Developing a Model Using Homer for a Hybrid Hydrogen Fuel Cell System

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Abstract

Hydrogen is widely considered be the fuel of the near future. Combined wind/PV energy hybrid systems can be used to sources energy to hydrogen production. This paper describes design, simulation and feasibility study of a hybrid energy system for a household in Malaysia. One year recorded wind speed and solar radiation are used for the design of a hybrid energy system. In 2000 was average annual wind speed in Johor Bahru is 3.76 m/s and annual average solar energy resource available is 5.08 kWh/m^2/day. National Renewable Energy Laboratory's HOMER software was used to select an optimum hybrid energy system. In the optimization process, HOMER simulates every system configuration in the search space and displays the feasible ones in a table, sorted by total net present cost (TNPC). The optimization study indicates that sensitivity analysis of the HOMER is shown in the overall winner which shows that the most least cost and optimize hybrid system is combination of 10 kW of PV array, 1 unit of wind turbine, 2 kW of fuel cell, 120 units of batteries and 6 kW converter as well as 1 kW of electrolyzer so as to generate the minimum COE, \$2.423 kWh^{-1}. Although renewable sources (wind and PV) involved in the power generation, 1 kg of hydrogen was produced in this system.

Keywords: Optimization design, Hydrogen production, HOMER, Wind/PV Energy Hybrid System, Malaysia.

Pengembangan Model Dengan Menggunakan Homer Untuk Sistem Sel Berbahan bakar Hidrogen Hibrida

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Abstrak

Hidrogen secara luas dianggap sebagai bahan bakar masa depan. Gabungan sistem hibrida energi angin/fotovoltaik dapat digunakan untuk sumber energi produksi hidrogen. Makalah ini menjelaskan desain, simulasi dan studi kelayakan dari sistem energi hibrida untuk rumah tangga di Malaysia. Satu tahun kecepatan angin tercatat dan radiasi matahari digunakan untuk desain sistem energi hibrida. Pada tahun 2000 adalah kecepatan angin rata-rata tahunan di Johor Bahru 3.76 m/det dan rata-rata sumber daya energi surya tahunan yang tersedia adalah 5.08 kWjam/m2/ hari. Software HOMER digunakan untuk memilih sistem energi hybrida optimal. Dalam proses optimasi, HOMER mensimulasikan setiap konfigurasi sistem dalam ruang pencarian dan menampilkan yang layak dalam sebuah tabel, diurutkan berdasarkan total net present (TNPC). Studi optimasi menunjukkan bahwa analisis sensitivitas HOMER ditampilkan dalam hasil keseluruhan yang menunjukkan bahwa paling sedikit biaya dan mengoptimalkan sistem hibrida adalah kombinasi dari 10 kW array PV, 1 unit turbin angin, 2 kW bahan bakar, 120 unit baterai dan 6 kW converter serta 1 kW electrolyzer sehingga menghasilkan COE(cost of energy) minimal, \$2,423 kWjam-1. Sumber-sumber terbarukan (angin dan PV) yang terlibat dalam pembangkit listrik, 1 kg hydrogen akan diproduksi dalam sistem ini.

Kata kunci: Desain Optimasi, roduksi Hidrogen, HOMER, angin/ PV, Sistem Energi Hybrid, Malaysia

I. INTRODUCTION

Depleting of fossil and gas reserves, combined with the growing concerns of global warming, has necessitated an urgent search for alternative energy sources to cater to the present day demands. Alternative energy resources such as wind and solar energy is becoming increasingly attractive and is being used widely, for substitution of fossil produced energy, and eventually to minimize atmospheric degradation. Hydrogen production is of great significance on seeking a better way to use natural gas resources. Hydrogen energy is a permanent and environmentally friendly source of energy. It can be presented to consumer in a convenient form at the desired location and time. It is the most economical synthetic fuel to produce, the cleanest fuel, and it can be converted to other forms of energy more efficiently than other fuels. Experimental facilities for investigating the viability of hydrogen production using wind/PV hybrid have been established in Johor Bahru.

