IJCTA, 9(29), 2016, pp. 131-139

Design of Energy Management System for Residential Grid-Connected Microgrid with HRES

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Abstract : Abstract:This paper presents the planning of an optimal Energy Management System (EMS) supported by a fuzzy logic Controller (FLC) for a residential grid-connected micro grid with hybrid renewable generation (Wind & Photo Voltaic) and storage system. Modelling hybrid system includes Renewable Energy Sources given at intermittent supply conditions and dynamic energy demand, and to make conceptual energy storage. Designing an appropriate scheme that dynamically changes modes of renewable integrated system based on availability of RES power and changes in load. Wind and PV are the primary power supply of the system; battery is going to be used as a backup. A Fuzzy based controller is developed and implemented for the proposed hybrid energy system to integrate the renewable energy sources to the Utility either to grid or to any specific load. Simulations are carried out on the proposed Hybrid energy system using MATLAB/ SIMULINK.

Keywords : Energy Management System (EMS), Microgrid, Fuzzy logic, Renewable Energy resources.

1. INTRODUCTION

The continuous growth of renewable generation has increased the utilization of micro-grids, since they have evidenced to be a helpful instrument to manage the power provided by distributed generators set close to consumption location. Microgrid's are outlined as low voltage systems comprising loads, Distributed Generation (DG) units Associate in storage devices with an EMS associated and connected to the grid at a single Point of Common Coupling (PCC) [1]; so, the power exchanged with the grid is locally controlled by the EMS. Renewable Energy (RE) sources will become an increasingly vital part of power generation because the reserves of fossil fuels get closer to depletion. Among the available RE technologies, wind and solar power sources are the foremost promising choices, as they're omnipresent, freely available, and environmental friendly. Though these technologies are rising in numerous aspects, the drawbacks related to them, such as their intermittent nature and high capital cost, are the main obstacles for their utilization.

Hybrid power system with energy storage can enhance system reliability, power availability, quality and operational efficiency. Several hybrid wind/PV power systems with maximum power point tracking (MPPT) control have been projected earlier[10]. They used a separate DC/DC buck and buck-boost converter connected in fusion in the rectifier stage to perform the MPPT management for each of the renewable energy power sources. These systems have a problem that, due to the environmental factors influencing the wind turbine generator, high frequency current harmonics are injected into it. Buck and buck-boost converters don't have the potential to eliminate these harmonics. So the system needs passive input filters to get rid of it, creating the system more bulky and costly[11]. The strategy related to the EMS

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is complicated based on the application and its design. For instance, using prediction methods, there are EMS's that focus on the optimisation of the battery usage and its lifetime[2]. Other studies center the EMS design on minimizing the Microgrid operating costs[3], [4]; or maximizing the revenues according to DG bids and market price [5]. Additionally, few studies focus on minimizing the power peaks and fluctuations on the grid power profile [6], [7]. Moreover, an empiric EMS is proposed in [8], which uses the battery SOC as the main input of the EMS inorder to calculate both the amount of power to be assigned to the storage system and the grid. A similar philosophy was carried out in[9], where the results of the previous strategy were improved employing a FLC.

Dynamic interaction between the load demand and the renewable energy supply can result in important issues of stability and power quality. Therefore, managing the flow of energy throughout the hybrid system is important to extend the operating life of the membrane and to ensure the continuous energy flow. The increasing variety of renewable energy sources and distributed generators need new methods for their operations in order to maintain the energy balance between the renewable sources and utility grid or Micro-grid [12].

2. RESIDENTIAL MICROGRID DESCRIPTION

2.1. Microgrid Description

Fig.1 shows the scheme of the hybrid wind-photovoltaic generating system with very low voltage DC bus. The variable output voltage of the photovoltaic generator is also controlled by DC/DC buck converter. The generator(PMSG) is first rectified and controlled by a DC/DC buck converter. The DC bus collects the total power from the wind and photovoltaic system and uses it to supply the required load demand.

