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# SIMULATION AND OPTIMIZATION OF HYBRID RENEWABLE ENERGY SYSTEMS FOR REMOTE AREA RESIDENTIAL APPLICATIONS

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## ABSTRACT
This paper shows the way to design the aspects of a hybrid power system that will target remote users. The main power for the hybrid system comes from the photovoltaic (PV) panels, while the fuel cell (FC) and secondary batteries are used as backup units. Converter is incorporated, since the system will feed an AC load which is not connected to the grid. During the day, the PV array produces much more power than needed by the load, with the surplus going to the electrolyzer and the battery. At night the FC will serve the load while drawing hydrogen from the storage tank. In this system, the hydrogen tank starts the year full and ends it empty. The optimization software used for this work is the Hybrid Optimization Model for Electric Renewable (HOMER). HOMER is a design model that determines the optimal architecture and control strategy of the hybrid system. A sensitivity analysis reveals how sensitive the outputs are to changes in the inputs. In this system we specified one sensitivity variable with two values; which are the slope of fuel consumption in FC and the marginal fuel consumption of the FC. It shows that the Net Present Cost (NPC) and the Cost of Energy (COE) have increased due to the rise in fuel consumption in the FC from 0.03 to 0.05 L/hr/Kw..
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**KEYWORDS**: Hybrid; Photovoltaic; Fuel cell; Cost of energy, Stand-alone.

## INTRODUCTION
Renewable energy sources (solar, wind, etc) are attracting more attention as alternative energy sources than conventional fossil fuel energy sources. This is not only due to the diminishing fuel sources, but also due to environmental pollution and global warming problems. Among these sources is the solar energy, which is the most promising, as the fabrication of less costly photovoltaic (PV) devices becomes a reality. With increased penetration of solar PV devices, various antipollution apparatus can be operated such as water purification through electrochemical processing and stopping desert expansion by PV water pumping with tree plantation However, control problems arise due to large variances of PV output power under different in solution levels. To overcome this problem, PV power plants are integrated with other power sources or storage system such as hydrogen generator, storage and fuel cells (FC) [1-2].

Commonly hybrid energy systems use solar, wind, and hydro energy sources, although most of the renewable energy available on earth consists of different forms of solar energy. A system of the combination of these different sources has the advantage of being balance and stability [3].

Solar energy is one of the in-exhaustible energy sources available for the implementation of renewable energy system in remote areas. It has been pursued by a number of countries with monthly average daily solar radiation in the range of 3-6 kWh/m2 in an effort to reduce their dependence on fossil fuels [4]. Malaysia, being gifted with abundance of solar radiation, has a wide potential of solar energy applications to meet the electricity demand of remote villages

## MATERIALS AND METHODS
### Energy demand and resources:
**Electrical load:** Electrical load is one or more devices that consume electric energy. While, electricity demand is the rate at which electric energy is required by the load, measured in kilowatts (kW) . The data were measured for the total hourly basis daily electrical load requirement of a residential of a small remote village in India. The electrical load components include fluorescent lamps, ceiling fan, television, refrigerator and also washing machine which are the main components for a small house. The hourly load consumed by the house is presented in Fig. 1.

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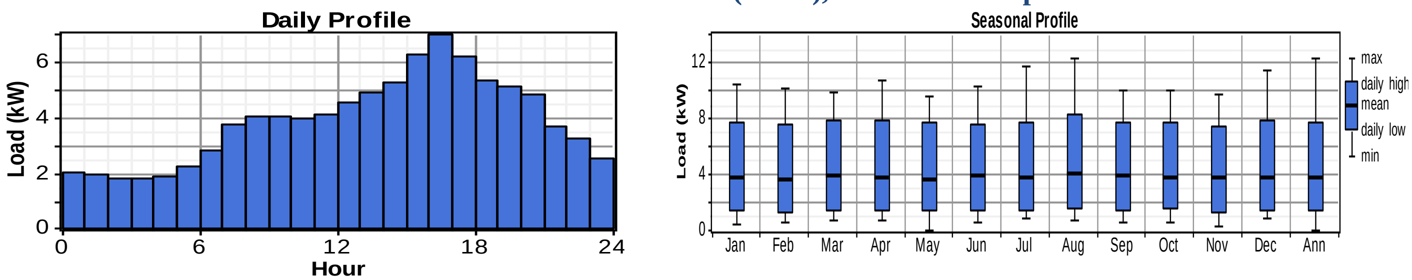


*Fig. 1: Monthly and Daily load Profile*

**Solar radiation resources:** Hourly solar radiation data for year 2015 was collected from India Meteorological Department (IMD). Using this data the monthly average daily solar radiation shown in Fig. 3 and long-term average annual solar radiation (1.28 kWhm□1 day□1) were calculated for India. From the latitude information and solar radiation of the site under investigation, the HOMER software calculated the clearness index (a measure of the clearness or cloudiness of the atmosphere) shown in Fig.2.

