Balancing Cost, Operation and Performance in Integrated Hydrogen Hybrid Energy System

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ABSTRACT

This paper shows the way to design the aspects of a hybrid power system that will target remote users. It emphasizes on the hydrogen hybrid power system to obtain a reliable autonomous system with the optimisation of the components size and the improvement of the capital cost. This system is chosen to provide electricity for a small and remote located community. A methodology is developed for calculating the correct size of the system and for optimizing the management. The main power for the hybrid system comes from the photovoltaic panels, while the fuel cell and secondary batteries are used as backup units. The optimization software used for this paper is the Hybrid Optimization Model for Electric Renewables (HOMER). HOMER is a design model that determines the optimal architecture and control strategy of the hybrid system. It can also determine the sensitivity of the outputs to changes in the inputs. It performs an hourly time series analysis on each of hundreds or thousands of different system configurations

1. INTRODUCTION

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 the balance and stability [2].

This paper concern with an investigation of the cost related to hydrogen hybrid system. It was found that under which conditions wind turbines and PV systems could feasibly power electrolyzers to generate and store hydrogen for remote power generation using fuel cells and diesel engines. This study concludes that fuel cell systems appear competitive today at the radio repeater station and appear competitive in the village system if fuel cell prices are reduced to 40% of their current capital cost.

HOMER performs comparative economic analyses on a distributed generation power systems. Inputs to HOMER will perform an hourly simulation of every possible combination of components entered and rank the systems according to user-specified criteria, such as cost of energy (COE) or capital costs. Furthermore, HOMER can perform "sensitivity analyses" in which the values of certain parameters (e.g., fuel cell cost) are varied to determine their impact on the COE. To obtain the input data for HOMER, hydrogen component information is collected from research literature and manufacturers. This data with the HOMER can also estimate the present and future of hydrogen system costs and efficiencies.

2. SYSTEM DESCRIPTION

Hybrid systems made up of a renewable energy generator (PV or wind turbine generator), a back-up unit (diesel engine) and a storage system (batteries, fuel cell/gas storage/electrolyzer).

PV System

Figure 1 below shows the current output of a PV panel as a function of voltage and as a function of solar radiation. As solar radiation (insolation) increases, so do both the current and the voltage of the panel. The panel's power output can be found by multiplying the current and the voltage. The black points on the diagram denote the point at which the maximum power is output from the panel. If a Maximum Power Point tracker is included in the PV system, the load on the panel is adjusted so that the panel always outputs its maximum power.

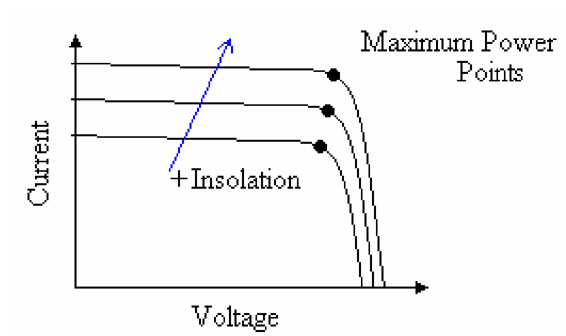


Figure 1: I-V Characteristic of PV Array

The simulated array has a rated efficiency of 12%. The rated (peak) power of the array, as well as the slope and azimuth can be adjusted. The peak power is obtained under 1000 W/m² for a cell temperature of 25°C. The PV array is assumed to be equipped with a Maximum Power Point Tracker (MPPT) which optimizes its power output [4].

Array slope angle describes the angle at which the photovoltaic modules are tilted. Often modules are tilted to an angle equal to the location's latitude. In order to maximize summer energy collection, modules should be tilted less (they should be more horizontal). In order to maximize winter energy collection, they should be more vertical [3]. A slope of 0 indicates that the modules are horizontal and the slope of 90 means that they are vertical.

