International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 02, February-2015

A Grid Integrated Hybrid System: PV, Wind and FC

Silpa K L[3], Aparna S Nair [2]
Department of Electrical and Electronics
Toc H Institute of Science and Technology
Ernakulam, India

Kamala Devi V [1]
Research and Development Wing
ANERT
Trivandrum, India

Abstract **-As a result of rising concern of global warming and the depletion of fossil fuel reserves, many are looking at sustainable energy solutions to preserve the earth for the future generations. Environmentally friendly solutions are becoming more prominent than ever as a result of concern regarding the state of our deteriorating planet. This paper presents one of the alternate ways for the power generation, which is clean and economical for the future generation. The three sources which are used for power generation are solar, wind and fuel cell. DC output of photovoltaic panel, rectified dc output of Wind energy conversion system (WECS) and DC output of fuel cell is fed to their individual boost converter. It consists of wind turbines with permanent magnet synchronous generator (PMSG). The output of boost converter is feed to the common dc link which is connected to the 3 phase Sinusoidal pulse width modulation (SPWM) inverter, which converts its dc input to 3 phase AC output.**

Keywords – PV system, WECS, PMSG, FC, SPWM, boost converter.

I. INTRODUCTION

As a result of rising concern of global warming and the depletion of fossil fuel reserves, many are looking at sustainable energy solutions to preserve the earth for the future generations. Environmentally friendly solutions are becoming more prominent than ever as a result of concern regarding the state of our deteriorating planet.Now a days Renewable Energy (RE) systems and technologies are gaining mass importance in the world. There are various types of RE technologies. RE generates either DC power or AC power depending upon the type and natural behaviour. The present scenario is tempting us to connect more and more RE systems to Grid. Stand-alone renewable-based systems are not reliable enough. Hence a hybrid system is used in this paper and is connected to the grid. The three sources which are used for power generation are solar, wind and fuel cell.This is the aim of my thesis.

MPPT techniques automatically find the voltage or current maximum power point at which a PV array and wind turbine should operate. Under partial shading conditions it is possible to have multiple local maximum at the same points so maximum power point shifts according to it. In order to harvest the maximum amount of energy from the wind, the wind turbine must have a specific rotation speed to maintain the optimum tip-speed ratio. The purpose of the MPPT is to maintain the tip-speed ratio of the wind turbine as close as possible to the optimal tip-speed ratio.

II. PROPOSED TOPOLOGY

The proposed system consist of three sources: PV, WECS and FC as shown in fig 1. The output from PV will vary depending on the two factors like solar irradiance and temperature. Maximum power from PV is tracked by using MPPT algorithm and is connected to a boost converter and then to a DC bus. The wind turbine in WECS is connected to a permanent magnet synchronous generator (PMSG). The electrical output from generator is given to a three phase full wave bridge rectifier. The dc output from rectifier is boost and then is given to a dc bus.

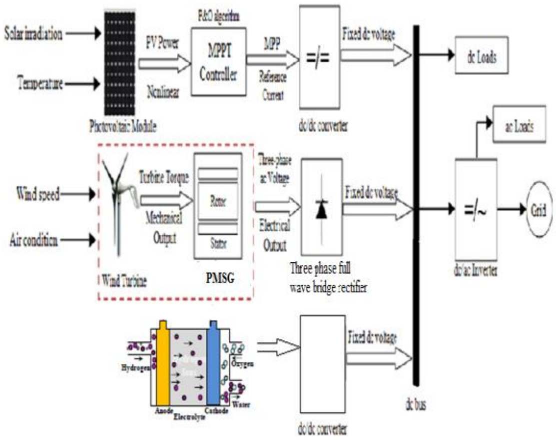


Fig. 1: Block diagram of the proposed system.

MPPT is also used in WECS to track maximum power from wind turbine. The FC used here is a hydrogen fuel cell, the output is taken to a boost converter and then given to the dc bus. The dc loads can be connected to this dc bus else this dc is converter to ac by using a three phase inverter and is given to ac loads or grid.

III. MATHEMATICAL MODELING

A. Mathematical Modelling of PV module

The general mathematical model for the solar cell has beenstudied over the past three decades. The circuit of thesolar cell model, which consists of a photocurrent, diode,parallel resistor (leakage current) and a series resistor; isshown in Fig. 3. According to both the PV cell circuit shownin Fig.2 and Kirchhoff's circuit laws, the photovoltaic currentcan be presented as follows:

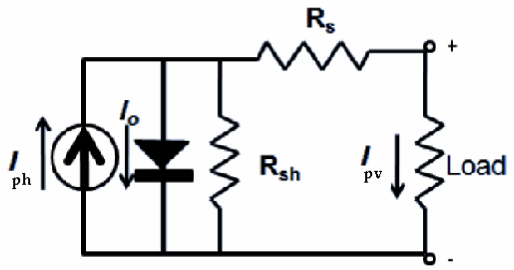


Fig.2: single diode PV cell equivalent circuit.