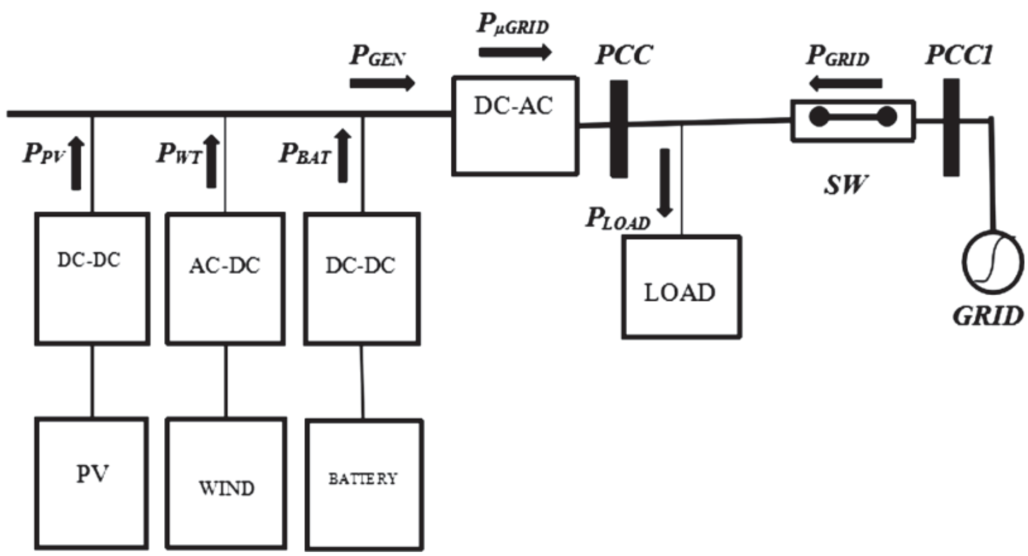


Fig. 1. Residential Microgrid scheme.

Where,

P_{PV} is the photo voltaic power generated;

P_{WT} is the wind power generated;

P_{GEN} is the renewable power generated;

P_{BAT} is the power supplied by the battery;

P_{GRID} is the power available within the Microgrid; P_{LOAD} is the power consumed by the load; and

P_{GRID} is the power delivered by the grid.

In Fig.1, the power of each variable is considered positive when the power flows according to the direction of the arrow (*e.g.* the battery power is positive when the storage system supplies energy to the microgrid and is negative when it absorbs energy from the microgrid).

For the configuration shown in Fig.1, the expressions establishing the microgrid behavior and the power exchanged with the grid are:

$$P_{GEN} = P_{PV} + P_{WT} \quad (1)$$

$$P_{\mu GRID} = P_{GEN} + P_{BAT} \quad (2)$$

$$P_{GRID} = P_{LOAD} - P_{\mu GRID} = P_{LOAD} - P_{GEN} - P_{BAT} \quad (3)$$

Defining the power balance within the Microgrid P_{LG} as the difference between consumed and generated power, the power exchanged with the grid can be defined as:

$$P_{LG} = P_{LOAD} - P_{GEN} \quad (4)$$

$$P_{GRID} = P_{LG} - P_{BAT} \quad (5)$$

3. ENERGY MANAGEMENT SYSTEM STRATEGIES

3.1. EMS and storage system

With an objective of keeping the voltage value at the bus constant, the FLC will adjust the value so that the buck-boost converter changes its mode of operation to act in either buck mode or boost mode to reduce or increase the change in voltage value.

The FLC will anticipate the suitable value of the voltage considering the microgrid's DC voltage over time and the reference value of DC voltage. Therefore a positive slope indicates that an energetic change has occurred in the Microgrid caused by a reduction of the renewable voltage generated or due to an increase of the power consumed by the load; whereas a negative slope indicates an energetic change in the microgrid as a result of increasing the voltage produced by the renewable generators or decreasing the load consumption.