Array azimuth angle describes the direction that the photovoltaic array modules face. Due south is defined as an azimuth of 0. Angles that are east of due south are defined as negative azimuths and angles that face west of due south are defined as positive azimuths. For instance an Array facing due West has an azimuth angle of 90 degrees, while an array facing South-East has an azimuth angle of -45 degrees.

Wind Energy Conversion System

The wind turbine model can be selected in a pull-down list. Rated power and rotor diameter for each turbine are discussed in [7] by introducing a certain menu. A typical power curve used to simulate wind turbines is shown a figure 2.

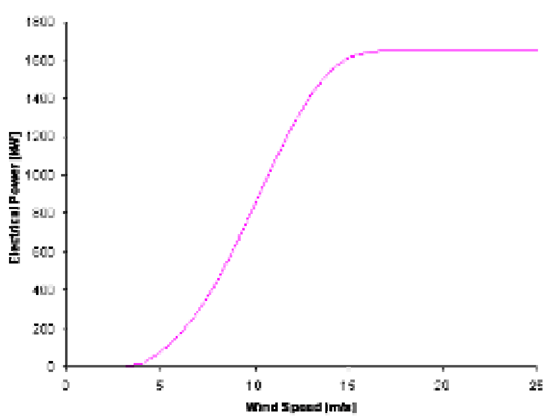


Figure 2: A Typical Wind Turbine Power Curve

Normally the on site rotor height is adjusted so that at least larger than the rotor radius. The site wind shear can be adjusted between 0 and 0.3.

Electrolyzers

Proton exchange membrane (PEM) electrolyzers from Proton Energy Inc. were used to obtain a cost estimate of a stand-alone ("hydrogen by wire") electrolyzer. The system used to obtain a \$/kW cost for electrolyzers include the PEM stack, power electronics, and control system. Cost reductions are expected to stem from improvements in the PEM stack, power electronics, control system, and manufacturing improvements such as replacing fittings with welded tube assemblies. These costs assume production of 500 units per year [5].

Conventional electrolyzers produce hydrogen at low pressure (100-200 psi). Compressors are used to elevate the pressure for gas storage. However, 2,500-3,000 psi production pressures have been demonstrated recently at Proton energy and are expected to be in production in the very near future; targets are upward of 6,000 psi. Such technologies will likely eliminate the need for compressors. Accordingly, this study assumed that a compressor was not required.

Hydrogen Storage

Hydrogen can be stored in several ways. Small amounts of hydrogen are most commonly stored as a compressed gas or as a metal hydride. Compressed gas storage is currently the most cost effective for small-scale system tanks, so it is used for this study [6].

Fuel Cells

A PEM fuel cell is considered in this study. The cost of fuel cells varies widely depending on scale, power electronics requirements, and reformer requirements. A survey performed for this study identified PEM fuel cell that currently sell for between \$3,000/kW to 6,000/kW [9].

Stationary fuel cells are targeted to last 30,000 to 40,000 operating hours, during which the membrane will likely have to be replaced one or more times. This study assumed the fuel cell would last 30,000 hours. The efficiencies of PEM fuel cells running on pure hydrogen are roughly 40% to 50% (lower heating value) at rated power with slightly higher values at partial load. The electrical efficiency used for this study is held constant at 45% to compensate for parasitic losses, which occur at partial load.

2.1. SYSTEM SIMULATION

HOMER can simulate a wide variety of hybrid system configurations, comprising any combination of a PV array, one or more wind turbines, a run-of-river hydro-turbine, and up to three generators, a battery bank, an ac–dc converter, an electrolyzer, and a hydrogen storage tank. The system can be grid-connected or autonomous and can serve ac and dc electric loads and a thermal load.

Figure 3 shows schematic diagrams of some examples of the types of hybrid systems that HOMER can simulate.

