International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296

Dynamic Modeling, Design and Simulation of A Wind / Solar / Fuel Cell / Ultra-Capacitor Based Hybrid Power Generation System

Premkumari .S[1], Prof. Harikumar[2]

[1]Dept. of Electrical and Electronics Engineering, CET, Trivandrum, India
jayajayan123 [at]gmail.com
[2]Dept. of Electrical and Electronics Engineering, CET, Trivandrum, India
harikumar.cet [at]gmail.com

Abstract: ***This paper discusses the dynamic modeling and simulation of a small wind-photovoltaic-fuel cell-ultracapacitor hybrid energy system. This hybrid system contains a wind turbine, a photovoltaic, a proton exchange membrane fuel cell (PEMFC), an ultra-capacitor, an electrolyzer, controllers and a power converter that is simulated using MATLAB. This hybrid system is completely stand-alone, reliable and has high efficiency. In order to minimize abrupt changes in voltage magnitude ultra-capacitors are used. Power converters and inverters are used to produce an ac output power of 9KW to grid. Control scheme of fuel-cell flow controller and voltage regulators are based on fuzzy and neuro fuzzy controllers. Dynamic responses of the system for a step change in the electrical load and wind speed are represented. The observation for various input conditions shows that the system can withstand any abrupt variations.***

Keywords: NeuroFuzzy, Fuel cell, PEMFC, Ultra-capacitor, Electrolyzer, Fuzzy, On-Grid, Hybrid System, Photovoltaic

1. Introduction

There is a huge increase in the consumption of energy especially in residential areas and it seems that it will increase in the coming years [1]. Almost 30 percent of the energy consumption is by both commercial and domestic sectors [2]. People are in search of alternative renewable energy sources like solar, wind, fuel cells in order to meet their residential needs.

Due to the depletion of energy from fossil fuels, the need for energy in domestic area is very large. They cannot afford their daily energy needs from these sources. Alternative energy sources, like solar and wind, seems to be very clean, inexhaustible and eco-friendly potential sources of renewable energy choices [3]. The hybrid energy source contains more number of renewable energy sources that can manage themselves with maximum efficiency and a balance between them. The hybrid system constitutes the combination of more than two energy sources. In hybrid power systems we are mainly focusing on maintaining an optimum quality of power with limited amount of money, in turn an economic profit. The production techniques and power storage capability of hybrid systems is done through highly safe and secure means.

Another source of energy that can be used in the hybrid system is Wind power, as it acts as the clean energy source and can be installed in various areas where wind can be captured by generators with high power handling capabilities. Solar power is also a strongly clean energy resource as it has less mechanical components like generators in it. We can say that the solar power generation and wind power generation can be combined and can act as complimentary sources in some areas because usually heavy wind occurs in night time and during day time the wind is very mild, so a combination of both wind and solar can be effectively utilized to maintain a continuous output power when comparing with its individual operations. in the earlier days, the cost of solar modules were very high but later due to the advancement in the technology its price dropped down, so it became more economical. The payback time also decreased; hence it started using in various applications. In few years the overall efficiency has increased about 20 to 30 percentage, so we can say that photovoltaics can be used as a sustainable energy source for the future. [6]

The concept of PEMFC or Proton Exchange Membrane Fuel Cell has evolved from a novel idea to a real life demonstration phase. Also small PEMFC modules are available in commercial market which utilizes its scope in hybrid system design.

The combination of wind solar and fuel cell in energy system supplying to grid drastically reduces the cost of maintenance and improves the reliability of renewable energy generation to provide its load a continuous supply of power. Also by using more than one source of power, disadvantages of one system can be compensated by others. This Combination of hybrid system suits well in rural areas where the available grid system cannot meet its needs. In developing countries the hybrid energy system will be more economical will be a better source of energy generation. [8]

Since, hybrid energy systems are working under heavy conditions of load, variation in input conditions like wind speed, irradiance, availability of fuel etc. we need to design a proper combination of these systems in order to achieve an efficient self-standing system. For this purpose we need to analyze the output parameters for vast and variant input conditions [9]. From our analysis we concluded that the combination of solar and wind can normally supply load to the grid. In the absence of these systems or in conditions were it produces less power we can maintain the output using fuel cell. The description below gives a clear idea of the system configuration and basics of system design and modelling.