The current source Iph represents the cell photocurrent. Rsh and Rs are the intrinsic shunt and series resistances of the cell, respectively. Usually the value of Rsh is very large and that of Rs is very small, hence they may be neglected to simplify the analysis.

PV cells are grouped in larger units called PV modules which are further interconnected in a parallel-series configuration to form PV arrays.

The photovoltaic panel can be modelled mathematically as given in equations (1) to (4).

Module photo-current:

$$I_{ph} = [I_{sc} + K_1(T_c - T_{ref})]G \quad (1)$$

Module reverse saturation current – Irs:

$$I_{rs} = \frac{I_{sc}}{[\exp\left(\frac{qV_{oc}}{N_s KAT}\right) - 1]} \quad (2)$$

The module saturation current I_0 varies with the cell temperature, which is given by:

$$I_S = I_{RS}\left(\frac{T_c}{T_{ref}}\right)^3 exp\left[\left(\frac{qE_g(T_c - T_{ref})}{T_{ref}T_c K A}\right)\right] \quad (3)$$

The current output of PV module is:

$$I_{PV} = N_P I_{ph} - N_P I_0\left[\exp\left(\frac{q(V_{PV} + I_{PV}R_s)}{N_s AKT}\right)\right] \quad (4)$$

In this study, a general PV model is built and implemented using MATLAB/SIMULINK to verify the nonlinear output characteristics for the PV module. The proposed model is implemented, as shown in Fig. 3. In this model, whereas the inputs are the solar irradiation and cell temperature, the outputs are the photovoltaic voltage and current. The PV models parameters are usually extracted from the manufactures data sheet.

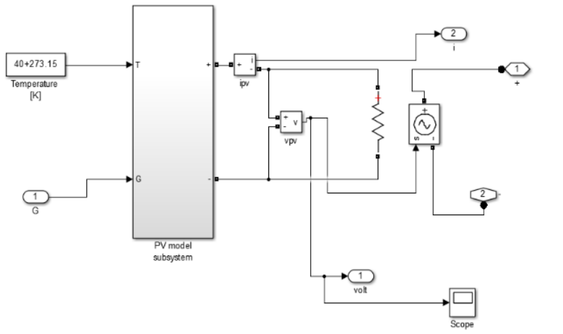


Fig. 3: Implementation of PV model

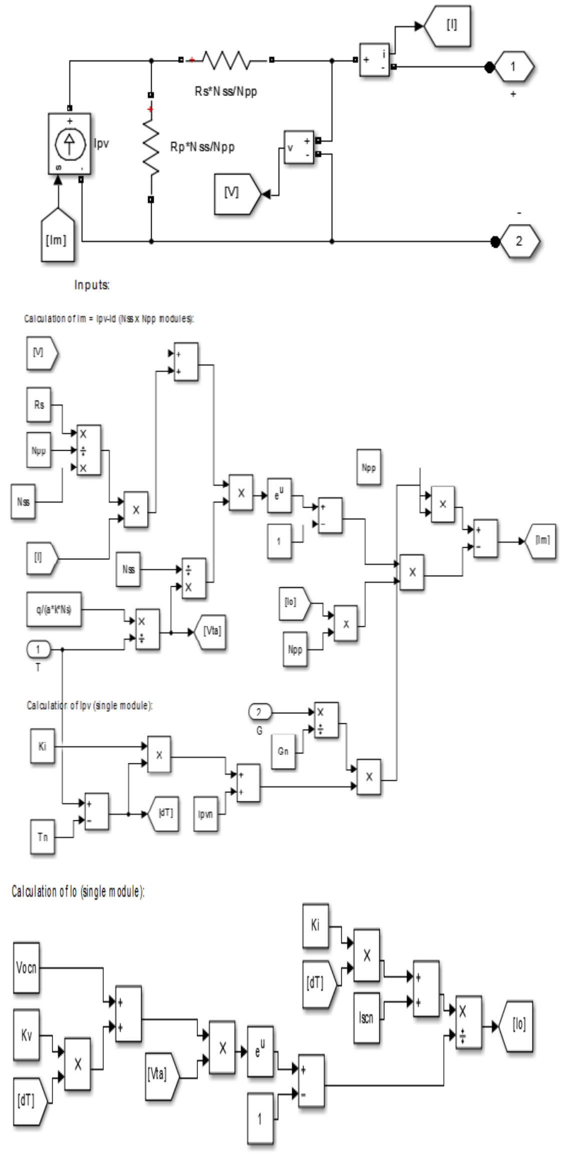


Fig.4: implementation of PV model subsystem

Fig 4 shows the implementation of PV model using the equations (1) to (4).

B. Mathematical modelling of WECS

The power captured from the wind turbine is given bythe equation (5)

$$Pw = \frac{1}{2} C_p \rho As \, V_w{}^3 \qquad (5)$$

Where C_p is the power coefficient, ρ is the air density, which is equal to 1.225 kg/m^3, V_w is the wind speed in m/s and A is the area swept by the rotor in m^2.

