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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 make 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 CO_2 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/m^2/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].

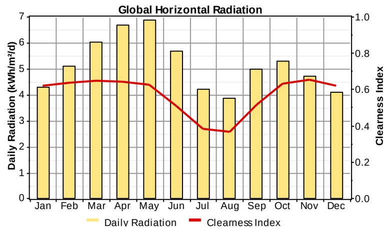

Figure 1. Monthly average solar radiation

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].

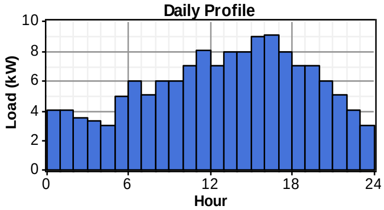

Figure 2. Daily load profile

"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.

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

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].

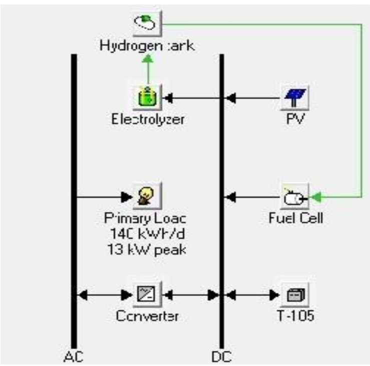

Figure 3. Proposed system configuration in HOMER

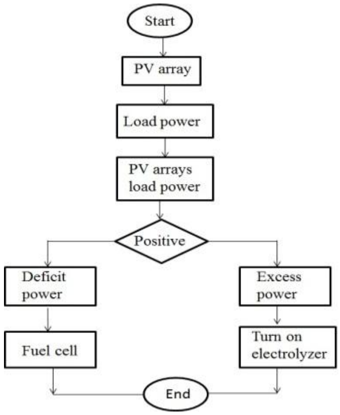

Figure 4. Flow chart of the project

Table I. Technical data and study of assumptions components

PV Array	
Capital Cost	7000 $
O & M Cost	0
Life time	20
Tracking System	No tracking
FC Array	
Capital Cost	30000 $
Replacement Cost	30000 $
Life time	40000 hours
Electrolyzer	
Capital Cost	20000 $
Replacement Cost	20000 $
Efficiency	85%
Lifetime	15 years

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/m^2/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).

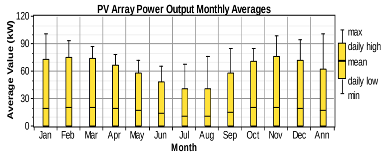

Figure 5. Powers evolutions during 24 hours

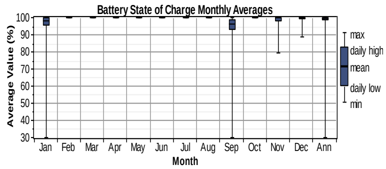

Figure 6. Battery SOC Monthly Averages

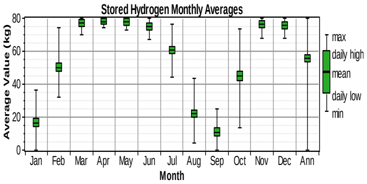

Figure 7. Stored Hydrogen Monthly Averages

Table II. Annual Electric Energy Production

Production	kWh/yr	Fraction
PV Array	150,117	86%
Fuel Cell	240,205	14%
Total	174,322	100%

Table III. Annual Electric Energy Consumption

Consumption	kWh/yr	Fraction
AC Primary Load	50,980	42%
Electrolyzer Load	70,637	58%
Total	121,618	100%

Table IV. Annual Emissions

Pollutant	Emissions (kg/yr)
Carbon dioxide	-14.8
Carbon monoxide	9.44
Unburned hydrocarbons	1.05
Particulate matter	0.712
Sulfur dioxide	0
Nitrogen oxides	84.2

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:

$$C_i = N_i * [CCost_i + RCost_i * K_i + OMCost_i]$$

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.

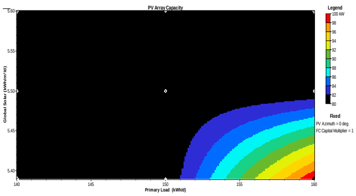

Figure 8. PV array capacity

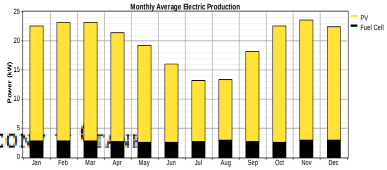

Figure 9. Monthly Average Electric Production

"6. Conclusion"

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.

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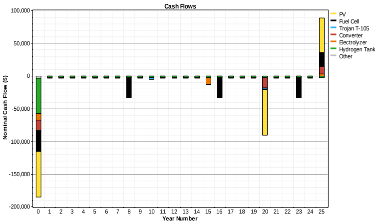

Figure 10. Cash Flow Summary

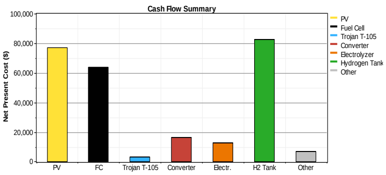

Figure 11. Cost Analysis of Configuration

"7. References"

[1] Souissi Ahmed, Hasnaoui Othman, Sallami Anis, "Optimal Sizing of a Hybrid System of Renewable Energy for a Reliable Load Supply without Interruption," *European Journal of Scientific Research.* vol.45, No.4, 2010, pp.620-629.

[2] R. Ramakumar, I. Abouzahr, and K. Ashenayi, "A Knowledge-Based Approach to the Design of Integrated Renewable Energy Systems," *IEEE Trans. on Energy Conversion,* vol. 7, No. 4, Dec. 1992.

[3] R. Chedid, H. Akiki, and S. Rahman, "A Decision Support Technique for the Design of Hybrid Solar-Wind Power Systems," *IEEE Trans. on Energy Conversion,* vol. 13, No. 1, Mar. 1998.

[4] National Renewable Energy Laboratory [Online]. Available:http://www.nrel.gov/international/tools/HOMER/homer.html.

[5] A. Jalilvand, H. Kord, and A. Rohani, "Design, Control and Power Management of a Hybrid PV/WG/FC System for Stand Alone Applications", *Electrical Power Distribution Conference (EPDC),Kerman, 2009.*

[6] S. Jalizadeh, A. Rohani, H. Kord and M. Nemati," Optimum design of a hybrid Photovoltaic/Fuel Cell energy system, for standalone applications", *IEEE Int. Conf. on Electrical Engineering, and Electronics (ECTI),vol. 1, Thailand, May 2009,* pp.152-155.

[7] H. Kord, A. Rohani, "An Integrated Hybrid Power Supply for Off-Grid Applications Fed by Wind/Photovoltaic/Fuel Cell Energy Systems", 24th *Int. Power System Conference (PSC), Tehran, Nov. 2009,*pp.1-11

[8] Mohammad Saad Alam, David W. Gao, "Modeling and Analysis of a Wind/PV/Fuel Cell Hybrid Power System in HOMER", *2007 Second Conference on Industrial Electronics and Applications,* pp:1594-1599.

ISSN: 2278-0181
Vol. 1 Issue 3, May - 2012

[9] M. Shakawat, Hossan, M. M Aruf Hossain, A.R.M Reazul Haque, "Optimization and Modeling of a Hybrid Energy System for off-grid Electrification", *IEEE Int. Conf. 2011.*

[10] Ahmed Rohani, Kazem Mazlumi, Hossein Kord, "Modeling of a hybrid Power System for Economic Analysis and Environmental Impact in HOMER", *proceedings of ICEE 2010,May 11-13,2010.*