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Design and Development of Energy Management System for DG Source Allocation in a Micro Grid with Energy Storage System

S. Ezhilarasan[1*], P. Palanivel[2] and S. Sambath[1]

[1]Department of Electrical and Electronics Engineering, Periyar Maniammai University, Vallam, Thanjavur - 613403, Tamil Nadu, India; arasan_mst@yahoo.co.in; yeses_eng@gmail.com
[2]M. A. M. College of Engineering, Trichy - 621105, Tamil Nadu, India; drpalanivelres@gmail.com

Abstract

This paper proposes an Energy Management System (EMS) with fuzzy logic controller for a grid connected hybrid power system. Modeling and simulation are implemented using MATLAB/SIMULINK package. The objective of proposed EMS for micro grid with battery storage system is to optimize the fuel cost, improving the energy utilization efficiency and to manage the peak load demand by scheduling the generation according to the availability of the fuel. The proposed energy management algorithm for grid connected hybrid energy system helps integration of PV panels and wind power in to the grid which manage the peak load demand, and also it improves the stability of the system under different transient conditions by maintaining the frequency and voltage close to the nominal value for different load. The simulation results of proposed EMS using fuzzy logic expert system shows the minimization on the operating cost and emission level of micro grid by optimal scheduling of power generation ,and maintains the State of Charge (SOC) of batteries in desired value which improves the battery life. The proposed multi objective intelligent energy management system offers a proper tool for improving the system reliability and operational efficiency of a micro grid.

Keywords: Distributed Generation (DGs), Energy Management System (EMS), Micro Grid (MG), Photovoltaic (PV), Renewable Energy (RE), Wind Turbine (WT)

1. Introduction

Micro Grid (MG) is a concept of defining the operation of distributed generation, in which DERs operate as a single controllable system that provides power and heat to a cluster of loads in the local area[1–3]. The schematic diagram of MG is shown in (Figure 1). M.G. has several advantages over conventional power system the most significant features are: 1. Reduction in Transmission and Distribution losses due to shorter distance between generator and load; 2. They can substantially reduce the carbon emission and 3. The presence of generation close to demand can increase the power quality and reliability of electricity delivered to sensitive load. The proposed method introduces an energy management system with an intelligent controller between four energy sources comprises PV panels, wind turbine, biomass gasifier and batteries. The overall aim is to: 1. Optimizing the fuel cost by allocating the source according the availability of fuel; 2. Managing the peak demand by forecasting the load and renewable energy resources; 3. Maximizing the micro grid operation profits under different mode of operation i.e., DG mode, battery mode, gasifier mode, grid mode and 4. Improving the energy utilization efficiency of a micro grid. This paper is organized as follows: Section 1 introduction, section 2 presents modeling of green energy

**Author for correspondence*

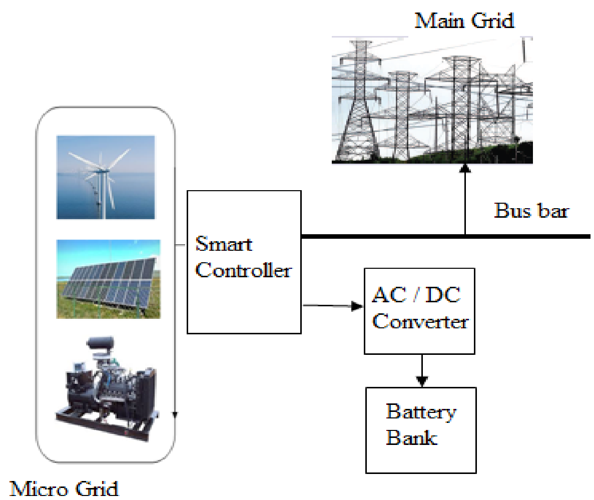

Figure 1. Schematic diagram for Micro grid.

component. Section 3 presents dynamic model of intelligent energy management systems. The proposed control algorithm with mode of operation is addressed in section 4, simulation results are proposed in section 5.

2. Modeling of Hybrid System

2.1 Modeling of Solar Cell

The single diode equivalent circuit model of a solar cell is shown in Figure 2. I_L represents the light generated current in the cell, I_D represents the voltage dependent current lost to recombination and I_{sh} represents the current lost due to shunt resistance, I_D is modeled using the Shockey equation for an ideal diode[5].

