IJESRT: 7(11), November, 2018 ISSN: 2277-9655

International Journal of Engineering Sciences & Research Technology

(A Peer Reviewed Online Journal)
Impact Factor: 5.164

IJESRT

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ISSN: 2277-9655
Impact Factor: 5.164
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IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

PERFORMANCE ANALYSIS OF A SOLAR/WIND/FUEL CELL BASED HYBRID POWER GENERATION SYSTEM FOR STABLE POWER DELIVERY

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DOI: 10.5281/zenodo.1503213

ABSTRACT

The electric utility industry is expanding continuously owing to rapid increase in population, economic growth as well as industrial developments. To meet the increasing load demand, it is essential to increase the generation capacity. For building a sustainable and eco-friendly energy economy in the future years, the alternative energy sources are perceived as a promising solution. A variety of energy sources with converters necessary to be incorporated for getting optimum utilization of the renewable energy to accommodate sustained load demands in the course of fluctuating natural conditions. This paper presents the design, dynamic modeling and simulation of a solar/ wind/Fuel Cell(FC) grid based hybrid power generation system for sustained power generation. This hybrid system comprises of a photovoltaic generation system, a wind generation system, and a Proton Exchange Membrane Fuel Cell (PEMFC) based system. Multiple source of energy is controlled and switched with the aid of an intelligent control algorithm, which optimizes load demand, economy and efficiency. The entire system is simulated using MATLAB/SIMULINK platform.

KEYWORDS: Photovoltaic, Wind, Fuel cell, PEMFC, Hybrid System, Intelligent Control.

1. INTRODUCTION

Global energy consumption has increased rapidly in the recent years and will be increased further in the future years. With the demand concern on energy issues and availability in present years, development of new energy sources like renewable sources is more useful and is creating a center of attention. The integration of various renewable energy sources used in transmission and distribution system can be termed as hybrid energy system, which can improve the power system efficiency and offers a better balance in energy demand.

The renewable energy sources like solar, wind etc. are clean, everlasting and nonpolluting environment friendly options for energy generation [1]. A hybrid energy source is an integration of many type of renewable energy systems integrated with each other to improve the power system efficiency and provides a better balance in the energy demand. The essential requirements of hybrid energy systems include improvement of quality and economy of power delivered to the load. Hybrid energy system has high level of secure energy via the innovative technologies and ease in combining a power storage system. Wind energy, one among the renewable sources is the most promising clean energy source with zero emission, environment friendly and can easily captured by wind turbines[2].

Solar energy is one of the potential sources of clean energy in the renewable type of energy systems as it is universally available and can be produced without using rotational generators and heavy machines. But wind power can be ineffective to some extent as strong winds happen during both the night and cloudy days,while sunny days are often quiet with weak winds which reduce the efficiency. Solar energy also gives feeble efficiency in rainy days and night times. Thus, a single renewable source alone cannot be used to meet the energy need. Hence wind solar hybrid system offers high reliability to maintain continuous power generation system. The efficiency of solar Photovoltaic (PV) modules also increased in recent years from 24% to 30%, and

ISSN: 2277-9655
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this gives advantage in PV technology and there is no doubt that solar energy will have a good value in the coming future years [3].

By the use of innovative technologies and researches, PEMFC technology has now reached test and demonstration phase [4].The integration of solar, wind and fuel cell systems in grid application can help to reduce the cost and improve the power system reliability for meeting the load demand and make systems more economical in standalone application. Integrating the different sources is a good method for the rural or remote electrification where the grid is not available to meet the load demand. Technologies in hybrid systems had increased since it creates new challenges and opportunities in developing countries [5].

2. MATERIALS AND METHODS

Design and Modeling of the Proposed System

The proposed system with automatic control is using a single inverter topology. The block diagram of an Integrated Multisource Energy System (IMSS)is shown infig. 1. It has six ports, two ports for connecting AC & DC loads separately and the other four ports for different energy sources.

