Grid Connected Hybrid Renewable Energy System with Various Controller Implementation

Debayani Mishra, M. K. Maharana

Abstract: ***In power industry due to fast industrialization the generation system has upswing towards strongly procuring energy from various non-conventional energy sources (RES). Persistent work is carried out in order to use additional energy obtained from the renewable sources and limiting the dependence on the conventional energy sources. The amalgamation of various Hybrid Renewable Energy Sources (HRES) i.e. Solar, Wind and Fuel cell including load forms a Micro grid, the realistic management of energy from these renewable sources to accommodate the demand at the consumer end with proper efficiency is necessary. This paper proposes a hybrid system comprising of three energy sources PV, Wind and Fuel Cell and is connected to the grid by using power electronic converters using MATLAB/SIMULINK. A control circuit is designed by using PI controller and fuzzy logic based controller for providing gate signals to the inverter. The voltage profile when connected to a load by using various controllers is studied. A comparison study and behavior of source voltage, source current, load voltage and load current is studied by using PI controller and fuzzy logic controller.***

Keyword: ***Distributed Energy Sources, Hybrid Renewable Energy System, Universal Inverter, PI Controller, Fuzzy Logic Controller***

I. INTRODUCTION

Renewable sources have become an integral part to generate power in order to curtail the need of fossil based fuels. Rapid industrialization, pollution, global warming and cost of fossil fuels has further increased the demand and need of renewable sources. Distributed Energy Sources (DERs) comprises of solar cell, wind generators, internal combustion engine and fuel cells provides leverage to power system. The DERs can alleviate peak power demand, increase security against faults in power system and also further enhance the power quality by using modern control design. Besides the above advantages the DERs are installed at places where it is close to load consumption and curtails transmission line losses and cost of investment to set up a main grid [1].

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Renewable sources has fluctuation in generation due to erratic nature of sun radiation and speed of wind. There is a discrepancy between demand of energy and production of energy which can lead to volatility of power and deterioration of quality of power [2].To monitor the power generated and to furnish a secure path for power generation and consumption it is required to interconnect the supply system with storage units so batteries and hydrogen based storage are used [3],[4].The system is known as Hybrid Renewable Energy System(HRES) comprising of more than two renewable sources that strengthens the system efficiency and provides proper balance of supply of energy.

The name Micro Grid has emerged from several DGs combinations (smaller in size < 500kw). A microgrid is an aggregation of various sources and loads that operates like an individual system and provides power to local area. Microgrid are also described as low voltage system that constitutes units of dispersed generation and tools for storage connected to the grid at the point of common coupling (PCC) [5]. Microgrid can function in grid connected mode as well as islanded mode. The power generation in RES is small as compared to conventional method of generating electricity and is based close to the load or to the utility grid [6].As multiple sources are connected together it requires a system to manage all the sources and assure uninterrupted supply of power to the load. The concept of Energy Management System (EMS) has been introduced for regulating the power production and consumption of energy in a MG. In literature there are many studies for proper energy management of Microgrid. The main objective of EMS is to manage different sources of energy and ensure at what time each source should be turned ON to meet the power demand.EMS monitors and controls the utility grids and enhances the performance of generation or transmission system by using computer aided tools.EMS has various advantages-1.Performance and stability of system improves 2.To curtail microgrid operating cost and increase the revenue 3.To maintain quality of the system.EMS has various challenges-1.Grid power profile is smooth 2.To Manage the balance between power generated and load.

To assimilate the microgrid to the utility system it is necessary to study the problems the associated with power quality. The microgrid and utility grid is connected through a circuit breaker that opens to disconnect the microgrid when there is an imbalance in voltage or any IEEE1547 events [7].Controllers are imminent for the management of microgrid and are required in its architecture.

During integration of all individual renewable sources that generates voltage and power various problem arises like voltage instability and current circulation [8]-[9].Droop controllers are designed but it has some disadvantages like poor current sharing [10].

II. DISTRIBUTED GENERATION

Distributed generation also known as decentralized generation refers to small energy sources in which power is generated locally and distributed close to end users. The generation sources are mainly renewable sources which can be connected to the grid and can supply power whenever required. Advantages of DGs are 1.Reduces peak power demand 2.Curtails transmission and distribution losses 3.Power supply to remote and inaccessible areas. 4. Improves supply reliability and management of power.

In hybrid power system there are various renewable sources of energy that are connected to the grid to meet the electrical power requirement of the power system. The proposed system includes PV cell, wind generators and fuel cell to meet the power requirement.

A. PV Array

The PV cell transfers energy obtained from light to electrical energy by the process of photoelectric [11]. The characteristics of the solar cell are homogenous to the p-n junction diode [12]. A PV cell is made up of silicon and is a semiconductor device that converts solar energy into electricity in DC form. Module contains a number of PV cells that are interconnected to increase the amount of power produced. In order to attain the necessary voltage and current the array are connected in series or parallel.