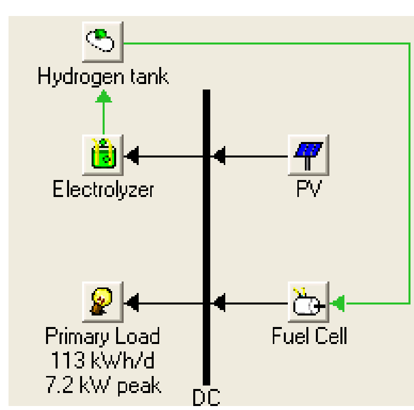


Figure 3(a)

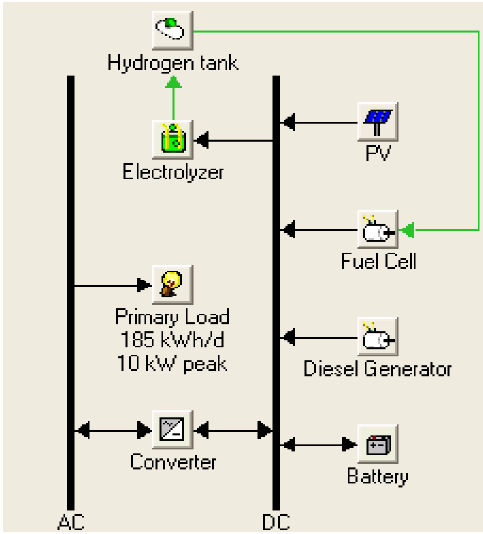


Figure 3(b)

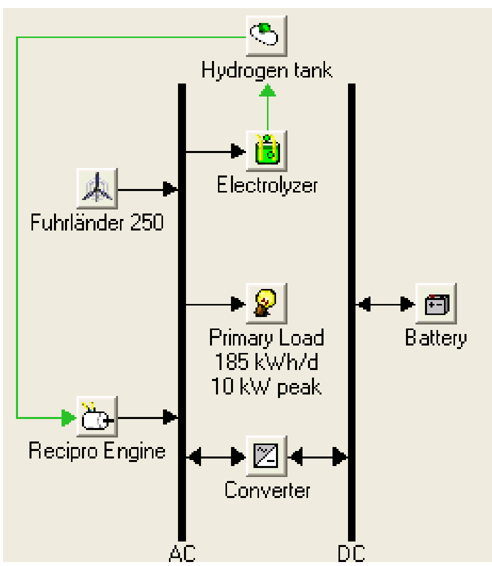


Figure 3(c)

In Figure 3(a) a PV–hydrogen system in which an electrolyzer converts excess PV power into hydrogen, with a hydrogen tank stores for use in a fuel cell during times of insufficient PV power. Figure 3(b) a PV-fuel cell–diesel system with battery backup and an ac–dc converter, and Figure 3(c) 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. First, it determines whether the system is feasible. 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. Second, it estimates the life-cycle cost of the system, which is the total cost of installing and operating the system over its lifetime. The life-cycle cost is a convenient metric for comparing the economics of various system configurations [8].

2.2. SYSTEM OPTIMIZATION

The goal of the optimization process is to determine the optimal value of each decision variable that interests the modeller. A decision variable is a variable over which the system designer has control and for which HOMER can consider multiple possible values in its optimization process. Possible decision variables in HOMER include:

- The size of the PV array
- The number of wind turbines
- The size of each generator (diesel / fuel cell)
- The number of batteries
- The size of the ac–dc converter
- The size of the electrolyzer
- The size of the hydrogen storage tank

Usually, batteries are used to store energy for the short term (efficiency 70%) and hydrogen allows the energy storage over the seasons. The round trip efficiency is about 40% (electrolyser 80% + gases storage 100% + fuel cell 50%) [1].

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. Hence it shows a subset of these overall optimization results by displaying only the least-cost configuration within each system category or type. In the overall list shown in Figure 4, the top-ranked system is the least-cost configuration within the PV–diesel–battery-converter system category. For that system figure 6 illustrates the total annual cost, and the corresponding power flow data in one day is given in figure 5.