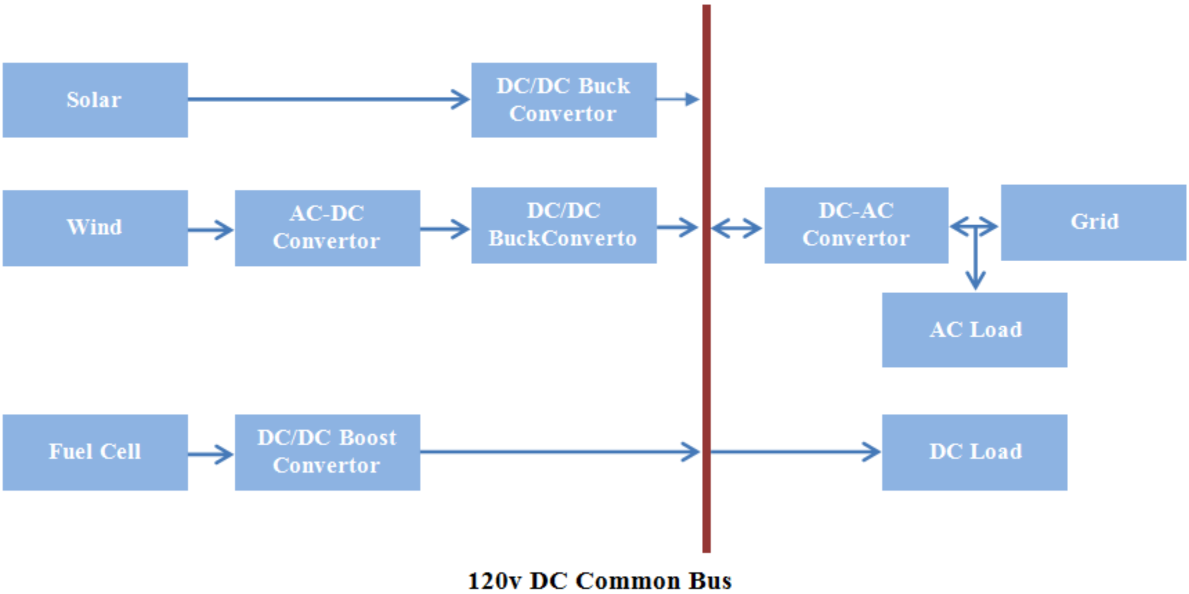

Fig.1. Block Diagram of Proposed IMSS

Each power source is connected to a common DC grid through a buck/boost converter via a control switch. The system accommodates both AC & DC loads separately. Solar PV system and fuel cell are varying DC sources which needs to be converted into a constant DC source and are done by using a buck/ boost converter. The buck/ boost converter output is fed back and compared with the reference. In this study, a DC grid voltage of 120V is considered, which is safe and optimal for residential applications. The output of wind source is varying AC and hence it is converted into DC by using an AC-DC converter. Further it is converted to a constant DC voltage by using buck converter and fed to the common DC bus.

Photovoltaic System

The main science behind the photovoltaic system is the process of converting solar energy to electrical energy by photovoltaic effect. It works on the basic principle of p-n junction diode. It consists of a p-type and n-type silicon semiconductor materials. When light falls on the diode, it ionizes the silicon atoms and the field generated in the PV device creates a gap between the electrons and holes. These charge carriers will create a difference in the potential of the junction and move through the external circuit. The current can be increased by increasing the irradiance. Temperature plays a vital role in the functioning of PV cells. It is noted that at low temperature, the maximum power can be achieved and higher will be the open circuit voltage. The equivalent circuit diagram of PV cell is displayed in fig. 2 and the simulink model of the Solar PV system is given in Fig. 3.

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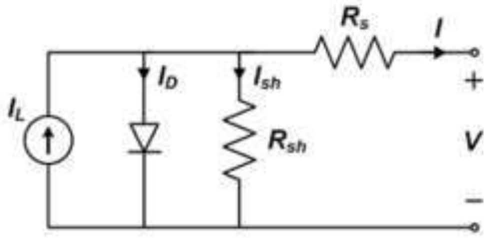

Fig.2. Equivalent Circuit Diagram of PV Cell

$$I_D = I(e^{q(V+IR_z)/KT} - 1) \qquad \text{(i)}$$
$$I = I_L - I_D - I_{sh} \text{(ii)}$$
$$I = I_L - I\left(e^{\,q(V+IR_z)/KT} - 1\right) - (V + IR_s)/R_{sh} \text{(iii)}$$

I_L = current produced by the cell (A), I_D =diode reverse saturation current, T = working temperature of the cell (K), q = electron charge (C) I_{sh} = current through the shunt resistance (A), V = output voltage (V), a = the diode quality/curve fitting factor, k = Boltzmann's constant.

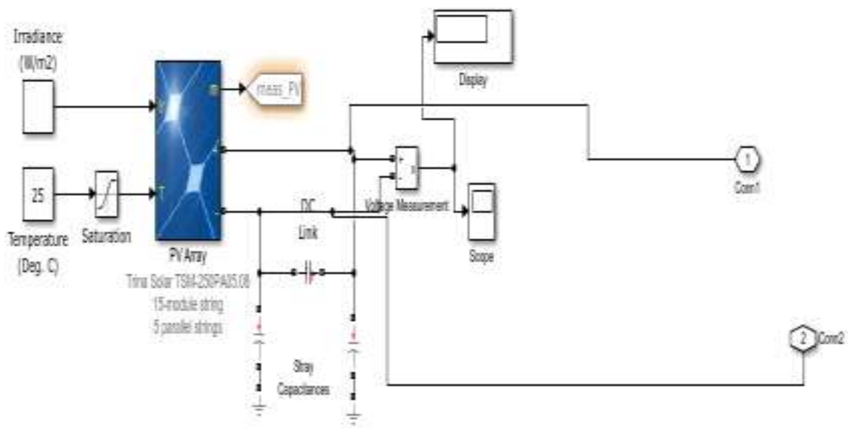

Fig.3. Solar PV system Simulink model

Wind Generation System

Wind is the movement of air mass and it possesses kinetic energy (K.E). The kinetic energy is transformed into mechanical energy with the help of a wind turbine. By the use of a generator, the converted mechanical energy can be transformed into electrical energy. The K.E of the wind is captured by the rotor with two or more blades. The gear box connected with the rotor alters the slow revolving speed of the wind turbine into a higher revolving speed on the generator coupled inside it. Electrical generator is capable of producing electricity, when the shaft is driven by the wind turbine with its output is retained in accordance with specifications, by incorporating suitable control and supervising techniques. Besides monitoring the output, these control systems also contain protection equipment to safeguard the whole system. The system is modeled using an efficient low speed permanent magnet wind generator (PMWG).