2. System Configuration

The system configuration of the proposed hybrid energy model is a complete eco-friendly energy efficient system wgere all the systems are properly stored and managed. [13]

Our proposed hybrid power system mainly consists of a solar array, a wind turbine with generator, a PEMFC or proton exchange membrane fuel cell, an ultra-capacitor and an electrolyzer, it also includes a power converter and DC-AC converter, a phase converters, and various controllers. The wind generator module has a wind turbine, a gear driver and PMSG generator. The fuel cell module includes an ultra-capacitor module to store the excess power and thereby supply to load if any shortage occurs. All these sources has its own controllers to monitor and control its operation. [15]

When there is additional wind generation available, the electrolyzer will produce hydrogen and then delivered to the hydrogen storage unit the hydrogen storage tank has some amount of hydrogen already stored in it. There are 60 single fuel cells which are connected in series to form a fuel cell steck. There are various controllers used to regulate the flow of O2 and H2 efficiently to produce maximum power with the available fuel. When the voltage drops below 45V the controller allows more fuel to flow preventing voltage variation. The ultra-capacitor is kept in parallel with the fuel cell which reduces the abrupt voltage fluctuation and also it stores excess power from the fuel cell. In the fuel cell block there is a DC booster which converts the output into 100V DC. The controller used for controlling the fuel cell is a neuro-fuzzy controller which monitors the output of the fuel cell and regulates the supply so as to obtain a uniform output for the grid.

3. System Design and Modelling

To design a complete and efficient power system we need to use various strategies and examine the performance under dynamic load condition. This can be done using mat lab Simulink software.

3.1 Photovoltaic

Photovoltaic effect is a simple process in which electrical energy is produced from solar cells when beams of light fall on the surface of this cell. This process mimics the semiconductor PN junction diode. There are two types of materials used to construct a solar cell mainly P-type and N-type silicon. When a beam of light with a certain wavelength falls on a solar cell it ionizes the silicon atoms and an electric field is produced across the junction with positive charge on one side and negative charge on other side. The movement of these ions produces electricity in solar cell.

A potential difference is created at the junction due to these charge carriers (electron-ion pair or electron hole pair) due to this electric field charge carriers get accelerated and a current is formed through the external circuit are shown in figure 1.

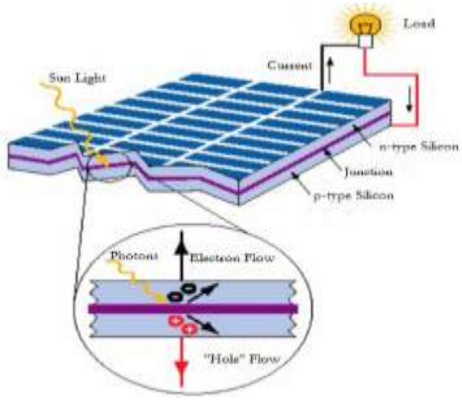

Figure 1: Construction of Solar Cell

The holes move to the positive or P region and electrons move to the negative or N region. Most charge carrier gets recombined through the external circuit even though opposite charges are attracted to each other. [5]

The working of a solar cell is similar to that of a semiconductor diode. In a solar array when the irradiance get higher the short circuit current (Ise) along with open circuit voltage (Voc) becomes higher. So the output solar power will be larger the behavior of solar cell mainly depends on temperature. As temperature decreases greater the Voc and output power.