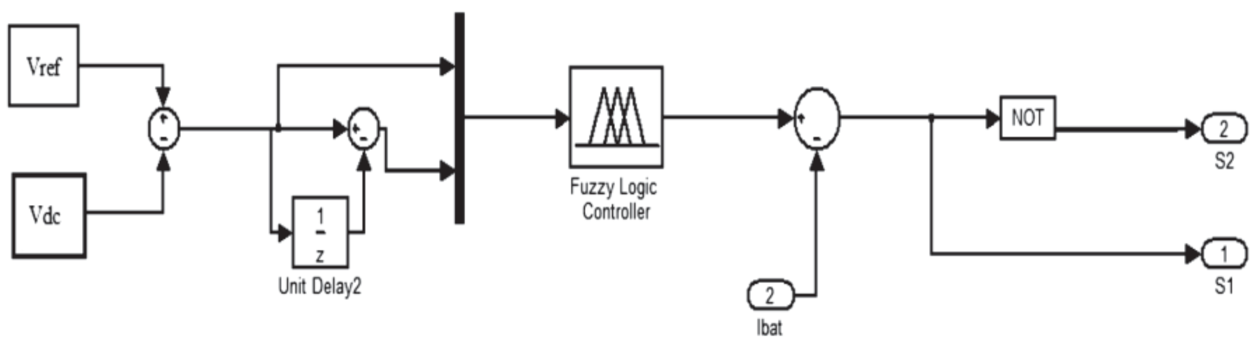
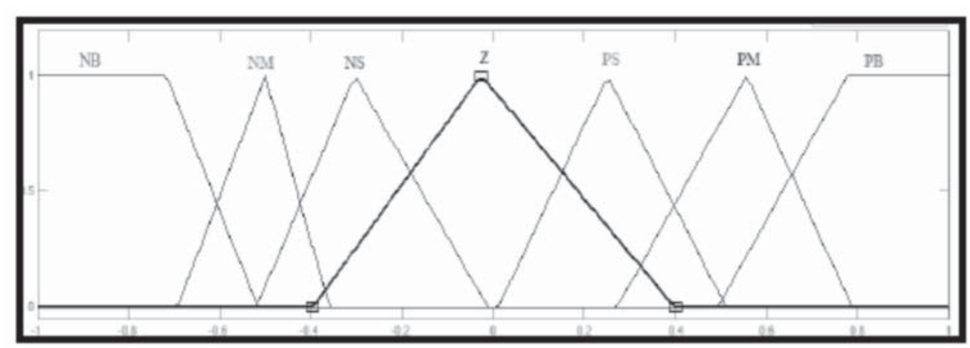
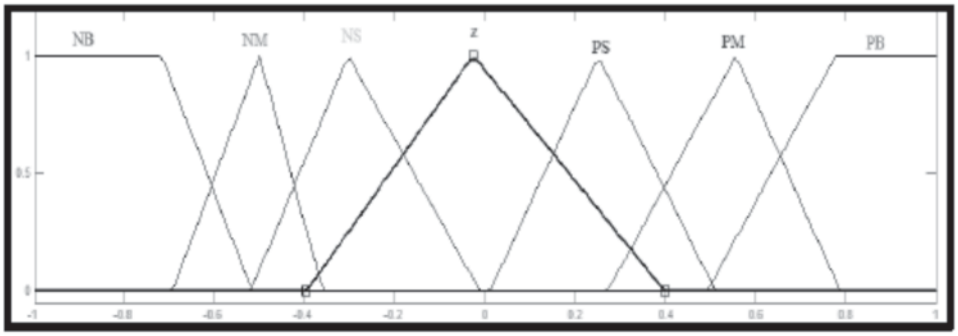


Fig. 2. Proposed fuzzy EMS block diagram.

For the controller inputs V_{ref} and obtained V_{dc} seven triangle Membership Functions (MFs) were defined. The MFs correspond to seven fuzzy sets identified as NB, NM, NS, ZE, PS, PM and PB where B stands for "Big", S for "Small", M for "Medium", N for "Negative",P for "Positive" and Z for "Zero". The MFs for both inputs are exposed in Fig.3.



(a)



(b)

Fig. 3. Membership functions for input variables (*a*) Vref. (*b*) Vdc.

