FUZZY BASED OPTIMIZED ENERGY MANAGEMENT STRATEGY OF RENEWABLE ENERGY SOURCES FOR STAND ALONE APPLICATIONS

R.Karthick, S.Manoharan
Department of Electrical and Electronics Engineering, SNS College of Technology, Coimbatore-641035, India
Department of Electrical and Electronics Engineering, Karpagam College of Engineering, Coimbatore-641032, India
karthick.ketti@gmail.com, manoish07@yahoo.co.in,

Abstract: *This paper proposes an optimized Energy Management System for a hybrid power system which includes a wind turbine, solar PV, fuel cell, an electrolyzer with hydrogen storage and a battery. From the list of the above sources, wind and solar systems are considered as primary sources of energy. It is very vital to manage the energy sources in a hybrid power system in order to provide a continuous supply to meet the load demand. The 'B' block load consisting of only fans of our institution(SNS College of Technology, Coimbatore) is considered as load profile to verify the proposed scheme. In this paper, a fuzzy logic based energy management system is used to maintain the State of Charge (SOC) of battery as well as the pressure level of hydrogen tank and thereby meet the load demand in an optimized manner. Optimal management of the hybrid power system under different source and load conditions was simulated using MATLAB/SIMULINK software.*

Key words: Hybrid system, energy management strategy, wind generator(WG), fuel cell(FC), electrolyzer(EL), Fuzzy Logic.

1. Introduction

Energy sources can be classified into renewable and non renewable energy sources. Non-renewable sources include fossil fuels and nuclear material that are extracted from the earth and are depleting at a rapid pace. Moreover these sources are the primary cause of CO2 emission which causes environmental pollution. On the other hand, renewable resources such as wind, water, solar, and geothermal, regenerate as fast as they are consumed and are clean in nature. Increased population, with increased energy consumption along with climate change and limitation of fossil fuels results in the increased usage of renewable energy sources. Wind and Solar energy are the primary renewable sources but are interim in nature and depends on uncontrollable parameters like wind speed and sun irradiance, therefore these sources should be always provided with energy storage devices.

Therefore a Hybrid power system seems to an alternative for supplying isolated sites. The renewable energy sources combination with energy storage can compliment each other to provide a continuous and reliable supply to isolated sites. Ref [1] – [5] highlights some important issues and challenges in the design and management of hybrid sources. System configuration, generator unit sizing, storage needs and energy management are addressed. Also the latest status of fuel cell technology development and its application in the transportation, stationary and portable micro power generation are discussed in these papers.

The hybrid energy system requires an efficient energy management system, so that the sources are utilized efficiently at low cost. In ref [6], the authors have discussed two power management strategies and compared their performance experimentally. The control system discussed is to co-ordinate the various sources, particularly their power exchange in order to meet the load demand reliably. Hybrid system consisting of wind turbine and micro turbine are addressed in ref [7]. In this reference the energy management is optimized using particle swarm optimization. Actual wind and end-use load profile were used for simulation studies. Various techniques of modeling, control and simulation of hybrid power system is discussed in Ref [7]-[10]. In Ref[11] an optimized energy management based on fuzzy logic was discussed where a fuzzy controller based on 3 inputs and 2 outputs was designed to manage the battery SOC and hydrogen level of the overall EMS (Energy Management System).

It is very vital to control all the energy components of the hybrid system to ensure reliability and continuous supply[12]. In this paper a fuzzy logic controller is designed to provide an optimized energy management to manage the sources depending on the real time load profile of SNS College of Technology, Coimbatore. The fuzzy rules for both sources and load parameters are developed for an optimized energy management.

The rest of the paper is structured as follows; section II describes stand-alone hybrid system. Section III explains modeling of components of the hybrid system. Section IV describes the fuzzy based optimized energy management [13]-[15]. Simulation results are described in section V and concluding remarks are given in section VI.

2. Stand Alone Hybrid System

The hybrid power system consists of a photovoltaic system, wind turbine, fuel cell, an electrolyzer and energy storage devices along with fuzzy controlled energy management system is shown in the Fig.1. The rating choose for photovoltaic system is 6kW and the rating of wind turbine is 5kW.A proton exchange membrane fuel cell is considered with rated power 4kW and the battery considered is 2kW in order to meet 15kW load demand.

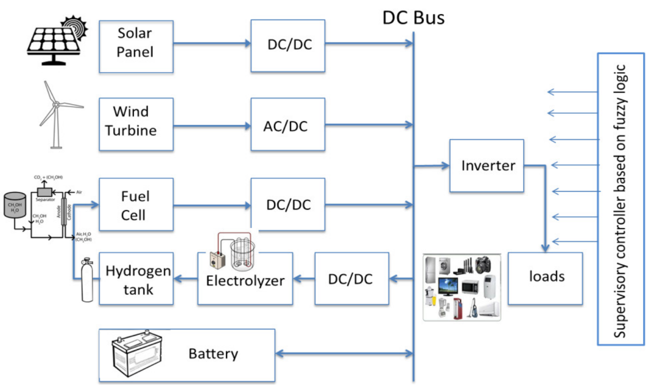

Fig.1. Block diagram of the hybrid power system

3. Modeling of the Components of Hybrid Power System

A. Wind Generator

Based on the turbine, wind energy conversion systems are of two types a) fixed speed b) variable speed wind turbine. The speed of the turbine is adjusted in order to capture maximum power in VSWT (Variable Speed Wind Turbine) whereas the turbine speed is fixed in FSWT (Fixed Speed Wind Turbine) in spite of varying wind speed [16].
The power in the wind is given by kinetic energy of air,

