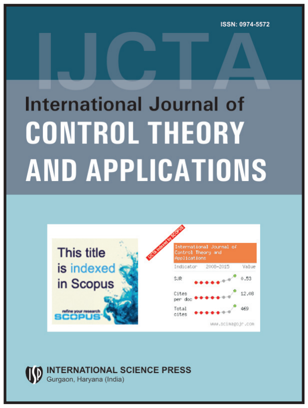

International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 10 • Number 24 • 2017

Energy Mangement for Grid Interconnected Solar and Wind System using Fuzzy Logic Controller

Shah Dhruvang Amitkumar[a], P. Kanakraj[b] and C. Subramani[c]

[a]*PG Student M.Tech (PSE), Department of Electrical and Electronics Engineering, SRM University, Chennai - 603203. Email: dhruvangshah94@gmail.com*
[b]*Department of Electrical and Electronics Engineering, SRM University, Chennai - 603203. Email: kanakaraj.p@ktr.srmuniv.ac.in*
[c]*Department of Electrical and Electronics Engineering, SRM University, Chennai - 603203*

Abstract: Renewable energy like solar and wind are used for generating power due to their unlimited existence and environment friendly nature. This paper deals with design of Fuzzy logic controller for the energy management of the grid interconnected solar and wind. This system is the combination of photovoltaic (PV) array, wind turbine, battery storage and multiple-input dc-dc converter. A control system is implemented which is consisting of fuzzy logic controllers and the local controllers for the photovoltaic, wind and battery unit. The fuzzy logic controller is used for the power management between the solar generation, wind generation, energy storage and grid. Simulation are performed in MATLAB/Simulink.

Keywords: Renewable Source, Multiple-Input DC-DC converter, Fuzzy Logic Controller, Energy Management, Battery, Grid.

1. INTRODUCTION

Demand of the renewable energy is increasing day by day because of the depletion of the fossil fuel. Renewable energy like solar energy and wind energy can directly get from the nature in the plenty amount. As they are environment friendly and freely available, but there are certain drawbacks to use solar energy and wind energy due to the high capital cost remain the main obstacles for the utilization of renewable energy. Interconnected wind and solar with the storage energy can enhance system reliability, operational efficiency, power availability and quality.

Earlier several techniques were used for the hybrid solar/wind power system with the Maximum Power Point Tracking (MPPT) control [3]. They used separate DC-DC Buck and Buck Boost converter to perform MPPT control. These system associated with the various problems such that the Buck and Buck Boost converter do not have the capability to eliminate harmonics which are injected due to the environmental factor. The wind turbine generator has a capability to generate high frequency current harmonics which are injected into it, so the system requires filter to reduce or eliminate the harmonics which makes the system more bulky and expensive [4]. This paper uses the multi input DC-DC converter. The wind and the solar energy sources are used combination of the CUK and SEPIC converters. It is used in such a combination that if one of the source is unavailable then the other sources will compensate for it. The advantages of CUK and SEPIC converter [2] is that it have the capability to reduce or eliminate high frequency current harmonic which are generated by the wind generator. Individual converter are replaced by a single converter called CUK and SEPIC converter. In the literature, there are a few studies related to energy management in smart microgrid for residential application, among them Mr. A. Albert Martin et. al., [1], it's main objective is to provide Uninterruptible power to the load. This system consists of the power sources, storage system unit and DC bus regulator system. Sanaa Faquir et. al., [5], presents a study of a HRES composed of Photovoltaic (PV) solar panels and a wind turbine as primary energy sources and batteries as storage units and proposes a computer algorithm based on type-1 fuzzy logic to control the energy between production and consumption and ensure the availability of power on demand. A.T. Tharakan et. al., [6], considers the modelling and energy management of a hybrid renewable source with battery energy storage. A dynamic programming based energy management strategy (EMS) is developed for the energy management of the system. GhadaMerei et. al., [7], shows the Combination of three different battery technologies as storage system is investigated: lead-acid, Li-ion and redox-flow batteries. To control both the power flow among the system components and the battery charging and discharging processes, an energy management system (EMS) is needed. It calculates the batteries state of charge in every time step and decides which battery technology is active (is being charged or discharged) as well as when the diesel generator has to be started.

A. Structure of Paper

In these paper the first part is introduction which explain the basic fundamental of energy management for grid connected PV/Wind , CUK and SEPIC converter and battery. The second part explain the proposed architecture in which the grid is connected PV and Wind using fuzzy logic controller. The third part explain the system modelling in which PV model, wind model, CUK and SEPIC model, battery modelling is explained. The forth part of the paper explain the fuzzy logic controller which explains about the fuzzy logic tool box, membership function and fuzzy logic rules base. In the fifth part simulation result is showed which gives the clear idea at the isolated mode and grid connected mode. The sixth part is of the conclusion.

2. PROPOSED ARCHITECHTURE

Figure 1 shows the overall architecture of PV and Wind with grid. The main sources are PV and Wind which are combined with CUK & SEPIC converter. Energy storage system (ESS) like Battery is also connected to the main dc bus in order to support local power production in an islanded mode particularly during blackouts or natural disasters. Fuzzy logic controller is used for the power flow through the grid.