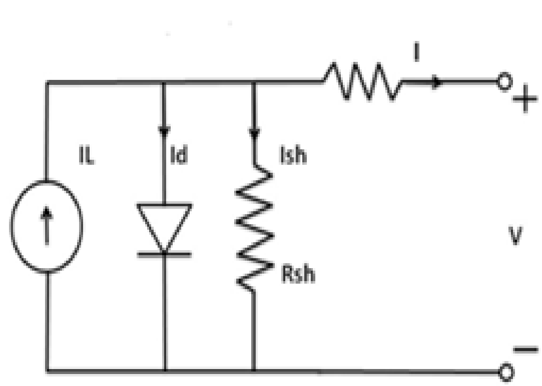

Figure 2. Single diode equivalent circuit model.

$$I = I_L - I_D - I_{sh} \tag{1}$$

$$I_D = I_0\left[\exp\left(\frac{V + IRs}{\eta V_T}\right) - 1\right] \tag{2}$$

Where n is the diode ideality factor, I_0 is the saturation current, and V_T is the thermal voltage given by $V_T = \frac{KT_c}{q}$, Where K is the Boltzmann's constant.

$$I_{sh} = \frac{(V + IRs)}{R_{sh}} \tag{3}$$

$$I = I_L - I_0\left[\exp\left(\frac{V + IRs}{\eta V_T}\right) - 1\right] - \frac{(V + IRs)}{R_{sh}} \tag{4}$$

I_L = light current (A).
I_0 = Diode reverse saturation current (A).
R_s = Series resistance in (Ω).
n = Diode ideality factor.

2.2 Mathematical Formulation of Turbine Model

The kinetic Energy (In joules) in air of mass m moving with a velocity V (Wind) can be calculated from the expression[6,7].

$$E = \frac{1}{2} m v^2 \tag{5}$$

The power P in the wind is given by the rate of change of kinetic energy.

$$P = \frac{dE}{dt} = \frac{1}{2}\frac{dm}{dt} vw^2 \tag{6}$$

But mass flow rate is given by

$$\frac{dm}{dt} = \rho A v w \tag{7}$$

Where A is the area through which the wind in this case is flowing and ρ is the density of the air. With this expression equation becomes

$$P = \frac{1}{2}\rho A v^3 w \tag{8}$$

$$P_w = \frac{1}{2}\rho A vw(v_u^{\ 2} - v_d^{\ 2}) \tag{9}$$

v_u = Upstream velocity entered in blade in m/s

v_d = Downstream velocity entered in blade in m/s

$$\rho A v_w = \frac{\rho A(v_u + v_d)}{2} \tag{10}$$

$$P_w = \frac{1}{2}\rho A(v_u^{\ 2} - v_d^{\ 2})\frac{(v_u + v_d)}{2} \tag{11}$$

$$P_w = \frac{1}{2}\left[\rho A\left\{\frac{v_u}{2}(v_u^{\ 2} - v_d^{\ 2}) + \frac{v_d}{2}(v_u^{\ 2} - v_d^{\ 2})\right\}\right] \tag{12}$$

$$P_w = \frac{1}{2}\rho A v_u^{\ 3} C_p \tag{13}$$

2.3 Power Co-Efficient Analysis

The power coefficient Cp is the most important parameter in the case of power regulation8. It is a non-linear function whose value is unique to each turbine type and is a function of wind speed that the turbine is operating in[8].

$$C_p(\lambda,\theta) = C_1(C_2\frac{1}{\beta} - C_3\beta\theta - C_4\theta^x - C_5)e^{-C_6\frac{1}{\beta}} \tag{14}$$

where the values of the coefficients C1–C6 and x depend on turbine type. θ is defined as the angle between the plane of rotation and the blade cross section chord[9].

$$\frac{1}{\beta} = \frac{1}{\lambda + 0.08\theta} - \frac{0.035}{1 + \theta 3} \tag{15}$$

3. Model Development

The objective of the proposed optimization model is to optimize the availability of energy to the loads according to the level of priority[10,11]. The block diagram of the proposed intelligent energy management system is shown in Figure 3. It is also proposed to maintain the SOC of the battery to meet peak load demand during the period where renewable energy sources failed to supply. The loads are classified as critical load and controllable load. In this paper Fuzzy Logic (FL) based expert system is applied for multi objective functions like allocation of different sources according to the availability[12,13]. The fuzzy based expert system is based on the following factors Battery state of charge, wind velocity, solar isolation, and availability of biomass fuel and load demand[14,15]. A fuzzy logic controller is used to decide the optimum operation of DG systems as shown in the fig there are four possible mode of operation DG mode, gasifier mode, battery mode and grid mode[17,18].

