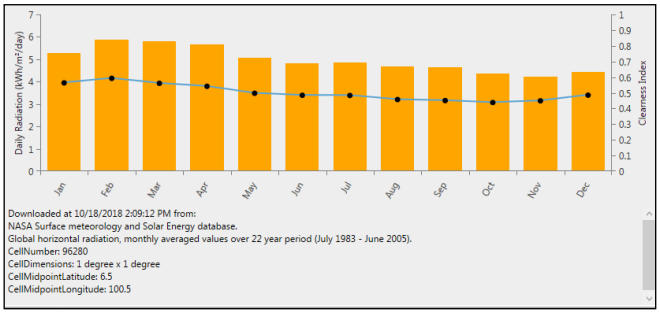
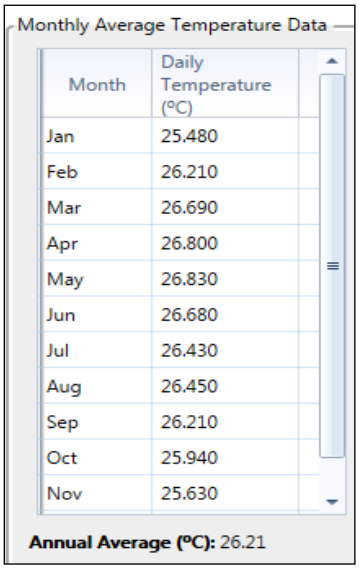


Fig. 4. Graph of monthly average solar irradiance [9]

Table 4. Monthly average temperature [9]



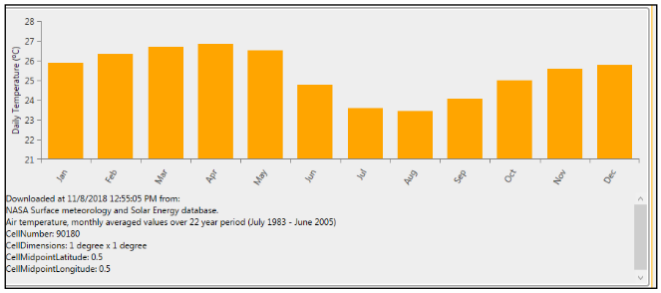


Fig. 5. Graph of monthly average temperature [9]

2.2 *Battery Converter and Grid*

The Generic Li – ion batteries rated with nominal voltage of 600 V and has a capacity 100 kWh (167 AH) was selected for this proposed HRES. However, only one battery was used in this proposed HRES. The capital and replacement cost for the entire system was RM 70 000 in a lifetime of usage. The operation and maintenance cost were RM 1 000 per year.

A Generic large – free converter was used in this proposed HRES where the grid was interconnected with a load of RM 0.10 per kWh grid power price while the grid sell back price was RM0.05. The emissions of carbon dioxide were 693 g/kWh [7] as shown in Figure 6.

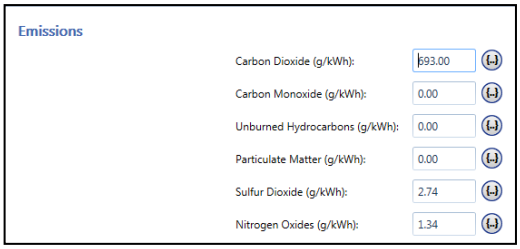


Fig. 6. Emission for carbon dioxide

The HOMER Pro software simulated the proposed HRES and gave optimum sizing with the best strategy operational for the development of a successful HRES. It also helped to determine any further optimization and sensitivity analyses to obtain the lowest cost involved with the best solution incorporatedin the proposed HRES.

3. RESULTS AND ANALYSIS

For a period of 25 years of operational lifetime, the net present cost (NPC) was RM 37 376 which was the lowest compared to the others. The cost of 10 years of operational lifetime had the highest cost at RM 0.04 while the initial capital investment was the same which cost RM 102 217.

3.1 *Proposed Hybrid Renewable Energy System (HRES)*

The simulation for the proposed HRES is shown in Figure 7 which accounted an NPC of RM 219 681.20 with the cost of electricity consumption per kWh was RM 0.14. The proposed HRES which was simulated had its operating cost at RM 177.46. Figure 8 depicted the cash flow while Figure 9 depicted the electrical consumption with the PV panels harvesting a total power of 57 701 kWh per year with grid purchases at 2082 kWh per year.

Fig. 7. Simulation results of proposed HRES

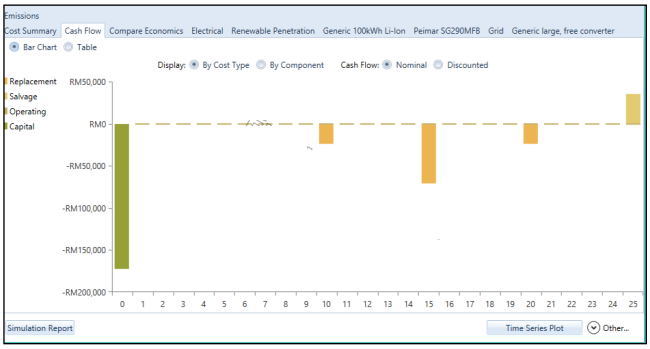


Fig. 8. Cash flow of proposed HRES

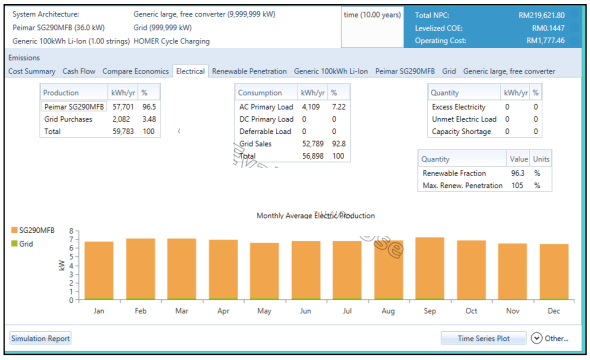


Fig. 9. Electrical consumption of proposed HRES

Based on the electricity produced for this configured HRES, solar power harvesting was the biggest contributor with a total of 96.5% power harvested while 3.5% of the power was obtained from grid. The total energy generated was 59 783 kWh per year and the consumption of alternating current (AC) primary loads for Kampung Sena was 4109 kWh per year.

