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Optimal Choosing of Hybrid Renewable Source for Varying Condition for Effective Load Managemet

Anand BB* **and Ramesh V**

Department of Electrical Engineering, VIT University, Vellore, Tamil Nadu, India

Abstract

The goal of this thesis is to evaluate the performance of a hybrid solar wind, fuel cell and battery energy system through Mat lab simulation studies. The main objective of this study is the development of dynamic models of an off grid (standalone) solar wind turbine, fuel cell and battery system which is used for charging and discharging. Maximum power can be extracted from PV module by using Maximum Power Point Tracking (MPPT) by controlling the duty cycle of a switch. The developed model of the wind energy conversion system consists of dynamic models for a wind turbine as well as induction motor or Permanent Magnet Synchronous Machine. In this thesis we have to control the sources depending upon the load condition. The solar installation cost is less than the remaining sources. So solar supplies the load continuously. If solar cell generated power is not sufficient, then the wind supplies. And if solar and wind generated power are not sufficient, then fuel cell will be operated along with solar and wind. A battery which is used for backup purpose will supply if solar, wind, fuel cell generated power is not sufficient.

Keywords: Solar cell; Wind turbine; Fuel cell; Battery; Converter

Introduction

The usage of non renewable energy sources (conventional energy sources) causes a hike in generation cost. In the world India is the 5th largest in generation and usage of electricity. By 2017 Electricity demand is approximately expected to be 1400 billion kwh. Now it is around 900 billion kwh. There is a deficit of 12% electricity by using non renewable energy. So to meet this demand we have to use other sources like renewable energy. Conventional energy sources also increase fuel consumption and pollution. Solar is the only entirely renewable alternative energy source to satisfy the energy needs of India.

Wind power is unreliable due to irregular nature of wind; the combination of solar photo voltaic (PV) and wind energy conversion system is preferred to improve the reliability of hybrid power generation systems in remote locations. Off grid, i.e., stand alone Hybrid Energy Systems (HES) based on renewable energy resources can provide supply of electrical energy in remote locations. Hybrid Energy Systems (HES) [1-4] can provide higher reliability and power quality. Standalone (off grid) system has been generated by single source systems using solar PV, wind turbine, fuel cell, biomass, diesel generators and battery for back up purpose or by the combining two or more types of these electricity generating sources (Hybrid Energy Systems). These systems include energy source like Lead Acid batteries. A hybrid system can supply power to AC and DC loads. So it requires AC, DC or both buses (Figure 1).

Solar Cell

A semiconductor device convert's sunlight into electrical energy is called Photovoltaic cell. PV module means group of PV cell [5,6] to produce high voltage. PV array means a group of PV module. Electricity is produced when a photon light energy is greater than the band gap of the semiconductor. PV modules are of two types. They are Current input PV module and voltage input PV module. The current input PV module is suitable when PV modules are connected in series and have same current. Voltage input PV module is suitable when PV modules are connected in parallel and have the same voltage.

Photovoltaic cell modelling

Photovoltaic cell contains a diode and current source. PV cell is shown in Figure 2 and equations given below.

Using KCL

$$I_{sc} - I_D - \frac{V_D}{R_P} - I_{pv} = 0 \quad (1)$$

Diode Characteristic equation

$$I_D = I_0(e^{V_D/V_T} - 1) \quad (2)$$

Using KVL (3)

Where V_D is voltage across diode, I_0 is reverse saturation current, $V_T = (K * T / q)$

K=Boltzmann constant = 1.38 × 10^{-19}Joule/k, T is junction temperature, q= electron charge

PV Panel Current-voltage and power-voltage equations are shown in Figure 3.

Generally solar cell efficiency is very low and it is around 20%. So we have to improve the efficiency of solar cell by maximum power point Tracking (MPPT). Maximum power [7] can be obtained by varying source but it is very difficult to vary source because Current – voltage curve of PV cell is non linear (Figure 4). So that by varying the duty cycle of switch by using various MPPT algorithms [5,6,8] like Perturb and Observe, Incremental Conductance, Fuzzy logic Control, artificial neural networks etc.