Fig. 4 shows schematic diagram of wind generation system. It consists of a permanent magnet alternator, rectifier, DC-DC converter and inverter as shown in Fig. 4. The voltage generated by the permanent magnet machine is rectified with a three-phase passive rectifier, which translates the AC voltage generated by the PMWG to a DC voltage. The DC voltage output is boosted to a higher DC voltage. This DC voltage is then converted to AC voltage by a Pulse Width Modulated (PWM) inverter which is connected to the grid. The simulink model of the wind generation system is given in Fig. 5.

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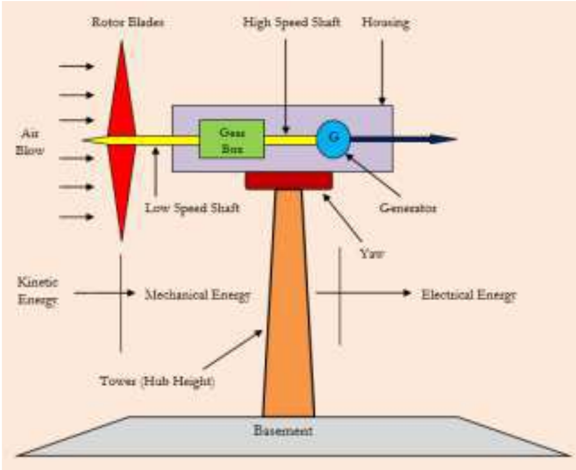

Fig.4.Schematic diagram of wind generation

The output power of the wind turbine is given by (iv),

$$P_m = C_p(\lambda, \beta)0.5A\rho v^3{}_{wind} \qquad \text{(iv)}$$

Where ρ = density of air [kg(m^3)$^{-1}$], A = area covered by rotor[m^2] and v = wind velocity[ms^{-1}], C_P – Performance coefficient of the turbine, β= blade pitch angle[°] and λ= tip speed ratio of the rotor blade tip speed to wind speed.

The coefficient of power is a function of the tip-speed ratio, $\lambda = r\Omega/v$ (v)
Where, r = radius of rotor and Ω = velocity of rotor.

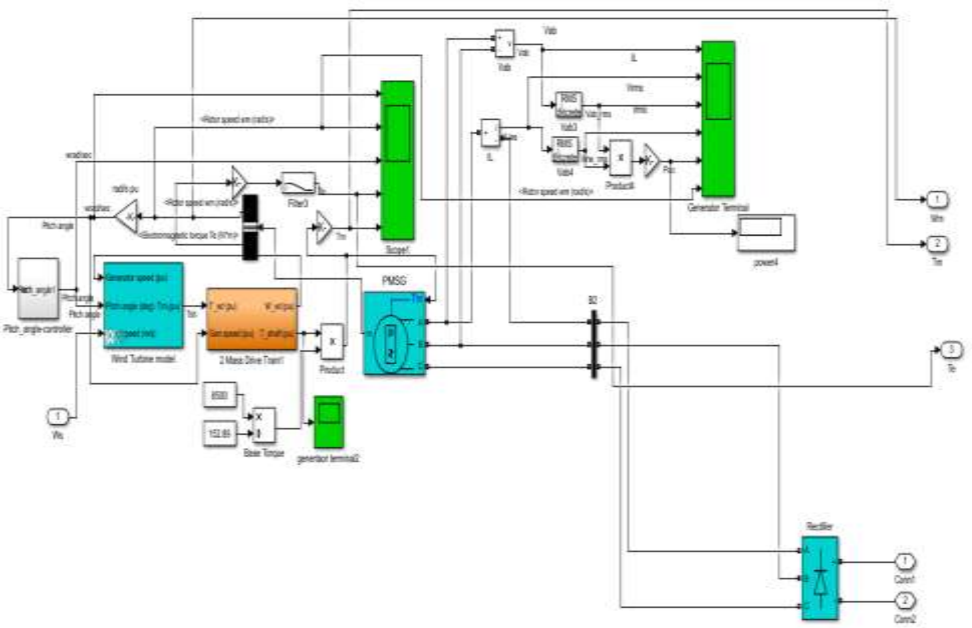

Fig. 5.Simulink Model of Wind generation system in MATLAB

Fuel Cell Generation System

A FC is an electro chemical system that is used to convert energy of a fuel (chemical energy) into electrical energy. As FCs have very high efficiency and they are more eco-friendly and sustainable the electro chemical

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transformation is more common. The FCs are considered as an alternative source of energy in a variety of areas like power stations, house applications, automobiles etc. Usually FCs will operate in low temperature conditions, but they have a very higher rate of density of power. One of the most important applications of FC is in vehicles due to its good performance. The FC and H_2 are part of the new vectors of power generation, offering interesting perspectives to the field of renewable energy. The equivalent circuit of the fuel cell is given in Fig. 6 and the internal diagram is given in Fig.7.

