Indian Journal of Science and Technology, Vol 9(48), DOI: 10.17485/ijst/2016/v9i48/91581, December 2016 ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Power Management of Standalone and Grid Connected Wind/Photovoltaic/SMC based Fuel Cell Energy System

Sravya Pudota* **and K. S. Srikanth Reddy**

Electrical and Electronics Engineering, KL University, Green fields, Vaddeswaram, Guntur - 522502, Andhra Pradesh, India;

Abstract

This paper proposes a concept of grid connected ac-linked stand-alone hybrid energy system. Generally, in this paper Wind and PV systems act as primary power sources, and a Fuel Cell based electrolyzer commonly acts as a backup and also as storage system. This paper also shows the information regarding power management strategies between stand-alone hybrid systems depending on the load demand. And also in addition a sliding mode controller is designed for fuel cell system to enhance the ability of tolerating perturbations and boost the functionality of system. The performance of this system is verified under different fault conditions which is occurred at place of grid system. And the harmonics which is caused by this fault condition is reduced by using active power filter. The proposed hybrid system is experimentally verified in Matlab/Simulink.

Keywords: Fuel Cell and Sliding Mode, Power Management, Solar System, Wind

1. Introduction

Increased utilization of renewable energy into power grid gave birth to several challenges those are experienced in integrating such sources amongst themselves as well as with the grid. Though the energy obtained from such sources is environment friendly, the power and voltage obtained from such sources varies randomly with the variation of weather. Furthermore, non-linear power converters, used for conditioning the outputs from such sources, distorts the waveform and hence degrades the quality of dispatched power thereby affecting sensitive loads connected to the grid[1]. Exhaustion of fossil fuels, their hazardous effect on environment and an increasing power demand results in an increased utilization of renewable energy sources into the utility grid. Li-ion batteries though costly have higher power density and can withstand higher charging/discharging cycles than lead-acid batteries while NiMH batteries are costlier and have carcinogenic effects on the atmosphere in spite of having higher power density than Li-ion batteries[2]. LCPV collectors used in this work have a degree of concentration of 2.2 X which does not require any extra tracking mechanism and cooling arrangements for their cells.

This paper presents a complete hybrid system which comprising of wind turbines, PV, FC, electrolyzer, and battery storage system. In this paper, the Wind and solar systems acts as a primary generating systems which to fulfill the advantages of non-conventional sources, and therefore the Fuel Cell based electrolyzer combination is utilized in this paper for backup device.

2. Configuration of Proposed Hybrid System

The operational diagram for proposed stand-alone hybrid system is shown in Figure 1. This technique is thought-about as an entire "green" power generation system as a result of the most energy sources and storage system square measure all environmentally friendly. Once

*Author for correspondence

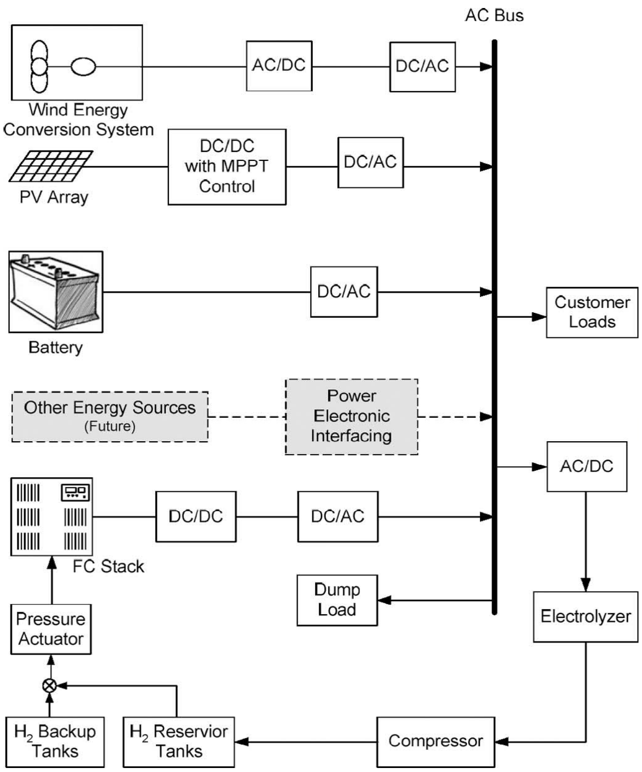

Figure 1. Basic architecture of hybrid system.

there's excess wind and/or solar generation offered, the electrolyzer activates to start manufacturing H that is delivered to the H storage tanks[3].