***Corresponding author:** Anand BB, Department of Electrical Engineering, VIT University, Vellore, Tamil Nadu, India, Tel: +91 8985616125; E-mail: bandreddyanandbabu@gmail.com

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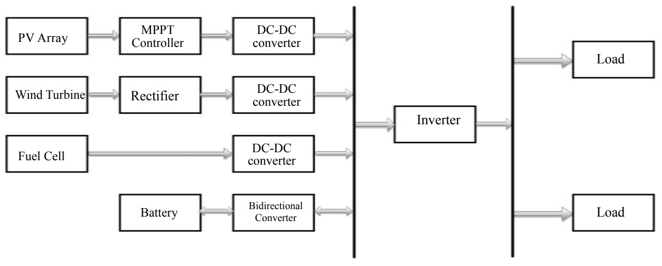

Figure 1: Hybrid system block diagram.

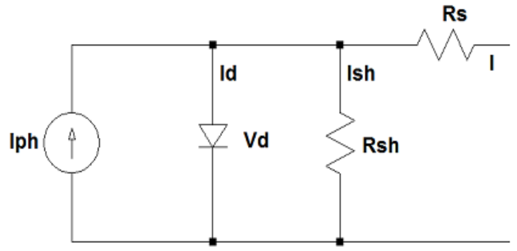

Figure 2: PV cell circuit.

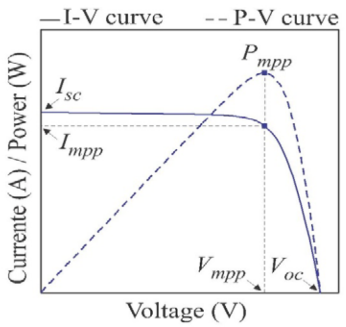

Figure 3: Voltage, current power curves of PV cell.

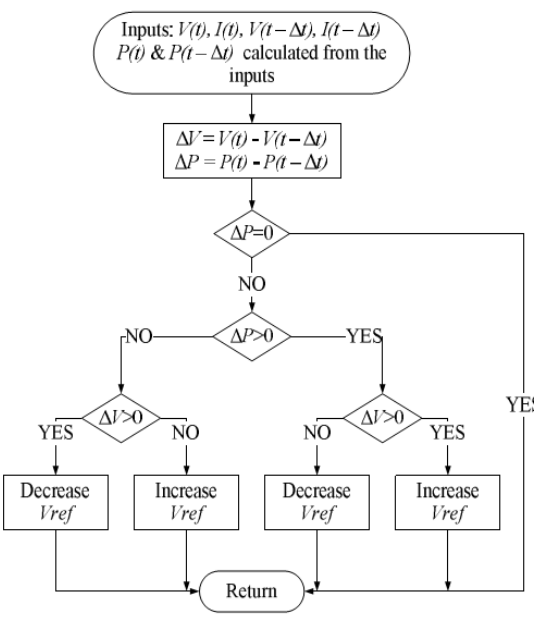

Figure 4: Flow chart of P&O algorithm.

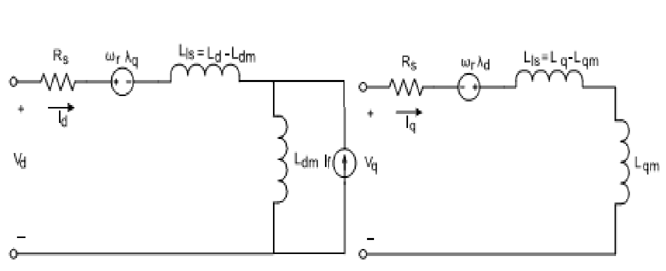

Figure 5: PMSM electric circuit diagram.

Perturbation	Change in power	Next perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

Table 1: Summary of the hill-climbing algorithm.

Flow chart of P&O MPPT Algorithm is shown in Figure 4 and Table 1.

