Solar PV based DC Microgrid for Rural Sustainable Development

Gudise Harikrishna
M. Tech scholar, EEE
VNR VJIET
Hyderabad, India

K. Anuradha
VNRVJIET
Hyderabad, India

Abstract- **The world, especially country like India has high grid transfer problem. The DC transmission is the most efficient transfer. Among the renewable Energy sources of solar, tidal, wind, biomass etc, solar energy has succeeding features such as Pollution free, Maintenance free, Silent operation, Extended life time, Simplest, Reliable, Cost effective and Scalable. And hence solar electrical energy is generally used for the development of economic growth. In the present work DC solar microgrid with power capacity ranging from 500W to 1KW is considered for development. The system consists of solar module, MPPT P&O algorithm controlled DC-DC Bidirectional converter with storage system. Modeling and design of solar PV module for the DC grid and the characteristics of photovoltaic panel under different irradiance and temperature conditions are explored. The total system is modeled in MATLAB/SIMULINK environment. This work focuses on implementation of DC microgrid, an effective way of solar power generation for un electrified remote villages which motivates the rural region people for sustainable development.**

Index Terms— Solar PV panel, MPPT technique P & O algorithm, DC-DC Boost converter, DC-DC Bidirectional converter, Storage System, DC loads**.**

I. INTRODUCTION

DC microgrid is a representative process to generate the electrical power and contributes for the best economic growth and success of a nation. Access to electrical power remains a distant dream for greater part of the developing countries. In India 237 million people do not access the electricity. In India more than 25% of households do not have access to electrical energy [2]. And mostly using other fuels sources for their lighting and regular electrical requirements.

The microgrid concept has evolved the DC microgrid design. It is normally considered as a network system for DC electrical energy, DC sources connecting alternate renewable energy sources and power storages.

DC microgrids have the advantages of low cost converters, high conversion efficiency, high transmission & distribution efficiency and concern in view of the power supply reliability, protection understanding and controllability which are to be focused.

DC microgrids are 25-30% more efficient than the AC microgrid. Implementation of the DC microgrid is smart energy based electrical power generation for the sustainable rural development. Solar Photovoltaic cells can produce the electrical energy [1]. Photovoltaic cells collect the light irradiation and convert into electricity.

Solar modules are mainly classified into three categories: Mono crystalline, Poly crystalline and Amorphous solar modules. Mono crystalline modules are the mostly used one because they have high efficiency compared to other modules. DC appliances like DC motor, DC fans, Mobile chargers, LED TVs, Bulbs, Street lighting etc. are the loads on the system.

The paper mainly discusses the Development of DC microgrid modeling as shown in Fig.1. The components of the DC microgrid are modeled using MATLAB /SIMULINK toolbox. The following sections deal with solar Photovoltaic system modeling, tracking of maximum power using P&O method as charge controller for DC-DC converter, storage system with Bidirectional converter and discussion of the obtained results.

II. SOLAR PHOTOVOLTAIC SYSTEM MODELING

The model of solar Photovoltaic cell is a basic device that can convert the light irradiation into an electrical energy. A photovoltaic consists of P-N semiconductor material. When the light irradiation falls on the P-N semiconductor, DC current is generated.

The solar Photovoltaic cell equivalent circuit is represented as an ideal photo current source, anti parallel connected diode, parallel connected resistor and series connected resistor as shown in Fig.2.

A Photovoltaic cell behavior depends on the type/size of load and environment conditions associated with it. This performance is also known as Photovoltaic cell characteristics. The Photovoltaic cell characteristics are explained by the current and voltage stages when dissimilar loads are coupled.
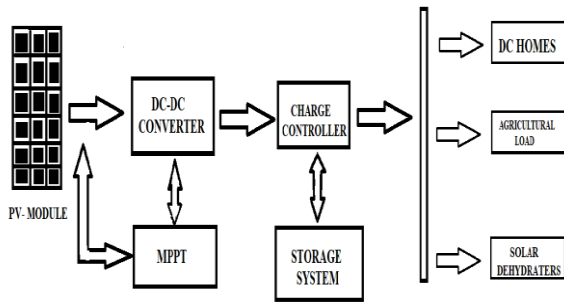
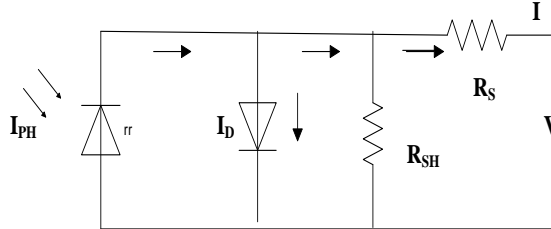Fig: 1. Block diagram of DC Microgrid