$$P_{air} = \frac{1}{2}\rho A V_w^3 \tag{1}$$

The power transferred to the wind turbine rotor is reduced by the power coefficient, Cp

$$C_p = \frac{P_{windturbine}}{P_{air}} \tag{2}$$

$$P_{windturbine} = C_p * P_{air} \tag{3}$$

$$= \frac{1}{2}\rho A V_w^3 \tag{4}$$

The aerodynamic power of the wind turbine is

$$P_{out} = \frac{1}{2}\rho \Pi R_w^2 V_w^2 C_p \tag{5}$$

The power coefficient Cp is related to the tip speed ratio (TSR) and pitch angle β

$$\lambda = \frac{\omega R}{V} \tag{6}$$

The tip speed ratio λ and the power coefficient Cp are dimension less and so can be used to describe the performance of any size of wind turbine rotor [17]. The wind turbine can produce maximum power when turbine operates at a maximum Cp. Therefore it is necessary to keep the rotor speed at an optimum value of the tip speed ratio λ_{opt}. The turbine is coupled to PMSG (Permanent Magnet Synchronous Generator) for the conversion of mechanical energy into electrical energy.

The voltage equation of the PMSG in the dq-axes reference frame can be expressed as follows

$$V_{sd} = R_s i_{sd} + L_s \frac{d}{dt} i_{sd} - \omega p L_s i_{sq} \tag{7}$$

$$V_{sq} = R_s i_{sq} + L_s \frac{d}{dt} i_{sq} + \omega p L_s i_{sd} + \omega p \varphi_m \tag{8}$$

$$T_{em} = p \varphi_m i_{sq} \tag{9}$$

(b). PV Model:

The PV module is a device which converts naturally available sunlight into electricity. Actually the solar cell acts as an interface which converts photons to electricity. The output from solar cell depends on various factors like sun irradiance and temperature which are natural parameters. Therefore it is very important to accurately model the solar PV module to reflect the above factors. An ideal solar cell is theoretically modeled as a current source in anti-parallel with a diode. Since the losses in a practical solar cell in inevitable, the practical model includes a series and a parallel resistance to make up the losses. Therefore the solar cell can be modeled as

$$I = I_L - I_0 \left[e^{\frac{(V+IR_s)q}{akT_{ck}}} - 1 \right] - \frac{V + IR_s}{R_{sh}} \tag{10}$$

Where the symbols are defined as follows:

I_L = current proportional to incident light (irradiation)

I_0 = saturation current of the diode (A)

V = cell voltage (V)

q = charge of an electron (1.6×10^{-19}C)

a = diode ideality constant

k= Boltzmann's constant (1.38×10^{-23} J/K)

T_{ck} = cell temperature.

Both k and Tc should have the same temperature unit, either Kelvin or Celsius [18]. The solar cell can be seen as a current generator, which generates the current (density) Jsc. The dark current flows in the opposite direction and is caused by a potential between the + and - terminals. In addition it would have two resistances; one in series (Rs) and one in parallel (Rp). Thus the above equation represents the output current from a solar cell that depends on sun's irradiation, atmospheric temperature, voltage of solar cell etc.

(c). Proton Exchange Membrane Fuel Cell:

A fuel cell is a device that converts the chemical energy of a fuel and an oxidant directly into electricity. Hydrogen is the fuel which is stored in a tank.

The empirical formula for fuel cell voltage is

$$V_{fc} = E_{cell} - V_{act} - V_{con} - V_{ohmic} \quad (11)$$

Where E_{cell} is the thermodynamic potential of the cell, V_{act} is activation overvoltage, V_{ohmic} is ohmic overvoltage and V_{con} is concentration over voltage.

A single fuel cell will produce less than one volt of electrical potential. To produce higher voltages, fuel cells are stacked on top of each other and connected in series.

$$V_{stack} = n_{fc} * V_{fc} \quad (12)$$

Where n_{fc} is the number of cells in series and V_{fc} is the voltage of single fuel cell. Modeling of the fuel cell depends on the pressure of hydrogen tank [19]-[20].

(d) Electrolyzer:

Electrolyzer plays an important role in the hybrid system. An electrolyzer is a well known electrochemical device which uses electrical current to split water into hydrogen and oxygen [18]-[19]. According to Faraday's law, the production rate of hydrogen in a electrolyzer cell is proportional to the electrical current in the circuit.

$$n_{H_2} = \frac{\eta_F . \eta_n . i_e}{2F} \quad (13)$$

$$\eta_F = 96.5 \times \left[e^{\frac{0.09}{i_e} - \frac{75.5}{i_e^2}} \right] \quad (14)$$

η_{H_2} = Hydrogen production rate, mol s^{-1}

η_F = Faraday's efficiency

n_c = The number of electrolyzer cells in series

i_e = Electrolyzer current [A]

F = Faraday constant [C kmol-1]

(e) Hydrogen Storage Tank:

