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Renewable Energy Hybrid Powered House For Rural Electrification

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Abstract

A photovoltaic/wind/fuel cell hybrid power system for stand-alone applications is proposed Hybrid powered house.Since, there are frequent power cut in our country this proposed model would help to focus in Renewable Energy System. This concept shows that different renewable sources can be used simultaneously to power off-grid applications. The presented Hybrid powered house can produce sufficient power to cover the peak load. Photovoltaic and wind energy are used as major sources and a fuel cell as backup power for the system. The power costing of the system is designed based on the local data of solar radiation and wind availability. The solar radiation and wind availability is taken from Agro Climatic Research Centre, Tamil Nadu Agricultural University for Coimbatore region.

1.Introduction

Providing reliable, environmentally friendly, and affordable energy has been a goal for many countries throughout the world. The rising consumption of energy and falling accessibility of natural resources are increasing the cost and demand of electricity. In addition, as the industry develops, greenhouse gases are becoming a threat to the natural ecosystem [1]. Therefore, renewable energy has received more attention recently. Solar radiation and wind are considered the most preferred renewable energy sources for their availability and inexhaustibility. However, due to the irregular characteristics of natural wealth, it has been a challenge to engender a highly reliable power with photovoltaic (PV) modules and/ or wind turbines [2]. To overcome this limitation, previous studies were conducted using a fuel cell as another energy source and simulated results showed that a PV/wind/fuel cell hybrid power system may be a feasible solution for standalone applications [3-5]. Since a multi-source hybrid power system increases energy availability significantly, it becomes advantageous for practical applications that need highly reliable power regardless of location [6], [7]. This paper presents a model of the use of a PV/wind/fuel cell hybrid power system to supply electricity to a Hybrid powered house. The hybrid power system is shown in Fig. 1.The proposed system shows that it is compatible touse hydrogen as an energy hauler with other renewableenergy sources such as PV and wind energy. This system will beinstalled in Karunya University, Coimbatore. PV and windenergy are used as the main energy sources for the system and the fuel cell performs as a backup power for the continuousgeneration of high quality power. The proposed mobile housedemonstrates that it can be used as a stand-alone powersystem in remote areas where there is no access to grid and asa backup power system to cover electricity shortage in certainsituations such as natural disasters.

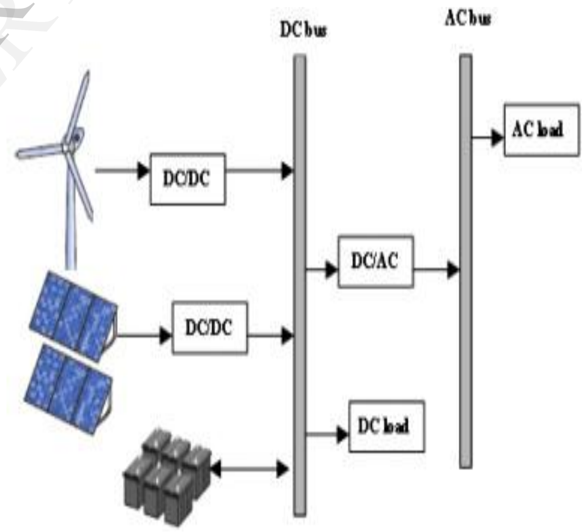


Fig.1.Hybrid Powered House model

The paper is organized as follows. Section 2 discusses thesystem design strategy and Section 3 presents the systemintegration of components. Finally, Section 4 concludes thepaper and proposes future research plans.

2. Design Strategy

2.1 Load Analysis

System design starts with deciding whether the mobile houseis connected to grid or not. Since the system is mobile, it has tobe designed as a stand-alone application, independent fromgrid. Moreover, the load profile of the mobile house isanalyzed to ensure that energy sources generate sufficientenergy throughout the year. Eq. (1) shows the estimation ofaverage daily energy consumption.