The volume of aerodynamic torque T_w in N-m is given by the ratio between the power from the wind and the turbine rotor speed Wwin rad/s, as follows

$$T_W = {}^{P_w}/_{W_w} \qquad (6)$$

Mechanical torque transferred to the generator is equal to the aerodynamic torque since there is no gearbox. The power coefficient Cp has its maximum value equal to 0.593 which means that the power extracted from the wind is at all times less than 59.3% (Betz's limit), this is because of the various aerodynamic losses depending on rotor construction. The common function defining the power coefficient as a function of the tip speed ratio and the blade pitch angle is given as

$$Cp(\lambda, \beta) = C1\left(\frac{C2}{\lambda} - C3\beta - C4\right) e^{\frac{-C5}{\lambda 1}} + C6\,\lambda 6 \quad (7)$$

Since this function depends on the wind turbine rotor type, the coefficient c_1-c_6 and x can be different for various turbine designs. The coefficients are equal to: C_1=0.5, C_2=116, C_3=0.4, C_4=0, C_5=5, C_6=21 (x is not used because C_4=0). Furthermore the parameter is also defined as

$$\frac{1}{\beta} = \frac{1}{\lambda + 0.08\vartheta} - \frac{0.035}{1 - \vartheta 3} \qquad (8)$$

Where ϑ is the pitch angle and the tip speed ratio λ is defined as

$$\lambda = \frac{W_w R}{V_w} \qquad (9)$$

Where R is the rotor radius [m], $W_w$is the angular velocity of rotor [rad/s] and V_w is wind speed [m/s].

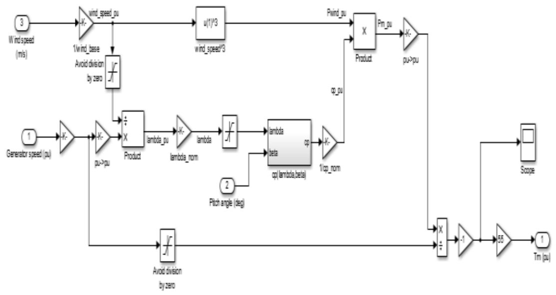


Fig. 5: Wind Turbine model

The model of the wind turbine realised in Simulink as shown in figure 5.

Input to the wind turbine is generator speed, wind speed and pitch angle and output is the torque which is given to drive the generator. Fig 6 represents the simulation results of power coefficient versus tip speed ratio characteristics for several blade pitch angle, figure 7 plots the power speed curves for various wind speeds and figure 8 shows the torque speed curves for different wind speed.

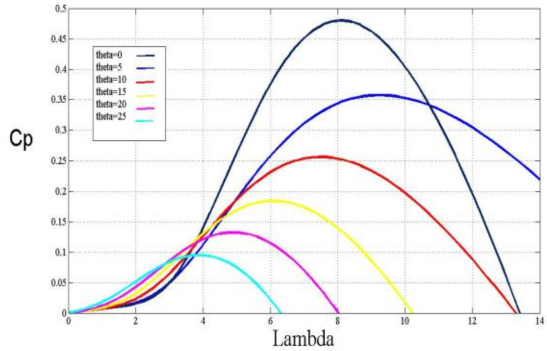


Fig.6: C_p vs. Lambda characteristics for various blade pitch angle.