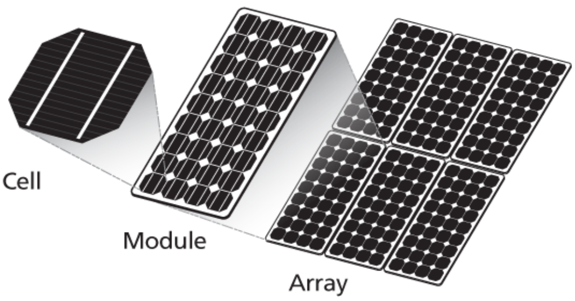

Fig.1.Cell, Module and Array of PV System

Fig.2 represents an equivalent PV cell that contains a current source to which a diode is connected in parallel. Current is generated by photons represented by a current source and output remains constant under constant radiation and light radiation.

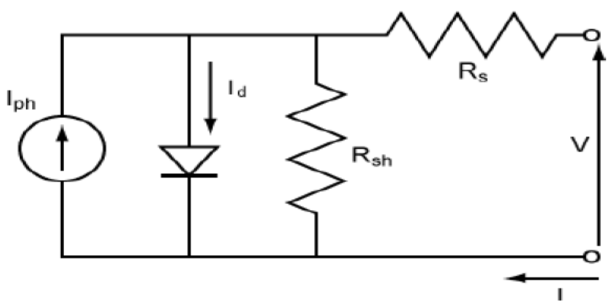

Fig.2.Basic equivalent circuit of PV cell

where,

I_{ph} = Short Circuit Current

I_d = Current across the diode

R_{sh} = Resistance connected in parallel

R_s = Resistance connected in circuit

By applying KCL to above Fig.2, the following equations are derived

$$I_{ph} - I_d - \frac{V_D}{R_{sh}} - I_{PV} = 0 \qquad (1)$$

The current flowing across the diode I_d is given by Shockley diode equation

$$I_d = I_o\left(e^{\frac{V_D}{V}} - 1\right) \qquad (2)$$

The equation (1) and (2) represents the characteristics of PV cell where

I_d = Reverse saturation current of pn junction

V = Terminal voltage

I_{PV} = PV Current

A PV module has 36 or 72 cells. A PV system exhibiting its characteristics of current vs voltage and power vs voltage is depicted in Fig.3.The design parameters of PV Cell are specified in Table 1

Table 1: Pv Cell Specifications

Irradiance	1000w/m^2
Operating Temperature	25°C
Voltage across open circuit	32.9V
Short Circuit Current	8.21A
Number of Cells	54
Rated Power	200W

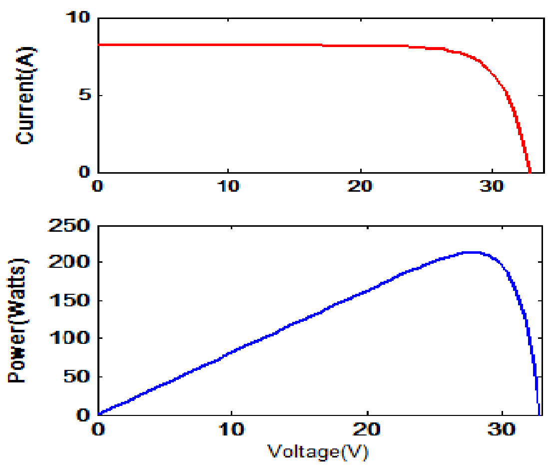

Fig.3.Characteristics of PV Cell

The voltage obtained from the PV system is fed to a buck converter and the circulating current is minimized by using controllers.

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B. Wind Turbine Generator Model

Depending on the speed of wind, the turbine generates power.Fig.4 represents the power curve that helps in determining the output power from the wind turbine [13] - [14].

In the wind turbine power generation starts at the cut in speed.

Table 2:Wind Model Specifications

Mechanical Output Power of Turbine	50W
Wind speed	6m/sec
Pitch Angle	10°
Air density	1.226 kg/m^3

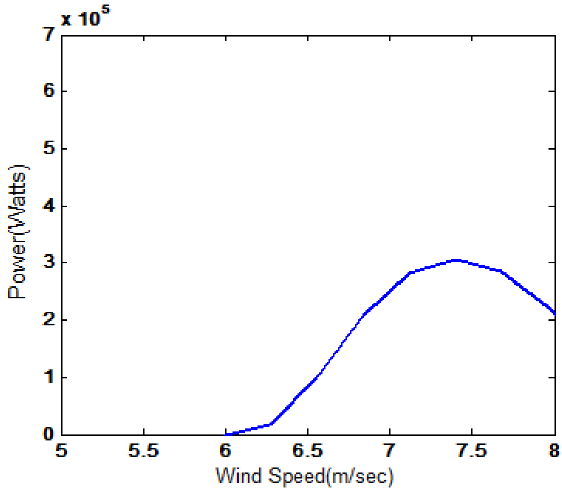

Fig.4 Wind turbine generator power curve

The generated power output from wind turbine generation system is expressed by,

$$P_{WTG} = \frac{1}{2}\rho A V^3 C_P(\lambda,\theta) \qquad (3)$$

Where ρ = density of air in kg/m^3

A = Blades swept area in m^2

C_p= coefficient of power

λ= tip speed ratio

θ = pitch angle

V = speed of wind in m/sec

The performance characteristic of a WTG fluctuates with the wind speed [15].