At the point when there's a shortage in power generation, the Fuel Cell stack can start to supply vitality exploitation H2 from the store tanks, or just on the off chance that they're vacant, from the reinforcement H2 tanks. Battery bank is furthermore used in the framework to create transients in power to load homeless people, swells, and spikes.

3. PV Generation System

In electrical wonder (PV) framework, photovoltaic cell is that the essential component. PV exhibit is nothing however solar cells zone unit associated nonparallel or parallel for increasing required current, voltage and high power. It delivers the streams once light-weight ingested at the intersection, by the electrical wonder result. Figure 3 shows at a protection yield power trademark bends for the PV exhibit[4]. It is seen that a most divider attachment exists on each yield power trademark capacity. The Figure 3 demonstrates the (I-V) and (P-V) attributes of the PV cluster at very surprising star intensities.

The analysis of current expression from PV system is expressed as:

$$I = Iph - ID - Ish$$

$$I = Iph - Io[\exp (q\ VD / nKT)] - (VD / RS)$$

Figure 3 shows the Solar panel I-V characteristics with constant temperature and irradiance.

Figure 4 shows the characteristics of solar panel between Voltage and Power under different irradiance.

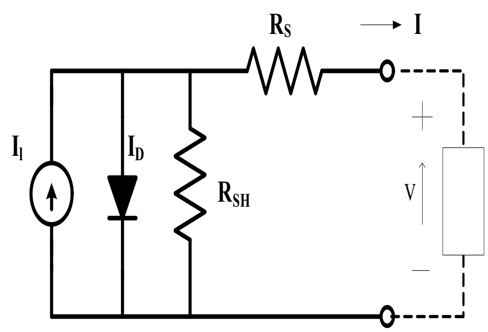

Figure 2. PV module electrical circuit.

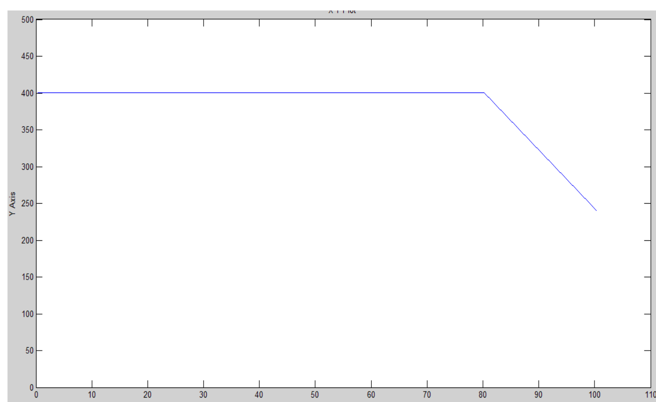

Figure 3. I-V characteristics of solar system.

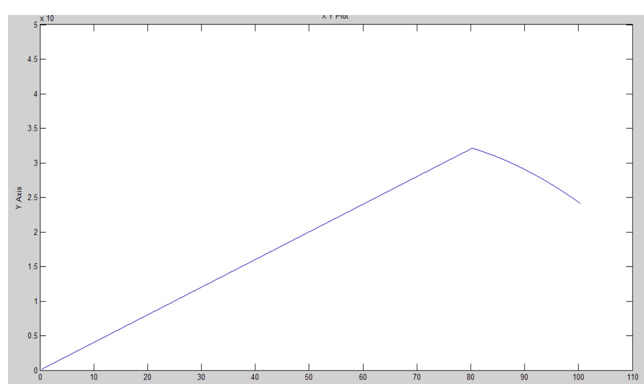

Figure 4. P-V characteristics of solar system.