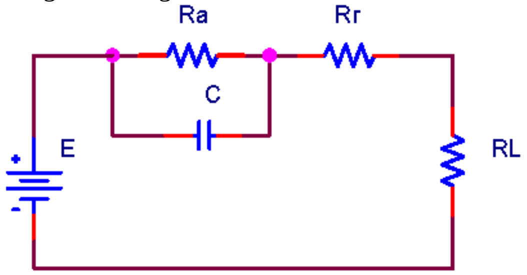

Fig. 6.Equivalent Circuit of Fuel Cell

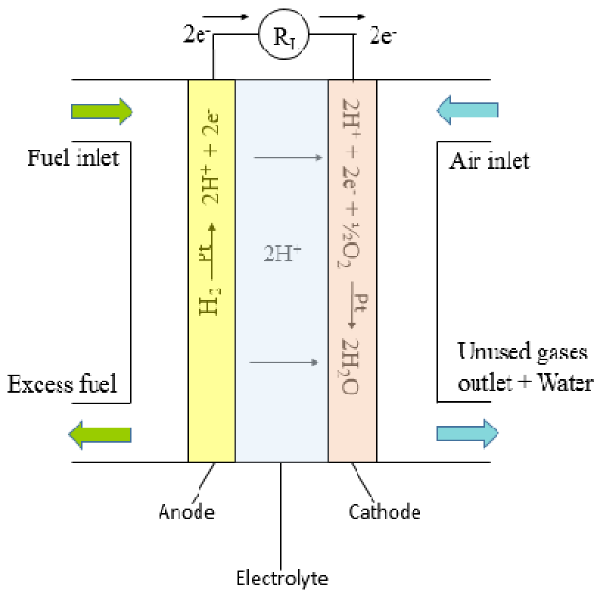

Fig. 7. Internal Diagram of Fuel Cell.

Amount of chemical energy depends on hydrogen pressure, oxygen pressure and FC temperature. Using change in Gibbs free energy, this amount can be expressed as,

$$\Delta g_f = \Delta g_f^0 - RT_{fc}\left[\text{In}(PH_2) + \frac{1}{2}\text{In}(PO_2)\right] \quad \text{(vi)}$$

Where $\Delta g^0{}_f$ is change in Gibbs free energy at standard pressure, R universal gas constant, T_{fc} PEM temperature and PO_2 and PH_2 gas pressures. The released chemical energy is equivalent to electrical work done by FC.

Value of open circuit fuel cell voltage,

$$E = \frac{-\Delta g_f}{2F} \quad \text{(vii)}$$

Where, F is Faradays' constant.

Their voltage drop was calculated using formula;

$$Vact = Vo + Va\left(1 - \bar{e}^{cic}\right) \quad \text{(viii)}$$

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Where activation voltage drop at zero current density,V_o, depends on FC temperature, cathode pressure and water saturation pressure,$V_o= f (T_{fc}, P_{ca}, P_{sat})$. Voltage drop in above equation at any current density depends on fuel cell temperature, oxygen pressure and water saturation,$V_a=f(T_{fc}, PO_2, P_{sat})$ and c_1 is activation voltage constant. Voltage drops are caused by these losses described in the equation.

$$Vact = i\left(C_2 \frac{i}{i\,\max}\right)^{C_3} \qquad \text{(ix)}$$

Where i_{max} represents current density, parameter c_2 is function of temperature oxygen pressure and water saturation pressure, $c_2 = (T_{fc}, PO_2, P_{sat})$ and C_3 is concentration voltage constant value of voltage drop of ohmic losses is expressed as