The MF's of the controller inputs are distributed along the variation range of each variable as follows:

$$V_{ref,min} \leq V_{ref} \leq V_{ref,max} \tag{6}$$

$$V_{dc,min} \leq V_{dc} \leq V_{dc,max} \tag{7}$$

Where,

$V_{ref,min}$ and $V_{ref,max}$ are the minimum and maximum values of the reference voltage, respectively;
$V_{dc,min}$ and $V_{dc,max}$ are the minimum and maximum values of the dc voltage of the microgrid.
Further more, for the controller output voltage seven triangle MF's, shown in Fig.4, were defined.

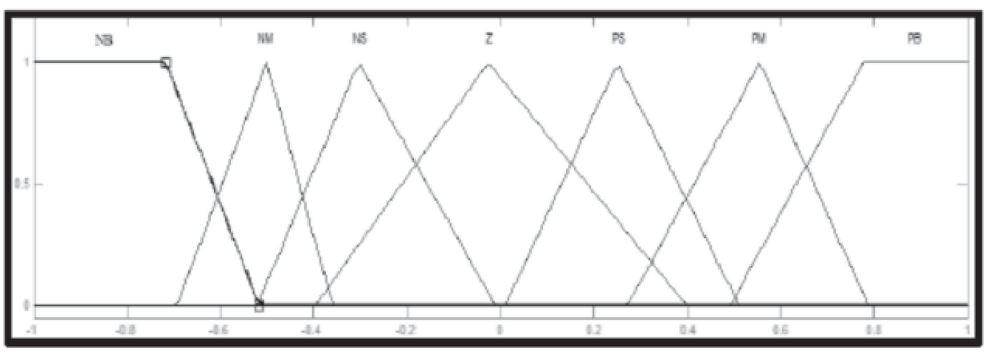


Fig. 4. Membership functions for the output.

Table 1 shows the FLC's rule base that establishes the evolution of the variable voltage according to the inputs and output MFs defined. In accordance to the input membership functions the FLC will anticipate the suitable value inorder to maintain the DC bus voltage as constant.

The FLC's rule base presents values corresponding to the Z fuzzy set in its diagonal indicating that under these conditions it is not necessary to have any change in voltage, the rules above the diagonal indicate an decrement in voltage value and to act in boost mode of operation and the rules above it specify are decrement in voltage at bus. The resulting grid voltage profile and the action of EMS in accordance with the change in load to maintain constant voltage will be presented in Section 4.

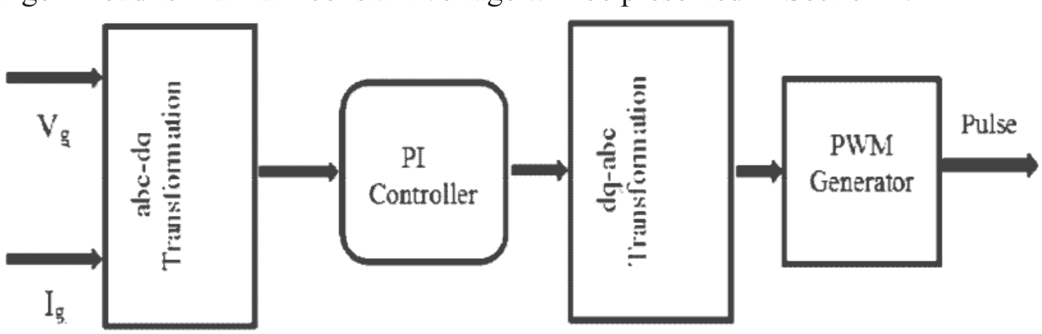


Fig. 5. Block diagram for inverter control

Table 1. Fuzzy EMS Rule Base.