Oxygen in water during electrolysis is usually released to the atmosphere whereas hydrogen which is absolutely non-poisonous is stored in a tank.

$$P_b - P_{bi} = Z \times \frac{N_{H2}\, RT_b}{M_{H2}\, V_b} \quad (15)$$

P_{bi} = Pressure of tank (pascal)

P_b = Initial pressure of the storage tank (pascal)

R = Universal (rydberg) gas constant (J/kmol K)

T_b = Operating temperature (K)

V_b = Volume of the tank (m^3)

Z = Compressibility factor as a function of the pressure

$Z = \frac{PV_m}{RT}$, P = pressure, V_m = molar volume,

T = temperature

(f) Battery:

Developing technology to store electrical energy so that it can be available to meet demand whenever needed would represent a major breakthrough in electricity distribution. The storage battery or secondary battery is such battery where electrical energy can be stored as chemical energy and again converted to electrical energy whenever required. The battery utilizes the excess energy to store energy, known as charging of battery. When the load demand exceeds the source, the deficient energy is supplied by the battery known as discharging of battery [21].

Lead acid battery is modeled and the electrochemistry equation are given as,

Negative plate reaction:

$$Pb(s) + HSO_4^-(aq) \rightarrow PbSO_4(s) + H^+(aq) + 2e^- \quad (16)$$

Positive plate reaction:

$$PbO_2(s) + 3H^+(aq) + HSO_4^-(aq) + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l) \quad (17)$$

The total reaction can be written as

$$Pb(s) + PbO_2(s) + 2H_2SO_4(aq) \rightarrow 2PbS_4(s) + 2H_2O(l) \quad (18)$$

4. Fuzzy Based Optimized Energy Management

In this paper, a fuzzy based optimized energy management strategy is developed, which acts as a supervisory controller for ensuring a proper coordination of energy generating units and loads [10-11]. The strategy first compares the load power to the source powers and then the sources are allocated accordingly, giving importance to the renewable sources, wind and fuel cell. The operating modes of the system are summarized in table 1.

Table 1
Modes of System Operating Conditions

Mode	Operating conditions
Mode 1	• The output power from solar is equal to the load demand ($P_{solar} = P_L$)
Mode 2	• The output power from solar is higher than the load demand ($P_{solar} > P_L$) • Surplus power is utilised by electrolyzer and battery • SOC of the battery is high or low
Mode 3	• The output power from solar is less than the load demand ($P_{solar} < P_L$) • The load power is less than the sum of power from solar and wind ($P_{wind} + P_{solar} \geq P_L$)
Mode 4	• The output power from solar is less than the load demand ($P_{solar} < P_L$) • The load power is less than the sum of power from solar, fuel cell and wind ($P_{solar} + P_{wind} + P_{fc} \geq P_L$) • State of Charge (SOC) of battery is high or low

Mode 5	• The output power from solar, wind, fuel cell and battery is less than the load demand ($P_{batt}+ P_{wind}+P_{fc}< P_L$)

The fuzzy conditions for sources and load are shown in the table 2&3

Table 2
Fuzzy Conditions for Sources

SOURCES (kW)	LOW (kW)	MEDIUM (kW)	HIGH (kW)
Solar (6)	0.51-2.00	2.01-4.00	4.01-6.00
Wind (5)	0.51-1.50	1.51-3.50	3.51-5.00
Fuel Cell (4)	0.51-1.50	1.51-2.50	2.61-4.00
Battery (2)	0.51-1.00	1.01-1.50	1.51-2.00

Table 3
Fuzzy Conditions for Load

	LOW (kW)	MEDIUM (kW)	HIGH (kW)
LOADS	0-5.00	5.01-10.00	10.01-15.00

The fuzzy rules are formed based on the conditions provided with sources and load data. Mamdani fuzzy controller is used, which has 5 inputs and 7 outputs. There are more than 200 feasible combinations available with the given inputs and outputs. Some selective combinations are shown in the table 4.

The source has to be allocated depending upon the load demand. The real time loads at our institution are considered as shown in table 5. The total load is approximately 143 kW, which includes fan, lights and machines loads. Considering only the fan loads i.e. 15kW, the ratings of the hybrid power system is provided. Therefore fuzzy based management strategy is used to allocate the sources in order to meet the demand.

Table 5
Load Parameters

LOADS	CONSUMPTION IN kW
Lights	13
Fan	15
Computers	20
Other Loads	94

5. Simulation Results

The proposed hybrid system consists of a PV, wind generator, a fuel cell, an electrolyzer, battery and inverter. The photovoltaic system supplies the load, when the load demand decreases the surplus energy is utilized by the electrolyzer. The electrolysis process is carried out in electrolyzer where the water gets splits into hydrogen and oxygen. The hydrogen is stored in the tank which serves the input to the fuel cell. The battery also utilizes the excess energy. When the demand is greater than generation, the deficient power is supplied by the wind. When wind generation does not meet the demand, fuel cell supplies the load by utilizing hydrogen from the tank. When the pressure in the tank decreases the fuel cell cannot support the load, then the battery supports the load. The condition when the battery is unable to support the load demand the unit is completely shut down. The performance of the proposed system can be evaluated under varying source and load conditions. The complete simulation diagram of entire system is shown in fig.2.