$$V_{ohm} = R_{ohm}. \dot{C}$$

V_{fc} is the actual cell voltage

$$V_{fc} = E – V_{act} = V_{conc} - V_{ohm} \qquad \text{(x)}$$

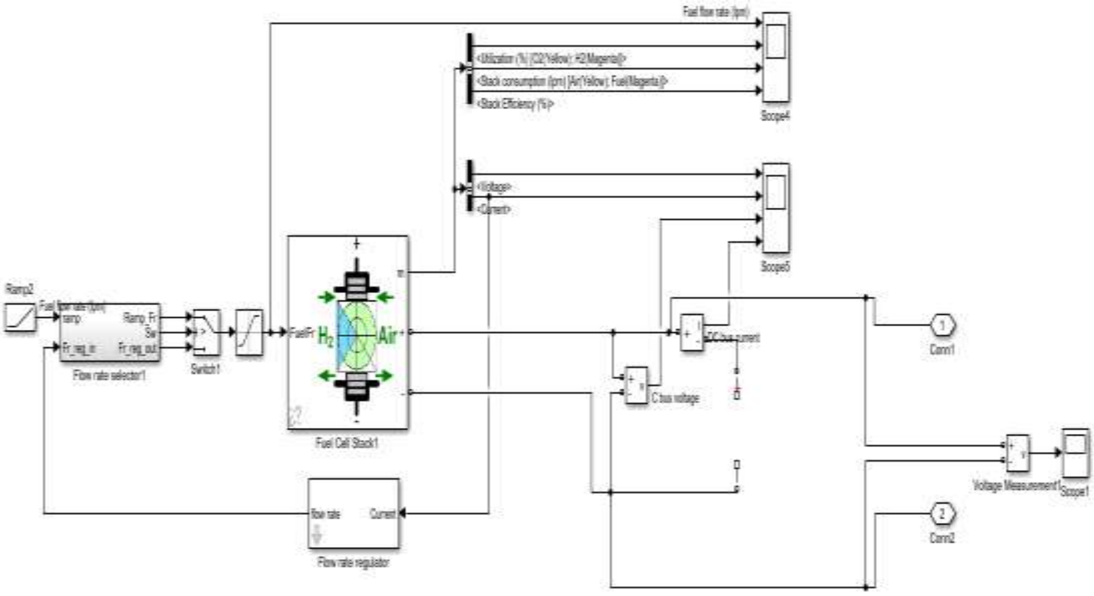

Fig. 9. Simulink model of Fuel cell generation system

Control strategy of the proposed system

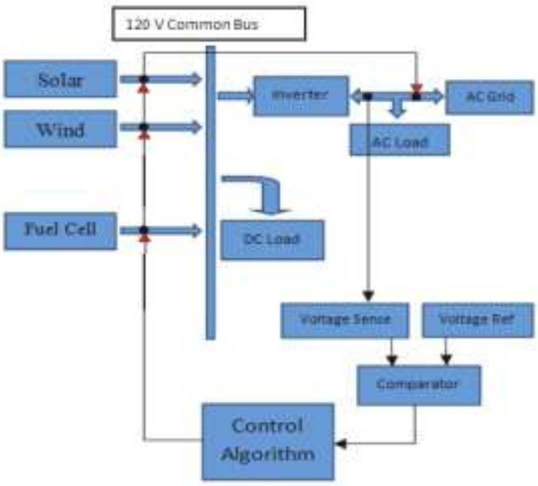

Fig.10. Control Mechanism of the system

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The simulink model of the FC generation system and the control mechanism are shown in Fig. 9 and Fig. 10 respectively.

The various energy sources are connected with control switches to a common DC Bus. AC grid is connected with a controlled switch and the AC grid is also connected to the AC loads. All the elements in the system is controlled by the same controller. The control mechanism activates the available energy sources by activating the developed intelligent algorithm. If the output voltage of the invertors is above the reference voltage, it indicates that power is excess. Then, the control mechanism deactivates the energy sources by intelligent control algorithm to manage the power.

Table 1. Switching Sequences

Solar	Wind	Grid	Fuel Cell
ON	OFF	OFF	OFF
ON	ON	OFF	OFF
OFF	OFF	ON	OFF
ON	ON	OFF	ON

Table 2. System parameters of the proposed system

Solar system	Power =2KW DC voltage =500 V Irradiance =1000 W/m2 Temperature=25 ºC
Wind system	Power =1.2 KW DC voltage=620 V Wind speed=10 m/s2
Fuel cell system	Power =1.5KW DC voltage=45V
Inverters	Output voltage =65 V AC Switching frequency =20KHz
LC filter	Capacitor voltage =70 V Switching frequency=20 KHz
DC grid voltage AC grid voltage	120 V 220V
Total load	Power =4.7KW, Voltage= 220V AC

3. RESULTS AND DISCUSSION

The Simulink model of the complete system is shown in Fig.11 and the current waveforms of the three AC loads, when switched ON manually are shown in Fig.12. Initially the load 1 is switched ON and after 0.2 S, the second load is switched ON, and similarly the third load is also switched ON. The rating of the load are: Load 1 =1.5 kW, load 2 =1.2 kW, load3 =1.5 kW.

The current waveform of dc load of 500W connected to 120 V DC grid is shown in Fig.13.Initially a 1.5 kW AC load with a 500W DC load is applied to the system. Since the solar photovoltaic system has the capacity of 2 kW it supplies power to the load. After 0.2 seconds, and additional load 1.2 kW is added.