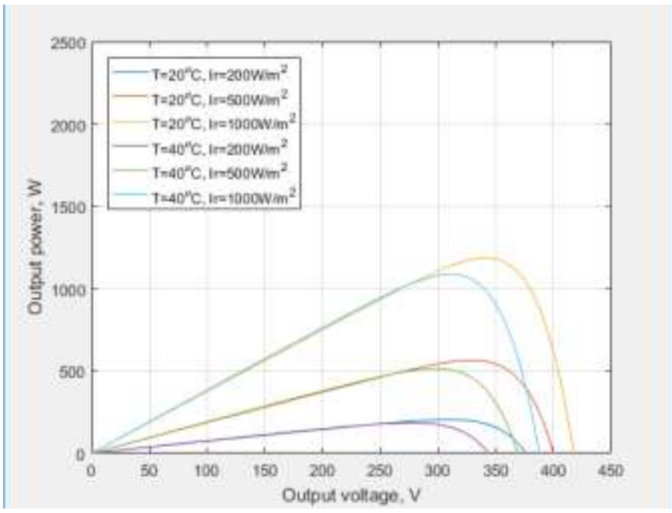

Figure 2: Behaviour of Solar Cell power at various temperatures

The equivalent electrical representation of a solar cell can be shown as a diode parallel to a current source. The current which is generated by photons (Iph or Il) is represented as the current source. Under constant temperature and light incidence the output remains constant. [10] The series resistance and shunt resistance in the equivalent circuit are represented as Rs and Rsh. The contact resistance and the semiconductor resistance are included in Rs.

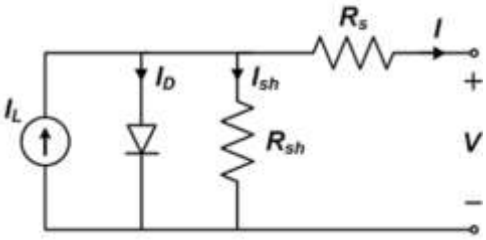

Figure 3: Electrical Equivalent of Solar Cell

In the above figure the photocurrent cell has a current source of IL. The shunt and series resistance of solar cell are denoted by Rs and Rsh usually Rsh is very high and Rs is too small hence Rs can be neglected for the easier of analysis. The overall current of the cell is given by the formulae:

I_D=I(e^(q(V+IR_z)/KT)-1)

I=I_L-I_D-I_Sh
I=I_L-I(e^(q(V+IR_z)/KT)-1)-(V+IR_s)/R_sh

Here (Is) is the saturation current of diode, q is the charge of electron, V being the output voltage of the cell structure, the diode ideality factor is represented by N, K is the Boltzmann constant and T the temperature of cell.

The basic constructional block of a solar cell system is photovoltaic cells. The amount of power which is produced by a single photovoltaic cell will not be sufficient to turn on small electric/ electronic devices. Each PV cell constitutes 0.5V to the system. To obtain higher voltage and higher current the modules are stacked in series or parallel to design panels. We use mat lab in built solar cell model to simulate the solar array.

3.2 Wind System

The movement of air is called wind. Due to this movement it has kinetic energy. The kinetic energy of this wind is converted to mechanical energy with help of a wind turbine. The wind turbine has rotor blades in it these are designed according to the speed of wind. The kinetic energy of wind is captured by the rotor of the wind turbine which contains multiple numbers of blades. The gear box converts the speed of rotation of the wind (which is usually in few meters per seconds) into higher rotational speeds. The generator side produces electricity when the shaft of the generator is rotated by the turbine. Using control and supervising techniques the output is maintained properly. The overall system is protected using the protection equipment which is also included in the control system.

The wind system contains alternator DC to DC converter various bridge rectifiers and also an inverter the power generated by the PMSG is converted using a 3 phase bridge rectifier. This converts AC voltage into DC voltage. The output DC voltage is boosted up to higher levels of DC voltage and again it is converted to AC using PWM inverters.