Photovoltaic System

A 6kW solar panel is designed in MATLAB. The PV array has been modeled using the equations. The PV array has been interfaced with the boost converter as shown in the fig.3.

The PV array has been designed taken into consideration its dependence upon the irradiance, temperature, number of PV cells connected in series and parallel. The PV array is interfaced across the boost converter. The output waveforms of the PV array and the boost converter are shown in the fig 4.

Table 4
Fuzzy Rules for Hybrid System

load	pv	wind	fc	batt	sw1 (p)	sw2 (w)	sw3 (f)	sw4 (b)	sw5 (l)	sw 6 (f) char	sw7 (b) char	sw8 (dl)
L	m	l	h	H	on	on	on	on	on	off	off	off
	m	l	l	L	on	on	on	on	on	off	off	off
M	m	m	l	L	on	on	off	on	on	off	off	off
	m	l	h	L	on	on	off	on	on	off	off	off
H	h	l	h	H	on	off	off	on	on	off	off	off
	h	h	h	H	on	on	off	on	on	off	off	off

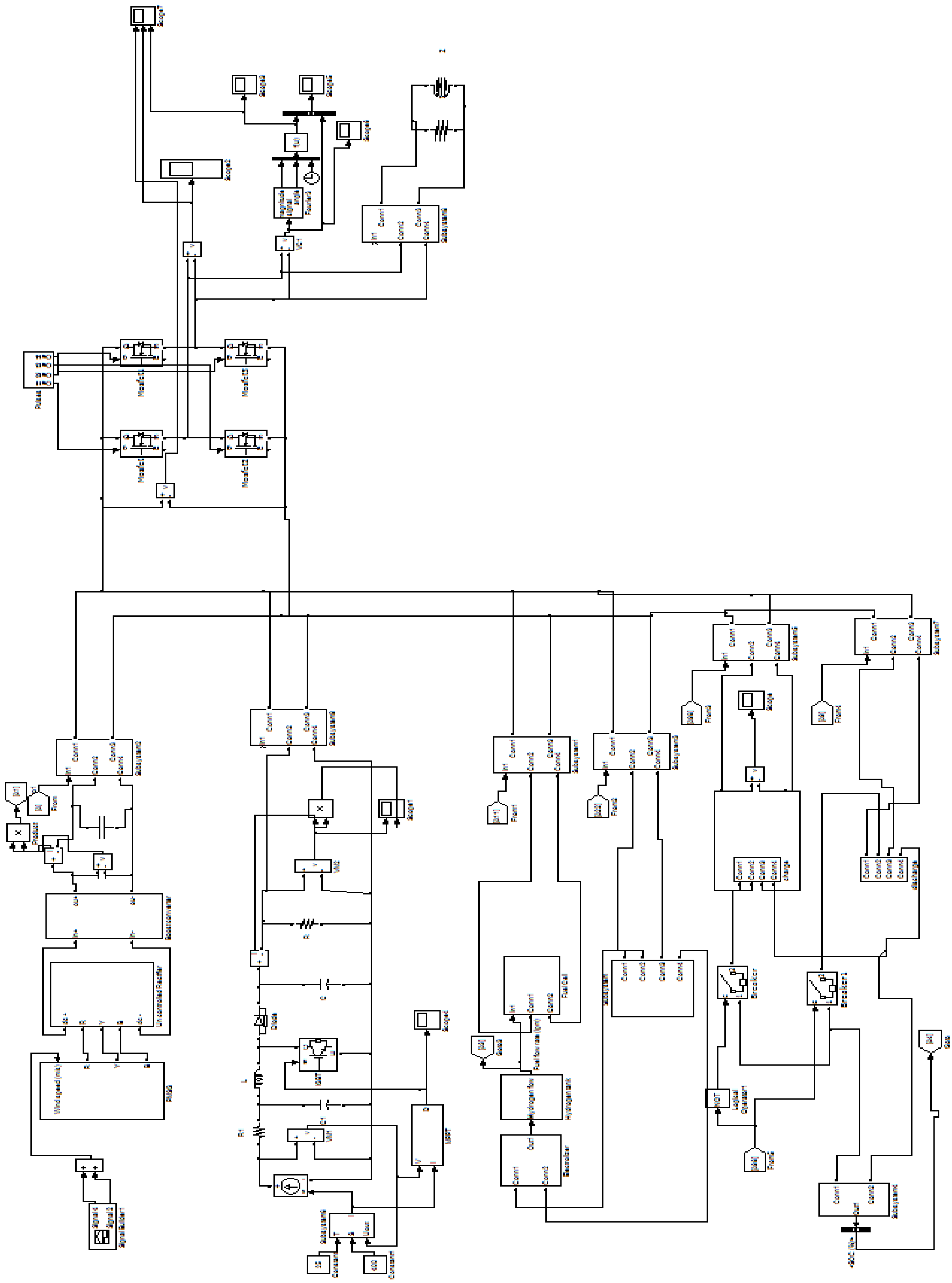

Fig.2.Simulation Model of the Overall System

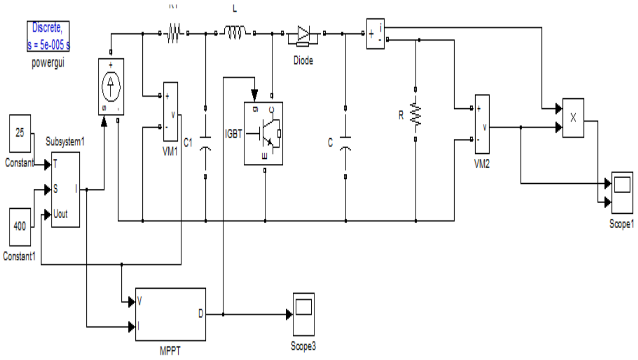

Fig.3.Simulation of PV With Boost Converter

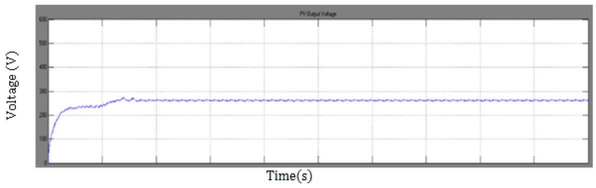

Fig.4.Output of PV Panel with DC/DC Converter

Wind Energy Conversion Unit

The amount of power that a wind turbine can extract from the wind depends on the turbine design. Factors such as the wind speed and the rotor diameter affect the amount of power that a turbine can extract from the wind.