$E_d = \sum_{i=1}^{n} I_n V_n D_n$ Eq. (1)

Where, I_n, V_n, and D_n are the current, voltage and duty cycle of each application used in one day, respectively and E_d shows the total energy demand for the Hybrid powered house. As shown in Table 1, the average daily energy consumption of the Hybrid powered house is calculated as 4220 Wh according to Eq. (1). The total power, 2835W, declares the maximum instantaneous power which the inverter should meet; in order to maintain the stability ofthe energy flow, an inverter rated at least 2835W is required for the design.To simplify the analysis, daily load was assumed to haveconstant value throughout the year and in energy supplyanalysis, December is chosen because the average solar irradiationin December is the lowest for Karunya University, Coimbatore. As shownin Fig. 2, the area under the daily load curve indicates theapproximate required energy for a day, which is equal to theresult 4220 Whfrom Table 1.Annual load of the Hybrid powered house is shown in Fig. 3.

2.2. Availability study

2.2.1. Solar energy

The Karunya University, Coimbatore has the lowest daily irradiance and sunhours in December, as shown in Fig. 4 [9, 10]. The averageradiation in December was calculated as 2030 Wh/m2/daywhen PV panels. Total area on the roof ofthe mobile house available for PV panels is 8.4m^2 and the total energy generated in a day of December can be calculated withEq. (2).

$E_{pv} = (\int_0^{24} I_r \, dt)\, S \eta_{pv} \eta_b \eta_i$ Eq. (2)

Table 1.Calculated Energy Consumption

Appliance	Power (w)	No Of Hrs/day	Energy/day (wh)
Lighting	100	2	200
Refrigerator	70	8	560
LCD TV	65	2	130
Electrolyser	400	0.5	200
AC	560	5	2800
Water Heater	1500	0.22	330
Total	2695		4220

Table.1-Calculated Energy Consumption

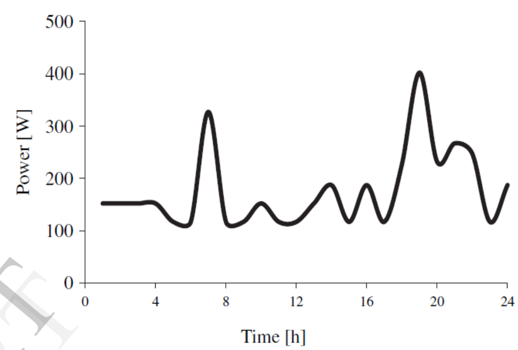


Fig.2- Assumed Daily Load Curve in a Winter Day

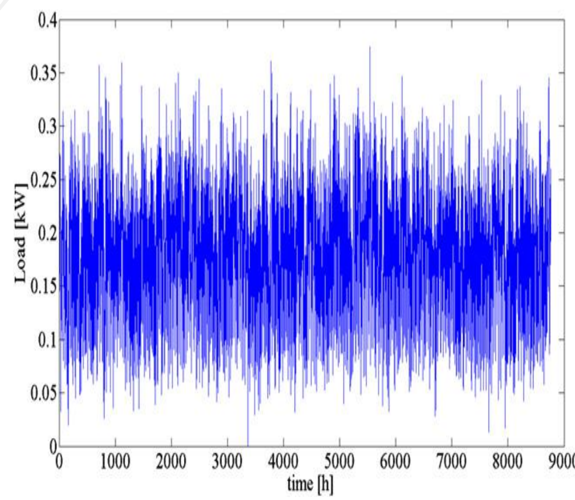


Fig.3- Annual Load of the Hybrid Powered House

S surface area of PV cells= 8.4 m^2

η_{pv} efficiency of PV panels = 16%

η_b efficiency of batteries =85%

η_i efficiency of inverter = 95%

I_r solar irradiance ($Wm^{-2}R$)

$\int_0^{24} Irdt$ total solar irradiance in a December day = 2030Whm^{-2}/day

E_{pv} PV panels' generated power to AC bus in a Decemberday= 2203 Wh/day According to the results from Eq.(2), 2203 Wh/day from thesolar radiation can be produced with the available surface onthe house roof.