4. Techniques for Maximum Power Point

The potency of turbine, electrical device is improved by MPPT after they set to control at purpose of most power. In several techniques MPPT the foremost in style techniques are: progressive electrical phenomenon technique, Perturb and Observe, symbolic logic, neural networks[5]. Initial electrical phenomenon array reference voltage and therefore the rotor speed for generator and for the turbine area unit modified if the 2 systems output powers area unit doesn't match to their most powers.

5. Perturb and Observe MPPT Algorithm

The main aim of this MPPT technique is to repeatedly observe the solar array voltage and measures the corresponding changes in output power. The main disadvantage of this algorithm is it forces the system to oscillate around MPP instead of continuously tracking it. This algorithm fails under rapidly changing environment. So this algorithm is not preferable under rapidly changing environmental conditions[5, 6]. It is designed to overcome the drawbacks of P&O algorithm under rapidly changing environmental conditions. In this algorithm the increase and decrease operations are performed continuously to achieve maximum power point in one direction. The output is continuously compared with previous to have better output.

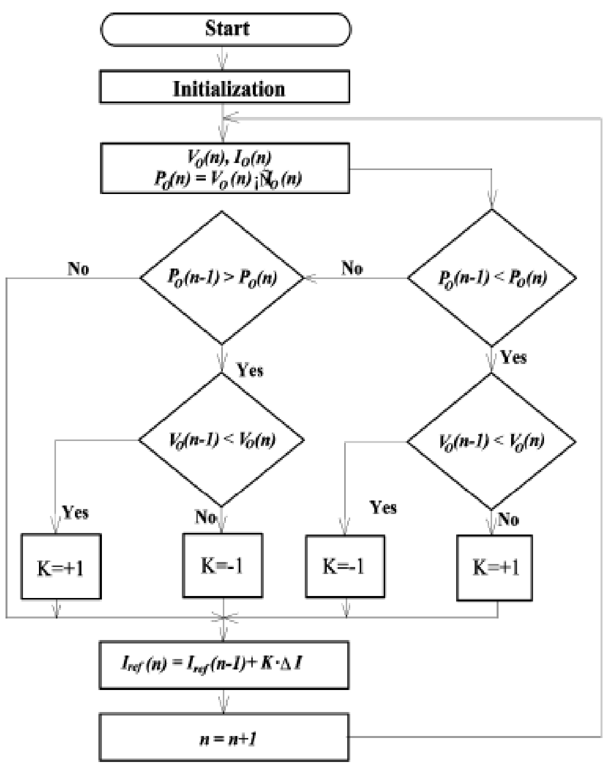

Figure 5. Algoritham for P&O based MPPT.

6. WIND TURBINE

Wind turbines square measure classified into 2 general types: Horizontal axis wind turbine and Vertical axis wind turbine. A vertical axis wind machine has its blades rotating on axis perpendicular to the bottom. The square measure variety of obtainable styles for each and every kind has bound benefits and downsides[7].

The wind turbines with a squirrel cage generator are equipped with a soft starter mechanism for reactive power compensation as coop generators consume reactive power. This generator and also the turbine rotor area unit coupled through a shell, because the best rotor and generator speed ranges are totally different.

7. Fuel Cell Model

The electro chemical process takes place at the anode side in the fuel cell and the H_2 molecules are also brought by

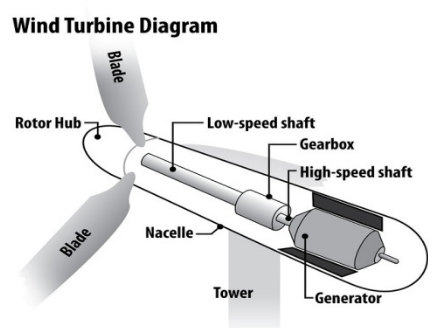

Figure 6. Basic wind turbine system.