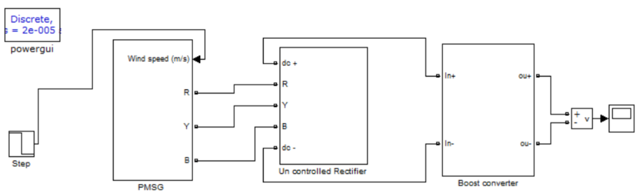

Fig.5. Simulation Model of WECS

Fig.5 describes wind energy conversion model consisting of PMSG model with uncontrolled rectifier and the boost converter. Due to the unpredictable characteristics of the wind, the output voltage from PMSG is variable so an uncontrolled rectifier with boost converter is used in order to get constant DC voltage. The fig.6 shows varying wind speed and the output voltage from PMSG.

Electrolyzer and Hydrogen Storage Unit

Electrolysis process is carried out in electrolyzer utilizing dc bus voltage and the hydrogen gas is stored in the hydrogen tank which is fed as the input to the fuel cell.

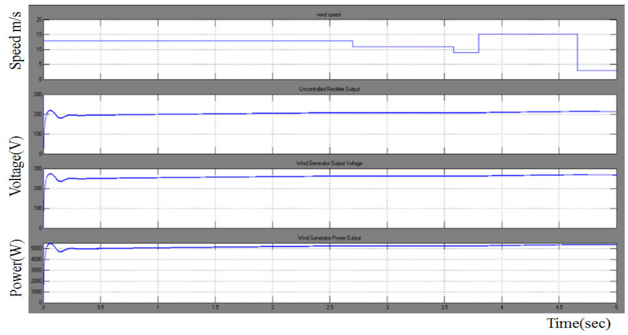

Fig.6 Output Waveform of Wind Energy Conversion Model

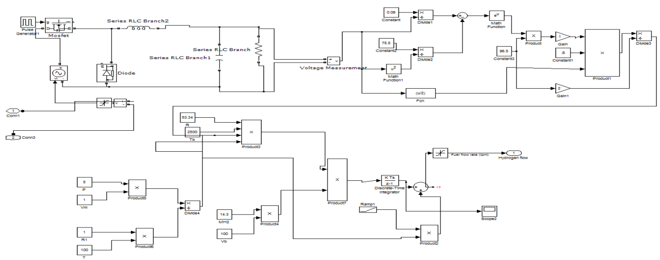

Fig.7 Simulation Model of Electrolyzer and Hydrogen Storage Tank

The electrolyzer and the hydrogen storage tank is modeled as shown in the fig.7.

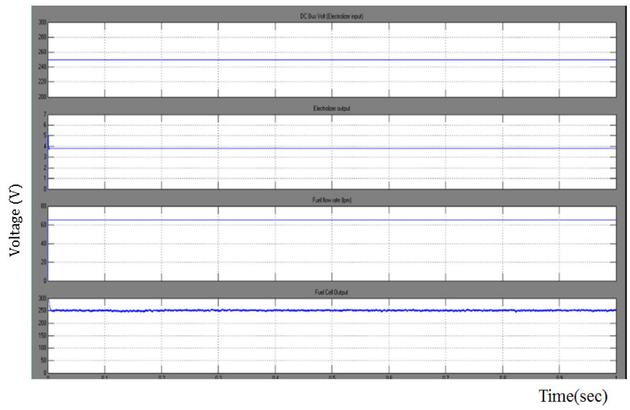

Fig.8.Output Waveform of Buck Converter

Fuel Cell Unit

Detailed descriptions of the individual component models required to simulate a hydrogen PEMFC (Proton Exchange Membrane Fuel Cell) hybrid system are presented. These models are mainly based on electrical and electrochemical relations.