3.1 PV Array Constraints

E p(t) is the sum of energy supplied by the PV array to the load and battery bank in hour t

$$Q_{pv}, B(t) + (\Sigma_i Q_{pv}, i(t)) = E\,p(t) \tag{16}$$

Where Q_{pv}, B (t) is the energy supplied by the PV array to the battery

Q_{pv}, I (t) is the energy supplied by the PV array to load

Since the energy generated by the system varies with insulation, therefore the

$$Ep(t) = V\,s(t) \tag{17}$$

Where V is the capacity of the PV array

S (t) is the isolation index.

3.2 Gasifier Constraint

E p(t) is the sum of energy supplied by the gasifier based power generation system to the load and battery bank in hour (t)

$$Q_g, B(t) + ((\Sigma_i Q_g, i(t))) = E\,p(t) \tag{18}$$

Where Q_g, B(t) is the energy supplied by the gasifier to the battery

Q_g, i (t) is the energy supplied by the gasifier to load

3.3 Wind Energy Constraint

E p(t) is the sum of energy supplied by the wind energy based power generation system to the load and battery bank in hour t

$$Q_{wt}\,B(t) + ((\Sigma_i Q_{wt}, i(t)) = E\,p(t) \tag{19}$$

Where Q_{wt}, B(t) is the energy supplied by the wind turbine to the battery

Q_{wt}, i(t) is the energy supplied by the wind turbine to the load.

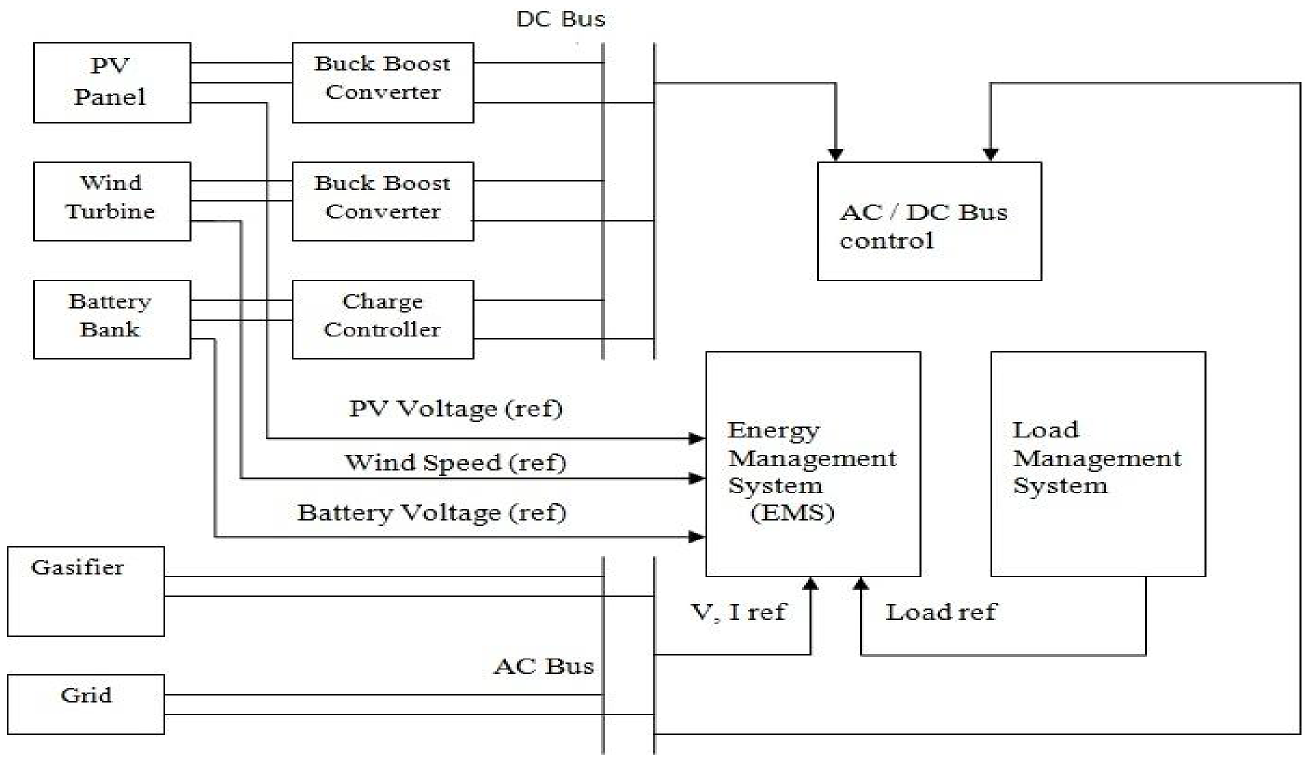

Figure 3. Block diagram of proposed Intelligent Energy Management System.