**Wind resources:** Hourly wind speed data for year 2015 also was collected from IMD and from this data the monthly average wind speeds were calculated, which, are shown in Fig. 4. It indicates that the annual average wind speed at hub height of 50 m in India is 3.16 m sec□1. Figure 4 shows that in May to November except June, the wind speeds are lower than the annual average wind speed. The higher wind speed during the monsoon season explained these conditions.

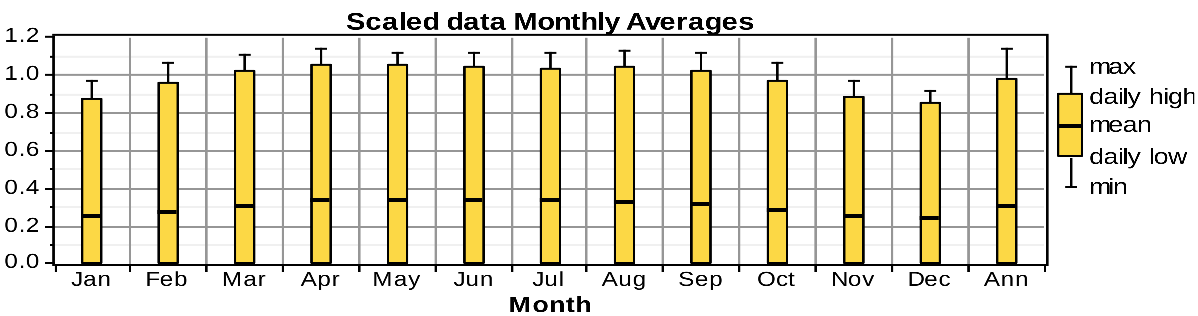


*Fig 2: Monthly solar radiation data*

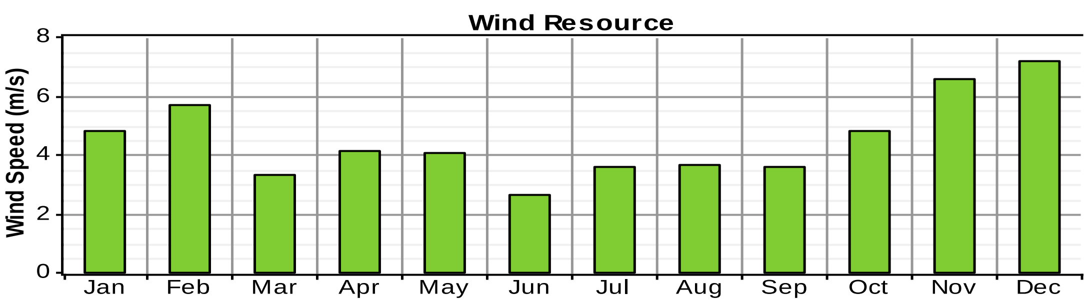


*Fig 3: Monthly wind speed data*

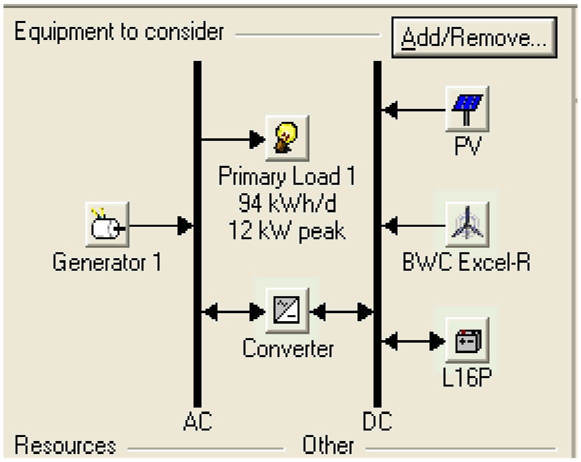


*Fig. 4: PV-wind-diesel power system components*

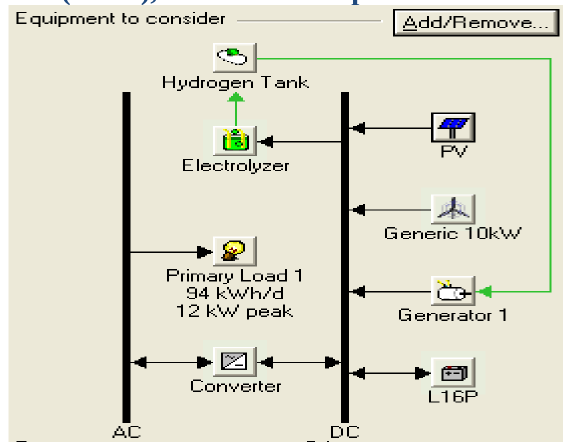


*Fig. 5: PV-wind- hydrogen power system components*

**PV-wind-diesel power system:** The schematic diagram of Photovoltaic (PV)-wind-diesel power system components are presented in Fig. 4. The energy system consists of diesel generator, PV arrays, wind turbine, battery and power converters. The cost, number of units to be used, capacity, operating hours and other specifications are needed to run the simulation using HOMER software. The details of the system components were obtained from manufacturers of the equipments and previous studies. The descriptions of these components are given below.