A 4kW PEMFC is connected to a controller to achieve the suitable operating point. The output of the fuel cell is controlled to 250V so that it can be interfaced with the DC bus as shown in the fig.9.When the hydrogen flow rate is 65 bar it is fed into the fuel cell, where electrochemical reaction is carried out and the output voltage of fuel cell is 400V dc and again it is bucked to 250V since the DC bus voltage is 250V

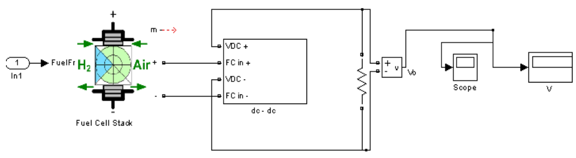

Fig. 9 Simulation Model of Fuel Cell

Battery Unit

A battery is used as energy storage to boost the power necessary to meet the load when weather conditions are not optimal**.**

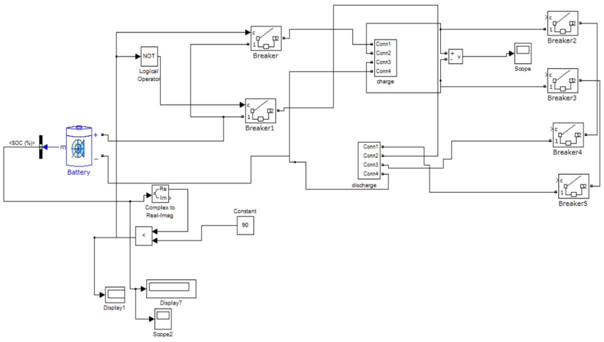

Fig.10 Simulation of Battery Model

The battery is modeled in such a way that when there is deficient in power the battery supports the source and when there is excess power it is utilized by the battery. The rating of the battery is 180V but the DC bus voltage is 250V hence during charging condition of battery the voltage is bucked using buck converter and during discharging condition the voltage is boosted using boost converter.

Inverter Unit

A DC/AC is used to generate AC waveform from the DC signal. Some harmonics have been found in the output of the inverter which has been eliminated using necessary filters as shown in fig.12.

DC bus voltage is converted into AC, again filter is used to eliminate harmonics in order to obtain pure

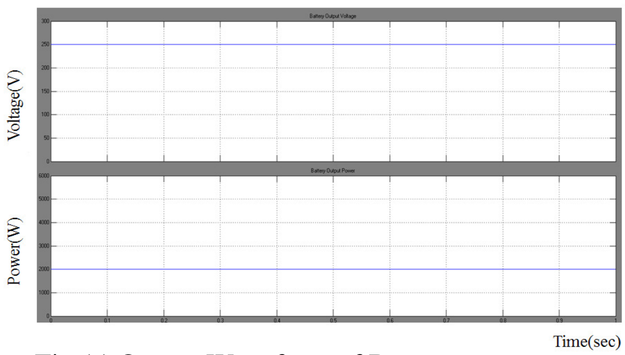

Fig.11 Output Waveform of Battery

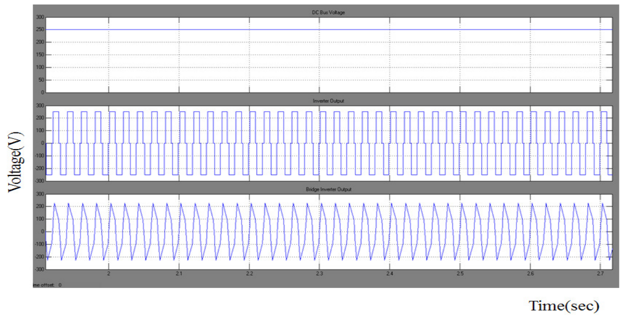

Fig.12 Output Waveform of Inverter

Fuzzy Controller Unit

There are two types of fuzzy logic controller Mamdani and Sugeno. In this project Mamdani fuzzy is used for the energy management of the hybrid system. It has 5 inputs and 7 outputs. The inputs are load demand, generation of solar, wind, fuel cell and SOC level of battery. The outputs are labeled as sw1, sw2, sw3, sw4, sw5, sw6, sw7, sw8 switches for solar, wind, fuel cell, battery discharging, load, electrolyzer charging, battery discharging and dump load respectively as shown in fig.13.

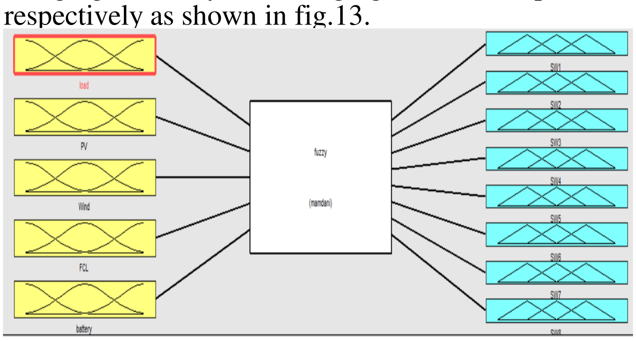

Fig.13 Mamdani Fuzzy Controller

Switching Sequence for Fuzzy Conditions

The fuzzy conditions are provided in the table 4. The output waveform for the first condition of the table 4 is shown in the fig.14.