2.3. 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 that is not a decision variable can be a sensitivity variable. Examples include the grid power price, the fuel price, the interest rate, or the lifetime of the PV array [10].

It can perform a sensitivity analysis with any number of sensitivity variables. Each combination of sensitivity variable values defines a distinct sensitivity case. For example, if the user specifies six values for the grid power price and four values for the interest rate that constitute 24 distinct sensitivity cases. HOMER performs a separate optimization process for each sensitivity case and presents the results in various tabular and graphic formats [11].

3. CONCLUSIONS

This paper investigates on the modelling of a stand-alone power system focusing on photovoltaic-hydrogen energy systems. Starting from the analysis of the models of the system components, a complete simulation model is realized in the software simulation environment.

During the day, the PV array produces much more power than needed by the load, with the surplus going

PV (kW)	FC (kW)	Gen2 (kW)	Batt.	Conv. (kW)	Elec. (kW)	H2 Tank (kg)	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
20		10	3	10			$ 90,700	$ 101,217	42.909	0.36	0.02
20		10	4	10			$ 92,067	$ 103,123	43.717	0.37	0.02
20		10	3	10		20	$ 114,000	$ 124,517	52.787	0.36	0.02
20		10	4	10		20	$ 115,367	$ 126,423	53.595	0.37	0.02
20		10	3	10		40	$ 136,000	$ 146,517	62.114	0.36	0.02
20		10	4	10		40	$ 137,367	$ 148,423	62.922	0.37	0.02
20	10	10	3	10	10		$ 139,360	$ 151,682	64.303	0.36	0.02
20	10	10	4	10	10		$ 140,727	$ 153,587	65.111	0.37	0.02
40		10	3	10			$ 145,300	$ 161,862	68.573	0.60	0.01
40		10	4	10			$ 146,667	$ 163,766	69.380	0.62	0.01
20		10	3	10		60	$ 158,000	$ 168,517	71.440	0.36	0.02
20		10	4	10		60	$ 159,367	$ 170,423	72.248	0.37	0.02
20	10	10	3	10	20		$ 152,520	$ 174,665	74.046	0.36	0.02
20	10	10	4	10	20		$ 153,887	$ 176,571	74.854	0.37	0.02
20	20	10	3	10	10		$ 174,860	$ 179,162	75.953	0.36	0.02
20	20	10	4	10	10		$ 176,227	$ 181,068	76.761	0.37	0.02

Figure 4: Overall optimization results table showing system configurations sorted by total net present cost.