The generated power of PV panels is also a function oftemperature; when the temperature increases, the efficiencyof the panel decreases. However, this paper does notconsider this point because the ±2.6deviation of the averagetemperature of 8 in December is assumed to be negligible.The basic mathematical model is used to calculate themaximum power output from the photovoltaic modules[14, 15];

$P_{pv}=Y_{pv}f_{pv}\left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right)[1+\alpha_p(T_C-T_{C,STC})]$ Eq.(3)

P_{PV} output power of the PV array (kW)

Y_{PV} the rated capacity of the PV array, sense its poweroutput under normal test conditions (kW) (100Wm^{-2} solarradiance, 25^{0}C PV module temperature)

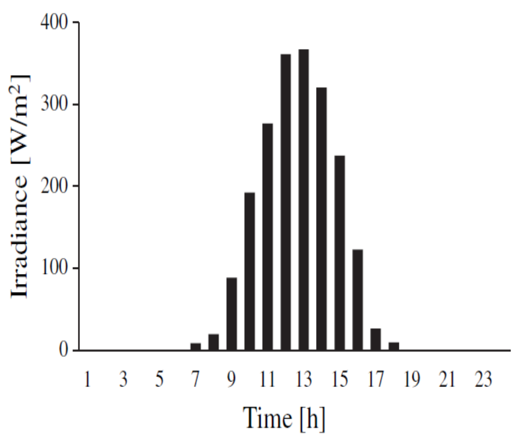


Fig.4 Solar Irradiance data for December

f_{PV} the PV derating factor (%)

$\bar{G}$T the solar radiation incident on the PV array in thecurrent time step (kWm$^-$2)

$\bar{G}_{T,STC}$ the incident radiation at standard test conditions(l kWm$^-$2)

αP the temperature coefficient of power ($^0C^{-1}$)

T_C the PV cell temperature in the current time step (^{0}C)

$T_{C,STC}$ the PV cell temperature under standard test conditions(25 ^{0}C)

Regarding the meteorological conditions of Karunya University in2010, the electricity generation from PV panels is highest onJune, July, and August, lowest on November, December andJanuary. Annual average PV output power at Fig. 5.

2.2.2. Wind energy

Since the energy from the PV panels is not sufficient to providethe average daily energy demand, a wind turbine and a fuelcell can be used to provide the remaining power needed. Asshown in Fig. 6, the availability of wind was determined by theaverage daily wind speed in December in Karunya University at 10 maltitude .The instantaneous power produced from wind is

$P_w = \frac{1}{2}\rho A C_p V^3$Eq.(4)

Where:

ρ air density (kgm$^-$3)

A rotor sweep area (m^2)

C_p power coefficient, a function of tip speed ratio and pitchangle

V wind velocity (ms^{-1})

The Hybrid powered house used a Ventura 1000 lkW wind turbinemodel which was found suitable for the hybrid power system.The energy produced from wind can be determined as follows.

$E_w = (\int_0^{24} P_w dt)\eta_s$Eq.(5)

Where:

P_w instantaneous power produced (W)

$\eta_s$system efficiency with battery and inverter = 80%

E_w wind turbines' generated power to AC bus ina day = 2177 Wh/day

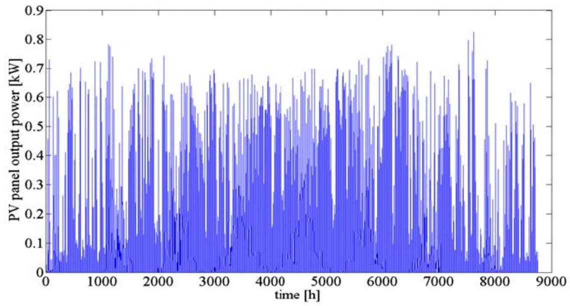


Fig.5-Annual PV Output Power

The area under the black dotted curve corresponds to which is 2177 Wh/day(Fig. 8). E_{eb}, the energy balance difference between energyproduction and demand, can be calculated as follows withEqs. (2), (4), and (5).Karunya in 2010, in terms of meteorological conditions, the electricity generation from wind turbine is highest on February, October, and December, lowest on May, June.Annual average wind turbine output power at Fig. 7

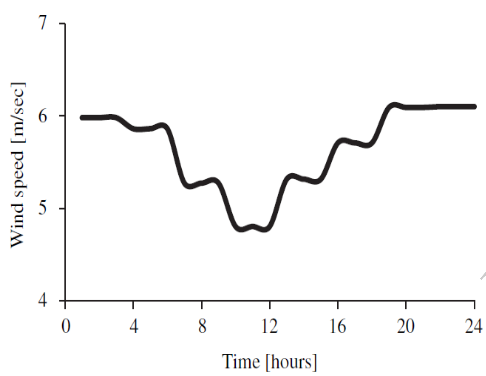


Fig.6-Average Daily Wind Speed in December

$E_{eb}=(E_{pv}+E_w)-E_d$Eq.(6)

$E_{eb}=(\int_0^{24} P_{pv}\,dt)\eta_s+(\int_0^{24} P_w\,dt)\eta_s-(\int_0^{24} P_d\,dt)\eta_s$Eq.(7)

Using Eq. (5), the value E_{eb} was calculated as 160 Wh which indicate that the Hybrid house has an energy surplus of 160Wh. When is negative, the fuel cell has to be activated.