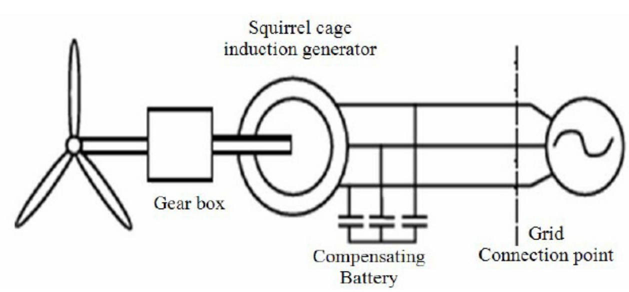

Figure 7. SCIG based WES.

the flow plate channels at the anode side. The catalyst which is present in anode can separate the hydrogen on the protons H^+ through proton membrane that the proton moves to the cathode and over the exterior circuit electrically the electrons travel to cathode. Catalyst usage at cathode gives oxygen combined with hydrogen protons and electrons for the formation of the H_2o and heat. And the reaction gives[8, 9].

$$H_2 \rightarrow H_2O + 2e^-(Anode)$$

$$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O(Cathode)$$

$$\Delta g_g = \Delta g^o{}_f - RT_{fc}[\ln(PH_2) + 0.5\ln(PO_2)]$$

The Gibb's free energy at the basic standard pressure is, Δg^0_f, T_{fc} is the PEM standard temperature $P_{O2,}$ P_{H2} shows the gas pressures and R is the universal gas constant. Fuel cell electrical work expression along with the chemical energy release is[10].

$$E = -\left(\frac{\Delta_{gf}}{2F}\right)$$

Due to the activation loss by cathode and anode the formation of electron-proton chemical bonds and breaking takes place, at the current zero through membrane hydrogen proton migration is caused by the parasitic electrochemical reactions. The fuel cell voltage drop is expressed as

$$V_{act} = V_0 + V_a(1 - e^{-C_1 i})$$

8. Fuel Cell Equivalent Electric Circuit

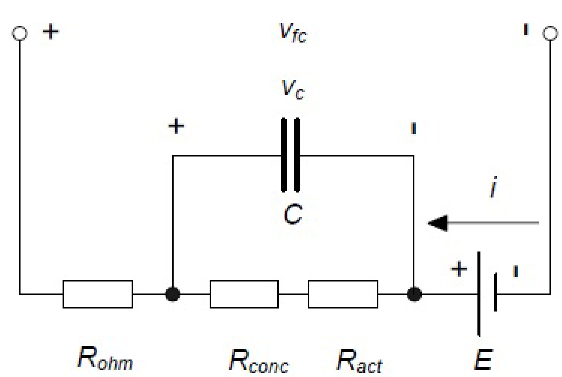

Figure 8. Equivalent circuit: Fuel cell system.

$$V_{fc} = E - V_c - iR_{ohm}$$

$$C\frac{dV_C}{dt} + \frac{V_C}{R_{act} + R_{conc}} = i$$

$$V_{fc} = E - \left(\frac{R_{act} + R_{conc}}{\left(sc\left(R_{act} + R_{conc} + 1\right)\right)} + R_{ohm}\right)i$$

9. Electrolyzer

The main purpose of electrolyzer is to decompose the electrical current into water molecules such as hydrogen and oxygen. From Faraday's law, the hydrogen production rate in particular associated electrolyzer cell is generally proportional to electrodes electrons transfer rate[11, 12], the expression for hydrogen production is expressed in below equation and shown in Figure 7

$$n_{H_2} = \frac{\eta_F . n_n . i_e}{2F}$$

Here, faraday efficiency is defined as relation between theoretical and actual values of hydrogen produced in electrolyzer. Let us consider the electrolyzer operating temperature is 40°C, efficiency of Faraday is expressed by:

$$\eta_F = 96.5\lambda\left[e^{\frac{0.09}{i_e} - \frac{75.5}{i_e^2}}\right]$$

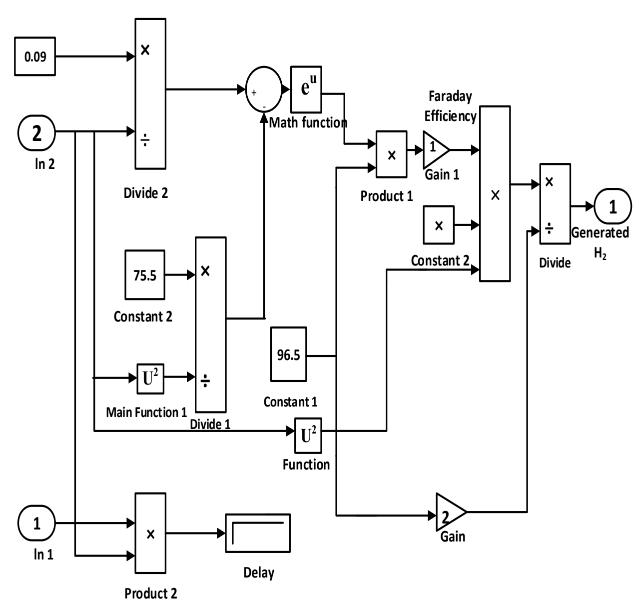

Figure 9. Block diagram for electrolyzer.

10. Hydrogen Storage System

Generally, this storage system is a physical hydrogen storage tank which is used to store either in the of form compressed hydrogen gas or in the form of liquid hydrogen[13].

Figure 8 shows the control diagram which is used for calculating tank pressure from the corresponding hydrogen flow to the tank. And the simulation is also done based on the figure shown in 8.

11. Control Structure

Figure 9 shows the complete control strategy of hybrid system for effective power management strategy. In this, the wind energy is generally controlled using pitch angle controller and an MPPT technique for controlling Photovoltaic system[1,14]. The power balancing equation for total hybrid system is expressed below,

$$Pnet = Pwind + PPV - Pload - Psc$$

12. SMC Controller

The state of charge for fuel cell is the main considerable parameter for maintaining under suitable range (VNom/2 ≤ VUC ≤ VNom). Coming up with a desired $V_{BUS}(t)$,[15] it directly defines the operating point of fuel cell. And the sliding mode controller for fuel cell system is shown in Figure 10. The surface of the siliding is expressed as,

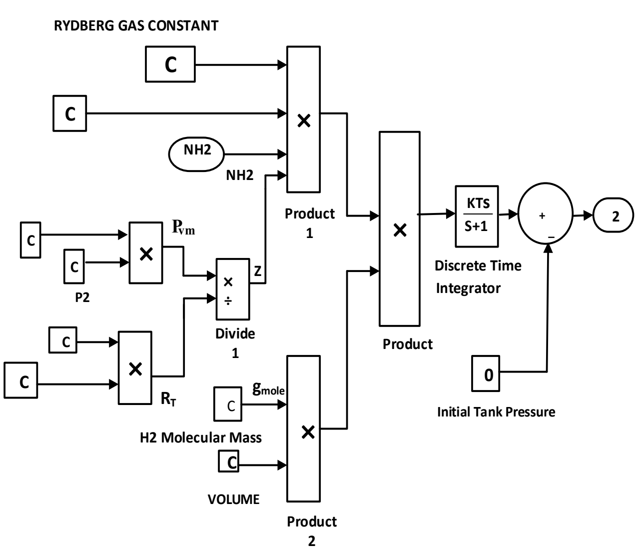

Figure 10. Block diagram for H_2 generation system.