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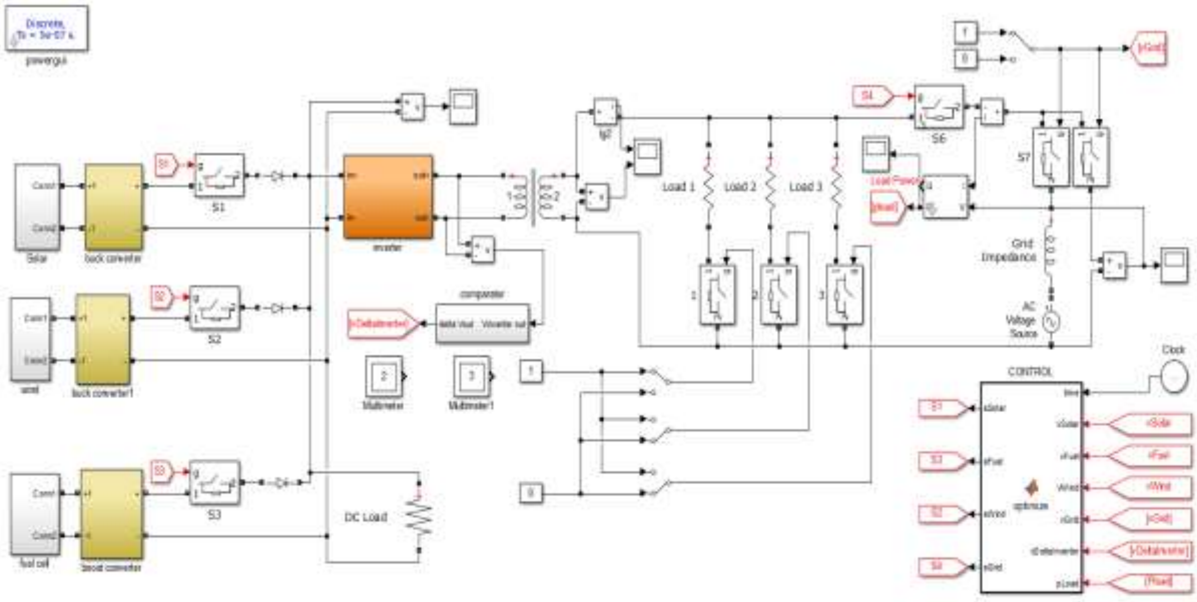