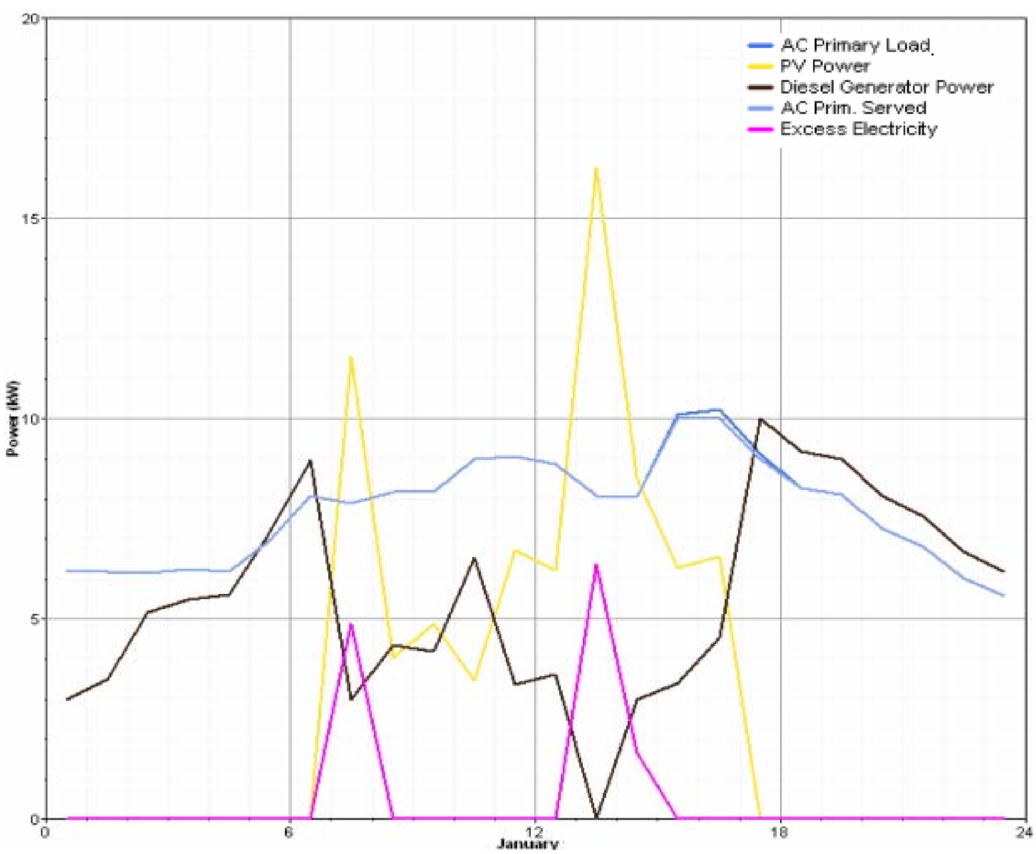
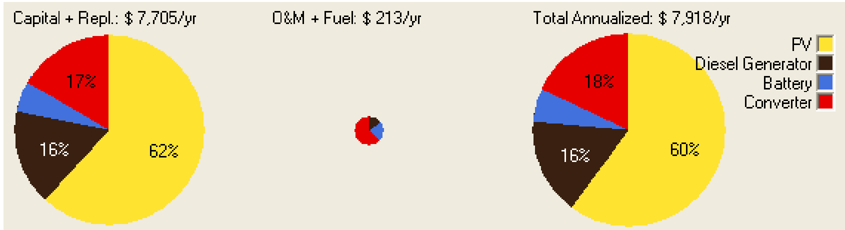


Figure 5: Hour Data Power Flow in 24 hrs



Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
PV Array	54,600	4,271	485	0	0.0	4,756
Diesel Generator	20,000	1,565	-280	14	20.5	1,318
Battery	4,100	321	87	45	0.0	453
Converter	12,000	939	319	133	0.0	1,391
Totals	90,700	7,095	610	192	20.5	7,918

Figure 6: Total Annualized cost for the PV-Diesel-Battery System

to the electrolyzer. Overnight, the fuel cell serves the load while drawing hydrogen from the storage tank. In the winning system, the hydrogen tank starts the year full and ends the year empty. That system would therefore probably not be able to serve the load as well in its second year as in its first. Introduction of an electrolyzer, powered by the PV generator is used to produce the fuel for the PEMFC.

Replacement of the conventional system by a PEM fuel cell can keep the system reliability of supply at the same level while decreasing the environmental impact of the whole system. Furthermore, gas (H_2 and O_2) storage that can be sized for seasonal operation thus increasing the performance ratio of the PV part. The energy is stored in gas form, allowing no loss for long-term storage.

The round-trip efficiency of the hydrogen storage system is less than 50%. Because so much power is lost in the storage system, the energy production of the PV array must greatly exceed the electrical load. For remote systems, such as low-hydrogen-penetration systems could certainly become competitive in the near future, depending primarily on the fuel cell cost. The fuel cells could be economically competitive in hybrid systems in 2010. As fuel cells will likely reach the price point, considering installed stationary fuel cell targets are $400/kW by the year 2010. The assumptions of component size, cost, and type can have a dramatic effect on the optimal system type.

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