Wind Turbine

One of the energy sources is wind energy which is the renewable energy source. The main drawback of wind energy is output power of wind turbine mainly depends upon nature of wind. So we have to control the speed of wind turbine. Wind turbine is coupled to Permanent magnet synchronous Machine. It depends upon nature of torque, Permanent magnet synchronous machine acts as generator when the torque is negative and acts as motor when torque is positive.

Wind turbine mechanical power [9] is

$$P_m = \frac{1}{2}\pi\rho R^2 Cp v^3{}_{wind} \quad (4)$$

Where

$$C_p = (0.44 - 0.0167\beta)\sin\frac{\pi(\lambda-2)}{13-0.3\beta} - 0.00184(\lambda-2)\beta \quad (5)$$

$$\rho = Air\ density = 1.226 kg/m^3$$

R=Radius of rotor blade,

λ=Tip speed ratio,

V_{wind}= wind speed in m/sec,

β=blade pitch angle

Let us assume C_p=0.4, λ=8.5, β=0, P_m=850 KW

Substitute above values in equation (1) and find R value

Tip Speed Ratio (TPR) is

$$\lambda = \frac{wR}{v} \quad (6)$$

Substitute λ=8.5, wind speed v=12 m/sec, R value obtained by using equation (1) in (2) and then find w value, w value is around 2.81 rad/sec. Increase β value, v value and fine C_p such that power should be maintain constant.

Permanent magnet synchronous machine

Wind turbine is connected to shaft of Permanent Magnet Synchronous Machine (PMSM) [6,7]. Output power of PMSM is not varies with change of wind speed and also PMSM has high torque permanent Magnet Synchronous machine acts as generator if torque is negative and it acts as motor if torque is positive. Three phase input can be converted into two quadrant by using parks transformation [8] and two quadrants d, q axis be rotor reference frame (Figure 5).

$$\begin{matrix} v_q \\ v_d \\ V_o \end{matrix} = \frac{2}{3}\begin{pmatrix} \cos\theta_r & \cos(\theta_r-120) & \cos(\theta_r+120) \\ \sin\theta_r & \sin(\theta_r-120) & \sin(\theta_r+120) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{pmatrix}\begin{matrix} V_a \\ V_b \\ V_c \end{matrix} \quad (7)$$

$$V_q = \frac{2}{3}((V_a * \cos\theta_r + V_b * \cos(\theta_r - 120) + V_c * \cos(\theta_r + 120)) \quad (8)$$

$$\lambda = \frac{wR}{v} \quad V_d = \frac{2}{3}(V_a * \sin\theta_r + V_b * \sin(\theta_r - 120) + V_c * \sin(\theta_r + 120)) \quad (9)$$

Flux linkages along d axis $[\lambda_d]$ q axis $[\lambda_q]$ equations are give below

$$\lambda_d = L_d i_d + \lambda_f \quad (10)$$

$$\lambda_q = L_q i_i \quad (11)$$

Voltage equations are

$$V_q = R_s i_q + w_r \lambda_d + \rho\lambda_q \quad (12)$$

$$V_d = R_s i_d - w_r \lambda_q + \rho\lambda_d \quad (13)$$

Where ρ is $\frac{d}{dt}$

Substitute λ_d, λ_q in above equations

$$V_q = R_s i_q - w_r(L_d i_d + \lambda_f) + \rho L_q i_q \quad (14)$$

$$V_q = R_s i_q - w_r L_d i_d - w_r \lambda_f = \rho L_q i_q \quad (15)$$

$$i_q = \frac{\int [V_q - R_s i_q - w_r L_d i_d - w_r \lambda_f]}{L_q} \quad (16)$$

$$V_d = R_s i_d - w_r(L_q i_q) + \rho(L_d i_d + \lambda_f) \quad (17)$$

$$V_d = R_s i_d + w_r(L_q i_q) - \rho\lambda_f = \rho L_d i_d \quad (18)$$

$$i_d = \frac{\int [V_d - R_s i_d + w_r(L_q i_q)]}{L_d} \quad (19)$$

Torque T_e is

$$T_e = \frac{3}{2}\frac{P}{2}(\lambda_d i_d - \lambda_q i_d) \quad (20)$$

$$T_e = \frac{3}{2}\frac{P}{2}(i_q(L_d i_d + \lambda_f) - i_d(L_q i_q)) \quad (21)$$