2.2.3. Fuel cell

A fuel cell is used as a backup power generator for the house. The fuel cell needs to be activated when wind and solarenergy are insufficient to supply the demand, depending onthe battery state of charge. A FutureE Jupiter 2 kW PEM fuel cellwas selected to back up the power of the house. It is50% efficient and consumes 22 standard liters of hydrogen perminute (slpm) at peak load. Hydrogen storage capacity shouldbe enough for one day autonomy.

The obligatory energy for a day can be calculated as follows:

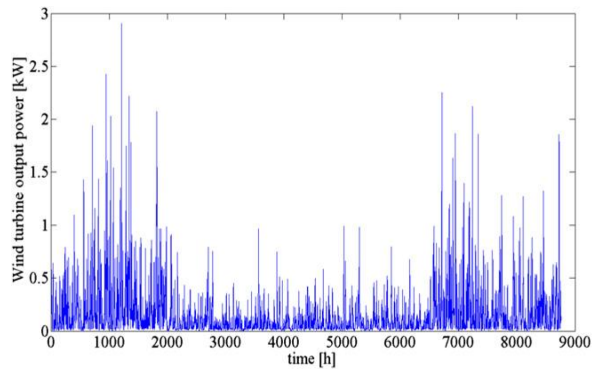


Fig.7-Annual Wind Turbine Output Power

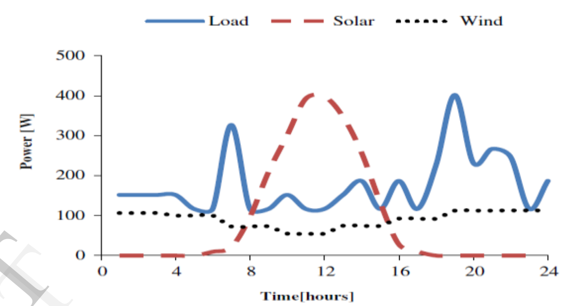


Fig.8-Energy Demand vs. Production

$E_n=\frac{E_d}{n_b n_{fc} n_i}$Eq.(8)

Where: E_d energy demand = 4220 Wh/day

n_b efficiency of startup batteries = 85%

n_{fc} efficiency of fuel cell = 50%

ni efficiency of inverter = 95%

E_h hydrogen energy needed for autonomy = 10452 Wh/day = 37.6 Mj/day Since the lower heating value of hydrogen is 120 Mj/kg,0.310 kg/day of hydrogen is required for autonomy. Eq. (9)calculates the required amount of hydrogen;

$n=\frac{PV}{RT_Z}$ Eq.(9)

Where: P pressure (bar)

V volume (l)

R gas constant ¼ 0.08314 (bar.l/_K.mol)

T absolute temperature (_K)

z compressibility factor 1.1054 @ 160 bar n amount of gas (mol)

As a result, two 10-liter tanks may store approximately 121 mol of hydrogen - 0.242 @ 160 bar 15^0C-which has8159 Wh energy. This amount of hydrogen can supply the fuel cellfor approximately 19 h. As shown in Fig. 9, manifold andcylinders of PEMFC.