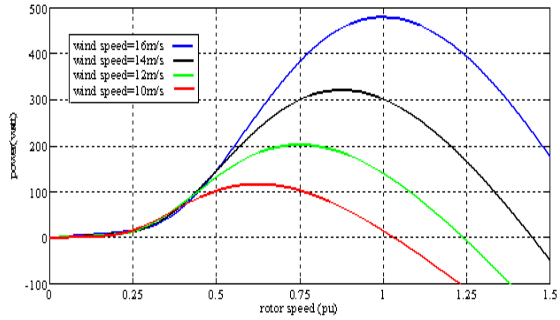


Fig.7: Power vs. speed curves for different wind speeds

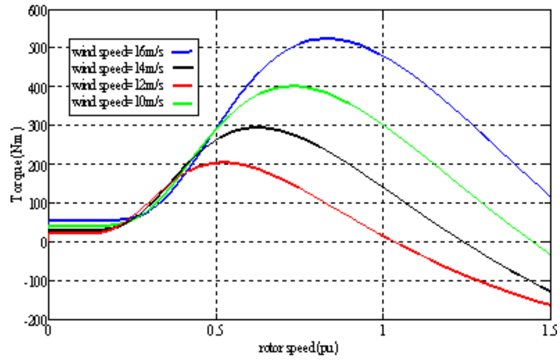


Fig.8: Torque vs. speed curves for different wind speeds

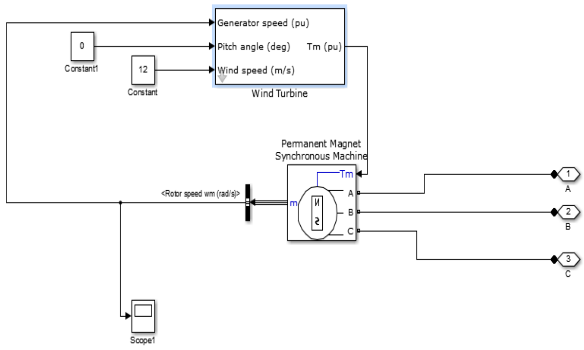


Fig.9: Implementation of WECS

C. Mathematical model of Fuel cell

The fuel cell stack block implements a generic model parameterized to represent most popular types of fuel cell stacks fed with hydrogen and air.

The block represents two versions of the stack model: a simplified model and a detailed model.

Simplified Model

The simplified model represents a particular fuel cell stack operating at nominal conditions of temperature and pressure. A diode is used to prevent the flow of negative current into the stack. This model is based on the equivalent circuit of a fuel cell stack shown in Figure 10.

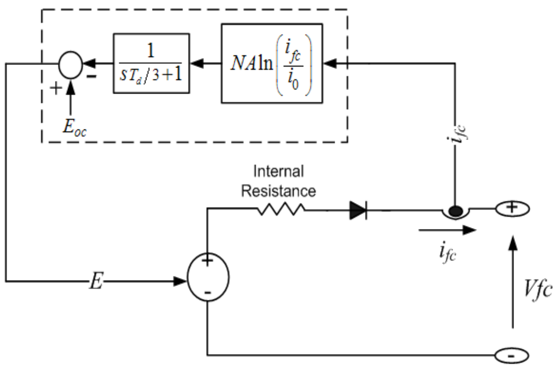


Fig. 10: Equivalent circuit of Fuel cell stack.

The parameters of the equivalent circuit can be modified based on the polarization curve obtained from the manufacturer datasheet. You just have to input in the mask the value of the voltage at 0 and 1 A, the nominal and the maximum operating points, for the parameters to be calculated. A diode is used to prevent the flow of negative current into the stack. A typical polarization curve consists of three regions:

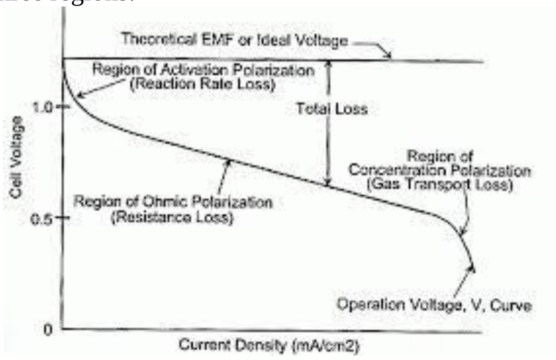


Fig. 11: Ideal and Actual Fuel cell voltage and current curve.

The first region represents the activation voltage drop due to the slowness of the chemical reactions takingplace at electrode surfaces. Depending on the temperature and operating pressure, type of electrode, and catalyst used, this region is more or less wide. The second region represents the resistive losses due the internal resistance of the fuel cell stack. Finally, the third region represents the mass transport losses resulting from the change in concentration of reactants as the fuel is used.

Fig. 12 shows the implementation of fuel cell using MATLAB simulation.

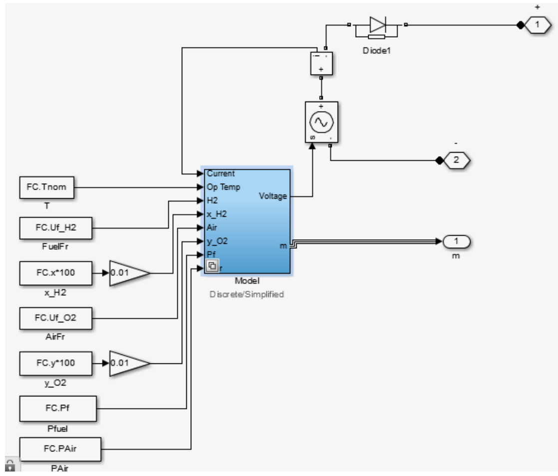


Fig. 11: Implementation of Fuel Cell subsystem.