$$T_e = \frac{3}{2}\frac{P}{2}(Flux * i_q + (L_d - L_q) * i_q i_d) \quad (22)$$

$$T_e = T_L + Bw_m + J\frac{dw_m}{dt} \quad (23)$$

Rotor mechanical speed

$$w_m = \int [\frac{T_e - T_L - Bw_m}{J}]dt \quad (24)$$

$$w_m = w_r * (2/P) \quad (25)$$

Where w_r is rotor electrical speed.

Fuel Cell

Fuel cell defines as a device that converts chemical energy into electrical energy through a chemical reaction. Generally fuel cell uses hydrogen, methanol, and natural gas as fuel and produces protons, electrons, heat and water. Now a day's various types' fuel cells are available and all those have anode, cathode, electrolytes but different electrolytes and fuel is different (Figure 6). One of fuel cell generally used is Proton Exchange Membrane Fuel cell [10]. Chemical reaction is done at anode when hydrogen is reacts with anode then hydrogen is separated into two parts one is protons (H+ ions) and other one is electrons (e-). Electricity means flow of electrons (Figure 6).

Chemical reaction at anode is

$H_2 \rightarrow 2H^+ + 2e$- (26)

Chemical reaction at cathode is

½$O_2 + 2e^- + 2H^+ \rightarrow H_2O$ (27)

Overall reaction:

$2H_{2\,(gas)} + O_{2\,(gas)}$ ---------->$2H_2O$ +energy (28)

Controlling Algorithm for generation sources

function y= fnc (u)

if ((u>2.5) && (u<3.5))

y= [1; 1; 1; 0];

elseif (u<1.2)

y = [1; 0; 0; 0];

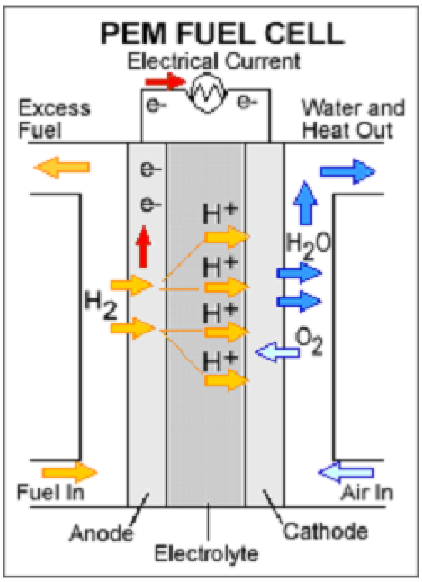

Figure 6: Proton exchange membrane fuel cell (PEMFC).