Wind and solar energy are connected directly to multi input dc-dc converter. The main advantage of multi input dc-dc converter it can be operated separately or simultaneously operation and it contain filter which will reduce harmonics so extra filter requirement is not needed. PWM inverter will convert dc voltage to ac voltage of 415V phase voltage which is connected by the LC filter to reduce harmonics and fed to the ac load whose phase voltage is 415V. Three phase utility grid is connected to the ac transmission line which will fed the load when renewable energy is not sufficient to satisfy the load demand.

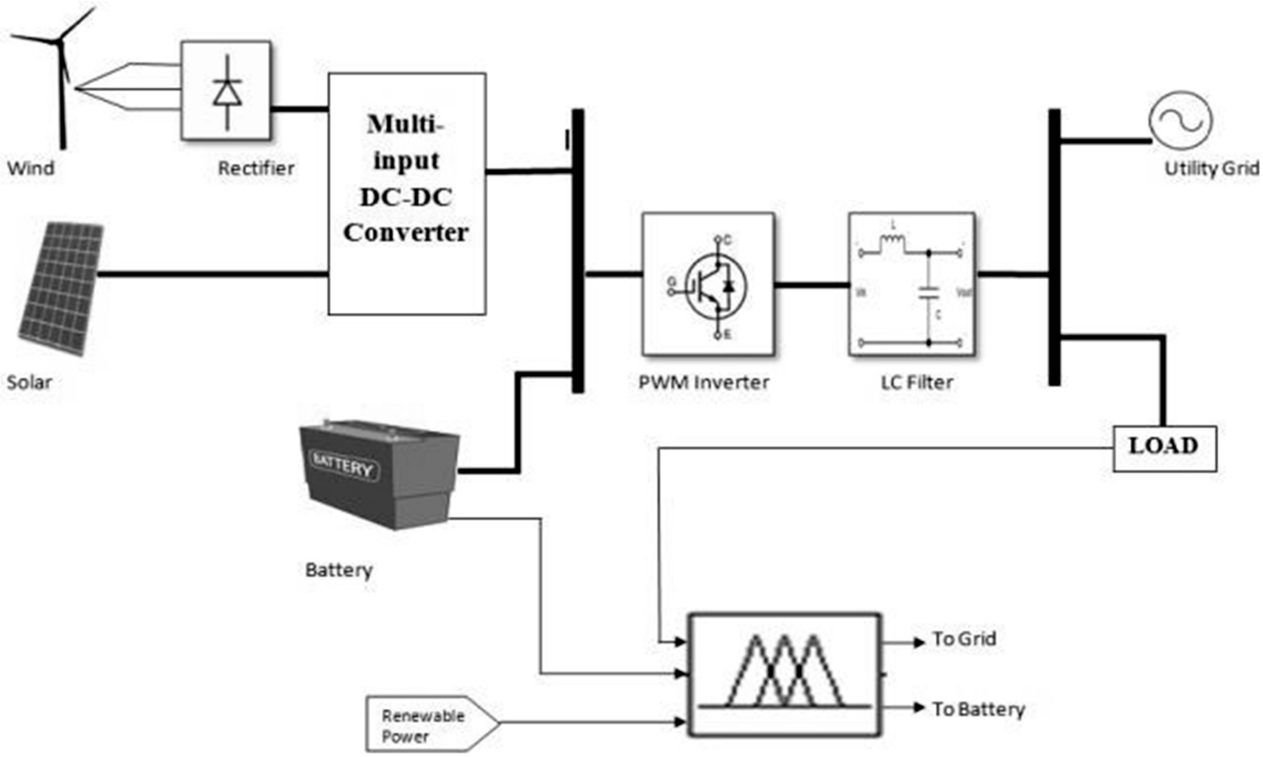

Figure 1: Proposed architecture of grid connected PV and Wind using fuzzy logic controller

3. SYSTEM MODELLING

A. PV Model

More accuracy is obtained by the model by adding a series resistance. The configuration of the model is shown in the Figure 2.

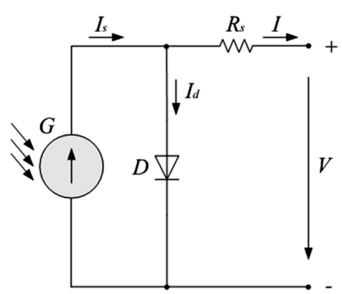

Figure 2: Solar cell with single diode and series resistance

The output power is given by:

$$P = V\left[I_{sc} - I_o \left(e^{\frac{q(V + R_s I)}{mkT}} - 1 \right) \right] \tag{1}$$

Where the symbols are defined as, e is electron charge, k is Boltzmann constant, I_{sc} is short circuit output current, A. I_o is reverse saturation current of diode, R_s is series resistance of cell, T is reference cell operating temperature and V is cell output voltage, V. Both k and T_c has the same temperature unit, it can be either Kelvin or Celsius. It has one series resistance (R_s). The series resistance is caused due the reason that a solar cell is not a perfect conductor.