Fig. 11. Simulation diagram of the proposed system

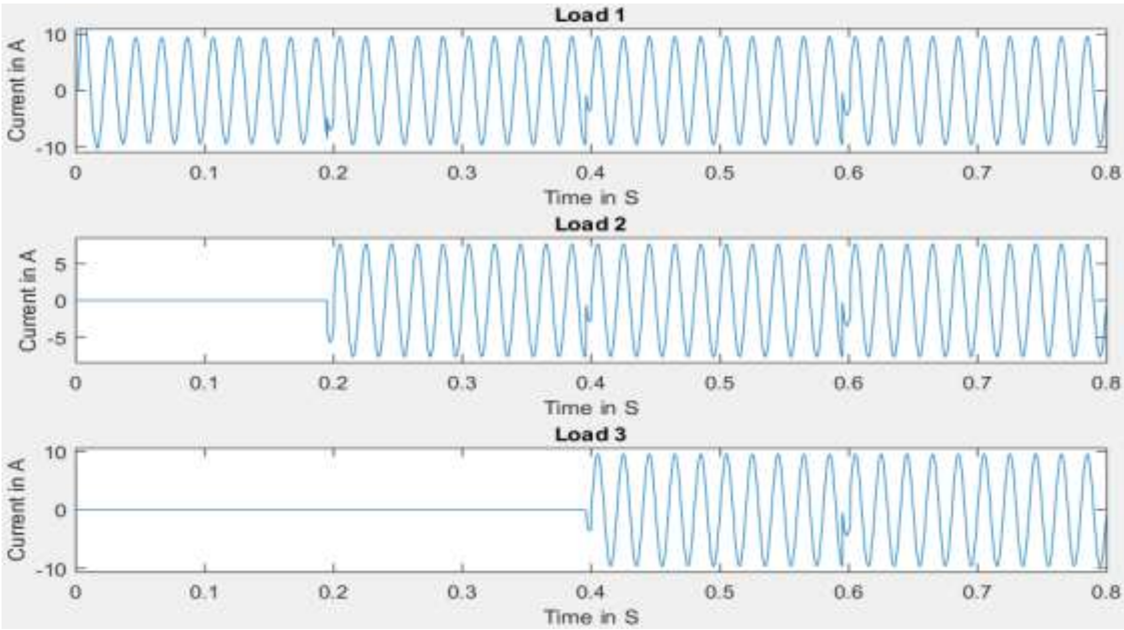

Fig. 12. AC load current wave form

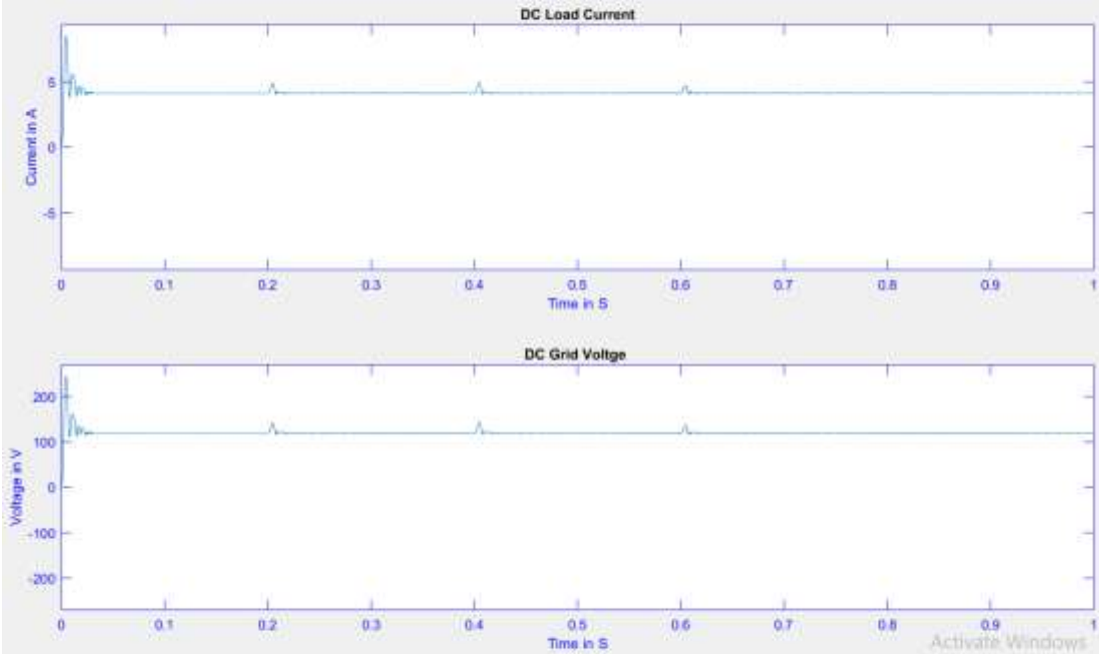

Fig. 13. Waveform of the DC Load current and Grid voltage for a 500W DC load

The increase in load results in a deficiency of supply at that moment because the source has not enough capacity to supply that load. So, a dip occurs in the output of the inverter. Then the wind generation system of capacity 1.2 kW is activated automatically. Again after 0.2 seconds third load 1.5 kW is activated manually. Then the solar photovoltaic system and wind generation system cannot meet the load demand. Then the solar photovoltaic system and wind generation system are disengaged and the grid is used to meet the demand. This condition avoids anti-islanding. At 0.6 seconds the grid supply is cut off by using manual switch, solar, wind &FC systems are activated, and the grid system is disengaged for meeting the load demand. When load current increases on each 0.2 S, the corresponding voltage decreases. A voltage dip occurs on every 0.2s and is shown in Fig.14. The waveform of the AC load on each 0.2 s is indicated in Fig. 15.The wave form of the DC load is shown in Fig. 16 and the total load power is given in Fig. 17.

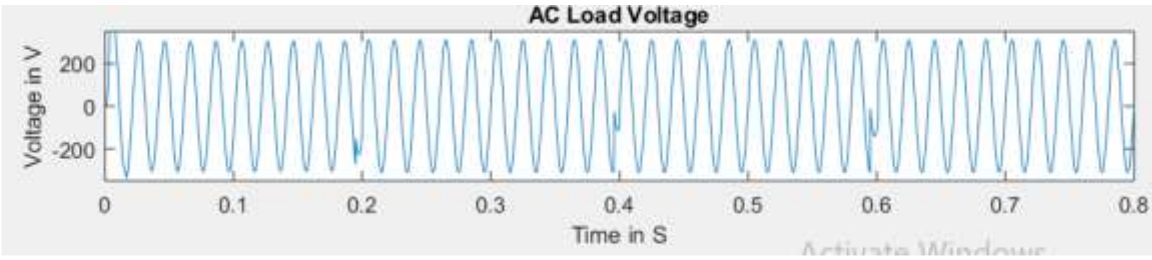

Fig. 14. AC load voltage wave form

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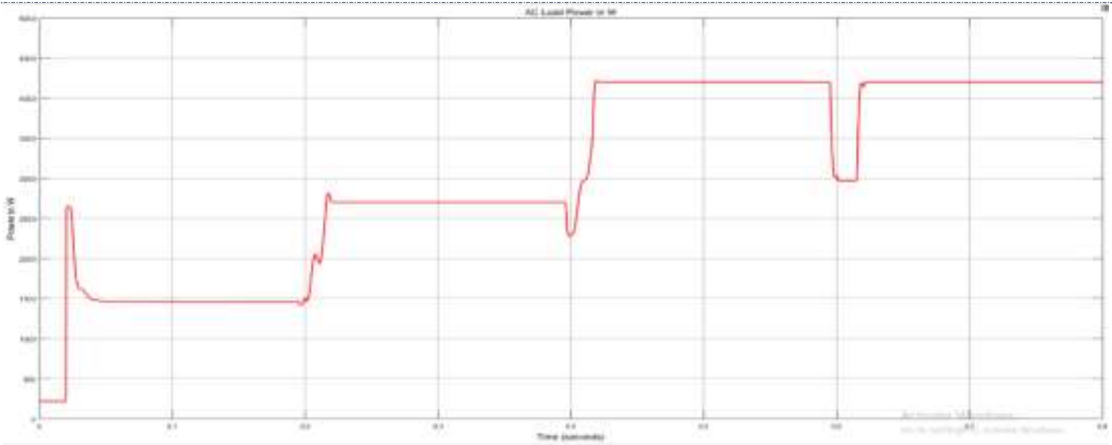