**Diesel generator:** The cost of a commercially available diesel generator may vary from $250-$500 kW□1 for larger units per kW cost is lower and smaller units cost more. The 5 kW diesel generator at cost $1500 was being used as the peak power demand is less than 5 kW. Replacement and operational costs are assumed to be $1200 and $0.50 h□1, respectively. While, the lifetime is 15000 h. In this study no diesel generator (0 kW) or a 5 kW unit were used for simulation by HOMER.

**PV-array:** The installation cost of PV arrays may vary from $6.00-$10.00/W. A 1 kW solar energy system installation and replacement costs are taken as $1000 and $1000, respectively. Various sizes were considered, ranges from 0-1 kW in this study. The lifetime of the PV arrays are taken as 20 years and no tracking system was included in the PV system.

**Wind turbine:** Availability of energy from the wind turbine depends greatly on wind variations. Therefore, wind turbine rating is generally much higher compared to the average electrical load. In this analysis, Bergey wind power's BWC Excel-R model was considered. It has a rated capacity of 7.5 kW and provides 48 V DC as output. Cost of one unit was considered to be $30,000 while replacement and maintenance costs were taken as $25,000 and $500 year□1 respectively To allow the simulation program hit an optimum solution, provision for using several units (0, 12, 24, 26, 28, 30 and 32) were considered for the study location. The lifetime of the turbine was taken as 15 years.

**Batteries:** Batteries are considered as a major cost factor in small-scale stand-alone power systems. A battery bank of commercially available units, Trojan L16P model (6 V,360Ah and 2.16kW) was considered in this simulation. The estimated lifetime is 5 years and the cost of one battery is $300with a replacement cost of $300 while the O and M cost is $20 year□1 were considered for this study. The battery stacks may contain a number of batteries range from 0- 125 units.

**Power converter:** A power electronic converter needs to maintain flow of energy between the ac and dc components. For a 1 kW system the installation and replacement costs were taken as $1000 and $1000, respectively. Four different sizes of converters (0, 6 and 12 kW) were considered for the simulation. Lifetime of a unit was considered to be 15 years with an efficiency of 90%.

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**Stand alone PV-wind-hydrogen power system:**
Subsequently, the conventional hybrid energy system has been upgraded to hybrid system of standalone PV-wind-hydrogen energy system that schematically designs as in Fig. 5. All the meteorological data that were used are same as the previous simulation.

The equipments needed to build the system are PV array, wind turbine, battery, fuel cell, electrolyzer, hydrogen tank and power electronic converters. In this hybrid energy system also, the type of wind turbine and battery were used same as the previous system, which are Generic 10kw and Trojan L16P, respectively. But different sizes were selected in order to define optimum combination of equipment dimensions. Stand alone PV-wind hydrogen system components are described more detail below.

**PV-array:** For this stand alone hybrid system, the PV capital, replacement and O and M costs, as well as component lifetime described under 3.2 were used. The considered sizing range from 0-21 kW.

**Wind turbine:** In the optimization process, the costs of the wind turbine were the same as the one used in previous energy system. Generic 10kw model was considered. It has a rated capacity of 10kW and provides 48 V DC as output. Cost of one unit was considered to be $30,000 while replacement and maintenance costs were taken as $25,000 and $500 year□1 respectively The quantity of wind turbines considered for this systems were 0, 2 units.

**Electrolyzer:** Currently production cost of electrolyzers is $1500-$3000 kW□1. With improvements in polymer technology, control systems and power electronics it is expected that costs would reduce much in 10 years. In this analysis, various sizes of electrolyzers (0-50 kW) were considered. A 1 kW system is associated with $1000 capital, $1000 replacement and $100 maintenance cost. Lifetime is considered as 155years with efficiency 85%.

**Power converter:** Power electronic converter description is similar as describe above. For a 1 kW system the installation and replacement costs are taken as $1000 and 1000, respectively. Three different sizes of converter (0, 6,12 and 24 kW) were taken in the model

**Fuel cell system:** The cost of fuel cell varies greatly depending on type of technology, reformer, auxiliary equipments and power converters. At present, a fuel cell cost varies from $3000-$6000 kW□1 Here, the capital, replacement and operational costs were taken as $1500, $1200 and $0.50/h for a 1 kW system, respectively. sizes of fuel cells were taken in the simulation process: 0 (no fuel cell used), 15 kW. Fuel cell lifetime and efficiency were considered to be 15,000 h and 30%, respectively.

**Hydrogen tank:** Cost of a tank with 1 kg of hydrogen capacity was assumed to be $150. The replacement and operational costs were taken as $150 and $50 year□1,respectively. Seven different sizes (0, 1 and 1.5 kg) were included, to widen the search space for a cost effective configuration and the lifetime was also considered as 25 years.