B. Wind Model

In wind turbine mechanical energy which is produced by the wind is converted to electrical energy. Wind turbine model is developed on the basis of the steady state power characteristic of wind turbine. The equation of the mechanical power produced by the wind turbine is shown below.

$$P_m = \frac{1}{2}\rho \cdot \pi R^2 \cdot V^3 \cdot C_p \tag{2}$$

Where the symbol are defined as P is Air density (kg/m^3), R is Turbine radius (*m*), C_p is Turbine power coefficient power conversion efficiency, V is Wind speed (m/s)

C. Multi-input DC-DC Converter

CUK and SEPIC converter are used in the multi input DC-DC converter. A hybrid wind and solar energy system is shown in Figure 2. These design incorporates two input and one output, where one of the converter inputs is connected to the output of the PV array and the another converter input is connected to the output of a wind generator.

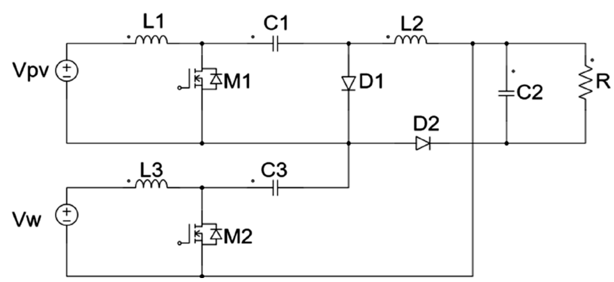

Figure 3: Multi input DC-DC converter

Mode I (M_1-ON, M_2-ON): In the mode I both solar energy and wind energy is available, the switches M_1 and M_2 are turn ON. The capacitors C_1 and C_2 are connected across diode D_1 and D_2 respectively, due to these diodes D_1 and D_2 experience reverse biased. The equivalent circuit for the mode I is as shown Figure 4.

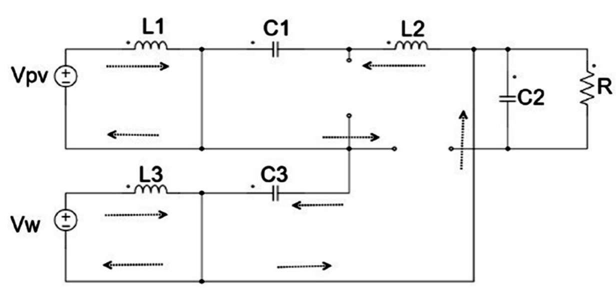

Figure 4: Mode I of multi input DC-DC converter

$$IL_1 = I_{PV} + V_{PV}/L_1 t, \ (0 < t < d_1 T_s) \tag{3}$$

$$IL_2 = I_{dc} + (V_{c1} + V_{c2}/L_2)t, \ (0 < t < d_1 T_s) \tag{4}$$

$$IL_3 = I_W + V_W/L_3 t, \ (0 < t < d_1 T_s) \tag{5}$$

Mode II (M_1-ON, M_2-OFF): In this mode II only solar energy is available and wind energy is not available. Hence switch M_1 turns ON and switch M_2 turns OFF. The diode D_1 experience reverse biased due to the inductor current in L_3 forces diode D_2 to conduct. The equivalent circuit for the mode II is as shown in Figure 5.

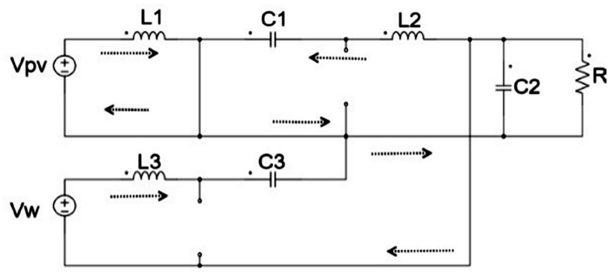

Figure 5: Mode II of multi input DC-DC converter

$$V_o = V_{in}[D/(1 - D)] \tag{6}$$

Mode III (M_1-OFF, M_2-ON): In this mode III only wind energy is available and solar energy is not available. The switch M_1 is turn OFF and switch M_2 is turn ON so current in the inductor L_1 forces diode D_1 to conduct and diode D_2 experience reverse biased. The equivalent circuit for mode III is as shown in Figure 6.

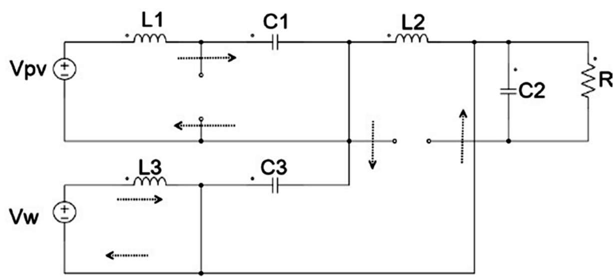

Figure 6: Mode III of multi input DC-DC converter

$$IL_1 = I_{PV} + ((V_{PV} - V_{c1})/L_1)t, \ (d_1T_s < t < d_2T_s) \tag{7}$$

$$IL_2 = I_{dc}(V_{c2}/L_2)t, \ (d_1T_s < t < d_2T_s) \tag{8}$$

$$IL_3 = I_W + (V_W/L_3)t, \ (d_1T_s < t < d_2T_s) \tag{9}$$

Mode IV (M_1-OFF, M_2-OFF): In this mode IV both solar energy and wind energy is unavailable. The switches M_1 and M_2 both are turn OFF due to these inductor current L_1 and L_3 forces diode D_1 and D_3 to conduct respectively. The equivalent circuit for mode IV is as shown in Figure 7.