Fig. 15. Waveform of the ac load power

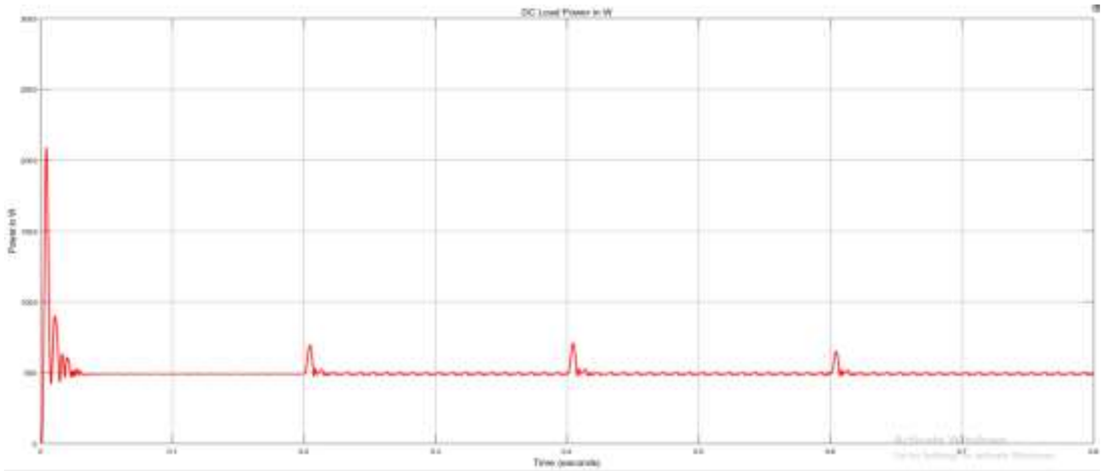

Fig. 16. Waveform of the dc load power

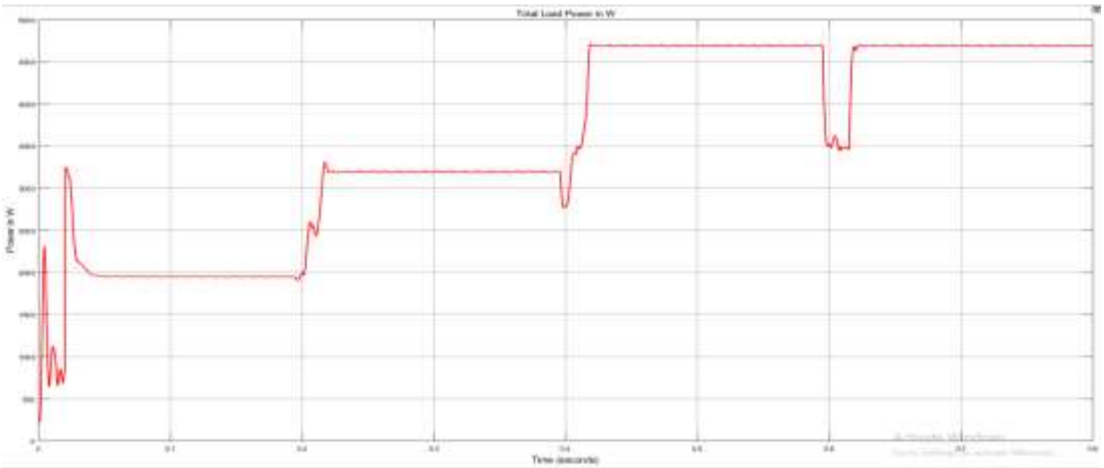

Fig. 17. Waveform of the total load power.

4. CONCLUSION

The proposed system can support both AC&DC loads. By separating AC& DC loads, the harmonic contents will be eliminated. The complete system is automatically switched by means an intelligent algorithm which optimizes economy and efficiency. The system employs a simple control mechanism rather than grid synchronized systems to improve reliability. This integrated multi source system is applicable in almost all locations, if the renewable energy sources are available with or without considering the grid availability. The

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proposed system is simulated using MATLAB/Simulink environment and the performance characteristics are verified. The simulation results showed that the proposed system is effective in load management. Significant improvement in the system performance is also made by incorporating automatic control using a single inverter topology. The proposed system is consistent for load variations and it avoids anti islanding.

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Premkumari, S., & Kumar, H. R., Dr. (2018). PERFORMANCE ANALYSIS OF A SOLAR/WIND/FUEL CELL BASED HYBRID POWER GENERATION SYSTEM FOR STABLE POWER DELIVERY. *INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY*, *7*(11), 134-144.