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```
elseif ((u>1.21) && (u<2.5))
y= [1; 1; 0; 0];
else
y= [1; 1; 1; 1];
end
```

Matlab Simulation

MATLAB simulation of the system which has power generation solar, wind, fuel cell, battery. DC bus voltage is nearly 1 KV and the loads are of AC load type and 5 loads and power rating of loads are 1 KW, 2.5 KW, 1 KW, 1 KW, 1 KW respectively. So DC should be converted into AC by using inverter. In each source one breaker is connected to control the source depending upon the load connected to the system [11,12]. The input condition of breaker is output of control algorithm code and code is given above.

Simulation Results and Discussion

When input of circuit breaker of load (1) is 1 that means circuit breaker closes then only solar supplies generated power up to current be below 1.2 A. When the circuit breaker of load 2 is ON and the load is between 1.21 A to 2.5 A wind supplies generated power along with solar. Before wind supplies power fuel cell is used because wind turbine blades have to rotate and have to settle [13]. After wind supplies generated power then fuel cell turns off. When circuit breaker of 3rd load turns on and the load reaches between 2.5 A to 3.5 A fuel cell also supplies generated power to loads along with solar, wind. When the load is beyond 3.5 A then all the sources supply generated power to load. Battery has to be charge when the input of battery is 0 and at this time bi directional converter will acts as buck converter , the source to buck converter is DC bus. Battery input is 1 that means battery discharges and at this time bi directional converter works as boost converter, battery supplies generated power to loads (Figures 7-11).

Figure 7: Solar ON state when load is below 1.2 A.

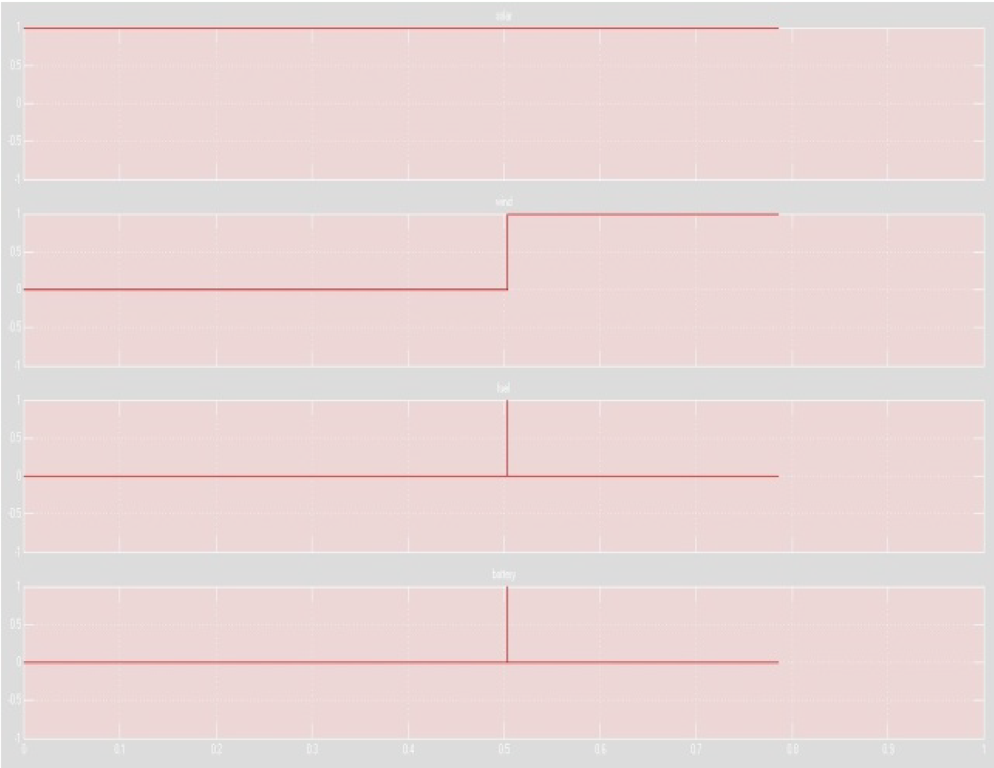