D. Modelling of hybrid system.

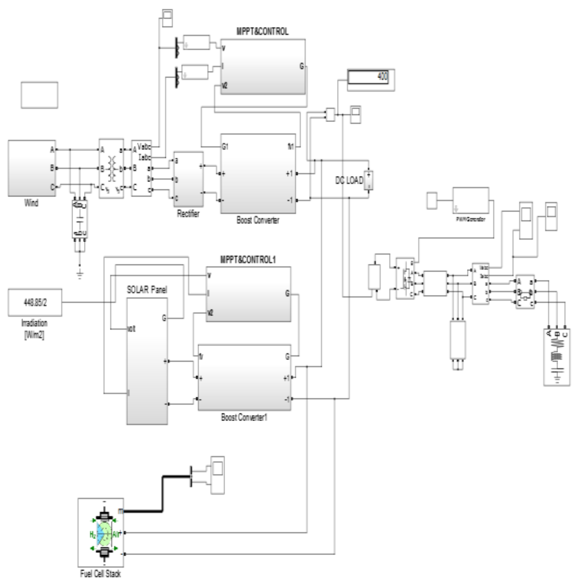


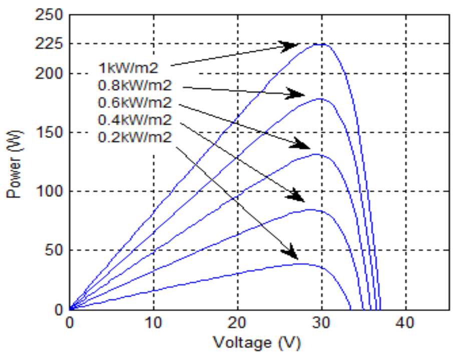
Fig. 12: Modelling of complete hybrid system.

In simulated hybrid system the boost output of PV, WECS and Fuel cell is connected to a DC bus. The DC loads are connected to the DC bus and this DC voltage is converted to AC by using an inverter and given to AC load or to a grid.

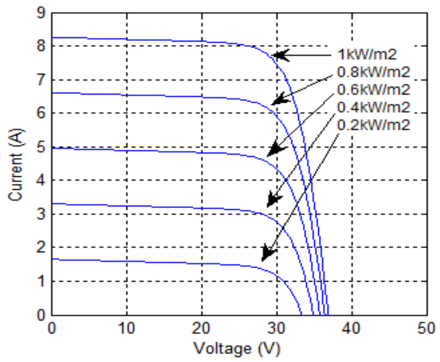
IV. SIMULATION RESULT

The block diagram of the integrated photovoltaic/wind turbine system, and the power controllers are shown in Fig. 12. The major inputs for the proposed PV model were solar irradiation, PV panel temperature and PV manufacturing data sheet information's.

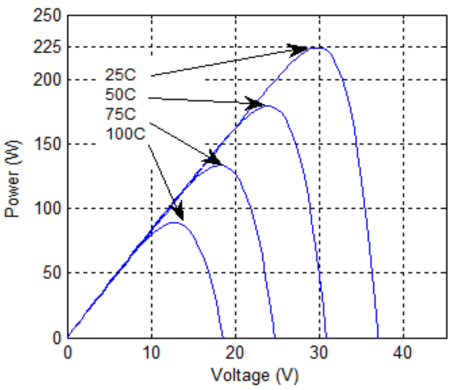
The I-V and P-V output characteristics for the PV model are shown in Fig.13. The output power and current of PV module depend on the solar irradiance and temperature, and cell's terminal operating voltage as well. It was found from Fig. 13(a) and 13(b) that with increased solar irradiance there is an increase in both the maximum power output and the short circuit current. On the other hand, we observe from Fig. 13(c) and 13(d) that with an increase in the cell temperature, the maximum power output decreases whilst the short circuit current increases



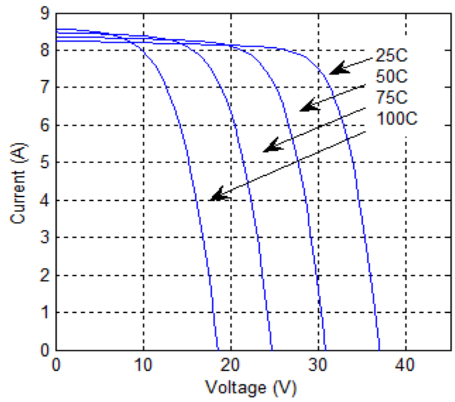
a



b



c



d

Fig. 13. I-V and P-V output characteristics (a - b) with different *G* (c - d) with different *Tc*

The generator speed (rpm) and the generator power (p.u.) characteristics for the WT model are shown in Fig. 14 corresponding to various wind speed values. The output power of WT depends on the wind speed and generator speed. As depicted in Fig.14, wind speed is the most influential factor on the amount of power produced by the wind turbine. Because the power in the wind is a cubic function of wind speed, changes in speed produce a profound effect on power.