V_{OUT}		$V_{DC,REF}$						
		NB	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
V_{DC}	**NB**	NB	NB	NB	NB	NM	NB	Z
	NM	NB	NB	NB	NM	NB	Z	PB
	NS	NB	NB	NM	NB	Z	PB	PM
	Z	NB	NM	NB	Z	PB	PM	PB
	PS	NM	NB	Z	PB	PM	PB	PB
	PM	NB	Z	PB	PM	PB	PB	PB
	PB	Z	PB	PM	PB	PB	PB	PB

Block diagram for inverter control is represented in Fig.5. Since the controlled current has to be in phase with the grid voltage, the phase angle used by the abc → *dq* transformation module has to be extracted from the grid voltages. Phase-locked loop (PLL) technique is adopted to provide the phase information of the grid voltage, which is needed to transform the grid currents I_d and I_q in the in the dq frame and then transform the voltage control signal back to the abc frame. Two PI controllers are adopted to regulate I_d and I_q according to the current reference I_d^* and I_q^*, which determines the real power and reactive power exchanged with the grid respectively. The inverter is assumed to be powered by a constant DC power source and hence no controller is needed to regulate the DC link voltage. Otherwise a controller can be introduced. The reference for the reactive current is usually set to zero, if the reactive power control is not allowed. In the case that the reactive power has to be controlled, a reactive power reference must be imposed to the system. The *dq* control structure is normally associated with proportional–integral (PI) controllers since they have a satisfactory behavior when regulating dc variables. For improving the performance of PI controller in such a structure as depicted, cross-coupling terms and voltage feed forward are usually used. This scheme has the particular advantage of independent control of the real and reactive power components of the grid currents, which can be directly translated into real and reactive power. So, it is possible to set the real and reactive power sent to the grid directly.

3.2. Inverter Control

Since the generated voltage from renewable energy sources is DC, we need inverter for converting DC voltage to AC before connecting it to grid. Grid is a voltage source of infinite capability. The output voltage and frequency of inverter should be same as that of grid frequency and voltage. The output of grid connected inverter can be controlled as a voltage or current source and pulse width modulated (PWM) voltage source inverters (VSI) are most widely used. The three phase full bridge inverter topology is the most widely used configuration in three phase systems. The inverter selected is current controlled voltage source inverter.

3.3. Grid Synchronization

The inverter output current that is injected into the utility network must be synchronized with the grid voltage. The objective the synchronization algorithm is to extract the phase angle of the grid voltage. The feedback variables can be converted into a suitable reference frame using the extracted grid angle. Hence, the detection of the grid angle plays an essential role in the control of the grid-connected inverter. The synchronization algorithms should respond quickly to changes in the utility grid. Moreover, they should have the ability to reject noise and the higher order harmonics. Many synchronization algorithms have been proposed to extract the phase angle of the grid voltage such as zero crossing detection, and phase-locked loop (PLL).

4. SIMULATION RESULTS

The Energy Management System proposed above was modelled and simulations are carried for the analysis by using MATLAB. The parameters considered for analysis is as follows:

Photovoltaic power(PPV) — 4*k*W
Wind Power(PWT) — 3*k*W
Load Power(PLOAD) — 5*k*W
Voltage At PCC(VPCC) — 586.6V
Wind Speed(WS) — 15m/s
Irradiance(IR) — 1000W/m^2
Frequency(*f*) — 50Hz

4.1. Grid voltage:(Voltage at PCC1)

Fig.6 shows the simulated grid output voltage at PCC1. The voltage of 586.6 *i.e* $\sqrt{2} \times 415$V(VRMS) is obtained after stepping it down from 11kV by using the step-down transformer.