Stand-alone hydrogen energy system with different renewable energy sources, namely solar hydraulic and wind energy were analyzed by Santarelli et al, in view of their design and operation. The analysis showed that the preferred solution is case specific, depending on meteorological resources and load profile. The storage of renewable energy (mostly solar energy) in the form of elecrolycally produced hydrogen in stationary stand-alone power system has been investigated in many demonstration system is relevant to non grid-connected communities and remote areas. Design of a hybrid energy system is site specific and it depends upon the resources available and the load demand. This paper describes design, simulation and feasibility study of a hybrid hydrogen energy system for a 1 kW system. One year recoded wind speed, solar radiation and estimation of the hydrogen load are used for the design of a hybrid energy system. National Renewable Energy Laboratory's HOMER software was used to select an optimum hybrid hydrogen energy system. A detailed design, description and expected performance of the system are presented in this paper.

II. ENERGY RESOURCES

A monthly for over one year wind data and solar radiation used in this design is obtained from the data collected at 19m height above ground level one of the houses in Johor Bahru (1° 28'N 103° 46' E) by using NRG Symphonie data acquisition system is shown in Figure 1,2 and 3.

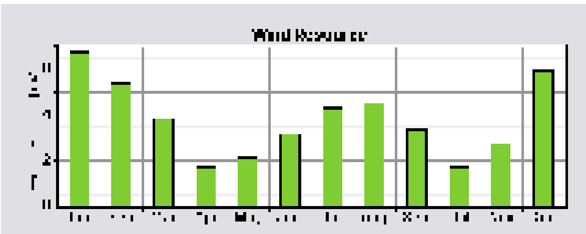

Figure 1. Monthly average wind speed

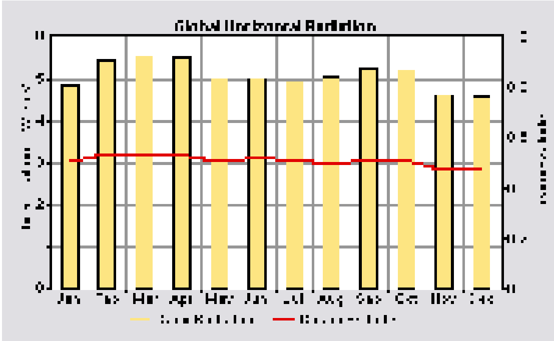

Figure 2. Daily radiations in Johor Bahru

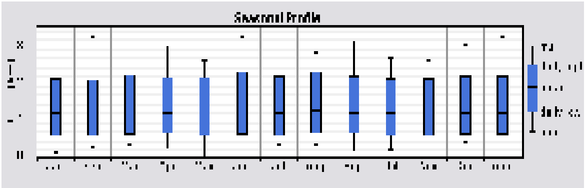

Figure 3. Monthly average solar radiations in Johor Bahru

From the latitude and longitude information also solar radiation resources, HOMER software calculated the clearness index. Mean daily radiation is 5.08 kWh/m^2 and clearness index is 0.509.

Table 1. Mean Monthly radiation and clearness index in Johor Bahru

Month	Clearness Index	Daily Radiation (kWh/m2/d)
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
Average	[illegible]	[illegible]

III. Configuration and Optimization of Hybrid Energy System

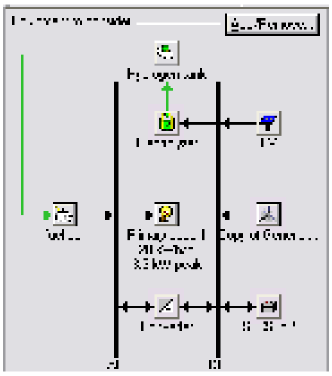

Figure 4. Schematic diagram of the type of systems that HOMER can simulate

Stand alone PV-wind-hydrogen power system: The conventional hybrid energy system has been upgraded to hybrid system of standalone PVwind-hydrogen energy system that schematically designs as in Fig. 4. 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 Copy of Generic 10 kW and Surrette 6CS25P, 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: 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 $15000 and $12000, respectively (Dalton and Lockington, 2009). Various sizes were considered, ranges from 5-10 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 Copy of Generic 10 kW model was considered. It has a rated capacity of 10 kW and provides 12 V DC as output. Cost of one unit was considered to be $18,500 while replacement and maintenance costs were taken as $15,000 and $200 year-1 respectively (Bergey Wind Power, 2007). To allow the simulation program hit an optimum solution, provision for using several units (1, 2, 3, and 4) were considered for the study location. The lifetime of the turbine was taken as 20 years.