C. FC Model

The fuel cell transforms the chemical energy that is stored in fuel is converted into electricity. Fuel cells are dissimilar from batteries and only when and it supplies active chemicals which further is involved in converting chemical energy into electrical energy. To attain this FC needs a sustained source of fuel. Fuel cells are integrated with other renewable sources ascribed to their high efficiency, viable and low maintenance. Fig.5. represents the block diagram of fuel cell

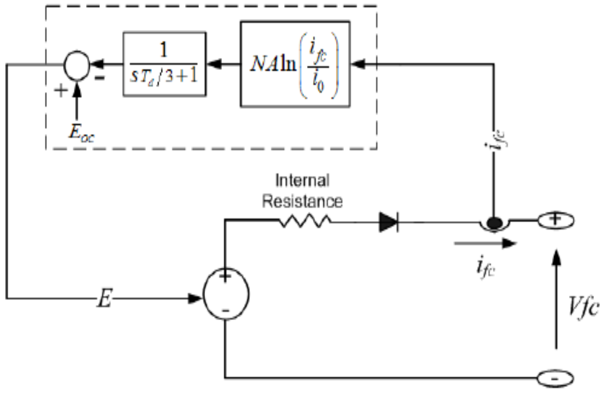

Fig.5. Fuel Cell circuit

Table 3: Fuel Cell Specifications

FUEL CELL CLASS	PEM
Power	6KW
Voltage	45V

The voltage current characteristics is plotted in the figure below Fig.6

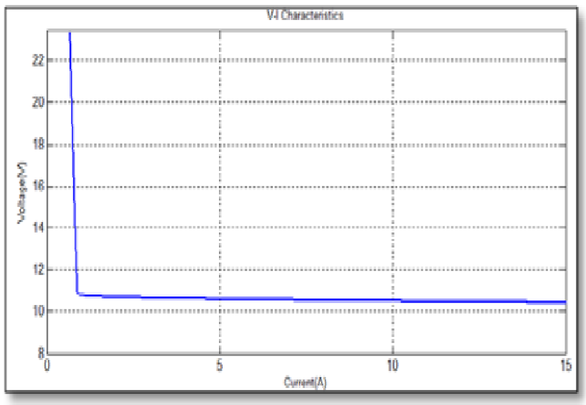

Fig.6. Voltage Current characteristics of fuel cell

III. PROPOSED HYBRID SYSTEM ARCHITECTURE

In the proposed architecture PV, Wind and Fuel Cell are considered as inputs to the system and comprises the integrated renewable energy system as shown in Fig.7. A universal bridge inverter, synchronous PLL controller, LC filters is connected to a load and grid. The synchronous DQ reference frame controller controls the inverter connected to the grid and supplies the voltage to the grid. Solar and fuel cell are connected to the dc-dc converter to increase the voltage and wind energy system is rectified. In the whole integrated system circulating current is minimized and is further connected to a boost converter that regulates the voltage to 330V.The output dc voltage is then transformed to an ac voltage by an inverter.PLL technique is used to generate gate pulses to the inverter.

Two different control strategies are used to generate gate pulses. A LC filter is connected to reduce harmonics of output voltage and output current.

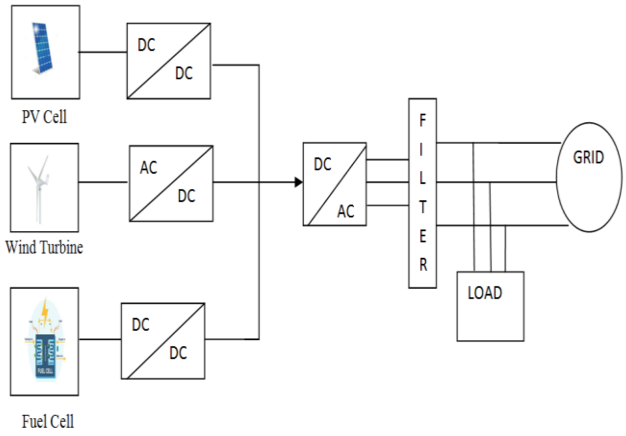

Fig.7.Proposed Hybrid System

A. Concept of PLL

An integral part for grid connected system is synchronization of grid, the voltage of the grid is synchronized with the output frequency and phase. There are many papers available in literature using the concept of PLL [16]-[19].By using d-q transformation and proper filter design PLL system is implemented in three phase grid connected system.