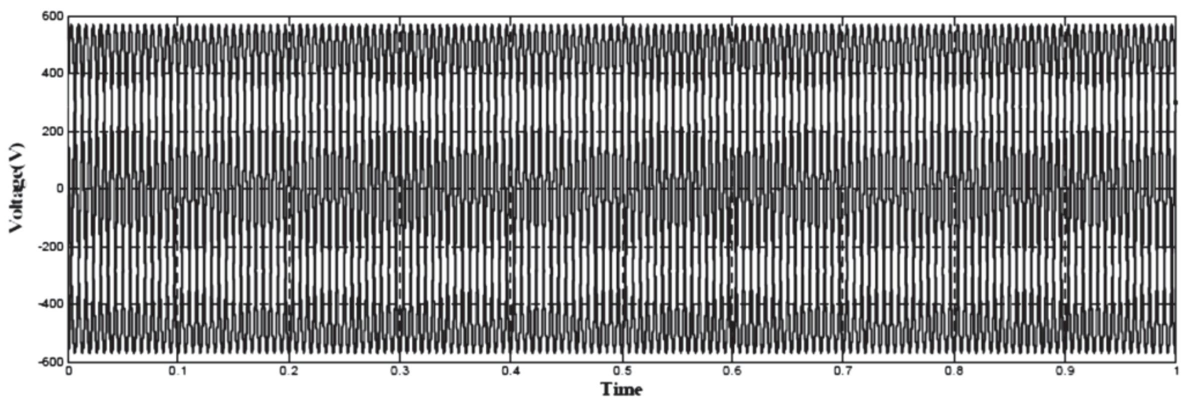


Fig. 6. Grid voltage (Voltage at PCC1).

4.2. Output voltage at PCC without controller action

Fig.7 shows the output voltage at PCC without the controller. Without the action of controller, the simulated output voltage is distorted when disconnected from the grid. Because of the intermittent nature of the renewable energy resources, there should be controller along with a backup storage device. Hence, the voltage is been distorted without the action of controller in the considered system.

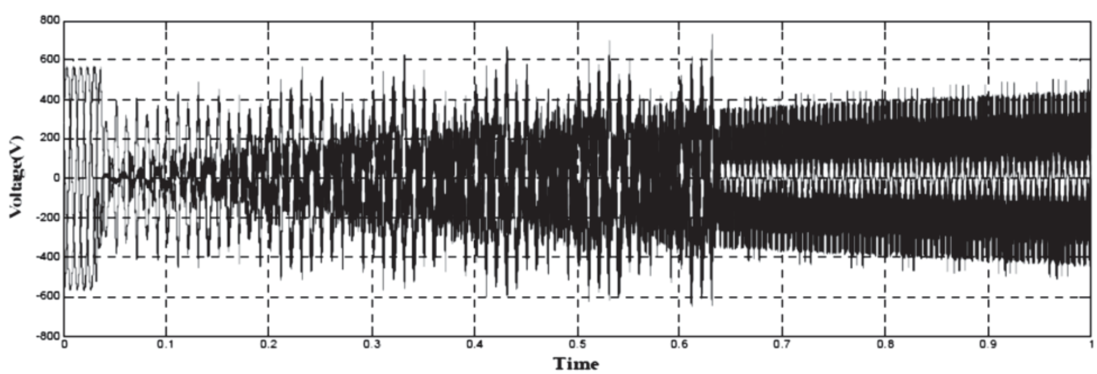


Fig. 7. Voltage at PCC without controller.

4.3. Output voltage at PCC with controller action

Case (*i*) : Islanded mode-When load is 5kW

Fig.8 shows the switching action of SW in accordance with the power obtained from the microgrid. The switch SW will act whenever the load exceeds the power obtained from the microgrid, as the load should be supplied without any interruption.Whenever the load is equal to 5kW, the switch SW = 0. That is, the grid will be disconnected from the microgrid (islanded condition).The microgrid output voltage in this condition is shown in Fig.9 *i.e.*, when the load power is equal to 5kW. Until it reaches the required rated power, the switch SW is connected grid and later reaching the rated power the grid is disconnected and maintains the constant voltage profile with the action of controller as shown in below Fig.9