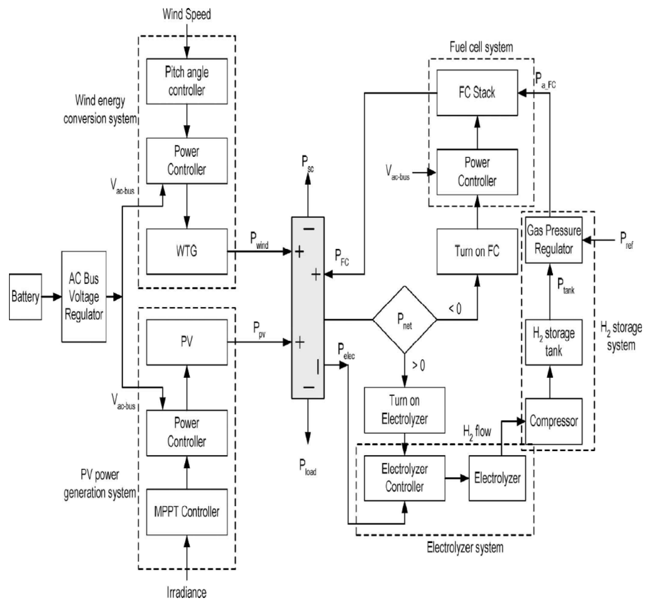

Figure 11. Control diagram for power management strategy in hybrid system.

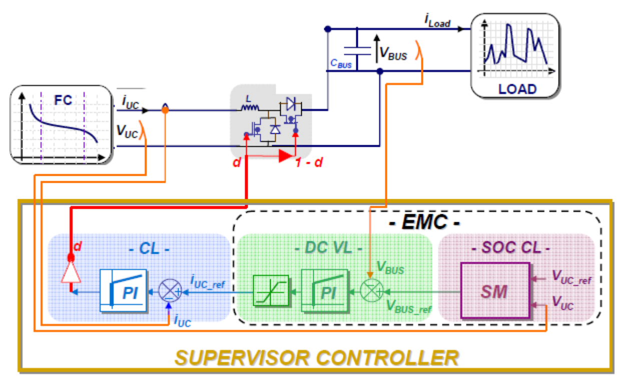

Figure 12. Sliding mode controller in FC system.

$$S(t) = \tau(t) + \tau \frac{d\tau(t)}{dt}$$

$$V_{BUS_{ref}}(t) = \int u dt$$

$$u = -\alpha sign(S)$$

From the simulations, we observe high speed transient behaviour which shows effect on the FC, given its low rate dynamic requirments. In order to overcome these limitations, a SM controller has been introduced for the reduction of convergence of robust to sliding surface in limited time. In the above expression α can be defined as the tuning parameter based on sliding surface rate of convergence.

Figure 11 shows the simulation result for output voltage from the fuel cell. Generally, the output at fuel cell is non-linear. For the output to be constant a sliding mode based DC-DC converter is proposed. The basic control diagram for sliding mode based fuel cell system is shown in Figure10. The experimental result for SMC based fuel cell system is shown in Figure 12.

13. Simulation Diagram and Results

The simulation can be done based on Figure 1. The experimental verification for proposed grid based hybrid unit is done under two cases based on the weather conditions of solar system.

Case 1: Summer Scenario

In this case the performance of the system is observed for different load demand conditions under criteria of summer scenario. The performance result for this case is represented in Figure 13. Figure (a) represents the simulation result for Wind power. Figure 13 (b) shows the output result for Solar Power. The hydrogen rate for this system is shown in Figure (c). The simulation result for load voltage for complete hybrid system is shown in Figure 14.

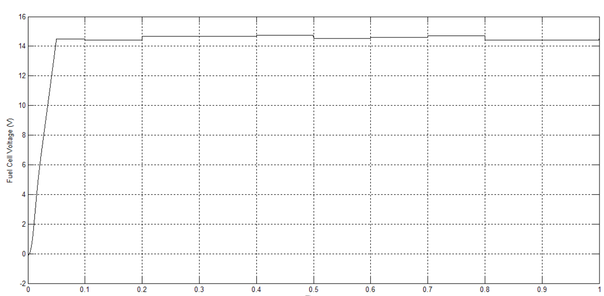

Figure 13. Simulation results for fuel cell voltage.