Fig: 2. Solar PV cell equivalent circuit

By applying Kirchoff's current law for the above equivalent circuit

$$I_{PH} = I_D + I_{SH} + I \qquad \text{.... (1)}$$

The photovoltaic output current from the above equation is

$$I = I_{PH} - I_D - I_{SH} \qquad \text{.... (2)}$$

$$I = I_{PH} - I_0 \left[\exp\left(\frac{V + I.R_S}{V_T} \right) - 1 \right] - \left[\frac{V + I.R_S}{R_{SH}} \right] \qquad \text{.... (3)}$$

By Substituting V = 0 in (3), the short circuit current is as follows.

$$I_{SC} = I_{PH} - I_0 \left[\exp\left(\frac{V + I_{SC}.R_S}{V_T} \right) - 1 \right] - \left[\frac{V + I_{SC}.R_S}{R_{SH}} \right] \qquad \text{.... (4)}$$

For the above equation at given temperature, V_T and I_o are constants. 2nd, 3rd terms nearly equal to a constant. Thus short circuit current I_{SC} depends on I_{PH}, the irradiance current.

$$I_{SC} \alpha I_{PH} \qquad \text{.... (5)}$$

Photovoltaic cell open voltage results if the current is zero. The following expression for open circuit voltage is obtained by substituting I = 0 in (3).

$$V_{OC} = V_T \ln\left[\frac{I_{PH}}{I_0} - \frac{V_{OC}}{I_0 R_{SH}} + 1 \right] \qquad \text{.... (6)}$$

Where

I_{PH} = Photo current or Insolation current
I = Output current of Photovoltaic cell
I_D = Reverse saturation current or leakage current
V = Output voltage of Photovoltaic cell
I_{SH} = Shunt current
R_{SH} = Shunt resistor
R_S = Series resistor
V_T = Thermal constant = $\frac{KT}{q}$
A = Diode ideality constant (1.6)
K = Boltzmann constant (1.3805×10^{-23}J/K)
T = Temperature in Kelvin (298^0K)
q = Charge of an Electron (1.602×10^{-19} Coulomb)
I_{SC} = Short circuit current

V_{OC} = Open circuit voltage
V_{max} = Maximum voltage of Photovoltaic cell
I_{max} = Maximum current of Photovoltaic cell
P_{max} = Maximum power of Photovoltaic cell
Iscr = Short circuit current at reference temperature (8.45Ampere)
I_{SH} = Current by the shunt resistance (Ampere)
N_P = Cells interconnected in parallel (1)
N_S = Cells interconnected in series (72 cells)

II (a) Photovoltaic module I-V&P-V Characteristics

Each Photovoltaic cell is rated as 0.5 to 0.7 V and a current of 30mA/cm^2 area [3]. A solar photovoltaic cell delivers different range of currents which depends upon the solar irradiation and temperature.

A typical solar photovoltaic cell I-V and P-V characteristics are shown in Fig.3&Fig.4.
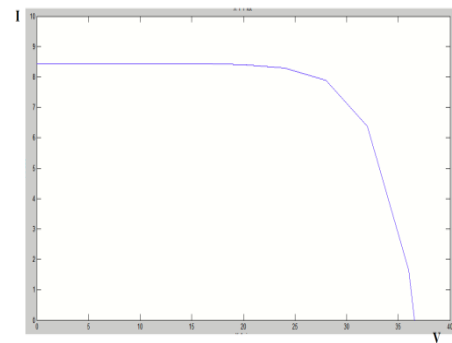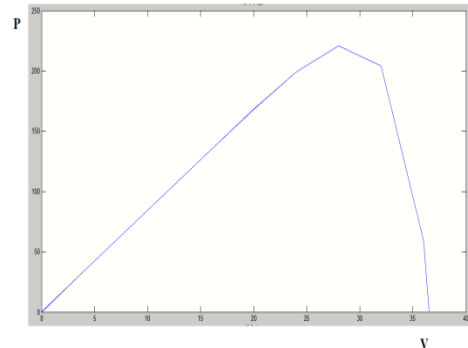

Fig: 3. Current vs. Voltage

Fig: 4. Power vs. Voltage

The photovoltaic cell efficiency is the ratio of maximum power to irradiance(S) and area (m^2)
Efficiency of the photovoltaic cell is given by

$$\eta = \frac{V_{MP}.I_{MP}}{I\left(\frac{kw}{m^2}\right).A(m^2)} \qquad \text{.... (7)}$$

The fill factor (FF) is the ratio of maximum power to the open circuit voltage and short circuit current.

$$\text{Fill factor} = \frac{V_{MP}.I_{MP}}{I_{SC}.V_{OC}} \quad \text{Fill factor} = \frac{V_{MP}.I_{MP}}{I_{SC}.V_{OC}} \qquad \text{.... (8)}$$

The FF should be 1. The value of FF is about 0.8 for a good photovoltaic cell.