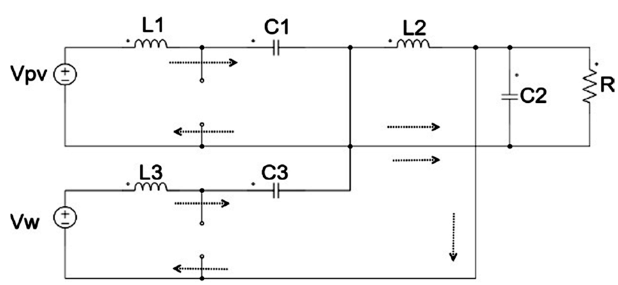

Figure 7: Mode IV of multi input DC-DC converter

$$IL_1 = I_{PV} + ((V_{PV} - V_{c1})/L_1t, \ (d_2T_s < t < T_s) \tag{10}$$

$$IL_2 = I_{dc} - (V_{c2}/L_2)t, \ (d_2T_s < t < T_s) \tag{11}$$

$$IL_3 = I_W + (V_W - V_{C2} - V_{dc})/L_3)t, \ (d_2T_s < t < T_s) \tag{12}$$

D. Battery Modelling

The mathematical modelling of Nickel metal hydride is used in the simulation. The state of charge of battery is calculated as follows,

$$V_{batt} = E_{batt} - R_i$$

During discharge the equation of the battery is:

$$E_{batt} = E_e - K\frac{Q}{Q - it}it - k\frac{Q}{Q - it}i^* + A\exp(-Bit) \tag{13}$$

During charge the equation of the battery is:

$$E_{batt} = E_e - K\frac{Q}{Q - it}it - k\frac{Q}{it + 0.1}i^* + A\exp(-Bit) \tag{14}$$

Where the symbol are defined as E_{batt} is No-load voltage, E_o is Battery constant voltage, K is Polarization constant, Q is Battery capacity, i^* is Low frequency current dynamics, A is Exponential zone amplitude, B is Exponential zone time constant inverse $(Ah)^{-1}$, V_{batt} is Battery voltage and I is Battery current. The main feature of this battery model is that the parameters can easily be deduced from a manufacturer's discharge curve.

4. FUZZY LOGIC CONTROLLER

To implement energy management algorithm several techniques are available. Fuzzy logic technique has a low power dissipation, optimized cost, more reliable and stable. To design fuzzy logic controller fuzzy set theory is used. Figure 11 shows the proposed fuzzy logic tool box. An advance fuzzy logic controller is implemented according to the weather variations, load demand and SOC. Membership function of the fuzzy logic controller is shown below:

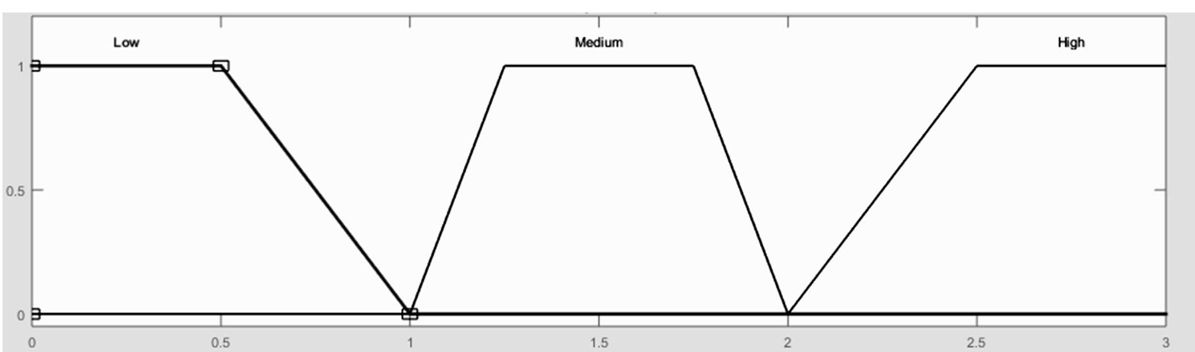

Figure 8: Membership functions of FLC Generated power

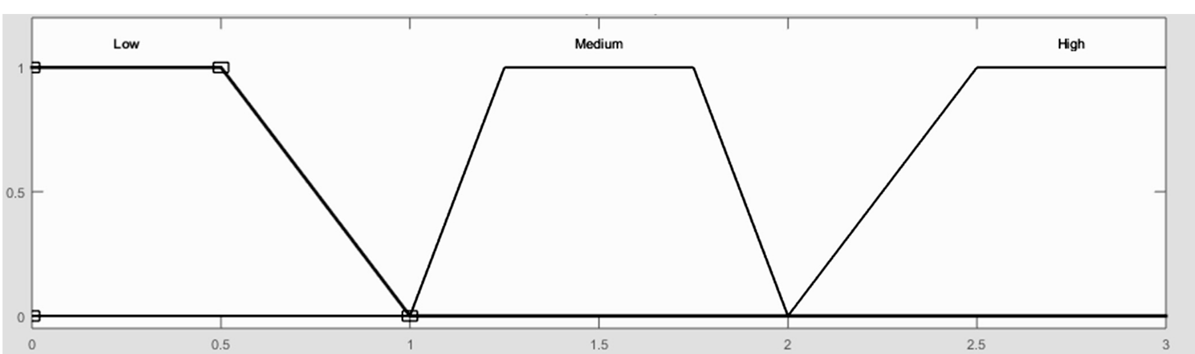

Figure 9: Membership functions of FLC Load demand

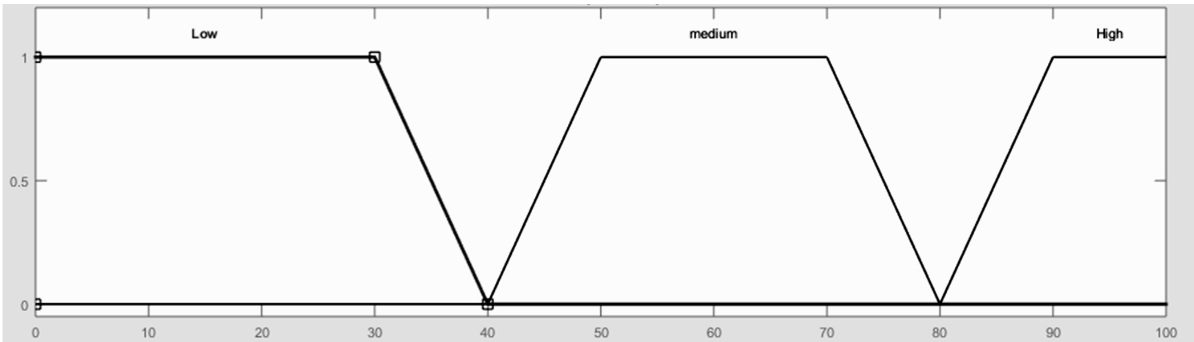

Figure 10: Membership functions of FLC Battery state

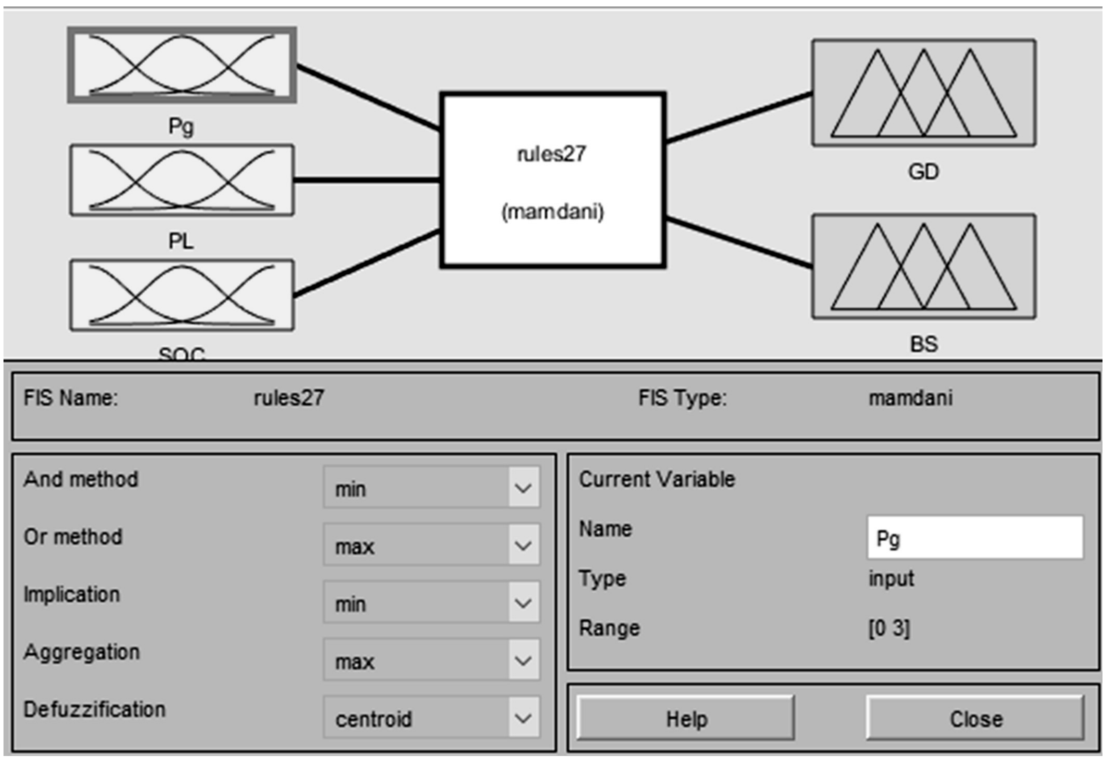

Figure 11: Fuzzy logic tool box

Under normal operation, system power changes smoothly so that the grid operating point deviation is minimized. The battery management system maintains the SOC at a level (40% – 80%) and it protects against voltage collapse by controlling the power level required from the battery. The fuzzy logic controller controls the reference power of the grid by splitting the power demand (PL) as a function of the available power of the battery and the PV/Wind system (PG).