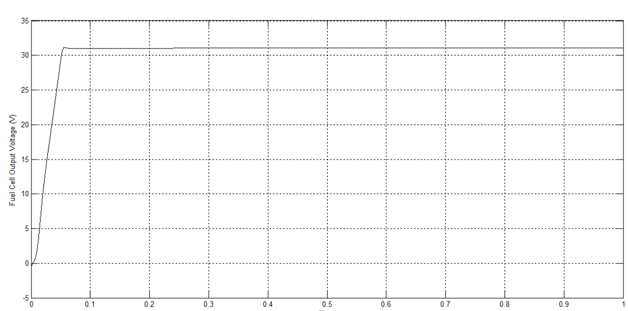

Figure 14. Simulation results for SMC based fuel cell voltage.

Case 2: Winter Scenario

In this case the performance of the system is observed for different load demand conditions under criteria of winter scenario. The performance result for this case is represented in Figure 15. Figure (a) represent the output result for Wind power. Figure 15 (b) shows the output result for Solar Power. The hydrogen rate for this system is shown in Figure 15 (c).

Case 3: During Fault Conditions

In this case a fault is created between the time 0.1s to 0.3s. Because of this fault the hybrid system is effected with some distortions. In order to overcome this distortion an active filter is considered. The Figure 16 shows the simulation results for load voltage during fault and its compensation.

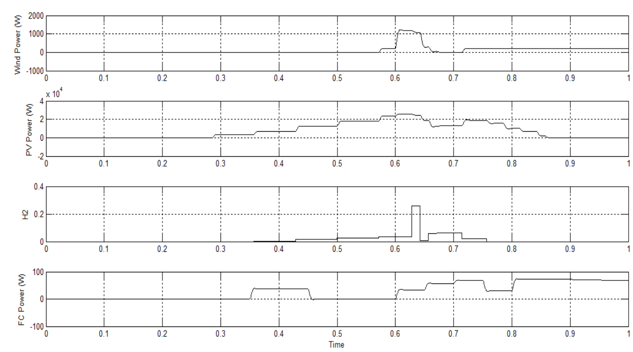

Figure 15. Simulation results for hybrid system under summer scenario.

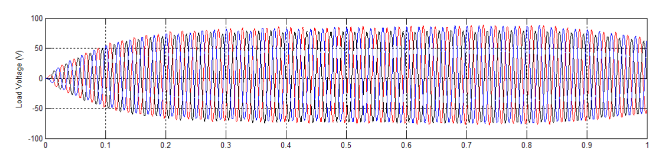

Figure 16. Simulation results for load voltage.

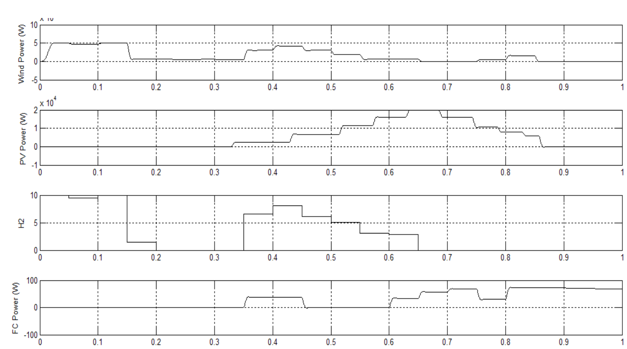

Figure 17. Simulation result for hybrid system under winter scenario.

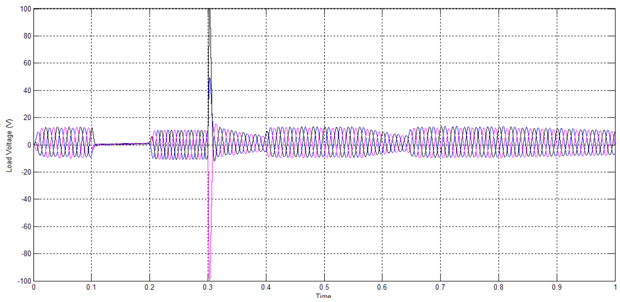

Figure 18. Simulation result for load voltage during fault condition.