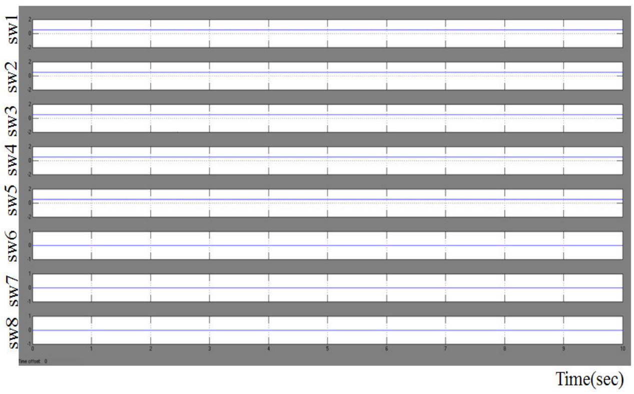

Fig.14 Output Waveform for Load Low Condition

When the load is in low condition and solar is medium and all other sources are low the then charging switches of electrolyzer, battery and dump load are in off condition, whereas solar, wind, fuel cell and battery are in on condition to meet the load demand.

When the load, solar and wind are in medium condition fuel cell and battery are low, similarly charging switches of electrolyzer, battery and dump load are in off condition, whereas solar, wind and battery supplies the load and fuel cell is in off state as shown in fig.15.

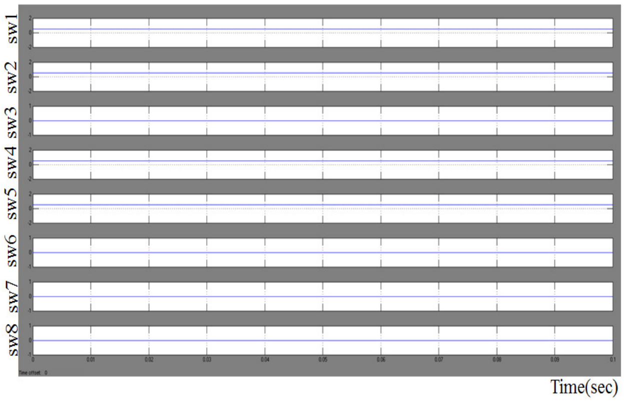

Fig.15 Output Waveform for Medium Load Conditions

When the load condition is high, sources like solar, fuel cell and battery are high only wind is in low condition all charging switches of electrolyzer, battery and dump load are in off state whereas solar and battery supplies the load and wind, fuel cell will be in off state as shown in fig.16. The switching sequences for the above conditions are consolidated in tabular form also as shown in table 6.

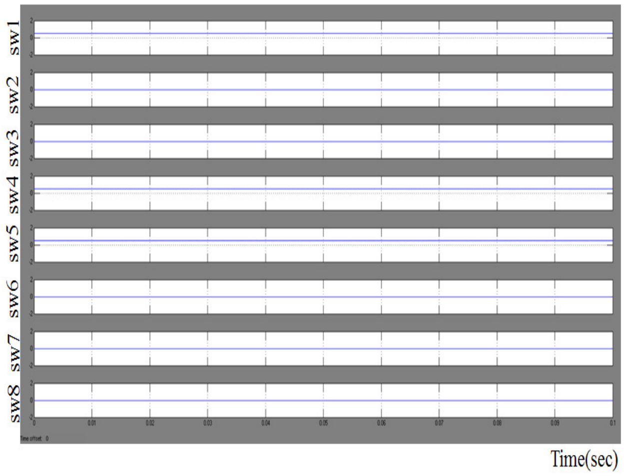

Fig.16. Output Waveform for High Load Conditions

Table 6
Operating sequence for various conditions

load	sw 1 (p)	sw 2 (w)	sw 3 (f)	sw 4 (b)	sw 5 (l)	sw 6 (f) char	sw7 (b) char	sw 8 (dl)
L	1	1	1	1	1	0	0	0
	1	1	1	1	1	0	0	0
M	1	1	0	1	1	0	0	0
	1	1	0	1	1	0	0	0
H	1	0	0	1	1	0	0	0
	1	1	0	1	1	0	0	0

6. Conclusion

This paper presents a fuzzy based optimized EMS for a standalone hybrid power system, consisting of Solar PV system and a wind turbine as primary renewable energy sources and battery, hydrogen system (FC, Electrolyzer and tank) as back up energy storage systems. The optimized controller monitors the battery SOC, hydrogen level and the net power and accordingly allocates the sources to meet the load. The ultimate aim of the control strategy is to provide continuous supply to meet the load. The controller performance under transient condition (like sudden load removal) is to be validated by implementing a hardware setup of the above system. Otherwise, the simulation results prove that the performance of the proposed system is satisfactory under different source and load conditions. Thus the ultimate aim to provide a continuous power supply to the load is achieved.

7. References

1. M. H. Nehrir, C. Wang, K. Strunz, H. Aki, R. Ramakumar, J. Bing, Z. Miao, and Z. Salameh.: A Review of Hybrid Renewable/Alternative Energy Systems for Electric Power Generation: Configurations, Control, and Applications. In: IEEE transactions on sustainable energy, vol. 2(2011), no. 4, October 2011, p.392-403.
2. Mehmed Eroglu, Erkan Dursun, Suat Sevencan, Junseok Song, Suha Yazici Osman Kilic.: A Mobile Renewable House using PV/Wind/Fuel Cell Hybrid Power System. In: International Journal of hydrogen energy , vol.36 (2011), no.13, July 2011, p. 7985–7992.
3. Yun Wanga, Ken S.Chen Jeffrey Mishler, Sung Chan Cho, Xavier Cordobes Adroher.: A Review of Polymer Electrolyte Membrane Fuel Cells Technology, Applications and needs on Fundamental Research. In: Applied Energy, vol. 88 (2011), no.4, April 2011, p. 981–1007.
4. S.J. Peighambardoust, S. Rowshanzamir, M. Amjadi.: Review of the Proton Exchange Membranes for Fuel Cell Applications. In: International Journal of hydrogen energy, vol.35 (2010), no.17, September 2010, p. 9349–