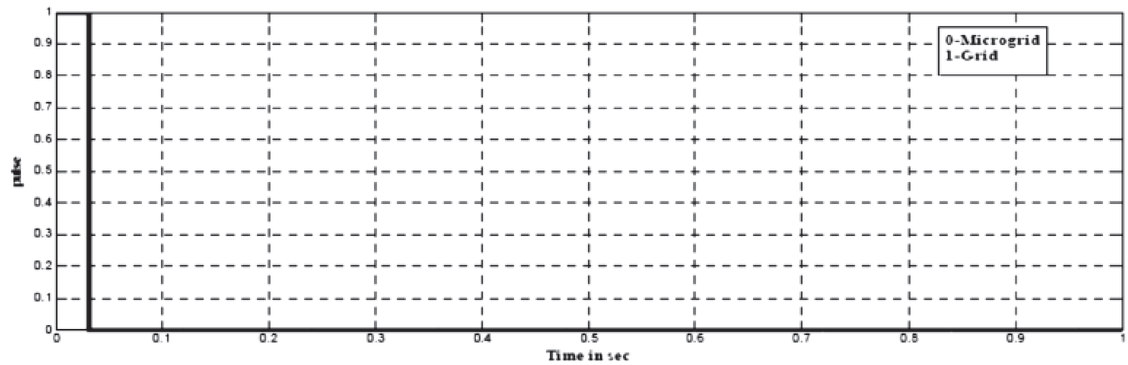


Fig. 8. Switching action at PCC when PLOAD = 5kW.

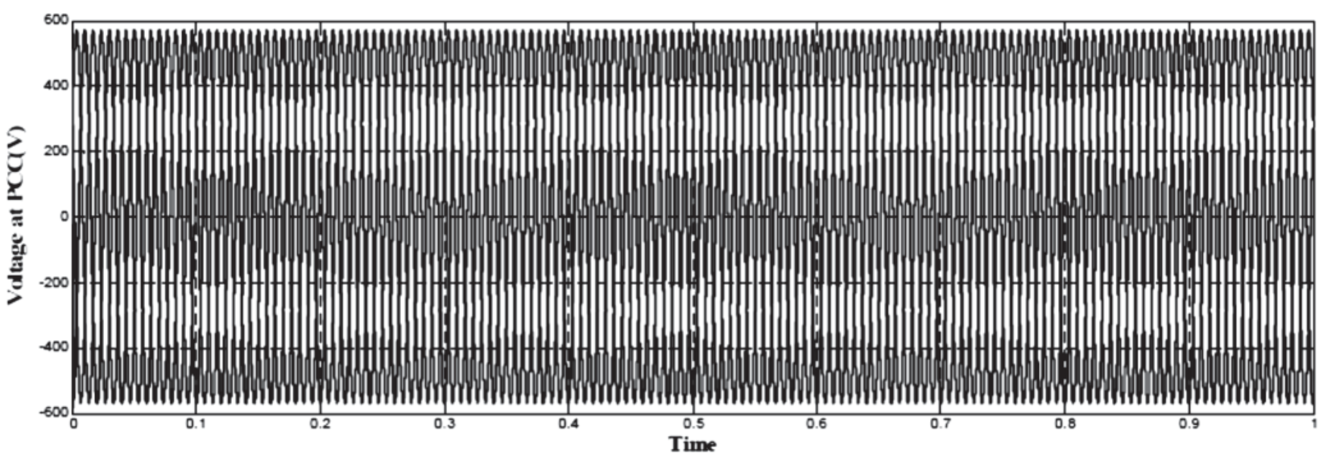


Fig. 9. Voltage at PCC with controller(Islanded mode).

Case (*ii*) : Grid connected mode -When load is greater than 5kW

Fig.10 shows the switching action when the load is more than the generation of the microgrid. The load should be supplied continuously without any interruption so that the system will be reliable. Hence the switch SW will connect the entire system to the grid under this condition so that the load is fed continuously.Whenever the load power is greater than 5kW(PLOAD = 7kW), the switch SW = 1. That is, the grid will be connected to the microgrid(Grid connected condition), and the voltage profile is kept constant. Whenever there is increase in the load, the switch SW will be closed and the system is connected to the grid. Thus the grid will supply the deficient power without change in voltage profile. The switch controller will provide the required action by closing the switch(SW = 1) by taking the reference power from the microgrid. The switch controller will operate and synchronize the grid with the microgrid. The constant voltage profile in this case is shown below in Fig.11 with the action of controller when the load power is greater than 5kW *i.e.*, 7kW.

