Optimization and Modeling of PV/FC/Battery Hybrid Power Plant for Standalone Application

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Abstract
The hybrid system of renewable energy can contribute in a significant way of the durable development of several isolated areas far away from the main utility grid. In this paper, a hybrid power generation system suitable for remote area for agricultural application is proposed. This system consists of a renewable energy sources namely photo-voltaic panels. The climate change which is one of the greatest challenges which must be made possible for the supply of these isolated areas with their needs of electricity by renewable energy sources. For that fuel cell used as auxiliary source and combined with PV system can ensure a reliable supply without interruptions. For the production and uniform supply of hydrogen of fuel cell, an electrolyzer is considered in the proposed system. Also it consists of a battery. The main power of the hybrid system comes from the photovoltaic panels, while the fuel cell and batteries are used as backup units. The analysis of such a hybrid system feeding a load centre is carried out with the application of HOMER software. HOMER is a design model that determines the optimal architecture and control strategy.
of the hybrid system. Based on simulation results, it has been found that these renewable energy sources would be a feasible solution for distributed generation of electric power for stand-alone application at remote location.

“1. Introduction”

Many villages in the world live in isolated areas far from the main utility grid. Despite rapid industrialization, agriculture forms a major contributor to the Indian economy. With the economy progressing and a lot of mechanization being done in agricultural practices, the demand of electricity among this segment has also increased. It is really responsible their meet by the conventional sources because of the high cost of transport and the distribution of energy to this remote areas. Currently, the electric provisioning of these sectors is done by the hybrid system of production of electricity. This hybrid system consists of the combination of different energy sources like photovoltaic, fuel cell and battery [1]. A system of the combination of different energy sources has the advantage of the balance and stability [2]. The concept of photovoltaic is well understood and currently thousands of PV based power systems are being deployed worldwide, for providing power to small, remote and grid independent applications [3]. In addition to this, use of renewable energy sources reduces combustion of fossil fuels and the consequent CO₂ emissions.

Despite abundant availability of solar, a PV standalone system cannot satisfy the loads on a 24 hours basis. Often, the variations of solar energy generation do not match the time distribution of the load. Therefore, the use of fuel cell with PV ensures the availability of power during the 24 hours [4]. The electrolyzer converts the excess generation of PV as hydrogen and stores in hydrogen tank. Fuel cell uses this hydrogen and convert is to the electricity. Fuel cell will operate only when the PV is inactive. PV generated electricity also stored in batteries also.

National Renewable Energy Laboratory’s (NREL) Hybrid Optimization for Electric Renewable (HOMER) software has been employed to carry out the present study. HOMER is a computer model that simplifies the task of evaluating design options for both off-grid and grid connected power systems for remote, stand-alone and distributed
generation (DG) applications. It is developed specially to meet the needs of renewable energy industry’s system analysis and optimization.

Inputs to HOMER will perform an hourly simulation of every possible combination of components entered and rank the system according to user specified criteria, such as cost of energy (COE, US$/KWh) or capital costs. Furthermore, HOMER can perform “sensitivity analysis” in which the values of certain parameters (e.g. solar radiation, primary load) are varied to determine their impact on the system configuration [4].

In this paper the simulation of a hybrid energy system composed of PV generator together with FC and battery storage has performed and a power management strategy has designed. Finally the simulation result and discussion has presented.

“2. System Description”

On the design point of view, the optimization of the size of hybrid plants is very important and leads to a good ratio between cost and performances. Before the system sizing, load profile and available insolation should be evaluated. Therefore, they are presented in the following sections:

2.1. Solar Radiation and PV Cost Inputs

With the latitude and longitude HOMER software can automatically collected the global solar rate for the place. The average solar radiation is 5.389 kWh/m²/d. The site is located at (GMT+5.30) zone. The initial size of PV array used for this project is 80 kW. Price for the capacity is retained at $7000 and replacement cost is also $7000. Different PV azimuths have been set for a lifetime of 20 years [9].

![Figure 1. Monthly average solar radiation](image)

2.2 Load Profile

An important consideration of any power generating system is load. As a case study this system is utilized in an agricultural (irrigation) application. The measured annual average energy consumption has been considered
to scale the load 140 kWh/d in the present study. The daily average load profile is shown in Figure 2. With added consideration for demand variation of 2.2% day-to-day and hour-to-hour, the peak load is estimated to be 13 kW [10].

HOMER is a simplified optimization model, which performs hundreds or thousands of hourly simulations over and over in order to design the optimum system. It uses life cycle cost to rank order these systems.

The model has been developed using HOMER, consists of a PV, a battery and a FC fed by hydrogen. The schematic of this hybrid power system is shown in Figure 3. In order to verify the system performance under different situations, simulation studies have been carried out using real weather data (solar irradiance). The goal of the optimization process is to determine the optimal value of each decision variable that interests the modeler. A design variable is a variable over which the system designer has control and for which HOMER can consider of multiple possible values in its optimization process. In this study decision variable in HOMER include:

- The size of the PV array
- The size of FC
- The capacity of batteries
- The size of DC/AC converter
- The size of electrolyzer and hydrogen tank

3.1 Power Management Strategy

Figure 2. Daily load profile

“3. HOMER Simulation”

In this present work, the selection and sizing of components of hybrid power system has been done using NREL’s HOMER software. HOMER is the general purpose hybrid system design software that facilitates design of electric power systems for stand-alone applications. Input information to be provided to HOMER includes: electrical loads, renewable sources, component technical details and costs, constraints, controls, type of dispatch strategy etc. HOMER designs an optimal power system to serve the desired loads.
The dispatch strategy is load following type and interaction between different components is as follows:

In normal operation, PV feed the load demand. The excess energy from PV is stored in the battery until the full capacity of the battery is reached. The main purpose of introducing battery storage is to import/export energy depending upon the situations. In the event, the output of PV exceeds the load, and the batteries state of charge (SOC) is maximum, the excess energy is fed to electrolyzer. The FC is bought into the line when PV fail to satisfy the load and the battery storage is depleted (i.e. when the battery’s SOC is minimum) [5]. The details of proposed hybrid system components can be found in table I[10] and the flow chat of this project is also shown in Figure 4 [8].