3.4 Wind Energy Constraint

The fuzzy Logic Controller (FLC) is applied in the proposed micro grid supply system. The input and output membership functions of fuzzy control contain five grade VL (very low), L (low), M (medium), H (high) and VH (very high). FLC is used to decide the optimum operation of the micro grid system with different mode of operation i.e., i) DG mode ii) gasifier mode iii) Battery charging/ discharging mode iv) grid mode[14,15]. FLC is also used for battery management system which maintains the SOC at reasonable level.

3.5 Fuzzy Control

A control algorithm is developed and implemented in the power conditioner hardware. This algorithm is used to control the entire operations of the hybrid energy systems[16]. Monitoring the load demand and solar radiation, windspeed, biomassfuel availability, battery state of charge and grid availability are the major tasks of the control algorithm. The state of charge of batteries in different mode of operation is shown in (Figure 4). The control algorithm is developed to satisfy the load demand by optimally allocate the sources. The controller first checks the availability of power generated from PV and Wind which are the main energy sources, If the power generated from PV and wind satisfies the load requirement than the system is operated in Dg mode. Excess power if generated from solar and wind is utilized to charge the battery, charging mode - Figure 4 (8–10 hrs). During the interval (10–12 hrs) in Figure 4, the energy supplied from solar and wind is not sufficient to meet the load requirement[20,21] then the shortage of power requirement is met by the battery. Controller also checks the SOC of battery to avoid over charging and deep discharging of batteries. During the peak load time, interval (12-13 hrs) power generated by solar and wind along with battery is not enough to satisfy the load requirement (4.0 Kw) therefore the load is met by gasifier.

4. Simulation and Experimental Results

The major input for the proposed EMS were solar irradiation, wind speed, load demand profile. In this study USL solar module of rating 2KW PV panel is taken as example. Specification of PV panel is listed in (Table 1).

Table 1. Specification PV panel Module Type KL 250 Rating 2 KW

Sl. No.	Specification	
01	Typical peak power	P_{max} = 250 W
02	Maximum Peak Power current	I_{mp} = 6.94 A
03	Maximum voltage	V_{max} = 36.0 v
04	Open circuit voltage	V_{oc} = 44.0 v
05	Short circuit current	I_{sc} = 250 W

The characteristics of PV module and availability of solar potential in a study area is shown in (Figure 5 and 6). It was found that maximum output power of SPV increased with increase in solar irradiance, load demand profile is shown in (Figure 7).

The simulation results are obtained by developing a detailed MATLAB/Simulink Package. MATLAB model for a proposed Energy management system is shown in (Figure 8.) and PV system is shown in (Figure 9). In order to avoid the voltage fluctuation Bi-direction inverter shown in (Figure 10.) is implemented in EMS, and the simulated output for change in load is shown in (Figure 11).

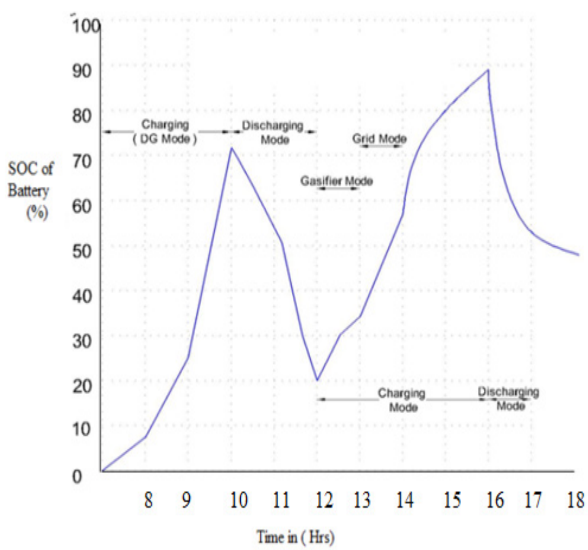

Figure 4. SOC of battery in a Proposed EMS.