The voltage V_{abc} from the grid is converted into DC component by using abc-dq transformation and by setting V_d to zero PLL gets locked. In order to reduce the component of high frequency and provide a controlled DC voltage a low pass filter is used. The PLL operates when the difference between phase angle of the grid and phase angle of the inverter decreases to zero. This emanates V_{dd}=0 and V_{qq} which determines the value of grid voltage.

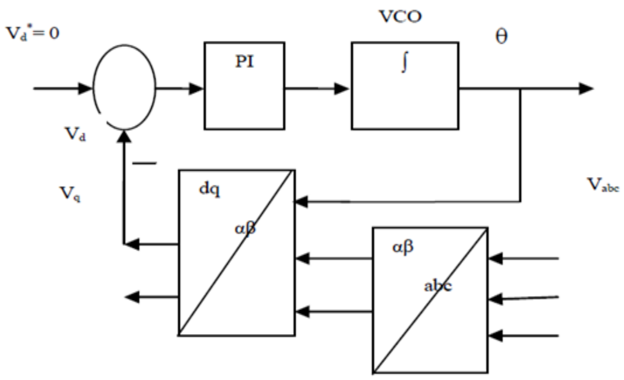

Fig.8.Structure of PLL[20]

B. LC Filter

A filter circuit is an amalgamation of inductor (L) and capacitor(C) and is used to remove component of high frequency present in the inverter output current and is utilized at the inverter output. Considering the factor of current ripple the value of inductor L is chosen. By using this filter sinusoidal voltage and current are obtained.

C. Droop Controller

Reliability and stability of a microgrid is achieved by regulating the voltage when a number of sources are connected. In a power system when multiple DGs are connected to a microgrid sharing of power is properly coordinated by using droop controller.

The use of droop controller in the proposed system eliminates the following three problems

1. Proportional sharing of load current
2. Excess voltage regulation
3. Current reversal in the hybrid system

The droop control consists of a primary control that comprises voltage current control and a secondary control that shares power and energy management as tertiary control. A PWM signal is generated by the output of the current droop controller that generates gate pulses for switching ON the MOSFET converters.

Equation for droop controller between voltage and current is given by:

$$v_i^{ref} = v_i^0 - d_i\, i_i \qquad (4)$$

where v_i^{ref} = Reference voltage
v_i^0 = Nominal voltage source
d_i = Droop gain of ‘i’ source
i_i = Current of ‘i’ source

In this paper three renewable sources such as Solar cell, Wind turbine and Fuel cell possess different characteristics the proposed controller is implemented in each system to reduce the circulating current and for stabilizing the voltage.

TABLE-4-Comparison of current of each source with and without controller

Source	Current without controller	Current using Controller
Solar	22.89A	1.436 A
WT	-22.56μA	65.56 μA
FC	-17.06A	0.1637 A

IV. CONTROL STRATEGIES

I. Integration of the Hybrid System to the Grid

The hybrid renewable system comprises of solar, wind and fuel cell is used to generate energy to fulfill the load demand. The voltage obtained from the wind energy system is rectified and output DC voltage of PV and Wind is connected to a boost converter to control the DC voltage. The voltage is fed further to an inverter where transformation method of Park and Clarke are used to regulate the voltage.

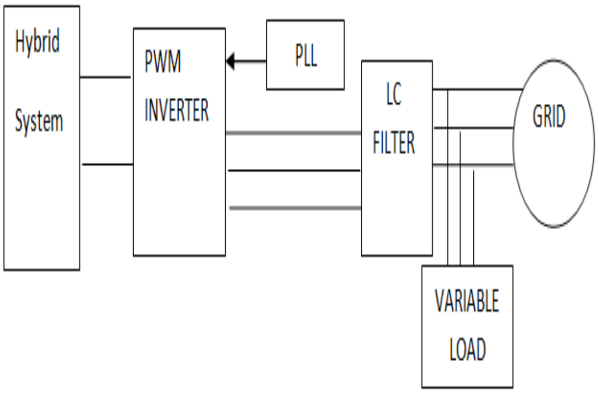

Fig.9.Proposed Model without Controller

II. Integration of the HRES to the Grid by Using PI Controller

The conventional PI controller has the following Transfer function

$$G(s) = K_p + K_I/s \quad (5)$$

Where K_p =Proportional gain
K_I =Integral gain

The grid voltage is considered as the input to the PLL and determines the voltage and frequency which is necessary to make the output voltage of the inverter and the grid angle equal. Three phase voltage and current are converted from abc to dq0 frame of reference by using dq0 transformer. Accurate control signals are achieved by converting into dq0 frame. The output voltage is tuned by a PI Controller and then transformed into dq0 frame to abc frame and then gate pulse are generated to the inverter by SPWM technique [21].The Proportional Integral Controller monitors the difference between the output and the pre set value and acts like a feedback controller.