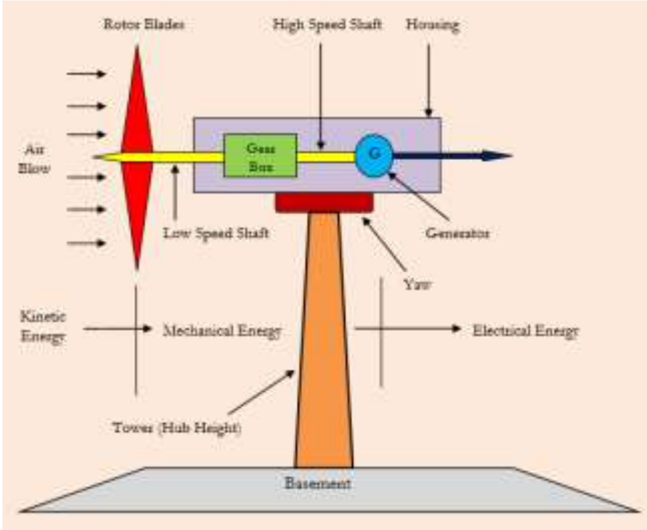

Figure 4: Schematic diagram of Wind turbine

The permanent magnet synchronous generator (PMSG) in the modal converts the wind power in mechanical forms into electrical. When we are analyzing different wind power generators we can see that PMSG has greatest advantages over others. It is because they are more stable in its operation; they are efficient especially in low speed, more secure. [2]

PWIND = 0.5AρV3

Here, ρ is the density of air, A is the area swept by the rotor and v is the speed of the wind. Only a few of the available wind is utilized for generation. A part of available energy in this wind can be represented as the power coefficient Cp. 0.59 is the maximum value of theoretical coefficient also known as Betz limit.

PTURBINE = 0.5CPAV3

The coefficient of power is a function of the tip-speed ratio λ of the blade,

λ=rΩ/V

Where r is the radius of the rotor and Ω is indicate the speed of angular rotor.

3.3 Fuel Cell

The electrochemical device which converts chemical energy into electrical energy is called Fuel cells. Proton Exchange membrane fuel-cell (PEMFC) has greater advantages when compared with other fuel cells available in the market. They have high scaling capabilities so that they can be used in industries also. A Polymer Electrolyte Membrane Fuel Cell fuel cell that uses a thin ion conducting solid electrolyte. Since we are using solid membrane instead of liquid membrane the overall power density is increased and corrosion rate is reduced. These are also used in transport industry sue to its low operating temperature, portability and quick startup time. A solid electrolyte, the polymer electrolyte membrane has its advantages over liquid electrolytes in that it has a high power density and reduced corrosion [11]. The low temperature of these cells ensures a quick start up time and its wide application range includes the transport industry.

4. System Modelling

The system model of this hybrid system consists of a wind, fuel cell-ultra capacitor, solar array and a micro-grid to which the power is given. The grid is designed in such a way that it gives out a continuous output to the users [13]. Neuro-fuzzy controller is used to optimize the inputs and provide a constant output of 9KW to the grid. The block diagram of the proposed system is given below.

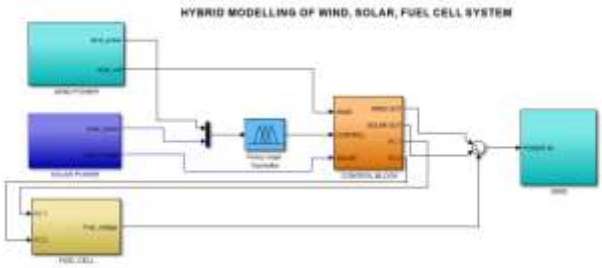

Figure 5: Model of the Hybrid System

4.1 Modelling of Solar power System

The hybrid power system discussed above consists of a 6KW solar power system. The system has a series connection of 10 solar cells and a combination of 5 parallel sets each. The temperature is kept as 50oC.The irradiance is 850W/m2. So the system will produce an output of 6KW.