Following steps are for fuzzy logic rules:

Step 1: IF PG is (L) and PL is (H) and SOC is (L) THEN GD is ON, BS is CO

Step 2: IF PG is (M) and PL is (H) and SOC is (L) THEN GD is ON, BS is CO

Step 3: IF PG is (H) and PL is (H) and SOC is (L) THEN GD is OFF, BS is CO

Step 4: IF PG is (L) and PL is (H) and SOC is (M) THEN GD is ON, BS is CO

Step 5: IF PG is (M) and PL is (H) and SOC is (M) THEN GD is ON, BS is CO

Step 6: IF PG is (H) and PL is (H) and SOC is (M) THEN GD is OFF, BS is CO

Step 7: IF PG is (L) and PL is (H) and SOC is (H) THEN GD is ON, BS is DO

Step 8: IF PG is (M) and PL is (H) and SOC is (H) THEN GD is ON, BS is DO

Step 9: IF PG is (H) and PL is (H) and SOC is (H) THEN GD is OFF, BS is DO

Step 10: IF PG is (L) and PL is (M) and SOC is (L) THEN GD is ON, BS is CO

Step 11: IF PG is (M) and PL is (M) and SOC is (L) THEN GD is OFF, BS is CO

Step 12: IF PG is (H) and PL is (M) and SOC is (L) THEN GD is OFF, BS is CO

Step 13: IF PG is (L) and PL is (M) and SOC is (M) THEN GD is ON, BS is CO

Step 14: IF PG is (M) and PL is (M) and SOC is (M) THEN GD is OFF, BS is CO

Step 15: IF PG is (H) and PL is (M) and SOC is (M) THEN GD is OFF, BS is CO

Step 16: IF PG is (L) and PL is (M) and SOC is (H) THEN GD is ON, BS is DO

Step 17: IF PG is (M) and PL is (M) and SOC is (H) THEN GD is OFF, BS is DO

Step 18: IF PG is (H) and PL is (M) and SOC is (H) THEN GD is OFF, BS is DO

Step 19: IF PG is (L) and PL is (L) and SOC is (L) THEN GD is ON, BS is CO

Step 20: IF PG is (M) and PL is (L) and SOC is (L) THEN GD is OFF, BS is CO

Step 21: IF PG is (H) and PL is (L) and SOC is (L) THEN GD is OFF, BS is CO

Step 22: IF PG is (L) and PL is (L) and SOC is (M) THEN GD is OFF, BS is CO

Step 23: IF PG is (M) and PL is (L) and SOC is (M) THEN GD is OFF, BS is CO

Step 24: IF PG is (H) and PL is (L) and SOC is (M) THEN GD is OFF, BS is CO

Step 25: IF PG is (L) and PL is (L) and SOC is (H) THEN GD is OFF, BS is DO

Step 26: IF PG is (M) and PL is (L) and SOC is (H) THEN GD is OFF, BS is DO

Step 27: IF PG is (H) and PL is (L) and SOC is (H) THEN GD is OFF, BS is DO

The Fuzzy logic controller relates the outputs to the inputs using a list of IF-THEN statements called rules. The if part of the rules describes the fuzzy set of the input variables. There are three input variables are PG, PL, and SOC and two output variables are GD and BS. The degrees of membership are evaluated to obtain the output controller, and then parts of all rules are averaged and weighted by the degrees of membership.

5. SIMULATION RESULT

These subsystems consist of primary sources of energy unit like PV array, wind unit and battery bank unit act as auxiliary source of energy. Fuzzy logic controller is developed to control the power management between different sources and the load. The Fuzzy logic controller control unit designed to control the battery current, grid power flow according to the supplement of the load with the required power. Fuzzy logic controller has three inputs and two output. The inverter control unit is used to convert the DC generated power from renewable energy sources to feed the load with the required AC power. The overall simulation diagram is shown in Figure 12.