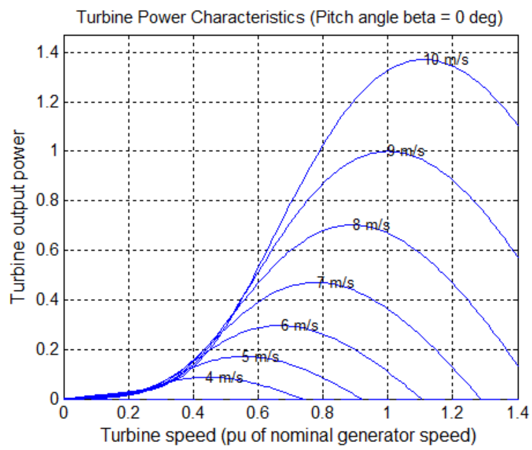


Fig. 14: Wind turbine characteristics

Although the photovoltaic voltage fluctuates due to solar radiation variations, the proposed control system of the solar power plant successfully keeps the load voltage stable at 400V. The output voltage of the dc/dc converter is depicted in Fig.15. The output voltage of the PV panel is depicted in Fig.16. The objective of the P&O algorithm is to adjust the dc/dc control variable (*Iref*), so that the PV array operates at the maximum power point (MPP). And that done, by periodically incrementing or decrementing the PV array operating current (*Ipv* = *Iref*).

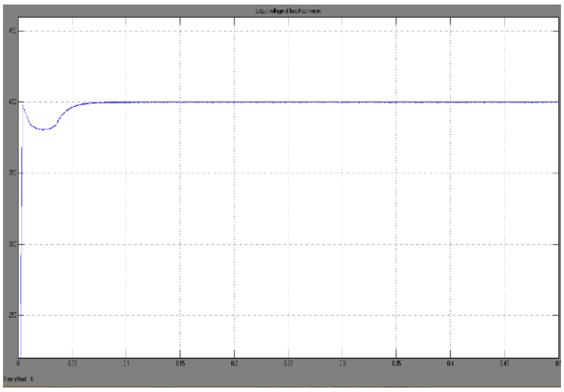


Fig. 15: Output voltage of DC/DC converter.

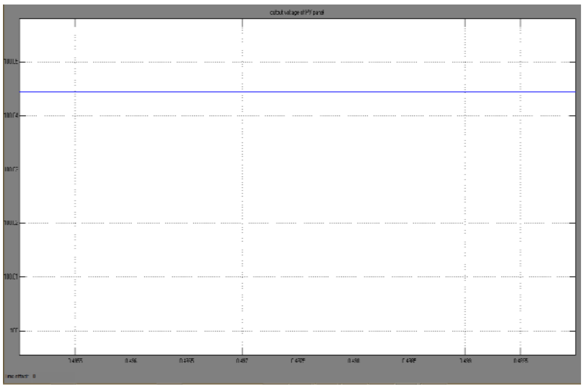


Fig. 16: output from PV panel

In this study, the stator winding is connected to the grid and the rotor is driven by the wind turbine. The power captured by the wind turbine is converted into electrical power by the induction generator and is transmitted to the grid by the stator winding. The output ac voltage from the generator is shown in fig.17.

From Fig. 18, we observe that although the available power from the wind generator fluctuates due to wind speed variations, by using the MPPT technique maximum power is tracked and by using a bridge rectifier successfully maintains the output voltage of the WTIG at 400V.

Since the voltage of the two dc buses is kept at 400V, dc/ac inverters are used to deliver the required power to the load side.

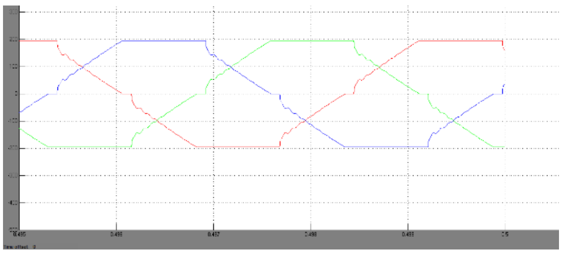


Fig. 17: The output ac voltage from generator

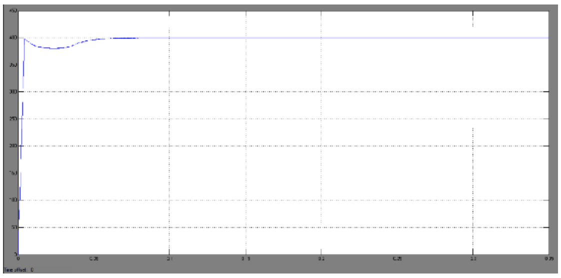


Fig. 18: Output from boost converter

Fig. 19 shows the DC bus voltage of the hybrid system. The DC bus voltage as we can see bus voltage is 400V. The DC loads are connected to this bus and to connect this to AC loads or grid the DC voltage is converted to AC by using an inverter.

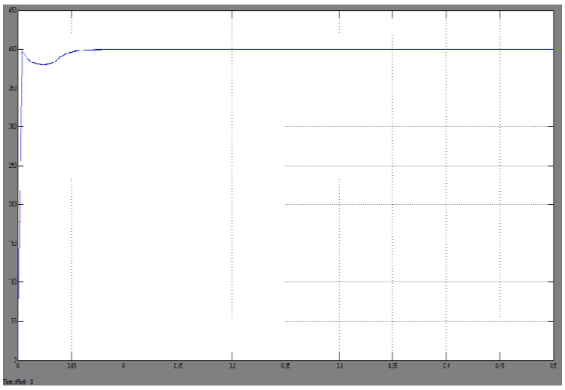


Fig. 19: DC bus voltage

Fig. 20 shows the output voltage of Fuel cell. The output voltage of fuel cell is around 65V.