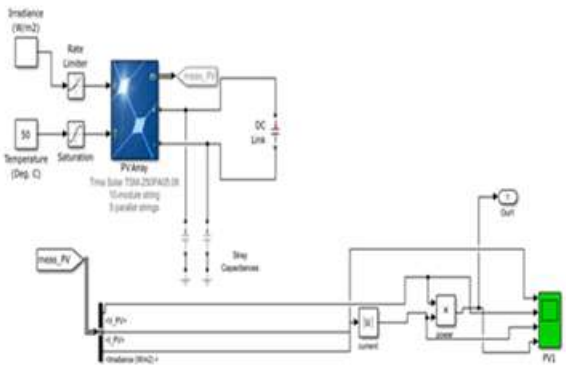

Figure 6: Simulink model of 6KW solar Power System

In the figure, we have represented the output characteristics of solar array. The irradiance to the system is given as 850W/m2 so that we will get an input of 350V and a current of 18A. So in effect, we will get an output of 6KW.

4.2 Modelling of Wind power System

The wind power generator consists of a wind turbine and PMSG generator. The output of wing turbine is mechanical torque, which is being attached to shaft of the generator. A speed controlling gear drive system is used in between the coupling of turbine and generator. The output of this system is a three phase AC power with 6KW output.

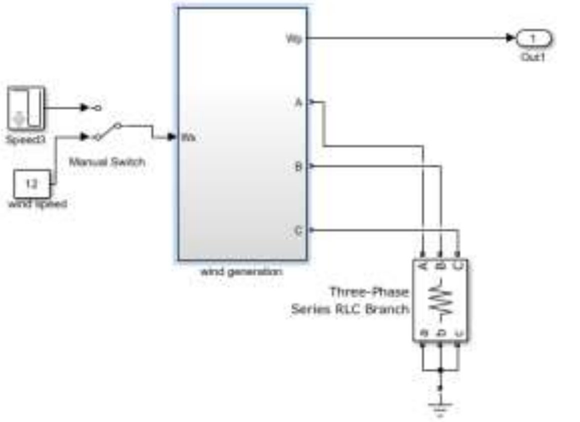

Figure 7: Matlab Model of wind system

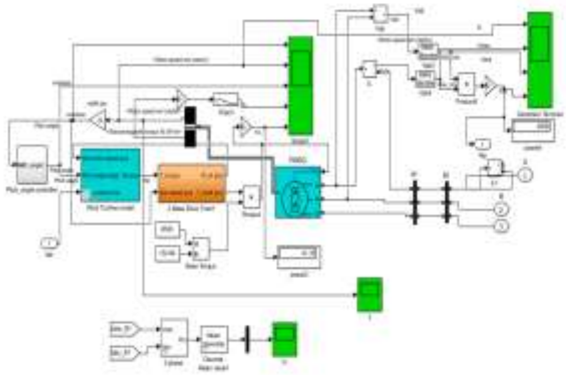

Figure 8: Internal block diagram of wind system

4.3 Modelling of Fuel-cell with Ultra Capacitor

The fuel cell designed is a45V DC PEMF fuel cell. Due to its high advantages, we use this fuel cell for our system. It has 60 series cells connected in it producing a power of 6KW [4]. The ultra-capacitor is also attached along with it parallel so as to obtain a stable output and also to store excess energy.