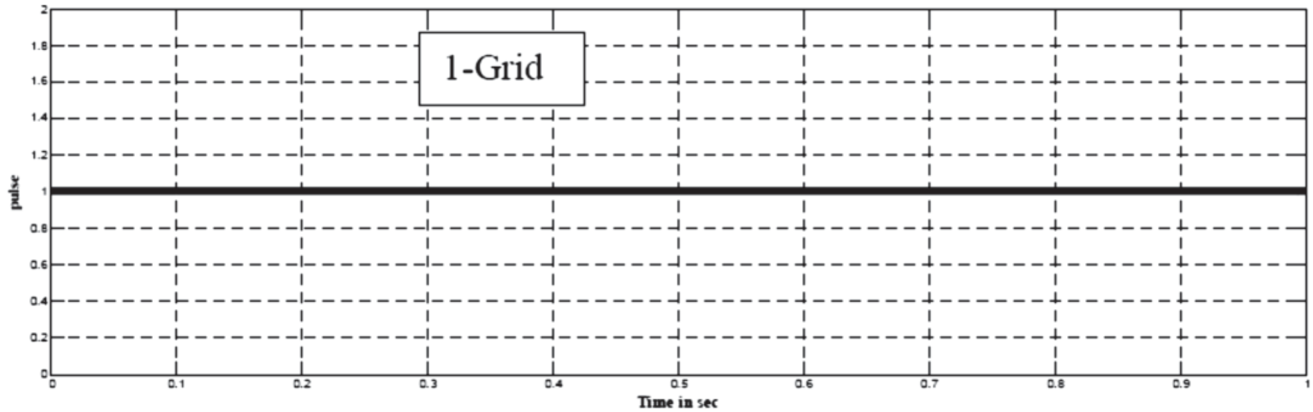


Fig. 10. Switching action at PCC when PLOAD = 7kW.

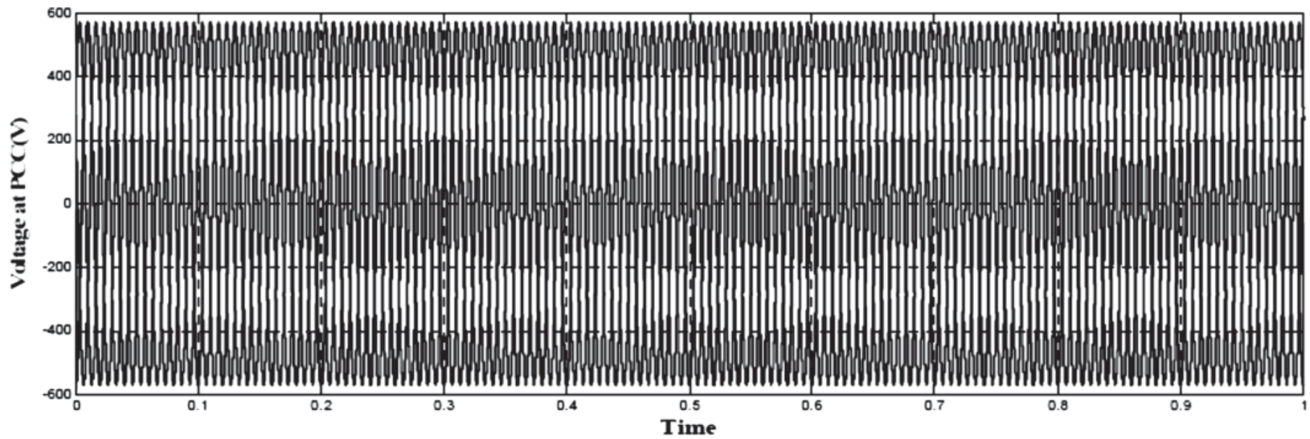


Fig. 11. Voltage at PCC with controller(Grid connected mode).

5. CONCLUSION

This paper presents complete design of modeling and simulation of Energy Management System for residential grid connected-microgrid with HRES. The different types of renewable sources are studied and a hybrid energy system comprising of PV array, wind and battery are simulated and the objectives for this work have been successfully realized through analysis and simulation in MATLAB/SIMULINK. The effectiveness of the Fuzzy Controller implemented and the inverter controller for grid synchronization is also been proved through simulation results by maintaining voltage profile at PCC.

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