Fig.9- PEMFC Cylinder

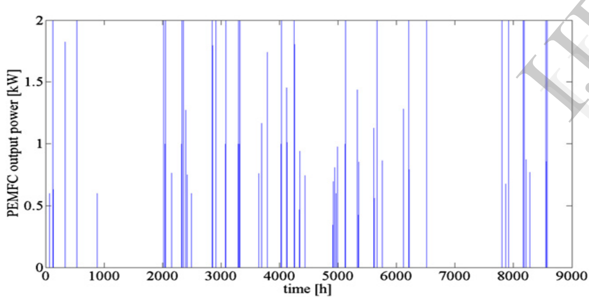
1 - Regulator 150 bare15 bar

2 - Hydrogen cylinders 150 bar, 1320 sl

3 - Automatic and manual relieves

4 - Check valves

February and July, the fuel cell is not working. The Hybrid PoweredHouse energy needs during these months are supplied by thewind turbine and solar panels. The fuelcell works at itsmaximum in April. Monthly average the PEMFC output powerat Fig. 10.



2.2.4. Batteries

Batteries are used as the energy storing units and the vitalcapacity can be calculated below

$$Ih=\frac{\alpha E_d}{n_s V_s (1-SOC_m/100)} \quad \text{Eq. (10).}$$

Where:

E_d =total energy demand = 4220 Wh/day

n_s = system efficiency = 80%

V_s = system voltage = 24 V

SOC_m = minimum state of charge =50%

α=days of autonomy = 2

The required capacity was calculated as 879 from Eq.(10).Because of space limitations, 8 modules ofHaze Professional's12 200 sealed lead acid monoblock gelled electrolyte batterywere used so 1.8 days of autonomy is provided. Fig. 11 showsthe battery cycle life respect to the depth of discharge.

As shown, (100 - SOC_m) of 50% corresponds to approximately 500cycles. Fig. 12 shows annual state of charge (SOC) of thebattery bank.

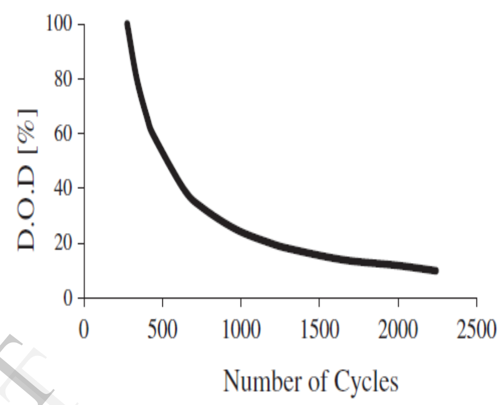


Fig. 11 - Battery cycle life vs. depth of discharge

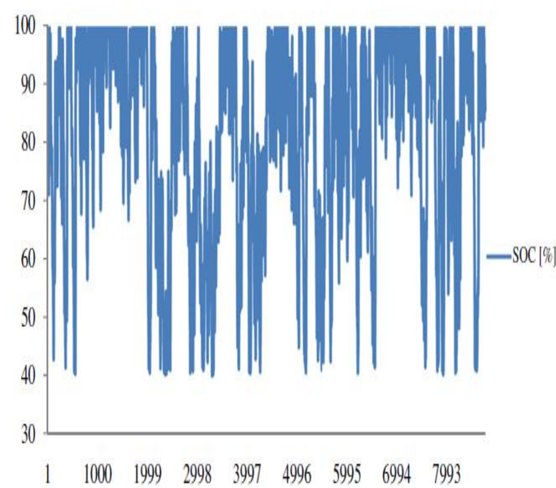


Fig. 12 - Annual SOC of the battery bank.

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3. System integration

The hybrid power system of the 24/365 powered house consists of an8 × 1 array of 100WPV panels, a 1 kWwind turbine, and a 2kWcell. As shown in Fig. 13, the block diagram of the systemdemonstrates the integrated components for power generation.In the following, each component of the system is presentedand discussed.

For PV panels, Solera GP-100/12 PV modules of E-Sistem -composed of Poly-Si PV modules - were used. Although Poly-Si modules have lower efficiency than Mono-Simodules, Solera models were selected to havebetter costefficiency. The wind turbine works in normal mode up to 20 ms^{-1} ofwind speed and after 20 ms^{-1}, the turbine activates a stallcontrol system which enables electromagnetic regenerativebraking and lets the wind turbine generate power under thebrake control. The turbine is installed on a foldable pole whichhas a height of 10 m from the ground. Although theturbines with permanent magnet synchronous generators aremore expensive, they are more suitable for the mobile applicationsdue to their compact and light structure. The windturbine is able to automatically change direction to face thepredominant wind in order to generate as much power as possible.