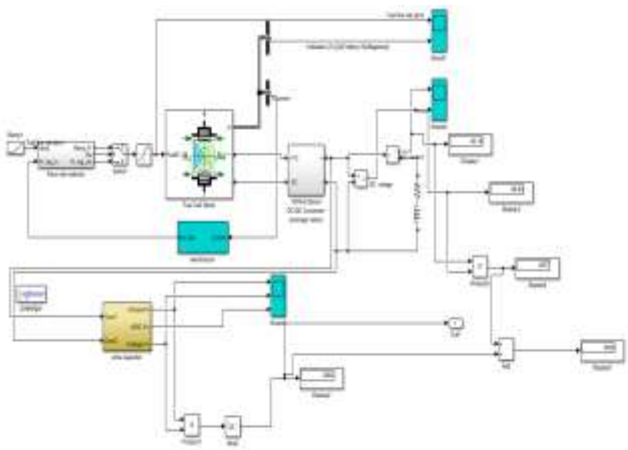

Figure 9: Modelling of Fuel-cell with Ultra capacitor

4.4 Modelling of Neuro-fuzzy controller

Since the three independent power generators are stand-alone itself, in order to make it hybrid, we need to implement a control strategy to control them [12]. Neuro fuzzy controller is the best method to model controller in matlab because of its easiness to model and use. In this hybrid system, we use neuro controller controllers are used to switch the sources according to the power each delivers and the load demands. If anyone system fails it will automatically switched to the other two sources to meet the need. Thus various control strategies are taken in account by the intelligent controllers.

A power of 9KW is always given to the grid. Solar and wind power are added to give 9KW power to the grid and in any of case these fails the balance power is taken from the fuel cell.

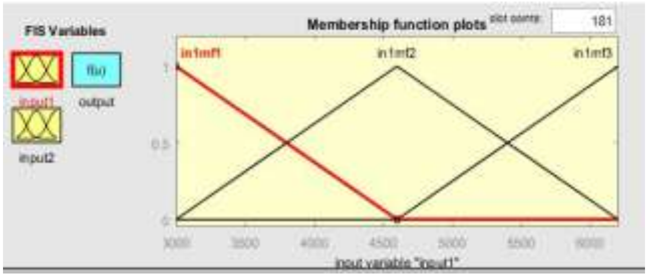

Figure 10: Membership function of fuzzy controller

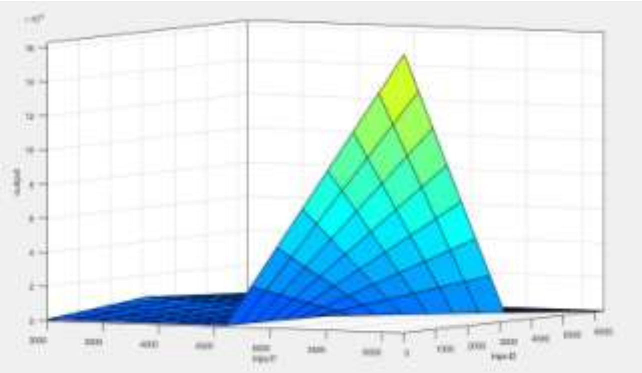

Figure 11: Input and output range of fuzzy controller

4.5 Modelling of Micro-Grid

Finally, after the modelling and simulation of the three power systems, we will design the grid to which the power is to be given [4]. The grid capacity is 9KW. Since most of the grids works on three-phase, we need to use phase converters to convert them. Using neuro fuzzy controller we can control the flow of power to the grid. The excess amount of power is stored in the fuel cell block using ultra capacitor. When there is a shortage of power, it supplies it back to the grid.

5. Results

In the figure 12, we have represented the output characteristics of solar array. The irradiance to the system is given as 850W/m2 so that we will get an input of 350V and a current of 18A. So in effect, we will get an output of 6KW.

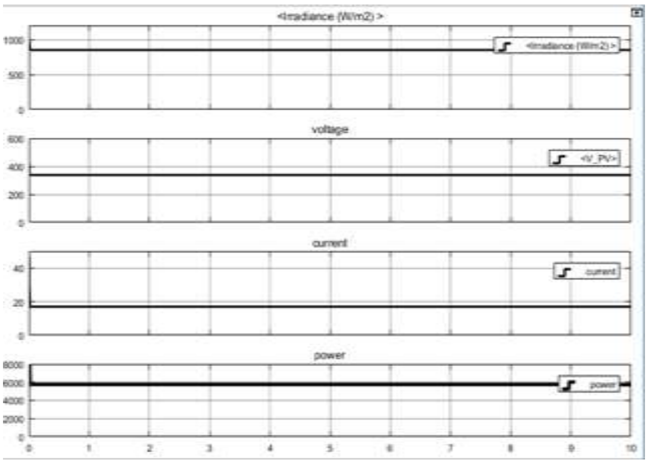

Figure 12: Output characteristics of Solar Power System

The output characteristics of wind turbine are given below. The input to the wind turbine is wind (m/s). Usually it is given as 12m/s, with a pitch angle of 00. So the turbine rotates at a speed of 150rad/s. The line voltage and current are respectively450V and 10A. Effectively it produces an output of 5KW.