Electrolyzer: 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 (Dalton and Lockington, 2009). In this analysis, various sizes of electrolyzers (0-3 kW) were considered. A 1 kW system is associated with $20000 capital, $16000 replacement and $20 maintenance cost. Lifetime is considered as 15 years 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 $500, respectively. Three different sizes of converter (6, 8 and 10 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 (Dalton and Lockington, 2009). Here, the capital, replacement and operational costs were taken as $800, $800 and $0.00/h for a 1 kW system, respectively. Five different sizes of fuel cells were taken in the simulation process: 60% (no fuel cell used), 2, 3 and 4 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$3600. The replacement and operational costs were taken as $3000 and $15 year^{-1}, respectively. Seven different sizes (1, 2, 3 and 4 kg) were included, to widen the search space for a cost effective configuration and the lifetime was also considered as 25 years.

IV. RESULTS AND DISCUSSIONS

The design of stand-alone power systems with hydrogen energy involves different energy components sizes, with regards to the cost of energy and overall system performance. 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 NPC of the system. The simulation for this system was difficult due to the quantity of equipment involved to build the system and overall simulation takes around 2 h and 27 min to be accomplished. The optimization results for this analysis shown in Fig. 7. It illustrates that the most optimum results obtained for this system comprises of 10 kW of PV array, 1 unit of wind turbine, 2 kW of fuel cell, 120 units of batteries and 6 kW converter as well as 1 kW of electrolyzer so as to generate the minimum COE, $2.423 kWh^{-1}. Although renewable sources (wind and PV) involved in the power generation, 1 kg of hydrogen was produced in this system.

Hence, the system generates the lowest COE of $ 2.432/kWh is concentrated in this study due to the potential of hydrogen energy. The difference in COE value of both systems is not too much, so this system is also considered feasible.

In this PV-wind-hydrogen energy system, the PV array capacity was enlarge in relation to the one used in the PV-wind diesel system, from 5-10 kW, in order to fully replace the diesel generator usage. The hydrogen tank is excluded from the system, as the storage tank is considered within the electrolyzer model and the hydrogen is supplied to the fuel cell directly from the electrolyzer.

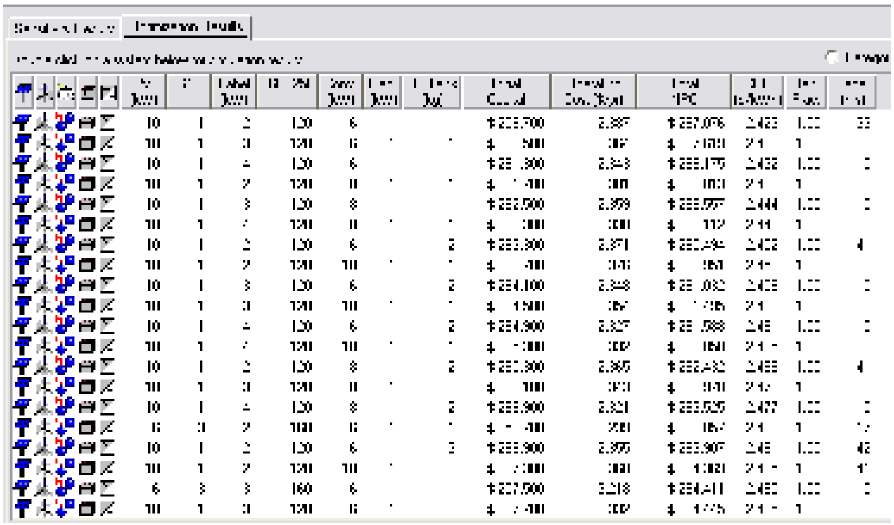

Figure 5. The Simulation Result for Standalone PV-wind-hydrogen energy system

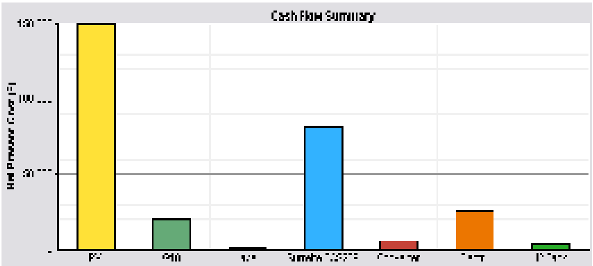

Figure 6. Cost for component of standalone PV-wind-hydrogen system

Table 2. Annualized cost for main components of the PV-wind-diesel system

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	150,[illegible]		0		0	150,[illegible]
[illegible]	18,[illegible]	[illegible]	2,294	[illegible]	935	19,[illegible]
Fuel cell	1,[illegible]		0		[illegible]	1,[illegible]
[illegible]	60,[illegible]	26,[illegible]	0	[illegible]	[illegible]	81,224
Converter	[illegible]		0		[illegible]	[illegible]
Electrolyzer	20,[illegible]	6,[illegible]	2,294	[illegible]	[illegible]	25,[illegible]
Hydrogen Tank	[illegible]		0		[illegible]	[illegible]
System	259,[illegible]	[illegible]	4,588	[illegible]	[illegible]	287,[illegible]