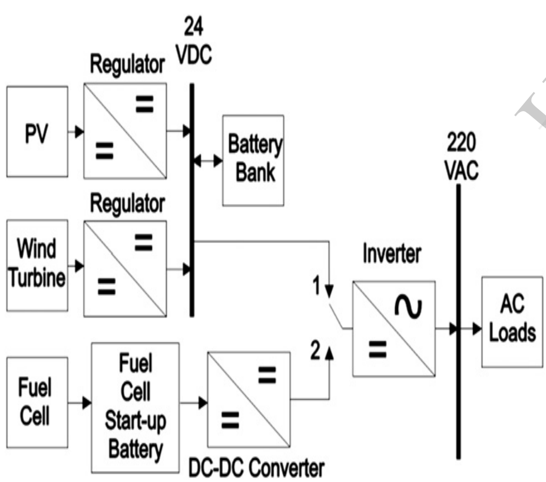

Fig. 13 - Block diagram of the system.

A Jupiter B from FutureE is a PEM air-cooled fuel cell with2 kW of rated power. Hydrogen is stored in two 10-liters tankswhich are pressurized at 160 bar. PEM fuel cellswith an air-cooled system are usually more suitable for applications due to their low working temperatures andcompact structure.

The battery bank consists of 8 gel type batteries of 200 Ah at12 V. Sealed lead acid monoblock gelled electrolyte batteriesare more tolerant of deep discharge, overcharge, and a highnumber of cycles. Due to their negligible gas emission, theyare appropriate for residential usage. The sources andstorage units are integrated on a single DC bus in order tomake the system cost-effective. Having the same voltage levelfrom the PV array and wind turbine allows both sources to beconnected directly to the DC bus. Since the output of the PVmodule is unregulated, a 60 Amp rated Xantrexmultifunction DC controller, which is capable of voltage regulation andthree-stage battery charging, was used. The Ventura 1000already has a rectifier with an internal regulator; hence, itgives an output of 24 V which is the same as the PV array. Thefuel cell has a 48 V output. Finally, a DC-DC converter wasinstalled to convert the output of fuel cell to 24 V.

The battery bank with a capacity of 19.2 kWh is used in thesystem to supply the transient power. When the minimumbattery state of charge (SOC) is considered, the usable capacitybecomes 9.6 kWh which is the sufficient level - according to(9) - for 1.8 days of autonomy. Hydrogen cylinders witha capacity for 8159 Wh at the given conditions were used.Moreover, the hydrogen storage is sufficient for 0.8 day ofautonomy when losses are taken into consideration; hence,the total number of autonomous days is 2.6 days. The fuel cellstartup battery warms up the fuel cell, and prevents unnecessaryswitch-on when there is only a short term powerdemand. When there is a long term power demand, thestartup battery functions as a backup power source.

A flow diagram, shown in Fig. 14, describes the systemoperation. Control system, programmed with Lab VIEW, preventsunnecessary switching and minimizes the use of hydrogenas afuel. Control system calculates the total power demand($\sum E_{dem}$) and the totalpower production ($\sum E_{prod}$)for a specifictime interval. At the end of thetimeinterval, system checksthe hydrogen pressure (P_n) if the energy demand is greaterthan the produced energy and SOC is less than 50%. If thehydrogen pressure is over 4 bar, the switch disconnects thesystemfromDCbus as shown inFig. 14; else the switch staysat position 1 and gives the warning about hydrogendepletion. After the disconnection, the fuel cell startup battery supplies the demand until the voltage leveldecreases to 49 V. When 49 V is reached, the fuel cell activatesto generate power. The switch stays at nullpoint untilwhen the amount of total produced energy is greater thanthat of total energy demand or battery SOC is greater than50% at the end of the time interval. When the hydrogenpressure level drops below 4 bar and the SOC is still less than50%, the switch changes its position to 1 and allows thebattery voltage to drop below 50% SOC.