Figure 13: Characteristics of wind power System

The mechanical characteristics of wind turbine are given below. Both the electrical and mechanical torque are given in the graph below

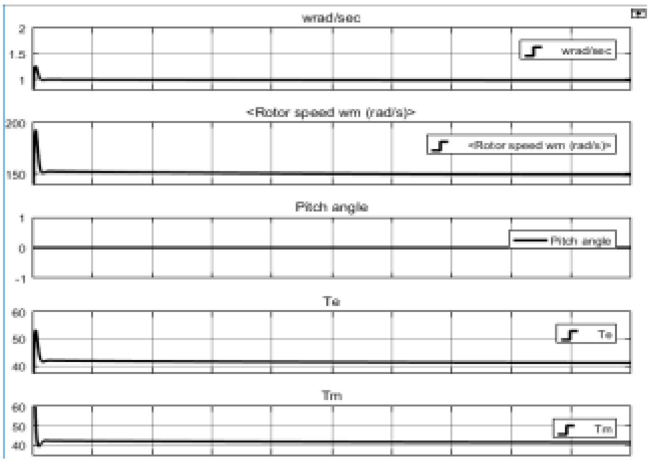

Figure 14: Mechanical Characteristics of wind turbine

The graph shown below is the characteristics of fuel cell. The output current of the fuel cell is 40A and voltage is 80V due to the usage a DC booster in the model.

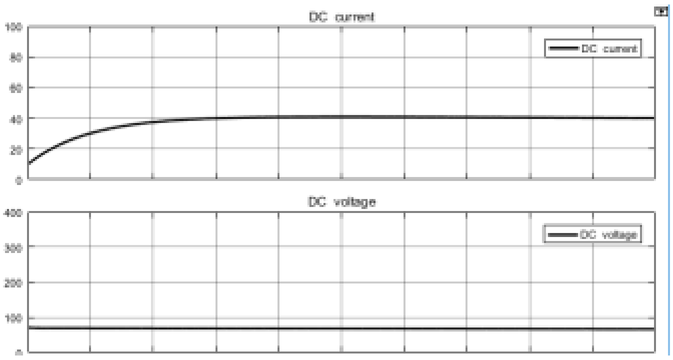

Figure 15: Characteristics of Fuel-cell

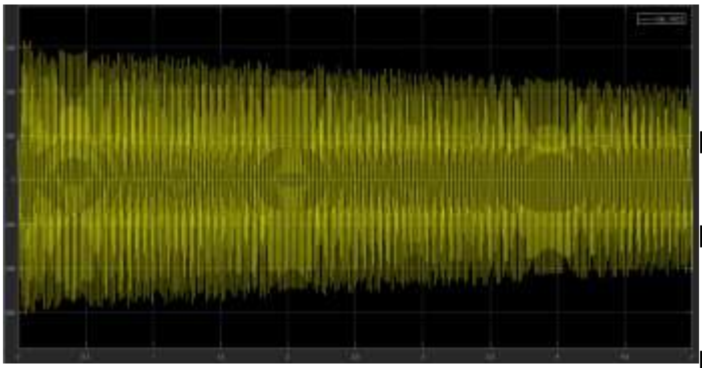

Figure 16: Output voltage graph od hybrid system

From the above graph our hybrid system is able to produce a constant power of 9KW for a given time period for various conditions. The power of fuel cell is taken at time where the wind and solar power fails to deliver the rated power. Thus the system can deliver the power to the grid connected throughout the time efficiently.