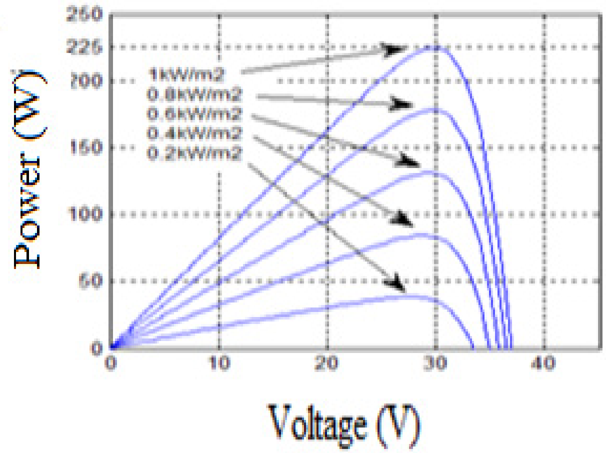

Figure 5. Characteristics of PV System.

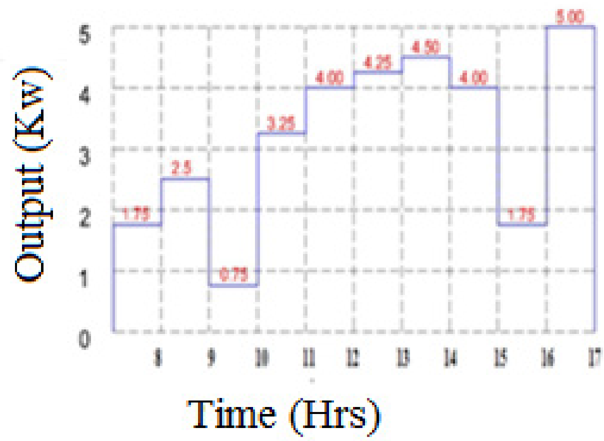

Figure 6. Output of 2Kw SPV system.

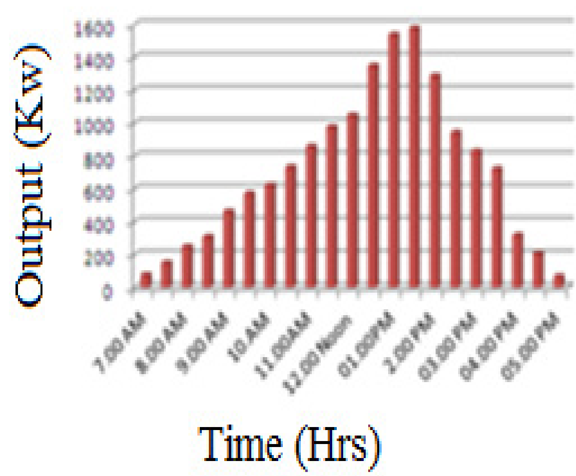

Figure 7. Load profile.