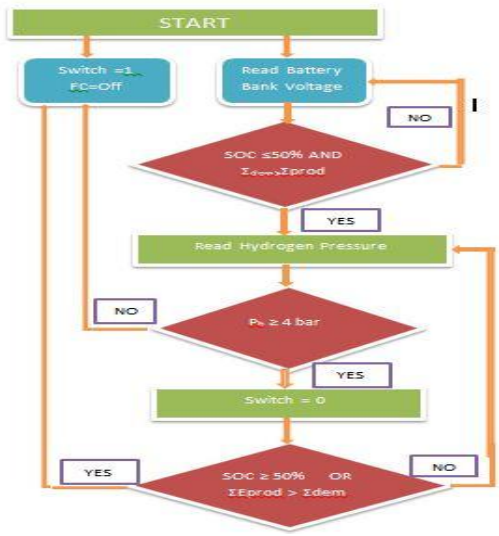

Fig. 14 - Flow diagram of the system.

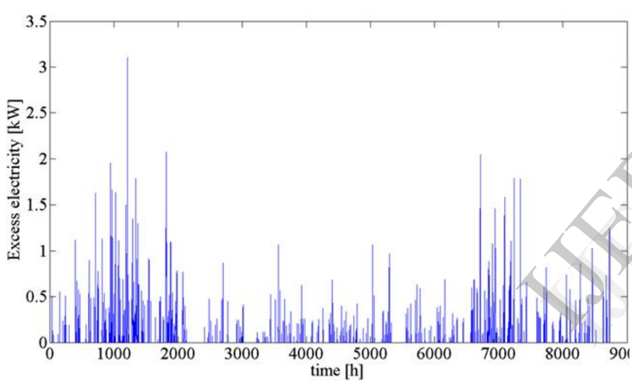

Fig. 15 - Annual excess electricity of the Hybrid powered house.

4. Conclusions

Demonstration of a PV/wind/fuel cell hybrid power systemwas presented. The hybrid power system increases poweravailability which is one of the key factors for many applicationsthat need reliable power in remote locations.The system was designed based on the results of a loadanalysis and a study of the renewable resources available inKarunya, Coimbatore. After the design, the componentsof the system will be integrated; a PV module (800 W), a windturbine (1 kW), and a fuel cell (2 kW) will be installed togenerate a maximum power of 3.8 kW. The presented systemuses PV and wind energy as the primary energy sources andfuel cell energy as a secondary source for power generation.Annual approximate energy production of house is2510 kWh. Annual approximate energy demand of Hybridhouse is 1550 kWh. So there is an excess energy which is shown in Fig. 15. In Hybrid house energy control system,surplus energy is converted to hydrogen via a PEM electrolyserand stored in a high pressure hydrogen tank until there isa high energy demand which triggers fuel cell unit thatconverts hydrogen gas back into electricity. Smart energycontrol system targets to source uninterruptible energy andsustainability property to the Hybrid Powered house.

As a future work, the correlation between the parametersand energy production will be demonstrated, and automaticcontrols will be designed and installed tooptimize the storageefficiency of the system.

References

1] Deshmukh MK, Deshmukh SS. Modeling of hybrid renewableenergy systems. Renewable and Sustainable Energy Reviews2008;12:235-49.

[2] Zahedi A. Technical analysis of an electric power systemconsisting of solar PV energy, wind power, and hydrogen fuelcell, Universities Power Engineering Conference AUPEC;2007, pp. 1-5.

[3] Alam, MS, Gao, DW. Modeling and Analysis of a Wind/PV/Fuel Cell Hybrid Power System in HOMER.IndustrialElectronics and Applications. 2nd IEEE Conference on ICIEA;2007, pp. 1594-1599.

[4] Tafreshi SMM, Hakimi SM, Optimal sizing of a stand-alonehybrid power system via particle swarm optimization (PSO).Power Engineering Conference IPEC; 2007, pp. 960-965.

[5] Lagorse J, Simoes MG, Miraoui A, Costerg P. Energy costanalysis of a solar-hydrogen hybrid energy system for stand-alone applications. International Journal of Hydrogen Energy2008;33:2871-9. 2nd World Congress of Young Scientists onHydrogen Energy Systems.

[6] Wang C, Nehrir MH. Power management of a stand-alonewind/photovoltaic/fuel cell energy system. IEEE Transactionson Energy Conversion 2008;23:957-67.

[7] Ipsakis D, Voutetakis S, Seferlis P, Stergiopoulos F,Elmasides C. Power management strategies for a stand-alonepower system using renewable energy sources and hydrogenstorage. International Journal of Hydrogen Energy; 2008:1-15.