The total capital costs and total NPC calculated for this system were $259,700 and $287,076 respectively (Table 3). The simulation result for standalone PV-wind-hydrogen energy system is shown in Fig. 5. Wind turbine dominated the cost with $19,859, followed by PV with $150,000. Battery had contributed $81,224 which was the third largest contributor for this system. Subsequently, electrolyzer, converter and fuel cell cost about $25,644, $5,813 and $1,667, respectively. The allocation of each device can be seen clearly from Fig. 6.

The values related to the electricity production and load served by the system are summarize in Table 2. The results of the simulation showed that the PV-wind hydrogen system had a total annual electrical energy production of 22,102 kWh $year^{-1}$. The biggest contributor is wind turbine with 7,252 kWh $year^{-1}$ (33%) followed by PV-array of 14,850 kWh $year^{-1}$ (67%), 66 kWh^{-1} (0%) of fuel cell.

Tabel 3. Operating characteritics of the standalone PV-wind-hydrogen system

Production	kWh/yr	%
PV array	14,850	67
Wind turbine	[illegible]	[illegible]
Fuel cell	66	0
Total	[illegible]	[illegible]

Consumption	kWh/yr	%
AC primary load	10,[illegible]	[illegible]
Electrolyzer	1,[illegible]	
Total	11,[illegible]	[illegible]

Quantity	kWh/yr	%
Excess electricity	[illegible]	[illegible]
Unmet electric load	[illegible]	0
Capacity shortage	[illegible]	0.[illegible]

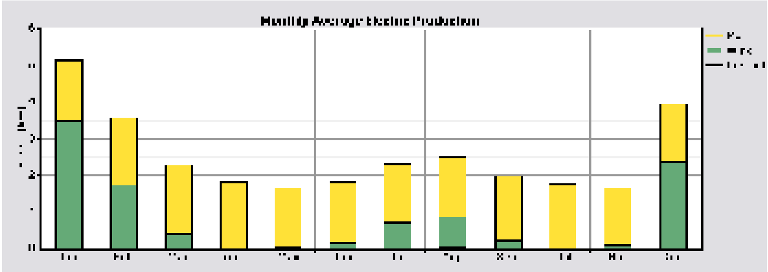

Figure 7. Monthly electricity production trend of the stanalone PV-wind-hydrogen system

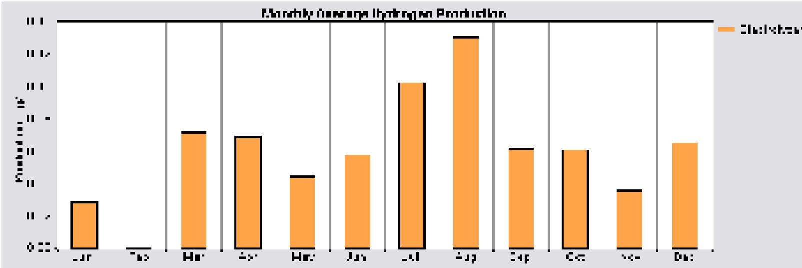

Figure 8. Monthly hydrogen production of the standalone PV-wind-hydrogen system

The consumption of electricity about 9% (1,329 kWh year^{-1}) goes to AC primary load served and 91% (10.329 kWh year^{-1}) goes to electrolyzer load. The difference of annual electricity production and consumption given the value of excess electricity for this system is 8.559 kWh year^{-1} (38.6%) The trend of monthly electricity production by these sources of energy is summarized in Fig. 7. The electricity from wind resources is higher in January, February and December.

The monthly hydrogen production from 1 kW electrolyzer can be seen in Fig. 8 The apparent months probable to produce hydrogen are July and August The hydrogen production comes from potential wind energy in that particular month. The amount of yearly hydrogen production is 22.4 kg year^{-1} make the average cost of hydrogen is 1.118$ kg^{-1}.

V. CONCLUSION

A primary simulation design of a hybrid energy system for a hydrogen production in Malaysia, load based on the weather data taken at Johor Bahru for period over one year is carried out. 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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