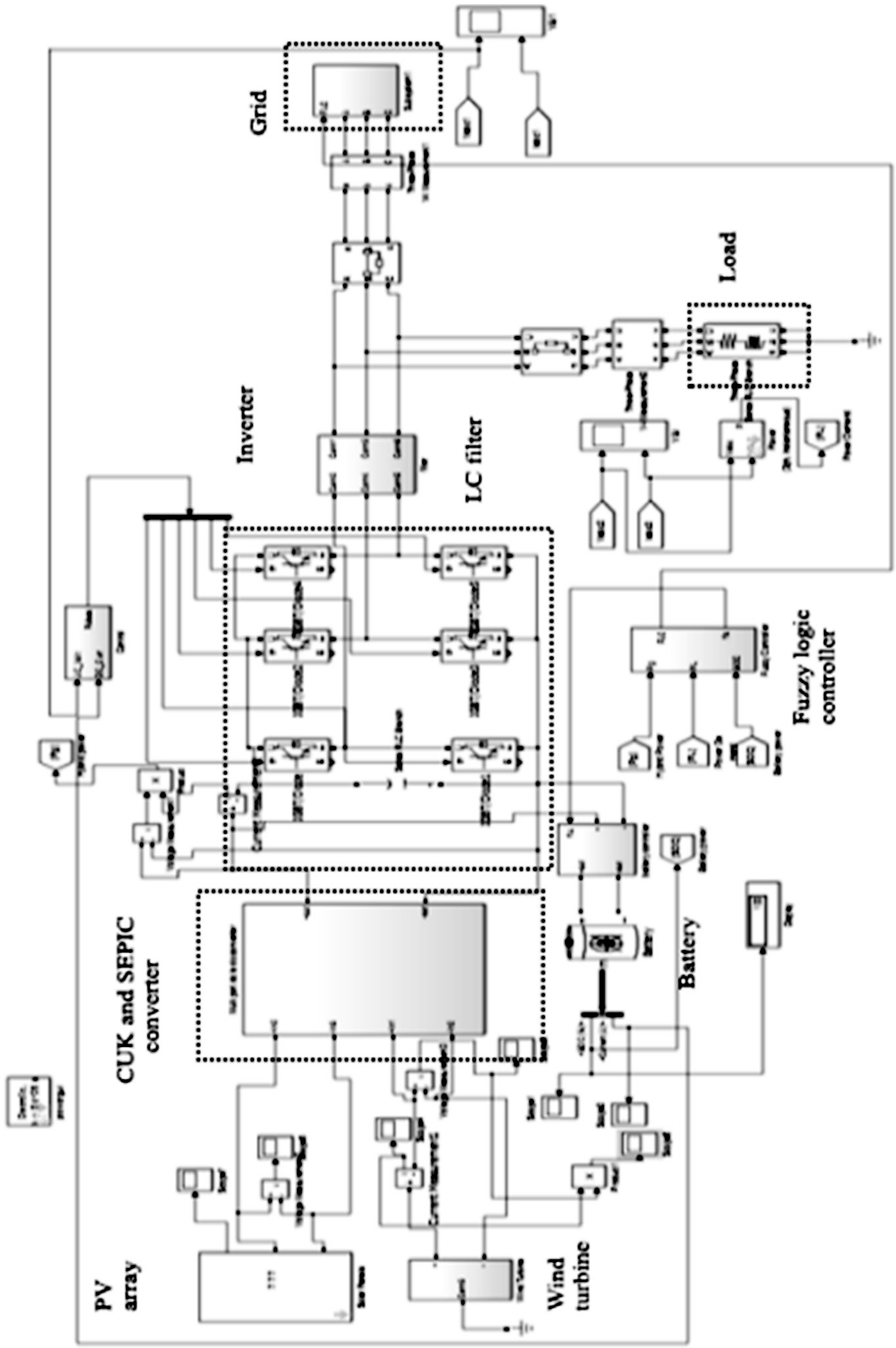

Figure 12: Grid interconnected solar and wind using fuzzy controller

A. At Isolated Mode

The initial SOC of the battery storage is 60%, Hence the SOC is medium, the low demand of load is satisfied by the RS and the extra power will be used to charge the battery. Battery will charge and renewable system is isolated from grid. The voltage and current waveform at point of common coupling is shown in Figure 13.

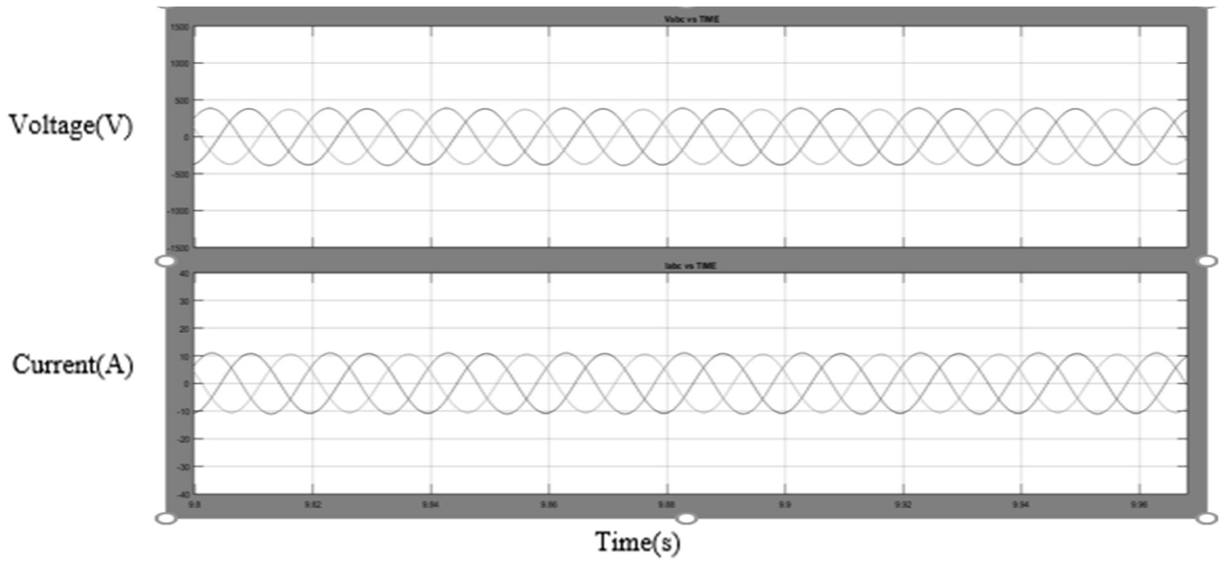

Figure 13: Voltage and current across PCC at the isolated mode

B. At Grid Interconnected Mode

When battery SOC is low 40%, demand of load is high which is not satisfied by renewable source then, the battery will charge and load is at grid interconnected mode. So due to these the grid will satisfied the demand of load, In above two cases the voltage at the point of common coupling will be regulated as constant 415 V three phase AC voltage, by controller used in inverter. The voltage and current waveform at point of common coupling is shown in Figure 14.