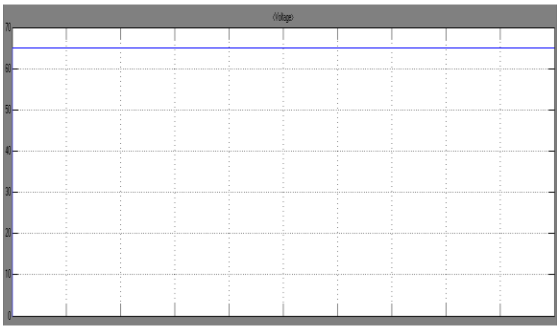


Fig. 20: output voltage of Fuel cell.

The output voltage (Vabc) and current(Iabc) of the hybrid system is shown in fig. 20. As we can see the output voltage is 800V and current is 2.6A.

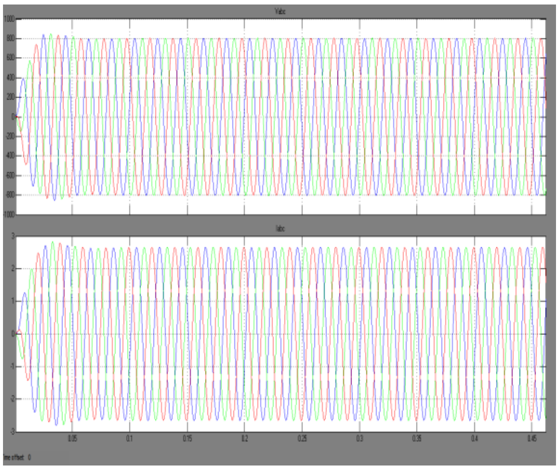


Fig.20: Vabc and Iabc of hybrid system.

V. CONCLUSION

In this paper, a novel PV, WT and FC hybrid power system is designed and modelled for smart grid applications. The developed algorithm comprises system components and an appropriate power flow controller. The model has been implemented using the MATLAB/SIMULINK software package, and designed with a dialog box like those used in the SIMULINK block libraries. The available power from the PV system is highly dependent on solar radiation. To overcome this deficiency of the PV system, the PV module was integrated with the wind turbine system. The dynamic behaviour of the proposed model is examined under different operating conditions. The developed system and its control strategy exhibit excellent performance for the simulation of a complete day.