9384.
5. G. Ganesh, G Vijay Kumar.: Performance Analysis and MPPT Control of a Standalone Hybrid Power Generation System. In: Journal of Electrical Engineering, vol.15(2015), no.1, p.1-10.
6. Tao Zhou and Bruno François. : Energy Management and Power Control of a Hybrid Active Wind Generator for Distributed Power Generation and Grid Integration. In: IEEE transactions on industrial electronics, vol. 58(2011), no. 1, January 2011, p.95-104.
7. S. Ali Pourmousavi, M. Hashem Nehrir, Christopher M. Colson, and Caisheng Wang.: Real Time Energy Management of a Stand-Alone Hybrid Wind-Microturbine Energy System Using Particle Swarm Optimization. In: IEEE transactions on sustainable energy, vol. 1(2010), no. 3, October 2010, p.193-201.
8. Thanaa F. El-Shatter, Mona N. Eskander, Mohsen T. El-Hagry.: Energy Flow and Management of a Hybrid Wind/PV/Fuel Cell Generation System. In: Energy Conversion and Management vol. 47 (2002), no.1, p. 1264–1280.
9. M.J. Khan, M.T. Iqbal.: Analysis of a Small Wind-Hydrogen Stand-alone Hybrid Energy System. In: Applied Energy , vol.86 (2009), no.11, November 2009, p. 2429–2442.
10. O.C. Onar, M. Uzunoglua,b,M.S. Alam.: Modeling, Control and Simulation of an Autonomous Wind Turbine/Photovoltaic/Fuel Cell/Ultra-Capacitor Hybrid Power System. In: Journal of Power Sources ,vol.185 (2008), no.2, December 2008, p. 1273–1283.
11. Pablo Garcia, Juan P.Torreglosa, Luis M.Fernandez.: Optimal Energy Management System for Stand-alone Wind turbine, Photovoltaic, Hydrogen, Battery Hybrid system with Supervisory Control based on Fuzzy Logic. In: Elsevier journal of hydrogen energy, vol. 38 (2013), no.33, November 2013, p. 14146-14158.
12. R.Karthick, S.Manoharan.: Simulation of Energy Management System and Power Control of a Hybrid Power System Based on Renewable Energy Sources. In: Advances in Natural and Applied Sciences, vol.9 ((2016), no.17, March 2016, p.201-211.
13. Achraf Abdelkafi, Lotfi Kriche.: Energy Management Optimization of a Hybrid Power Production Unit Based Renewable Energies. In: Electrical Power and Energy Systems, vol. 62 (2014), no.1, November 2014, p. 1–9.
14. Rong-Jong Wai, Shih-Jie Jhung, Jun-Jie Liaw and Yung-Ruei Chan.: Intelligent Optimal Energy Management System for Hybrid Power Sources Including Fuel Cell and Battery. In: IEEE transactions on power electronics, vol.28(2013), no. 7, July 2013, p.3231-3244.
15. K.Saha and D. Kastha.: Design Optimization and Dynamic Performance Analysis of a stand-alone Hybrid Wind-Diesel Electrical Power Generation System. In: IEEE Trans Energy Converters, vol. 25(2010), no. 4, December 2010, pp. 1209–1217.
16. Xu She, Alex Q. Huang, Fei Wanga and Rolando Burgos.: Wind Energy System with Integrated Functions of Active Power Transfer, Reactive Power Compensation, and Voltage Conversion. In: IEEE transactions on industrial electronics, vol. 60(2013), no. 10, October 2013, p. 4512-4524 .
17. Natalia Angela Orlando, Marco Liserre, Rosa Anna Mastromauro and Antonio Dell'Aquila.: A Survey of Control Issues in PMSG-Based Small Wind-Turbine Systems. In: IEEE transactions on industrial informatics, vol. 9(2013), no. 3, August 2013, p. 1211 – 1221.
18. Mustafa A. Al-Refai.: Matlab/Simulink Simulation of Solar Energy Storage System. In: International Journal of Electrical, Robotics, Electronics and Communications Engineering, vol. 8(2014), no. 2, 2014, p.297-302.
19. F.Méziane,A. Khellaf and F.Chellali.: Study and dimensioning of a Wind Electrolyzer-Fuel Cell System for the Power Supply of an Isolated Site. In: Revue des Energies Renouvelables SIENR'12 Ghardaïa (2012) 381 – 391.
20. Issarachai Ngamroo.: Application of Electrolyzer to Alleviate Power Fluctuation in a Standalone Microgrid Based on an Optimal Fuzzy PID Control. In: Electrical Power and Energy Systems, vol. 43 (2012), no. 1, December 2012, p. 969–976.
21. Abu Mohammad Osman Haruni.: A Stand-Alone Hybrid Power System with Energy Storage. In: Ph. D. Thesis, Centre of Renewable Energy and Power Systems (CREPS) School of Engineering, University of Tasmania, January 2013.