3.2 *Grid – Configuration System*

The simulation for grid power system only is shown in Figure 10. The NPC for grid power system was at RM 90 135.99 and the cost of electricity was RM 0.82 per kWh. The operating cost was RM 410.91 while the cash flow for grid power system was depicted in Figure 11. Figure 12 identifies the electrical consumption for the grid power system with grid purchases at 4109 kWh per year.

Fig. 10. Simulation results of grid power system

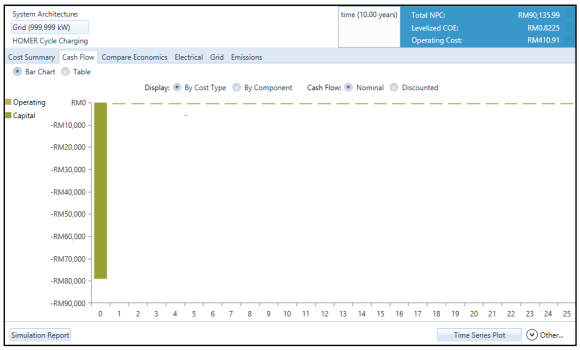


Fig. 11. Cash flow of grid system

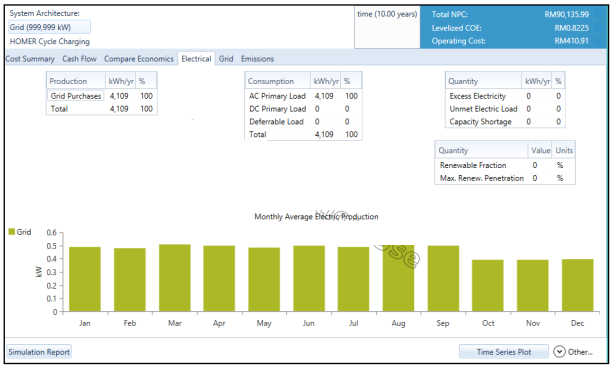


Fig. 12. Electrical consumption for grid power system

3.3 *Comparison between Hybrid Renewable Energy and Grid Power System*

. Present worth differences between them were RM 129 486 per year while the annual worth between them were RM 4855 per year. Their return of investment (ROI) was justified to be 5.5% per year. Their differences of cash flow is seen in Figure 13.

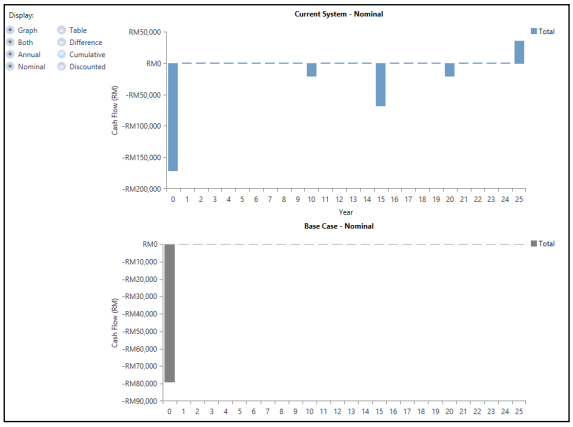


Fig. 13. Comparison between cash flow for HRES and grid power system

3.4 *Problem Identified and Solutions Employed*

The initial problem identified was identifying the actual rated power for equipment since the rated base power was too high for every equipment. The solution employed included in identifying the actual rated power of each equipment by re – calculating their power consumption manually and comparing with the rated power on the manufacturer's website.

The second problem encountered was false values keyed into the daily load profile data because the model did not match the data entry. The solution included in rechecking the daily load profile data with the relevant team members.

The cost of equity (COE) was too high at RM1.26 because of the usage of the Li – ion batteries at 1 MWh. The cost was estimated to be RM 700 000 per unit for the Li – ion batteries and was replaced with a Generic 100 kWh Li – ion batteries which cost RM 70 000 per unit. The reduced in COE was RM 0.14.

3.5 *Future Recommendations*

In the future, an alternative recommendation would be to include another energy harvesting resources in the HRES, for an example biomass. Kampung Sena has an abundant amount of molasses and bagasse from sugarcane factories which can be employed as an alternative energy generation. There are also rice husks and rice straw available as there are many rice mills in Kampung Sena. Palm kernel shells, empty fruit bunches and mesocarp fibre can also be obtained from the nearest palm oil plantation and municipal solid waste from the nearest landfills in Padang Sera which is a few kilometres away from Kampung Sena [8].

4. CONCLUSION

The proposed HRES was a success in development and simulation to cater for the load demand in Kampung Sena. The design included in solar, and grid connected resources with battery and converter. The proposed HRES had a total NPC at RM 219 681.20 and the cost of electricity per kWh was RM 0.14. The operating cost was RM 177.46. The results obtained illustrated that the HRES is much cheaper for electricity production, but the selection of the resources must be economical and sustainable.

ACKNOWLEDGEMENT

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