## SYSTEM MODELING AND SIMULATION
HOMER can simulate a wide variety of hybrid system configurations, comprising any combination of PV-wind-diesel power system components, and a battery bank, an AC - DC converter, an electrolyzer, and hydrogen storage tank. The system can be autonomous and can serve AC and DC electric loads and a thermal load. With a hydrogen tank stores for use in a fuel cell during times of insufficient PV power. Figure 4 a PV-wind-diesel system with battery backup and an ac–dc converter, and Figure 5 a wind-powered system using both batteries and hydrogen for backup, where the hydrogen fuels an internal reciprocating engine generator. The simulation process serves two purposes. It determines whether the system is feasible, and estimates the life- cycle cost of the system; which is the total cost of installing and operating the system over its lifetime. HOMER considers the system to be feasible if it can adequately serve the electric and thermal loads and satisfies any other constraints imposed by the user. The life-cycle cost is a convenient metric for comparing the economics of various system configurations [8].

*A. System Design*
For this design work, the photovoltaic module has been used as the main source of power generation. A battery bank is employed to store energy. A fuel-cell stack is used as a back-up source. The photovoltaic module with the battery

and the electrolyzer are connected to the load through the dc/ac converter as shown in figure 5. During operation, the fuel cell is also connected directly with the load. The idea of this system is to operate the load with photovoltaic electricity and use the battery bank during high in solution periods. The electrolyzer produces H2 from the excess photovoltaic energy during the day; which is stored for the time being and the fuel cell converts the H2 back to electricity during the time of low in solution. The battery storage system is used for short-term storage of electricity and to supply power to load.

The system specified the FC generator schedule (operation mode) as forced on from 7-pm to 8-am. Since the PV will not produce at the night. During that time the FC generator is adjusted as optimized source to either force on or off, HOMER decides whether it should operate based on the needs of the system and the relative costs of the other power sources. For the generator force on, HOMER decides at what power output level it will operate, which may be anywhere between its minimum and maximum power output.

*B.System Optimization*

The aim of the optimization process is to find the optimal value of each decision variable that interests the modeler. Possible decision variables in the system include:

- The size of PV array.
- The size of fuel cell generator.
- The size of the converter.
- The number of batteries.
- The size of the electrolyzer.

Usually, batteries are used to store energy for a short period of term (efficiency 70%) and hydrogen allows the energy storage over the seasons. The total efficiency is about 40% (electrolyzer 80% + gases storage 10% + fuel cell 50%).

In the optimization process, HOMER simulates every system configuration in the search space and displays the results in a table, sorted by total net present cost. In the overall list shown in Table I&,II, the top ranked system is the least cost configuration within the PV-FC-hydrogen system category. The last Row in Fig10 is the optimal system configuration, meaning that, the one with the lowest net present cost. In this case, the optimal configuration contains PV- 21 kW, the 50-KW FC generator, no batteries, 12 Kw of converter, 1 Kw of electrolyzer, and a 1 kg of H2 tank. The second-ranked system is the same as the first except that it has different dispatch strategy which is load following (LF) as against of cycle charging (CC). The daily load profile of an AC load is as shown in figure 1. It can be noticed that load requirement varies throughout the day, with the maximum demand occurs at afternoon and evening. However, at noon, electricity customers would be at home for lunch and rest, which caused the load demand to increase. Load requirements further changes according to each month. It was assumed that the hottest month occurs on August. Therefore, the load requirements would be a little higher for this month. However, it was assumed that almost all the months would require same electricity demand.

At the end of the year the hydrogen storage will be zero. The categorized optimization results list shown in Fig 11 makes it easier to see the least-cost configuration for each category by eliminating the need to scroll through the long list of systems displayed in the overall list.

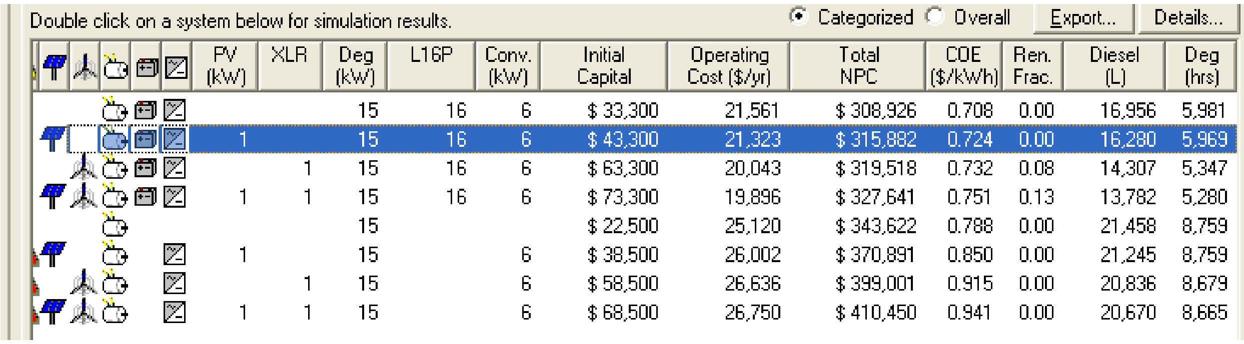
*C.System Sensitivity Analysis*

In a sensitivity analysis, a variable for which the user has entered multiple values is called a sensitivity variable. Almost every numerical input variable in HOMER which is not a decision variable can be a sensitivity variable. Examples include the fuel price, intercept coefficient, the interest rate, or the lifetime of the PV array.
HOMER performs a separate optimization process for each sensitivity case and presents the results in various tabular and graphic formats.