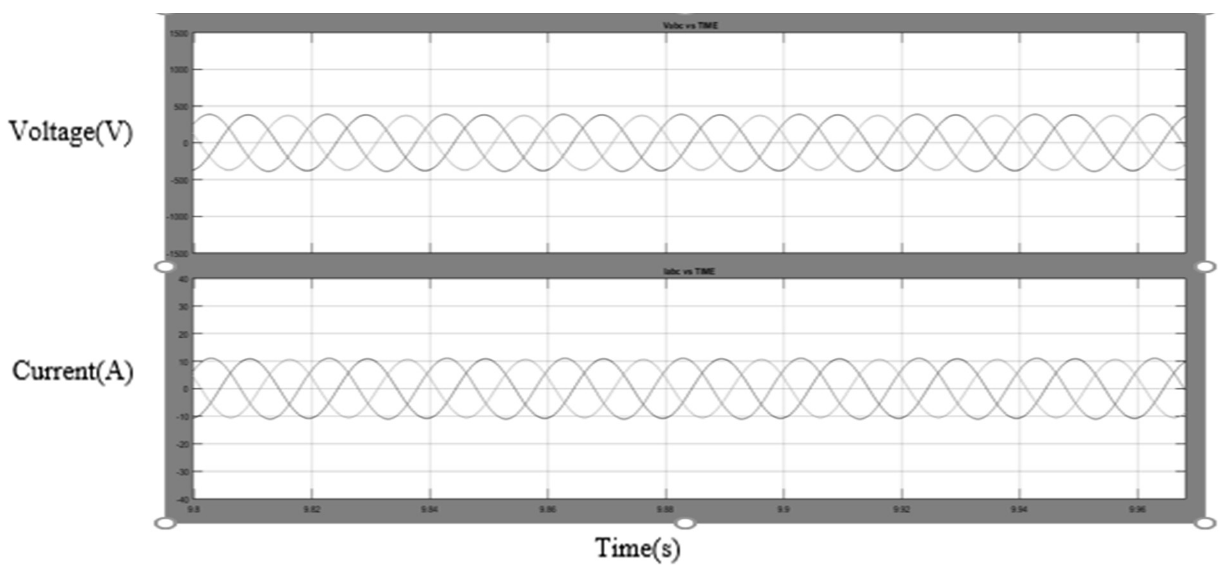

Figure 14: Voltage and current across PCC at the grid connected mode

6. CONCLUSION

The energy management between PV array, wind generator, battery bank and the load was controlled using Fuzzy logic controller. The simulation results are shown in MATLAB/SIMULINK, which showed the high performance of the proposed system. These results showed that the PV array and wind generator were capable of feeding the load with the required energy and charge the battery with its demands during night hours. During day time, high power generated from the PV system, so the excess power send to the utility grid after battery fully charged.

REFERENCES

[1] Mr. A. Albert, Martin Ruban G, Mathew Rajasekaran. "A Fuzzy-logic Based Management System in Smart Microgrid for Residential Applications" IEEE International Conference on Emerging Trends in Engineering, Technology and Science (ICETETS) 2016, pp. 1-7.

[2] Suresh K.V., Vinayaka K, Rajesh U "A CUK-SEPIC Fused Converter Topology for Wind –Solar Hybrid System for Standalone System" IEEE Power, Communication and Information Technology Conference (PCIT) 2015, pp. 48-53.

[3] N.A. Ahmed, M. Miyatake and A.K. Al-Othman, "Power Fluctuations Suppression of Stand-Alone Hybrid Generation Combining Solar Photovoltaic/Wind Turbine and Fuel Cell Systems," Energy Conversion and Management, Vol. 49, No. 10, 2008, pp. 2711-2719.

[4] O.C. Onar, M. Uzunoglu and M.S. Alam, "Modeling, Control and Simulation of an Autonomous WT/PV/FC/ Ultra-Capacitor Hybrid Power System," Journal of Power Sources, Vol. 185, No. 2, 2008, pp. 1273-1283.

[5] Sanaa Faquir, Ali Yahyaouy, Hamid Tairi "A Type-1 fuzzy logic algorithm to manage the flow of energy in a stand-alone PV/Wind/Battery hybrid system" IEEE Intelligent System and Computer Vision (ISCV) 2015, pp. 1-6.

[6] A.T. Tharakan, Asheesh K. & Pradeep Kumar "Dynamic programming energy management algorithm for battery based hybrid renewable source." IEEE International Conference on Industrial Technology (ICIT) 2016, pp. 400-405.

[7] GhadaMerei, Matthias Leuthold, Dirk Uwe Sauer "Optimization of an Off-grid hybrid PV-Wind-Diesel system with different battery technologies" IEEE 35th International Telecommunication Energy Conference, SMART POWER AND EFFICIENCY, 2013, pp. 1-6.