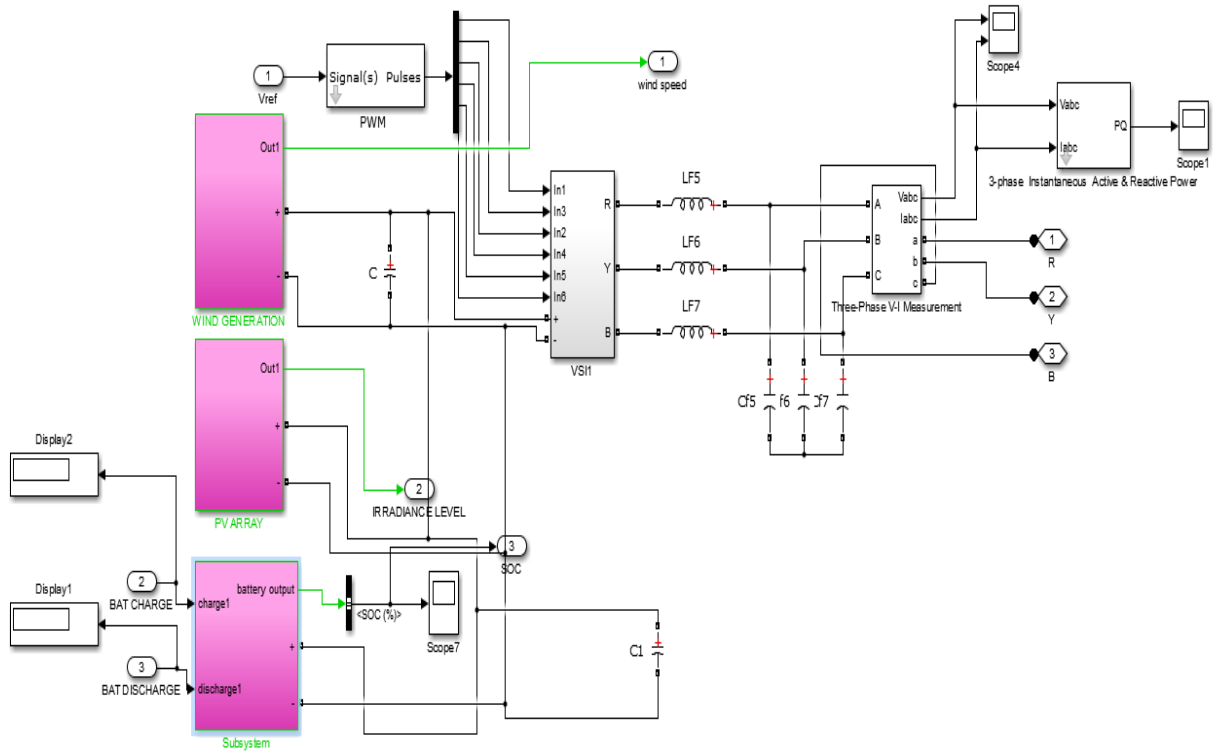

Figure 8. MATLAB model for a proposed EMS.

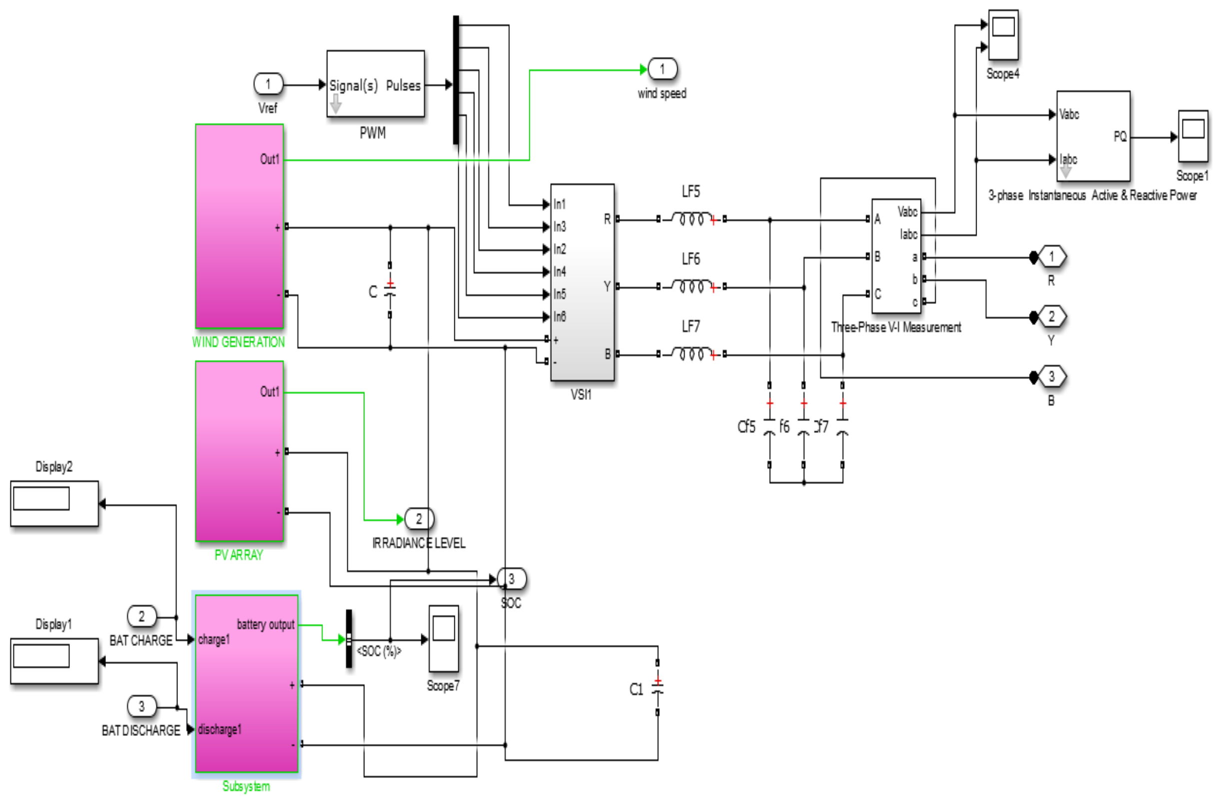

Figure 9. MATLAB model for PV system.