III. BOOST CONVERTER MODEL AND DESIGN PARAMETERS

Boost Converter is a converter which can convert the DC-DC voltage. The output voltage is more than the input. And input current is greater than the output current.
The circuit diagram of the boost converter shown in the Fig. 5.
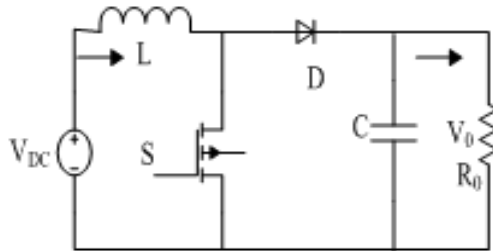

Fig: 5. Boost converter

Where V_{in} is input voltage, V_0 is the output voltage of boost converter, 'D' is diode, 'L' is inductance of boost converter and 'C' is capacitance of boost converter. The boost converter can operate in two modes continuous and discontinuous modes.

When the switch 'S' is in on condition: Current flows through inductor 'L' then switch, Inductor gets energized and stores the energy.

When the switch 'S' is in off condition: Current takes the path through the inductor 'L' and diode through capacitor 'C' and loads 'R_0'. Inductor 'L' delivers the stored energy for the load.

Boost converter design equations are given by

Gain of the boost converter $\quad \frac{V_0}{V_{IN}} = \frac{I_{IN}}{I_0} = \frac{1}{(1-D)} \qquad$ …. (9)

Critical inductance value $\qquad L = \frac{(1-D)DR}{2f} \quad$ mH $\quad$ …. (10)

Critical capacitance value $\qquad C = \frac{D}{2fR} \quad$ μF $\qquad$ …. (11)

Input Resistance is calculated by using equation. (12)

$R_{IN} = \frac{V_{IN}}{I_{IN}} = \frac{V_0(1-D)}{I_0/(1-D)} = \frac{V_0}{I_0}(1-D)^2 = R_0(1-D)^2$ …. (12)

Here input resistance R_{IN} varies from output resistance R_0 to 0 as D value varies from 0 to1.

TABLE. 1 Parameters of the Boost Converter

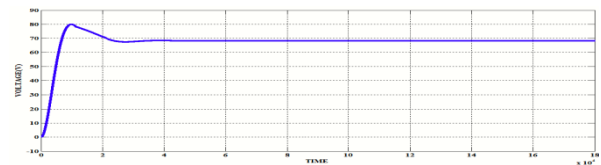| PARAMETERS	VALUE
Panel output current(I)	2.3A
Input voltage(Vin)	36.8V
Switching frequency(f)	25KHz
Output voltage(V0)	68.15V
Inductor(L)	4.25mH
Capacitor(C)	4700μF

Fig: 6. the output voltages of boost converter

DC-DC Boost converter is designed as per the required ratings of the system. These values are tabulated in Table .1. Boost converter is simulated in MATLAB SIMULINK and corresponding results are shown in Fig: 6. the open loop system of the boost converter with solar energy an input and pulse generator is as shown in Fig: 7
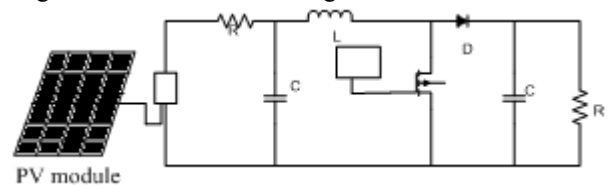

Fig: 7. DC-DC Boost converter with solar power input with open loop system

IV. MPPT TECHNIQUE & ALGORITHMS

Photovoltaic system can play an important role to get a Maximum power by using Maximum power point tracking (MPPT) Controller. Different types of techniques for MPPT [5] are (i) Fixed Voltage (ii) Fractional Open Circuit method (iii) Perturb and Observe technique (P&O) (iv) Incremental Conductance etc…

Solar photovoltaic modules have different current-voltage characteristics for various ratings. Maximum power point (MPP) depends on the environmental factors, like irradiance and temperature. PV modules are operated at MPP despite the predictable changes in the environment. The controllers are the solar electrical energy based power electronic converters which take up some method to achieve maximum power point tracking (MPPT).