## RESULT AND DISCUSSION

**PV-wind-diesel system simulation:** For hybrid PV-wind-diesel energy system, the equipments needed to build the system were diesel generator, PV array, wind turbine, batteries and power electronic converter with the type and quantity that mentioned before. 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 simulation of the system completed with in 2 min. The optimization results of this power system are show in Fig. 6.

The Monthly electricity production, Optimization Cost components and cost of energy systems are show in fig , 9,8,7.


Double click on a system below for simulation results. Categorized Overall Export... Details...

| PV (kW) | XLR | Deg (kW) | L16P | Conv. (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Diesel (L) | Deg (hrs) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 15 | 16 | 6 | $ 33,300 | 21,561 | $ 308,926 | 0.708 | 0.00 | 16,956 | 5,981 |
| 1 | | 15 | 16 | 6 | $ 43,300 | 21,323 | $ 315,882 | 0.724 | 0.00 | 16,280 | 5,969 |
| | 1 | 15 | 16 | 6 | $ 63,300 | 20,043 | $ 319,518 | 0.732 | 0.08 | 14,307 | 5,347 |
| 1 | 1 | 15 | 16 | 6 | $ 73,300 | 19,896 | $ 327,641 | 0.751 | 0.13 | 13,782 | 5,280 |
| | | 15 | | | $ 22,500 | 25,120 | $ 343,622 | 0.788 | 0.00 | 21,458 | 8,759 |
| 1 | | 15 | | 6 | $ 38,500 | 26,002 | $ 370,891 | 0.850 | 0.00 | 21,245 | 8,759 |
| | 1 | 15 | | 6 | $ 58,500 | 26,636 | $ 399,001 | 0.915 | 0.00 | 20,836 | 8,679 |
| 1 | 1 | 15 | | 6 | $ 68,500 | 26,750 | $ 410,450 | 0.941 | 0.00 | 20,670 | 8,665 |

*Fig 6: The simulation results for standalone of PV-wind-diesel power system*

*TABLE –I: Net Present and Annualized Costs of PV-wind-diesel power system*

| Net Present Costs | | | | | | | Annualized Costs | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Component | Capital ($) | Replacement ($) | O&M ($) | Fuel ($) | Salvage ($) | Total ($) | Capital ($/yr) | Replacement ($/yr) | O&M ($/yr) | Fuel ($/yr) | Salvage ($/yr) | Total ($/yr) |
| PV | 10,000 | 3,118 | 1,278 | 0 | -1,747 | 12,649 | 782 | 244 | 100 | 0 | -137 | 989 |
| Generator 1 | 22,500 | 83,588 | 57,228 | 83,243 | -217 | 246,342 | 1,760 | 6,539 | 4,477 | 6,512 | -17 | 19,271 |
| Trojan L16P | 4,800 | 32,366 | 4,091 | 0 | -74 | 41,183 | 375 | 2,532 | 320 | 0 | -6 | 3,222 |
| Converter | 6,000 | 2,504 | 7,670 | 0 | -466 | 15,708 | 469 | 196 | 600 | 0 | -36 | 1,229 |
| System | 43,300 | 121,576 | 70,267 | 83,243 | -2,504 | 315,882 | 3,387 | 9,511 | 5,497 | 6,512 | -196 | 24,710 |