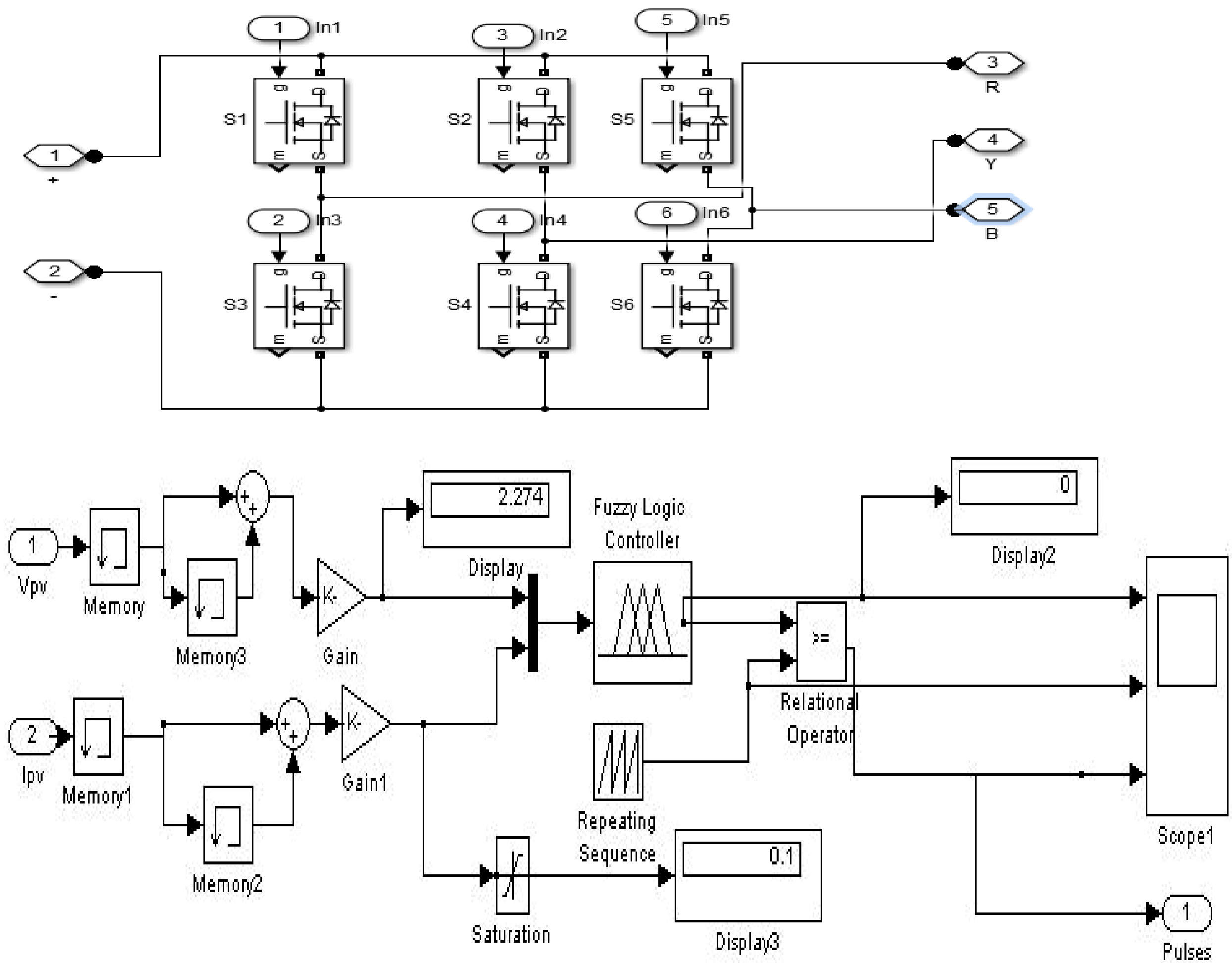

Figure 10. Circuit for Bidirectional inverter.