6. Conclusion

This paper represents the simulation of model used for studying and analyzing the behavior of hybrid systems on renewable energy. Due to the lack of availability and high rate of pollution by the fossil fuels, the demand for hybrid systems have been increased. Our model includes renewable energy sources like wind, solar, fuel cell managed efficiently by using a neuro fuzzy controller to connect the system into a grid. Using neuro fuzzy as the controller, performance of the system has been increased.

References

[1] Ronak Ahmad Saeed, Ergun Erceleb A Simulation Model for Hybrid Power System Sources (HPSS)Photovoltaic/Wind/Battery/ Diesel connected with Grid, Int'l Journal of Computing, Communications & Instrumentation Engg. (IJCCIE) Vol. 3, Issue 2 (2016) ISSN 23469 EISSN 2349-1477

[2] MODELING AND CONTROL OF A PEM FUEL CELL SYSTEM ,Yasemin saygili, Asst. Prof. Dr. Serkan Kıncal , Prof. Dr. İnci Eroğlu, September 2013

[3] M.T. Iqbal, "Simulation of a small wind fuel cell hybrid energy system", June 2002,Renewable Energy 28 (2003) 511–522, PII: S0960 -1481(02)00070-8

[4] Saeid Esmaeili, Mehdi Shafiee, "Simulation of Dynamic Response of Small Wind-Photovoltaic-Fuel Cell Hybrid Energy System" ,Smart Grid and Renewable Energy, 2012, 194-203 Vol.3 xxxxNo.3(2012)DOI:10.4236/sgre.2012.33027

[5] Suman Nath, Somnath Rana "The Modeling and Simulation of Wind Energy Based Power System using MATLAB", International Journal of Power System Operation and Energy Management, ISSN (PRINT): 2231–4407, Volume-1, Issue-2, 2011

[6] Jay Tawee Pukrushpan 2003, 'Modelling and control of fuel cellsystems and fuel processors', Ph D Dissertation, University of Michigan, USA.

[7] A. B. Cultura II, Z. M. Salameh, "Modeling and Simulation of a Wind Turbine-Generator System" , Published in: Power and Energy Society General Meeting, 2011 IEEE, 2011 IEEE 978-1-4577-1002-5, DOI: 10.1109/PES.2011.6039668

[8] J. Vera Gutierrez, Options for rural electrification in Mexico, IEEE Transl. Energ. Convers, vol. 7, pp. 426-430, 1992. (Article)

[9] M. Muselli, G. Notton, and A. Louche, Design of hybridphotovoltaic power generator, with optimization of energy management, Solar Energ, vol. 65, pp. 143-157, 1999. (Article)

[10] M.A. Elhadidy, Performance evaluation of hybrid (wind/solar/diesel) power systems, Renewable Energ, vol. 26, pp. 401-413, 2002. (Article)

[11] F. Fazelpour, N. Soltani, and M.A. Rosen, Feasibility of satisfying electrical energy needs with hybrid systems for a medium-size hotel on Kish Island, Iran Energ, vol. 73, pp. 856-865, 2014. (Article)

[12] B. S. Borowy and Z. M. Salameh, "Optimum Photovoltaic Array Size for a Hybrid Wind/PV System," IEEE Transactions on Energy Conversion, Vol. 9, No. 3, 1994, pp. 482-488. doi:10.1109/60.326466

[13] B. S. Borowy and Z. M. Salameh, "Methodology for Optimally Sizing the Combination of a Battery Bank and PV Array in a Wind/PV Hybrid System," IEEE Transactions on Energy Conversion, Vol. 11, No. 2, 1996, pp. 367-374. doi:10.1109/60.507648

[14] A. N. Celik, "Optimisation and Techno-Economic Analysis of Autonomous Photovoltaic-Wind hybrid Energy Systems in Comparison to Single Photovoltaic and Wind Systems," Energy Conversion and Management, Vol. 43, No. 18, 2002, pp. 2453-2468