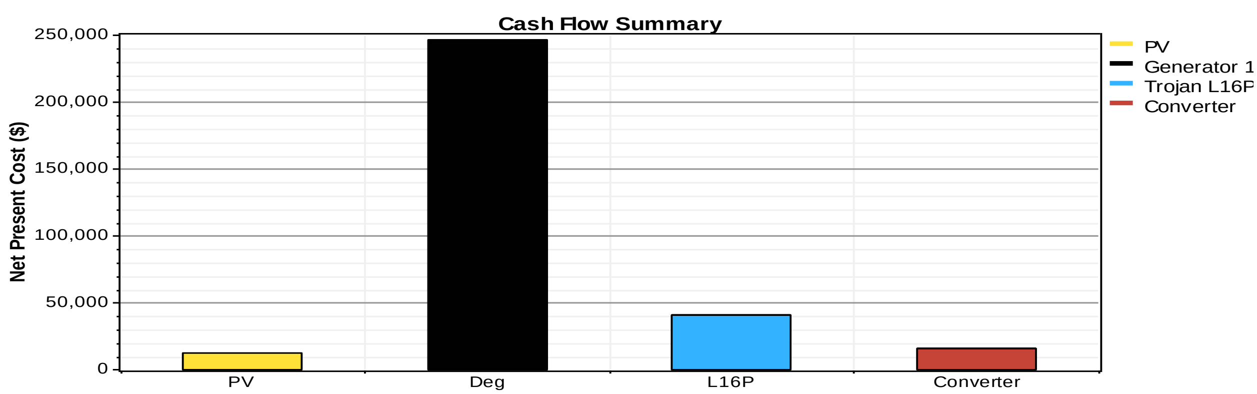



*Fig7 : Cost components of PV-wind-diesel power system*

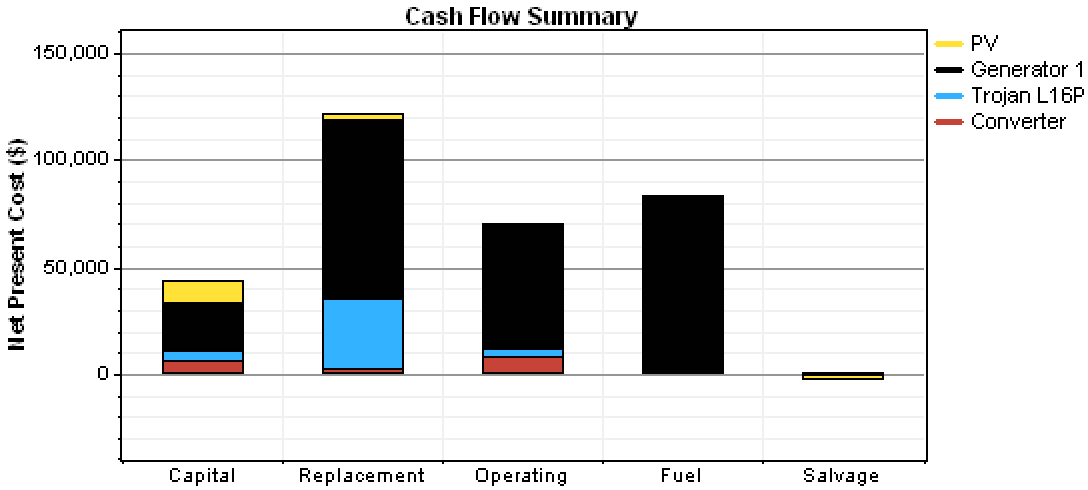



*Fig 8: Optimization Cost components of PV-wind-diesel power system*

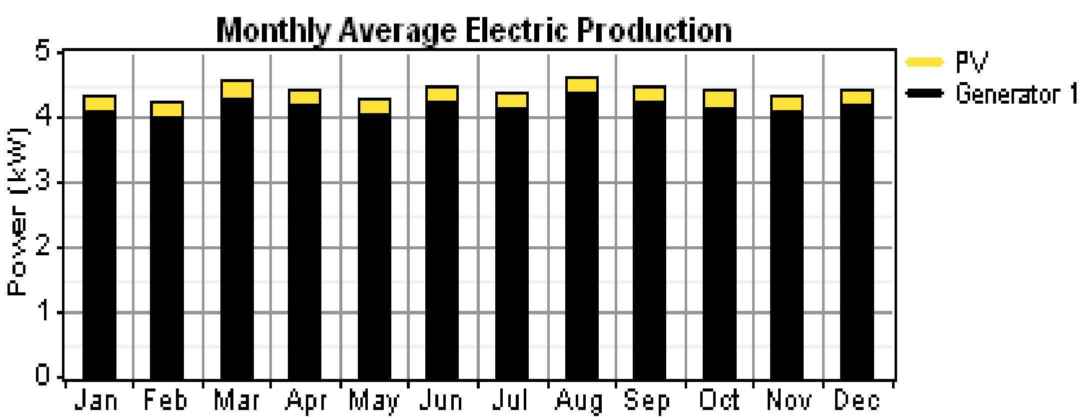



*Fig 9: Monthly electricity production trend of The PV-wind-diesel power system*

The least Cost Of Energy (COE), \$0.72 $kWh^{-1}$resulted from the 15 kW diesel generator alone without contribution from renewable sources. If considered the system, which is included the renewable energies is ninth least COE as \$0.94 $kWh^{-1}$, resulted from the combination of 15 kW diesel generator, 1 kW of PV array, 1 unit of wind turbine, 16 unit of batteries and 6 kW converter. The diesel used for first system is 16,280 L, while the second system is 20,670 L. Consequently, the consumption of diesel fuel can be reduced about 30.0% with involvement of renewable resources

The capital cost, total Net Present Value (NPC) and COE of the systems are \$43,300, \$315,882 and \$0.72$Wh^{-1}$ respectively. The most expensive cost draws from the diesel generator. Although the capital for the generator is just \$246,342, but the high cost of diesel fuel, \$83,243 sums it up to \$32,9785. Wind turbine is in the second placed with the cost of \$41,183, followed by battery and converter with \$41,182 and \$15,708, respectively. The least cost device is PV-array that contributes \$12,649 to the overall system. The allocation of each device can be seen clearly from Fig. 6.

**PV-wind-hydrogen power system:** For hybrid PV-wind-hydrogen energy system, the equipments needed to build the system were diesel generator, PV array, wind turbine, batteries and power electronic converter with the type and quantity that mentioned before. The HOMER simulation tool was used to optimize the sizes of different hardware components in the PV-wind- hydrogen system, taking into account the technical characteristics of system operation and minimizing total net present cost of the system. The simulation of the system completed with in 42 min. The optimization results of this power system are show in Fig. 10. The Monthly electricity production, Optimization Cost components and cost of energy systems are show in fig , 12,13,11.