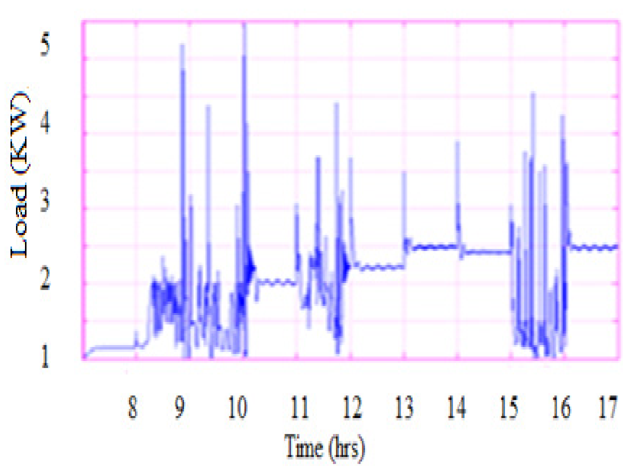

Figure 11. Simulated output for change in load.

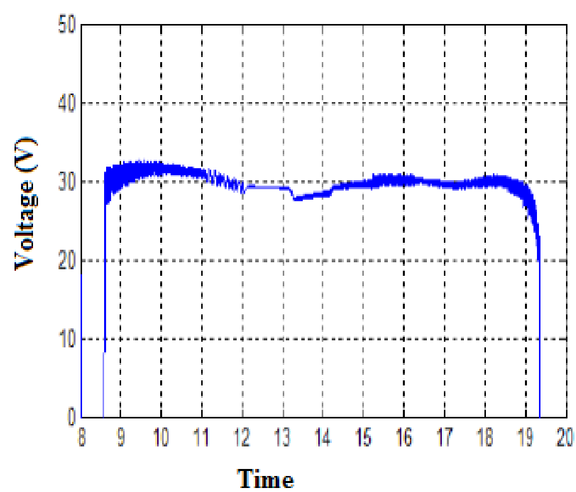

Figure 12. Simulated output voltage for PV.

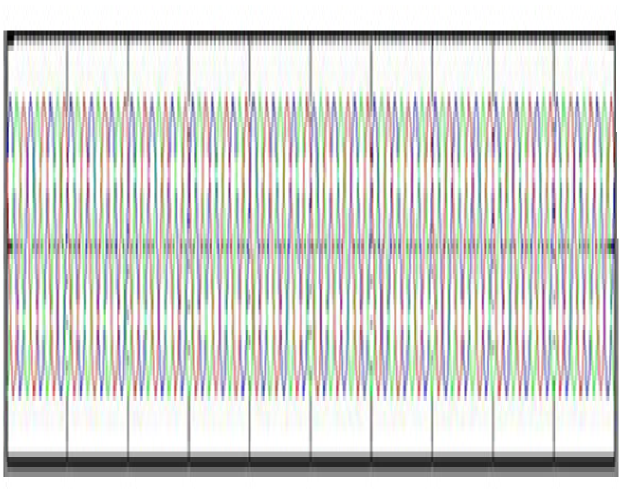

Figure 13. Output load voltage.

4.1 Experimental setup

Hardware implementation of proposed grid connected hybrid energy system are represented as shown in (Figure 14).

In this paper, energy management algorithm for grid connected hybrid energy system was proposed which optimally allocate the source according to the availability which minimize the operational cost and emission of gases. The proposed system presented day-ahead optimal energy management for a micro grid under different mode of operation i.e., DG mode, gasifier mode, battery mode and grid mode. A prototype for the proposed system was designed, implemented and tested in different mode of operation and the results were analyzed.

Figure 14. Experimental setup.

5. Conclusion

In this paper, optimized energy management system is designed and modeled for a micro grid. A power conditioner algorithm for the optimal control and operation of the hybrid energy system is presented. The developed algorithm comprises system components and an appropriate power flow controller. The model has been implemented using the MATLAB/SIMULINK software package; a system consists of PV/wind/ Biomass gasifier and battery setup. The parameters i.e. solar irradiance, temperature and wind speed data is gathered from a 4.05 kW grid connected solar power system and 5 KWe biomass gasifier located in Periyar Maniammai University, Tamil Nadu. Real time field test is conducted for a period of 24 hours. It is found that the implemented algorithm allots the sources effectively and the hybrid energy system supplies the demand of the particular site effectively.

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