<table>
<thead>
<tr>
<th>Components</th>
<th>Capital Cost</th>
<th>Replacement Cost</th>
<th>Life time</th>
<th>Efficiency</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Array</td>
<td>7000 $</td>
<td></td>
<td>20 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O &amp; M Cost</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tracking System</td>
<td>No tracking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FC Array</td>
<td>30000 $</td>
<td>30000 $</td>
<td>40000 hours</td>
<td>85%</td>
<td>15 years</td>
</tr>
<tr>
<td>Electrolyzer</td>
<td>20000 $</td>
<td>20000 $</td>
<td></td>
<td>85%</td>
<td></td>
</tr>
<tr>
<td>Primary Load</td>
<td>144 kWp/240 kWp</td>
<td>45 kWp/13 kWp</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AC/DC converter</td>
<td>T-105</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Battery Technology Trojan T-105
Capacity 1.35 kwh
Nominal Capacity 225 Ah
Voltage 6 V
Capital Cost 2100$
Replacement Cost 2100$
Converter
Capacity 20 kW
Capital Cost 15000$
Replacement Cost 15000$
Efficiency 92%
Lifetime 20years
Hydrogen tank
Capital Cost 54000$
Lifetime 25%
Initial tank Capacity 10years
Consider year end tank level Yes
System Data
Project Life time 25years
Operating Strategy Load following
Max. annual capacity 1%

"4. Simulation Results"

Several simulations have been made by considering different PV capacities. The PV capacity has been allowed to vary from 0 to 160 kW. The FC power considered to change from 0 to 10 kW. The simulation results for 5.389 (kWh/m²/d) solar radiations are presented in Table II. The first column shows the presence of PV modules, FC and Battery in hybrid system. It can be noticed from these results that the first system consists of PV/FC is the most commercial but in this paper the result of the second configuration has considered because of presence of all components.

The COE of hybrid PV/FC/Battery/Electrolyzer system(80kW PV,10kW FC, Battery and hydrogen storage,0.01% annual capacity shortage) has been found to be is 0.431 (US$/kWh).

Figure 5. Powers evolutions during 24 hours

Figure 6. Battery SOC Monthly Averages
Figure 7. Stored Hydrogen Monthly Averages

Table II. Annual Electric Energy Production

<table>
<thead>
<tr>
<th>Production</th>
<th>kWh/yr</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Array</td>
<td>150,117</td>
<td>86%</td>
</tr>
<tr>
<td>Fuel Cell</td>
<td>240,205</td>
<td>14%</td>
</tr>
<tr>
<td>Total</td>
<td>174,322</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table III. Annual Electric Energy Consumption

<table>
<thead>
<tr>
<th>Consumption</th>
<th>kWh/yr</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Primary Load</td>
<td>50,980</td>
<td>42%</td>
</tr>
<tr>
<td>Electrolyzer Load</td>
<td>70,637</td>
<td>58%</td>
</tr>
<tr>
<td>Total</td>
<td>121,618</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table IV. Annual Emissions

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Emissions (kg/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>-14.8</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>9.44</td>
</tr>
<tr>
<td>Unburned hydrocarbons</td>
<td>1.05</td>
</tr>
<tr>
<td>Particulate matter</td>
<td>0.712</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>0</td>
</tr>
<tr>
<td>Nitrogen oxides</td>
<td>84.2</td>
</tr>
</tbody>
</table>

In the proposed hybrid system the unmet load is 120 (kWh/yr). It can be depicted from Figure 8 the variation of PV capacity with solar radiation and primary load. Figure 9 shows the monthly average electrical production.

"5. Cost Optimization"

The aim of this study is to achieve a stand-alone hybrid generation system, which should be appropriately designed in terms of economic, reliability and environmental measures subject to physical and operational constraints/strategies [6, 7, 10].

The system cost is defined as sum of PV cost($C_{PV}$), battery cost($C_{BAT}$), electrolyzer
cost($C_{ELEC}$), FC cost($C_{FC}$), converter cost($C_{CONV}$) and hydrogen tank cost($C_{TANK}$).

$$C_{SYSTEM} = C_{PV} + C_{BAT} + C_{ELEC} + C_{FC} + C_{CONV} + C_{TANK}$$

The cost for each element should be deducted:

$$C_i = N_i \times [CCost_i + RCost_i \times K_i + OMCost_i]$$

$i$=PV, Battery, FC, Electrolyzer, Converter, Hydrogen Tank

Where $N_i$ is the number/size of the system component, $CCost_i$ is the capital cost, $RCost_i$ is the replacement cost, $K_i$ is the number of replacement and $OMCost_i$ is operation and maintenance cost through the system operation. The cash flow of the system elements can be seen in Figure 10. The cost of the system elements can be seen in Figure 11.

The simulation results indicated that a hybrid power system comprising of a 80 kW photovoltaic system together with a 10 kW fuel cell would be a feasible solution for distributed generation of electric power for stand-alone applications at remote locations.

The cost of generating energy from the above hybrid PV/FC/Battery system has been found to be 0.431(US$/kWh). The hybrid PV/FC/Battery power system offers several benefits such as: utilization rate of PV, FC and battery can occur. The environmental friendly nature of the hybrid system can also be depicted from annual emission of the system.

"6. Conclusion"
“7. References”