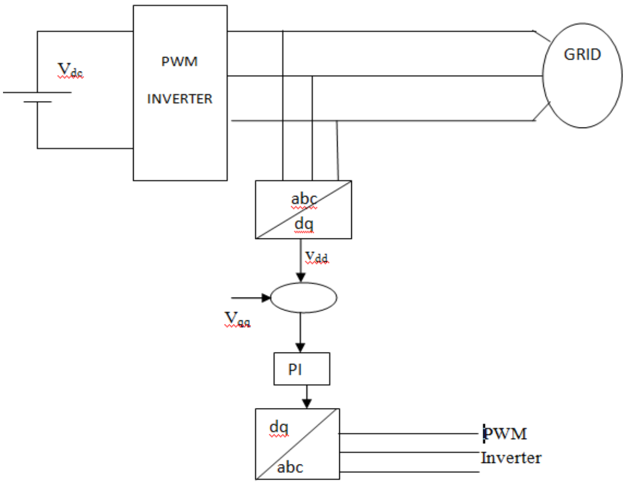

Fig.10.Proposed Model using PI Controller

III. Integration of HRES by Using FLC

Fuzzy inference system is a well known structure used for computing based on the concept of fuzzy rule, reasoning and set theory. The fuzzy logic controller is a subset in which the input set is mapped to the output set. The system constitutes of three components based on rules, data and a mechanism for reasoning. The fundamental part contains rules of fuzzy, data comprises of membership function and the third part contains a procedure to obtain the required output.

In the proposed system there are two inputs variables V_{DD} and V_{QQ} and one output V_{DQ}. The fuzzy model is used is of Mamdani and for defuzzification process centroid method is used . The first input has five membership functions such as low negative(LN), high negative(HN),zero(ZO),low positive(LP) and high positive(HP).The second has five membership functions such as low negative(LN),high negative(HN),zero(ZO),low positive(LP) and high positive(HP).The output has four membership functions such as zero(ZO),small(SL),medium(MN) and high(HH). The fuzzy rules are formed according to the following truth table

Table-5 Truth Table

VDD\VQQ	LN	HN	ZO	LP	HP
LN	SL	MN	SL	SL	MN
HN	MN	HH	MN	MN	HH
ZO	SL	MN	ZO	SL	MN
LP	MN	MN	SL	MN	HH
HP	MN	HH	MN	MN	HH

V. RESULTS & DISCUSSION

I. Integration of the HRES to the Grid

The output voltage of the hybrid system from three sources i.e solar, wind turbine and fuel cell is represented in the below figure where V_{dc}=330V

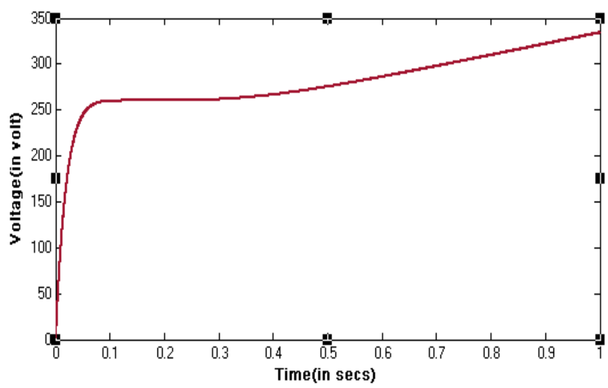

Fig.11.Output Voltage of Hybrid System without controller

The voltage and current obtained at the source side when connected to a grid of 230V, 50Hz supply is shown as below