Figure 8: Solar and wind ON state when load is in between 1.2 to 2.5 A.

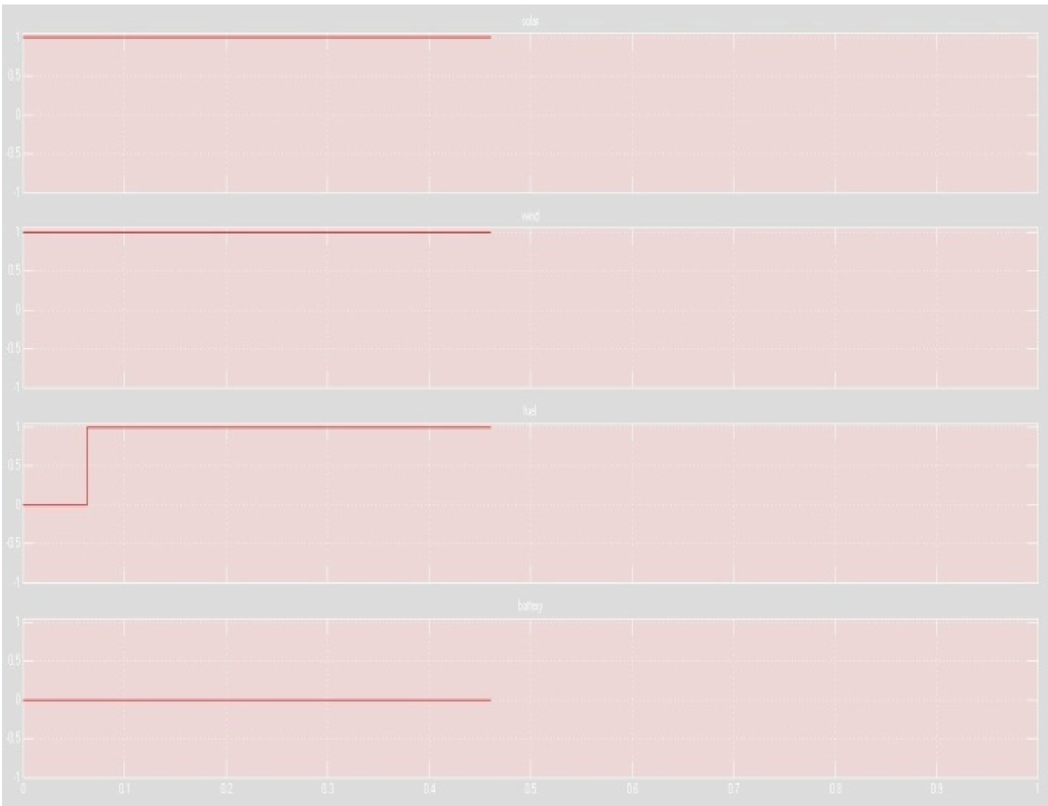

Figure 9: Solar and wind ON state when load is in between 1.2 to 2.5 A.

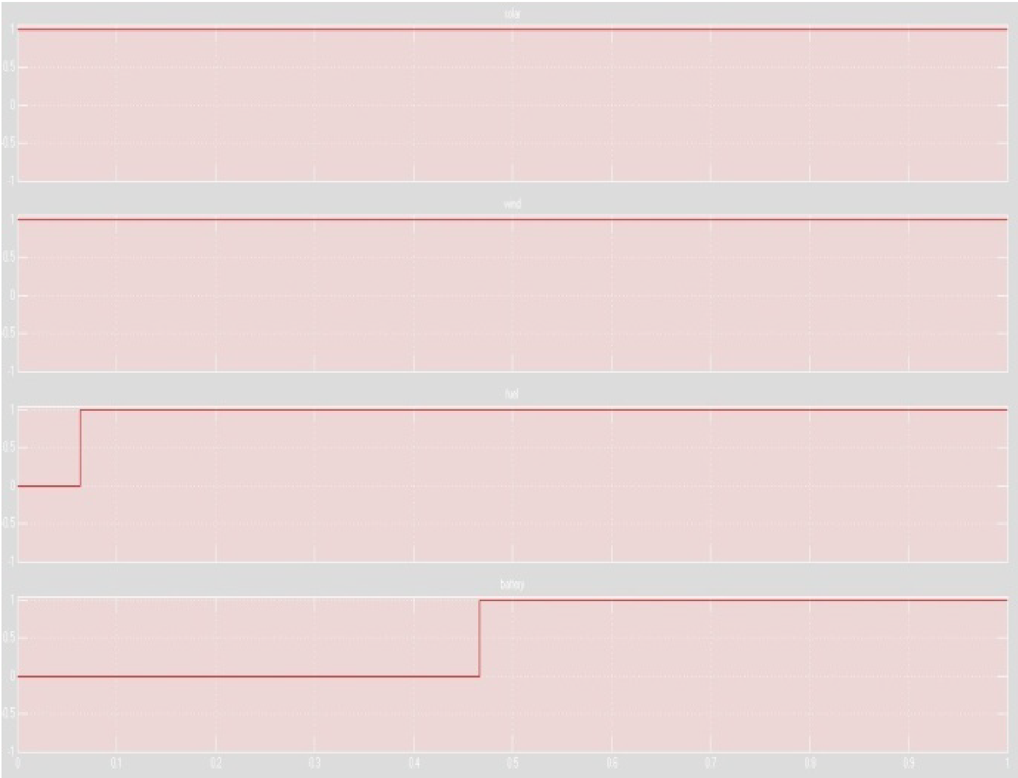

Figure 10: All sources is ON state when load is in beyond 3.5 A.

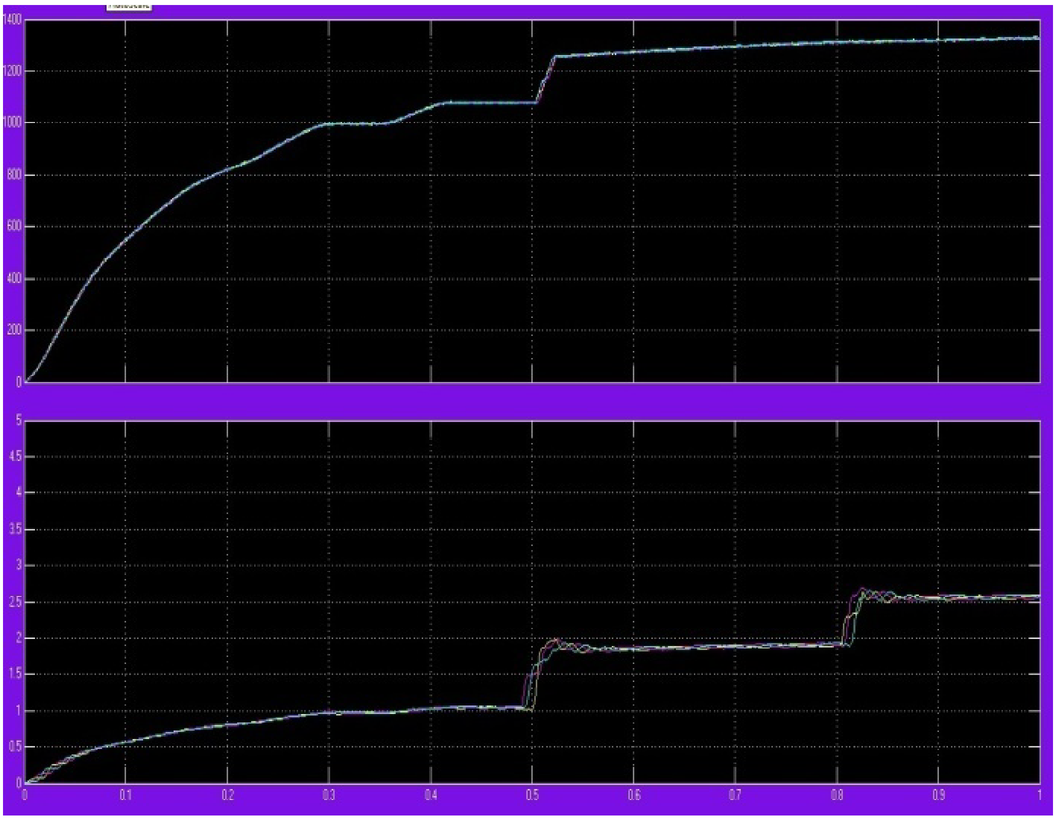

Figure 11: RMS values of load voltage and current.

Conclusion

Finally the simulation of the hybrid system generation system which controls the sources depending upon the load condition is performed. Here 5 loads are present. Load is connected and disconnected depending upon control signal connected to breaker input value. If the control signal is 1 then breaker closes, load is connected to the system and vice versa. To control the sources control algorithm needed. So in each source one breaker should be needed to switch on or off the sources.

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