REFERENCES

1. E. M. Natsheh, A. Albarbar, J. Yazdani, "Modeling and Control for Smart Grid Integration of Solar/Wind Energy Conversion System" International Conference 2013.
2. Joanne Hui, Alireza Bakhshai and Praveen K. Jain "A Hybrid Wind-Solar Energy System: A New Rectifier Stage Topology" International Conference 2010.
3. Sonam Mishra, Manju Gupta, Aarti Garg, Rahul Goel and Vimal Kumar Mishra "MODELING AND SIMULATION OF SOLAR PHOTO-VOLTAIC AND PMSG BASED WIND HYBRID SYSTEM" International Conference 2014.
4. F. Keyrouz, M. Hamad and S. Georges " A NOVEL UNIFIED MAXIMUM POWER POINT TRACKER FOR CONTROLLING A HYBRID WIND-SOLAR AND FUEL-CELL SYSTEM" 2013 Eighth International Conference And Exhibition On Ecological Vehicles And Renewable Energies
5. Amir Ghaedi1, Ali Abbaspour1, Mahmud Fotuhi-Firuzabad1, Moein Moeini-Aghtaie and Muhammad Othman "RELIABILITY EVALUATION OF A COMPOSITE POWER SYSTEM CONTAINING WIND AND SOLAR GENERATION." 2013 IEEE 7th international power engineering and optimization conference.
6. Rupesh G. Wandhare and Vivek Agarwal "NOVEL INTEGRATION OF PV-WIND ENERGY SYSTEM WITH ENHANCED EFFICIENCY."IEEE Transactions on Power Electronics.
7. Eman Beshr "COMPARATIVE STUDY OF ADDING PV /WIND ENERGY SYSTEMS TO AUTONOMUS MICRO GRID." 2013 3rd International Conference on Electric Power and Energy Conversion Systems.
8. S.Gomathy, S.Saravanan and Dr. S. Thangavel "DESIGN AND IMPLEMENTATION OF MAXIMUM POWER POINT TRACKING (MPPT) ALGORITHM FOR A STANDALONE PV SYSTEM." International Journal of Scientific & Engineering Research Vol 3, Issue 3, March -2012.
9. Rupesh G. Wandhare and Vivek Agarwal "A CONTROL STRATEGY TO REDUCE THE EFFECT OF INTERMITTENT SOLAR RADIATION AND WIND VELOCITY IN THE HYBRID PHOTOVOLTAIC/WIND SCIG SYSTEM WITHOUT LOSING MPPT." International Conference 2010.
10. Kazmi Syed Muhammad Raza, Hiroki Goto, Hai-Jiao Guo, Osamu Ichinokura "MAXIMUM POWER POINT TRACKING CONTROL AND VOLTAGE REGULATION OF A DC GRID-TIED WIND ENERGY CONVERSION SYSTEM BASED ON A NOVEL PERMANENT MAGNET RELUCTANCE GENERATOR." International Conference on Electrical Machines and Systems 2007.
11. Domenico Casadei, Gabriele Grandi and Claudio Rossi "SINGLE-PHASE SINGLE-STAGE PHOTOVOLTAIC GENERATION SYSTEM BASED ON A RIPPLE CORRELATION CONTROL MAXIMUM POWER POINT TRACKING." IEEE transactions on energy conversion vol. 21, no. 2, June 2006.
12. Weidong Xiao, William G. Dunford, Patrick R. Palmer and Antoine Capel "REGULATION OF PHOTOVOLTAIC VOLTAGE." IEEE transactions on industrial electronics, vol. 54, no. 3, June 2007.
13. Sohan Lal, Rohtash Dhiman and Mr.S.K.Sinha "ANALYSIS DIFFERENT MPPT TECHNIQUES FOR PHOTOVOLTAIC SYSTEM" International Journal of Engineering and Innovative Technology (IJEIT) Vol 2, Issue 6, December 2012.
14. N.Pandiarajan and Ranganath Muthu"MATHEMATICAL MODELING OF PHOTOVOLTAIC MODULE WITH SIMULINK" International Conference on Electrical Energy Systems (ICEES 2011), 3-5 Jan 2011.
15. Kinal Kanchhiya, Makarand Lokhande and Mukesh Patel "MATLAB/SIMULINK MODEL OF SOLAR PV MODULE AND MPPT ALGORITHM" National Conference on Recent Trends in engineering and Technology 13-14 May 2011.
16. P.Sudeepika and G.Md. Gayaz Khan "ANALYSIS OF MATHEMATICAL MODEL OF PV CELL MODULE IN MATLAB/SIMULINK ENVIRONMENT" International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering vol.3 March 2014.
17. Anaghat R Tiwari, Anuradha J Shewale, Anuja R Gagangras and Netra M Lokhande " COMPARISON OF VARIOUS WIND TURBINE GENERATOR" Multidisciplinary Journal of Research in Engineering and Technology, vol.1, no 2. July 2014.
18. Neeraj Pareta and Naveen Sen "MODELLING AND SIMULATION OF PERMANENT MAGNET SYNCHRONOUS MOTOER BASED WIND ENERGY CONVERSION SYSTEM" International Journal of Emerging Research in Management &Technology Vol.3, July 2014.
19. Mohammed Aslam Husain and Abu Tariq"MODELING AND STUDY OF A STANDALONE PMSG WIND GENERATION SYSTEM USING MATLAB/SIMULINK" Universal Journal of Electrical and Electronic Engineering, August 2014.

20. S. Samanvorakij and P. Kumkratug "MODELING AND SIMULATION PMSG BASED ON WIND ENERGY CONVERSION SYSTEM IN MATLAB/SIMULINK" International conference on Advances in Electronics and Electrical Engineering July 2013.
21. Lakshman Rao S. P, Dr. Ciji Pearl Kurian, Dr.B.K.singh, Kumar Abhinav, Gaurav Nandy "DESIGN AND SIMULATION OF GRID CONNECTED HYBRID SOLAR-WECS USING SIMULINK/MATLAB" International conference on Advances in Electronics and Electrical Engineering March 2014.
22. Aliasger Zaidi, Pooja Pokharkar, Rajesh Krishnan and Dayaram Sonawane "DYNAMIC MODELING AND SIMULATION OF A PEM FUEL CELL: MATLAB AND LAB VIEW MODELING APPROACH" International Conference on Non Conventional Energy July 2014.
23. E.Muljadi and C.P Butterfield "PITCH-CONTROLLED VARIABLE-SPEED WIND TURBINE GENERATOR" IEEE Industrial Applications October 3-7 1999.

BIBLIOGRAPHY OF AUTHORS

1. Mrs Kamala Devi. V is working as a Senior Research Assistant at ANERT (Agency for Non-conventional Energy and Rural Technology), an autonomous organization under the Government of Kerala.
2. Mrs Aparna S Nair is working as an Assistant Professor at the Electrical and Electronics Department of Toc H Institute Of Science and Technology, Ernakulam, Kerala.
3. Mr Silpa K L is an M Tech (Power Electronics) student of Toc H Institute Of Science and Technology, Ernakulam, Kerala.