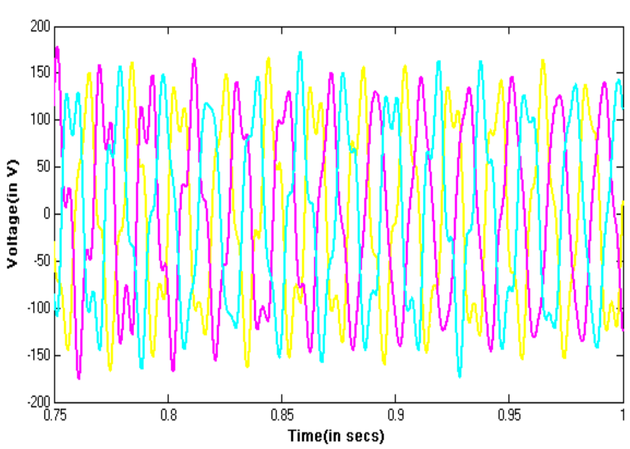

Fig.12.Source Voltage without controller

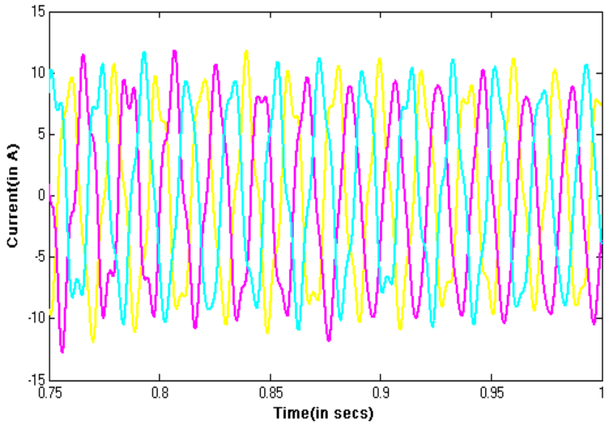

Fig.13.Source side current without Controller

The wavefom of load voltage and load current waveform after connecting a load of 8 kW and 5 KVAR is represented in the following figure

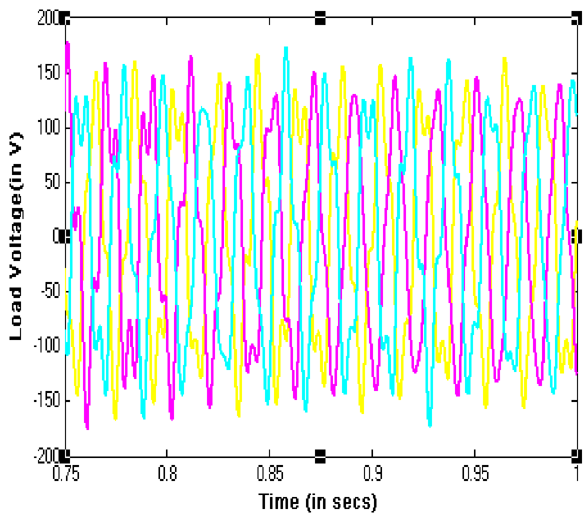

Fig.14. Load Voltage without Controller

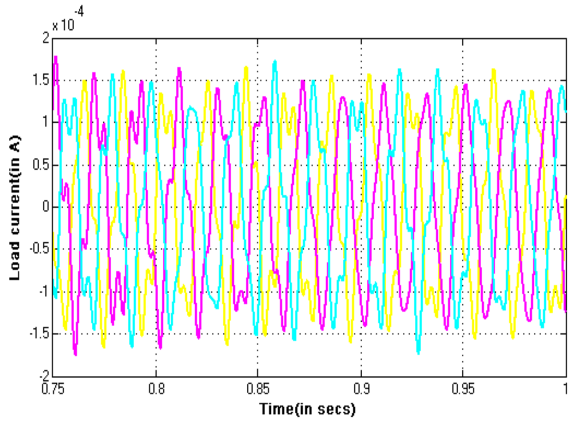

Fig.15.Load Current without Controller

II. Integration of HRES by Using PI Controller

The output voltage of the hybrid system from the three sources i.e. solar, wind turbine and fuel cell is represented in the below figure where V_{dc}= 330V

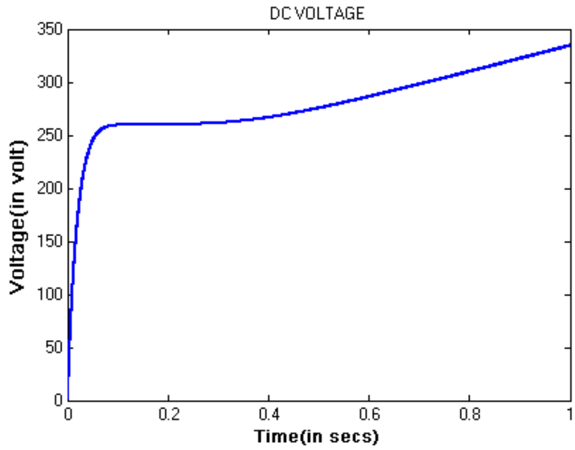

Fig.16.Output Voltage from Hybrid System by PI

The generated voltage and current at the source side when connected to a grid of 230V, 50Hz supply is shown as below