From result, the fault is created during the time 0.1sec to 0.3 sec. and the shunt filter is connected from 0.2 sec to 0.3 sec for reducing the harmonics as shown in Figure 16.

14. Conclusion

This paper, proposes a concept of grid connected stand-alone wind/PV/FC various energy system. This mainly concentrate on the proposal of power management strategy of hybrid system. In this the Wind and Solar systems are acting as a generation systems and the electrolyzer used in this paper behaves as dump load. And the fuel cell is for backup energy generation device and deliver power to hybrid system if there is any power deficit from primary sources. From the experimental result we observed the performance of hybrid stand-alone system under different variations in photovoltaic system. And also by using shunt active filter the harmonics which causes during fault scenario is successfully compensated.

15. References

1. Global wind 2007 report. Global wind energy council [Internet]. Available from: http://www.gwec.net/index.php?id=90.
2. Wind power today—Federal wind program highlights. NREL, DOE/GO- 102005-2115; 2005 Apr.
3. Trends in photovoltaic applications: Survey Report of selected IEA countries between 1992 and 2004. International Energy Agency Photovoltaics Power Systems Programme (IEA PVPS); 2005 Sep.
4. Agbossou K, Kolhe M, Hamelin J, Bose Tk. Performance of a stand-alone renewable energy system based on energy storage as hydrogen. IEEE Transactions on Energy Conversion. 2004 Sep; 19(3):633–40.
5. Nelson DB, Nehrir MH, Wang C. Unit sizing and cost analysis of stand-alone hybrid Wind/PV/fuel cell systems. Renewable Energy. 2006 Aug; 31(10):1641–56.
6. Lasseter R. Dynamic models for micro-turbines and fuel cells. 2001 PES Summer Meet. 2001; 2:761–6.
7. Zhu Y, Tomsovic K. Development of models for analyzing the load following performance of micro turbines and fuel cells. Electric Power Systems Research. 2002; 62:1–11.
8. Chan SH, Ho HK, Tian Y. Multi-level modeling of SOFC-gas turbine hybrid system. International Journal of Hydrogen Energy. 2003 Aug; 28(8):889– 900.
9. Dehbonei H. Power conditioning for distributed renewable energy generation. Ph.D. dissertation, Curtin University of Technology, Perth, W.A., Australia; 2003.
10. Lehman PA, Chamberlin CE, Pauletto G, Rocheleau MA. Operating experience with a photovoltaic-hydrogen energy system. Presented at the Hydrogen 1994: 10thWorld Hydrogen Energy Conference, Cocoa Beach, FL; 1994 Jun.
11. Arkin A, Duffy JJ. Modeling of PV, electrolyzer, and gas storage in a stand-alone solar-fuel cell system. 2001 National Solar Energy Conference, Annual Meeting, Am. Solar Energy Soc., Washington, DC; 2001.
12. Torres LA, Rodriguez FJ, Sebastian PJ. Simulation of a solar hydrogen- fuel cell system: Results for different locations in Mexico. International Journal of Hydrogen Energy. 1998 Nov; 23(11):1005–10.
13. Vosen SR, Keller JO. Hybrid energy storage systems for standalone electric power systems: Optimization of system performance and cost through control strategies. International Journal of Hydrogen Energy. 1999 Dec; 24(12):1139–56.
14. El-Shatter ThF, Eskandar MN, El-Hagry MT. Hybrid PV/fuel cell system design and simulation. Renewable Energy. 2002 Nov; 27(3):479–85.
15. Azib T, Talj R, Bethoux O. Sliding mode control and simulation of a hybrid fuel-cell ultracapacitor power system. 2010 IEEE International Symposium on Industrial Electronics (ISIE), 2010 Jul 4–7; 2010 Nov 15.