The least Cost Of Energy (COE), $1.409 kWh□1resulted from the 15 kW diesel generator alone without contribution from renewable sources. If considered the system, which is included the renewable energies is 22nd least COE as $10.409 kWh□1, resulted from the combination of 15 kW diesel generator, 21 kW of PV array, 1 unit of wind turbine, 56 unit of batteries and 12 kW converter. The diesel used for first system is 16,280 Lshown in fig 6, while the second system is 0 L shown in fig 10. Consequently, the consumption of diesel fuel can be reduced about 100.0% with involvement of renewable resources

The capital cost, total Net Present Value (NPC) and COE of the systems are $41,652, $641, $1.409 kWh□1 respectively. The least expensive cost draws from the diesel generator. Although the capital for the generator is just $1,760, but the Least cost of diesel fuel, $0. Wind turbine is in the second placed with the cost of $1,314, followed by battery and converter with $16,800 and $2,458, respectively. The most cost device is PV-array that contributes $32,768 to the overall system. The allocation of each device can be seen clearly from Fig.10.

***TABLE –II: Net Present and Annualized Costs of PV-wind-hydrogen power system***

| Net Present Costs | | | | | | | Annualized Costs | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Component** | **Capital** | **Replacement** | **O&M** | **Fuel** | **Salvage** | **Total** | **Capital** | **Replacement** | **O&M** | **Fuel** | **Salvage** | **Total** |
| | ($/yr) | ($/yr) | ($/yr) | ($/yr) | ($/yr) | ($/yr) | ($) | ($) | ($) | ($) | ($) | ($) |
| PV | 32,855 | 0 | 2,100 | 0 | -2,187 | 32,768 | 420,000 | 0 | 26,845 | 0 | -27,960 | 418,885 |
| Generic 10kW | 4,694 | 1,632 | 1,000 | 0 | -304 | 7,022 | 60,000 | 20,863 | 12,783 | 0 | -3,883 | 89,763 |
| Generator 1 | 1,760 | 0 | 0 | 0 | -320 | 1,440 | 22,500 | 0 | 0 | 0 | -4,089 | 18,411 |
| Trojan L16P | 1,314 | 1,846 | 1,120 | 0 | -127 | 4,153 | 16,800 | 23,603 | 14,317 | 0 | -1,629 | 53,091 |
| Converter | 939 | 392 | 1,200 | 0 | -73 | 2,458 | 12,000 | 5,007 | 15,340 | 0 | -932 | 31,415 |
| Electrolyzer | 78 | 24 | 100 | 0 | -14 | 189 | 1,000 | 312 | 1,278 | 0 | -175 | 2,415 |
| Hydrogen Tank | 12 | 0 | 50 | 0 | 0 | 61 | 150 | 0 | 639 | 0 | -6 | 783 |
| System | 41,652 | 3,895 | 5,570 | 0 | -3,025 | 48,091 | 532,450 | 49,785 | 71,203 | 0 | -38,674 | 614,765 |

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Double click on a system below for optimization results.

| PV (kW) | G10 | gen 1 (kW) | L16P | Conv. (kW) | Elec. (kW) | H2 Tank (kg) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 7,612 | $ 629,754 | 1.444 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 7,611 | $ 629,748 | 1.444 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 6,716 | $ 618,306 | 1.418 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 6,716 | $ 618,300 | 1.418 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 6,700 | $ 618,104 | 1.418 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 6,700 | $ 618,098 | 1.418 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 13,146 | $ 700,496 | 1.606 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 13,145 | $ 700,491 | 1.606 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 13,130 | $ 700,294 | 1.606 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 13,129 | $ 700,288 | 1.605 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 8,643 | $ 642,933 | 1.474 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 8,642 | $ 642,927 | 1.474 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 8,627 | $ 642,730 | 1.474 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 8,626 | $ 642,725 | 1.474 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 7,367 | $ 626,623 | 1.437 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 7,366 | $ 626,617 | 1.437 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 7,351 | $ 626,421 | 1.436 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 7,351 | $ 626,415 | 1.436 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 6,456 | $ 614,973 | 1.410 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 6,455 | $ 614,967 | 1.410 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 6,440 | $ 614,771 | 1.409 | 1.00 |
| 21 | 2 | 15 | 56 | 12 | 1 | 1.0 | $ 532,450 | 6,439 | $ 614,765 | 1.409 | 1.00 |