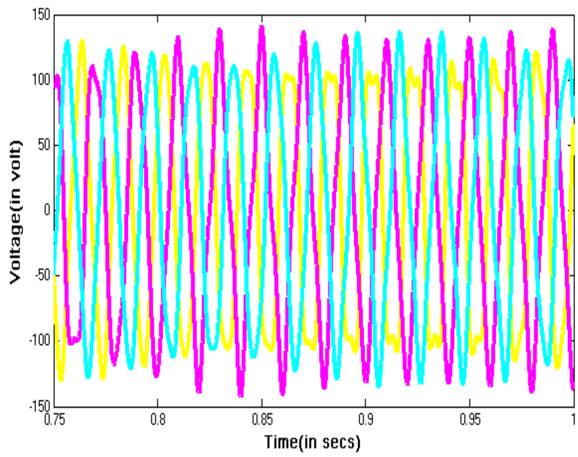

Fig.17.Source voltage by PI

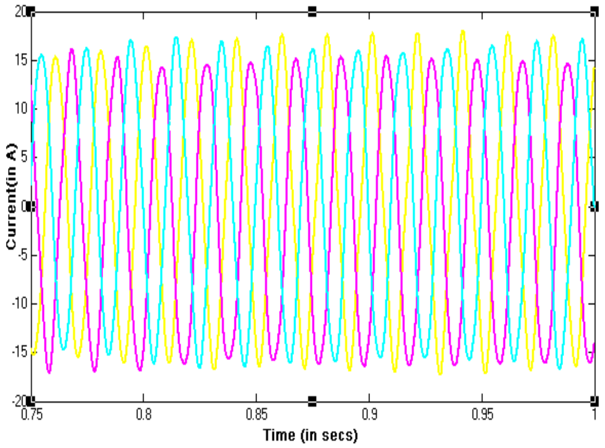

Fig.18. Source current by PI

The load voltage wavefom and load current waveform after connecting a load of 8 kW and 5 kVAR is represented in the following figure

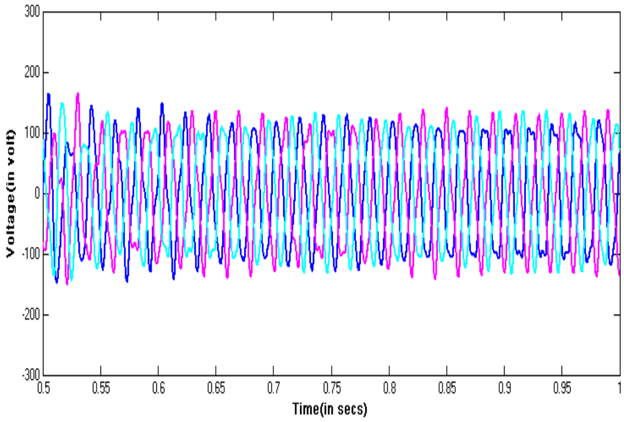

Fig.19.Load Voltage by PI

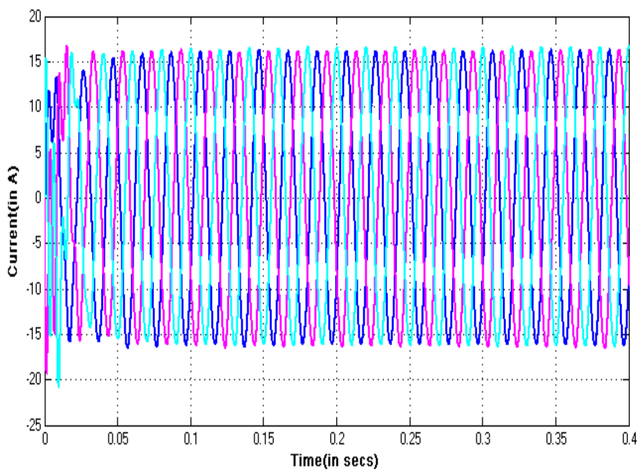

Fig.20.Load Current by PI

III. Integration of the HRES to the Grid by using FLC

The generated voltage from the hybrid renewable system from three sources i.e solar, wind turbine and fuel cell is represented in the below figure where Vdc= 330V

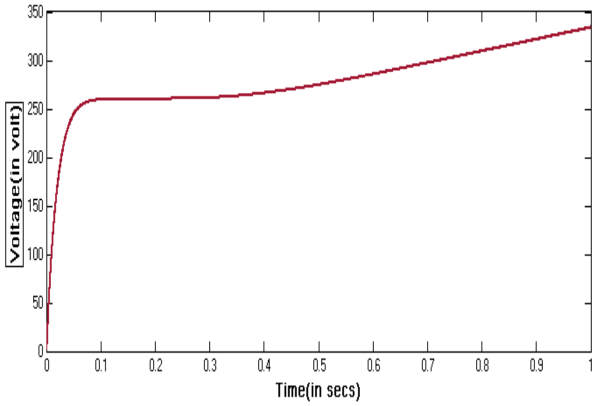

Fig.21.Output Voltage of Hybrid System by FLC

The output voltage and current at the source side when connected to a grid of 230V, 50Hz supply is shown as below

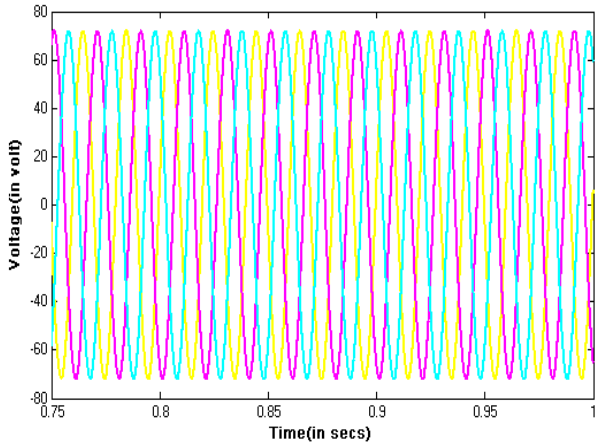

Fig.22. Source voltage by FLC

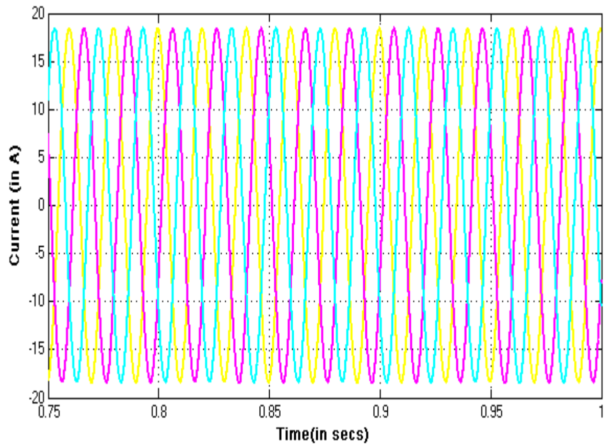

Fig.23.Source Current by FLC

The load voltage wavefom and load current waveform after connecting a load of 8 kW active power and 5 reactive kVAR is represented in the following figure

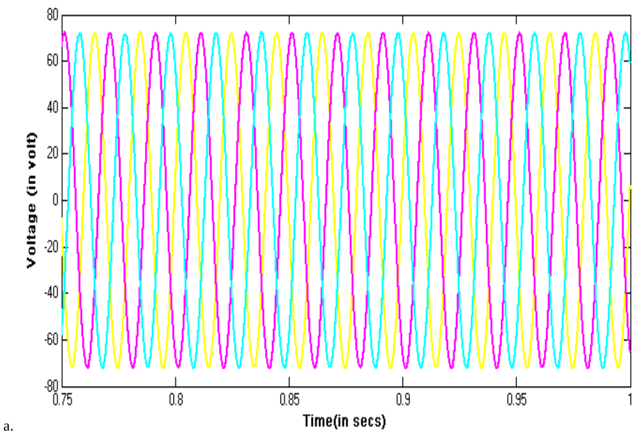

Fig.24. Load Voltage by FLC

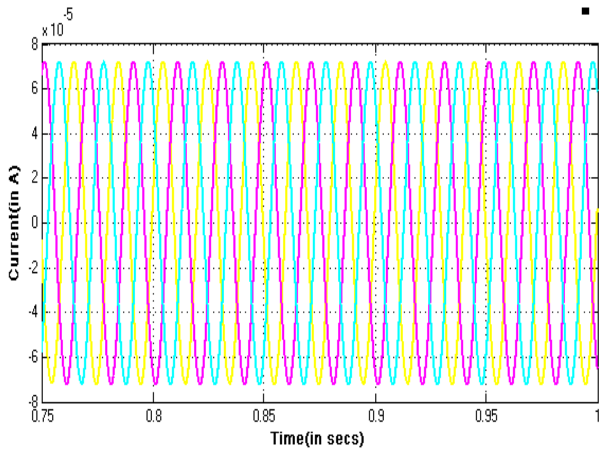

Fig.25.Load current by FLC

TABLE-6 Comparison of different controllers

Controllers	Source Voltage and Source Current	Load Voltage and Load Current
Without Controller	Larger oscillations with swell	Disturbed oscillations
With PI Controller	Less oscillations	Less oscillations as compared without controller
With FLC	Constant voltage and current	Constant voltage and current

In the hybrid system of PV, Wind and Fuel Cell when connected to a load it is found that output voltage from the renewable source remains constant 330V.The output voltage is further converted into ac and connected to a load and the model is simulated from1sec.It is found that without using controller output voltage and current waveform generated at the source and load side has ripples and the voltage is not pure sinusoidal. By using a PI controller it is found that voltage ripples has reduced but there is a voltage dip both at the source and load side. By using FLC the output voltage and current waveform both at source side and load side is regulated to provide uniform supply.

VI. CONCLUSION

The paper proposes a hybrid renewable system of PV, Wind and Fuel Cell that is connected to a grid. The proposed system supplies power to a load of 8 kW and 5 kVAR and is designed in SIMULINK environment. The simulation study depicts about the output voltage from the renewable source remains constant 330V. The proposed FLC shows that the output voltage and current waveform both at source and load side is regulated to provide uniform supply. A comparison study has been done using without controller, by using PI controller and by implementing FLC. The performance characteristics of the hybrid grid connected system under study have better performance.

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