*Fig 10: The simulation results for standalone of PV-wind-hydrogen power system*

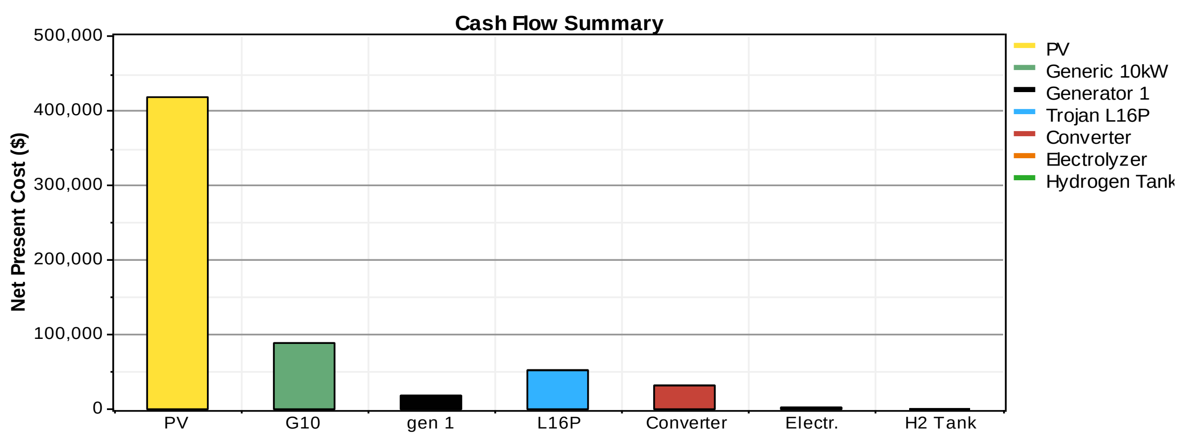


*Fig 11: Cost components of PV-wind-hydrogen power system*

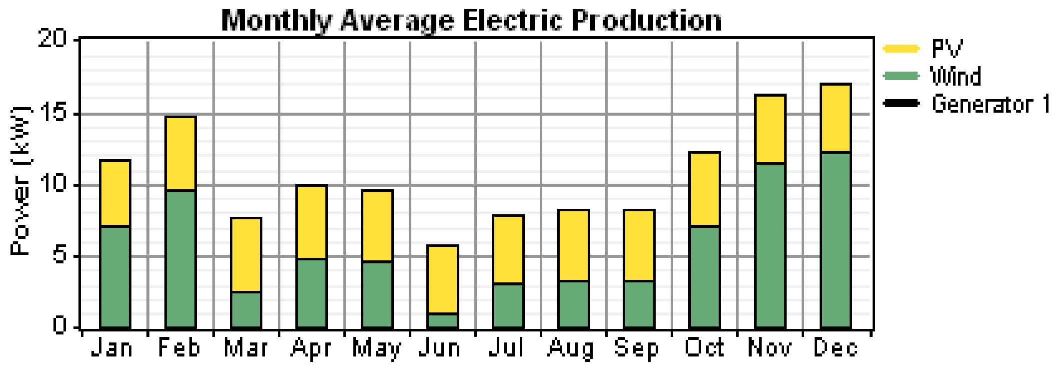


*Fig 12: Monthly electricity production trend of The PV-wind-hydrogen power system*

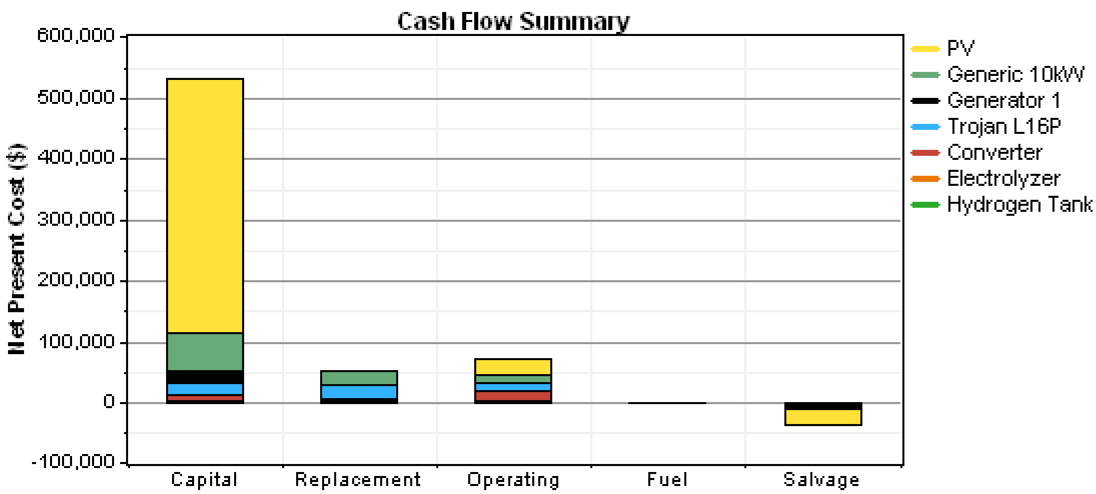


*Fig 13: Optimization Cost components of PV-wind-hydrogen power system*

## CONCLUSION

The comparisons prove that PV-wind-hydrogen energy system had the lowest total NPC and COE, which was $614,765 and $1.409 kWh$^{-1}$accordingly that makes it the most cost effective system and followed by PV-wind-diesel and PV-wind-hydrogen system. Consequently, it is the most suitable system at lower cost to be developed in this area. However, the hydrogen energy is feasible by standalone system rather than grid system.

Hence, it can be concluded that the hydrogen-based system can become a favorable system without aid from the grid system and bring advantage in technical and economic point of view and also suitable to be applied in the coastal residential application as energy carrier if only the current cost of wind turbine and hydrogen system technology have been reduced to its minimum rate.

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