Hill Climbing or Perturb & Observe technique is used to get Maximum Power from the panel the process to repeat from time to time.

By reducing the perturbation step size gives the MPPT. And the oscillations are minimized.

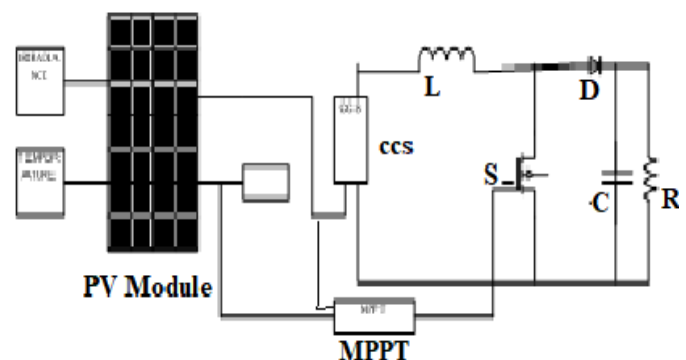The closed loop system with MPPT is as shown in Fig: 8.

Fig: 8. DC-DC Boost converter with solar power input with MPPT

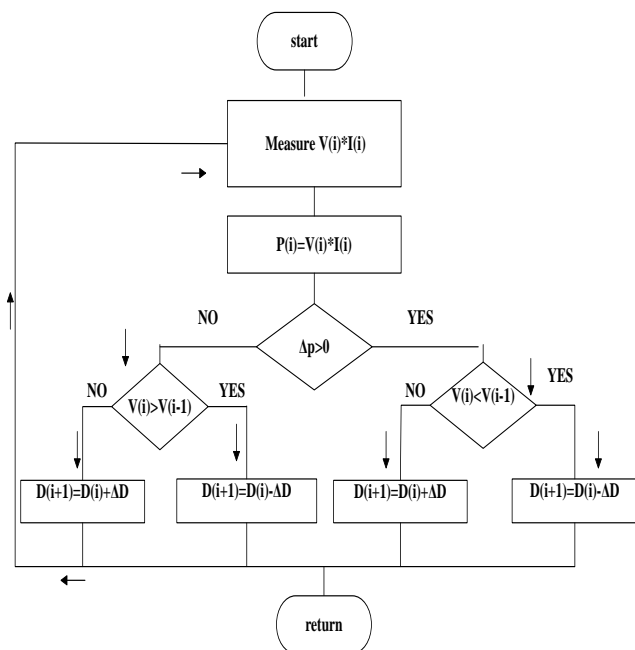Fig.9 shows the flow chart for MPPT technique using P&O control algorithm method.

Fig: 9. Flowchart for MPPT for P&O method

Solar photovoltaic panel gives the maximum power point that can be obtained at given irradiation. The point at which the resistive line crosses the V-I characteristic gives the maximum power it can transfer to the load. This can be achieved by translating the actual load line point to maximum power point by changing the duty cycle (D) in case of boost converter. To get the maximum power the following steps are followed: plot voltage Vs power graph of the photovoltaic module. The product of voltage and current gives the power it can provide. From the graph, voltage at which the maximum power occurs is located as shown in Fig.5. P&O controled algorithm has one of main disadvantage that sudden changes in environment conditions have effect on it.
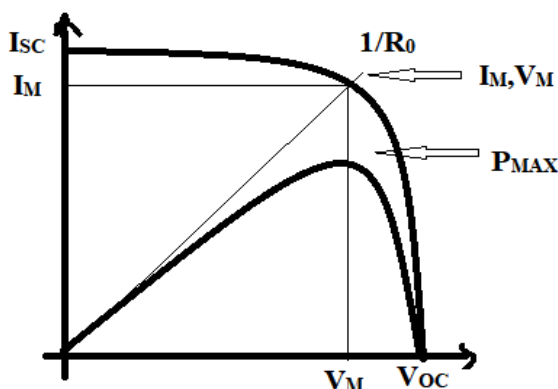

Fig: 10. MPPT with load line

V.   RESULTS AND DISCUSSION

The Proposed Model of Solar photovoltaic system equipped with P&O controlled MPPT Algorithm [5] using Boost converter along with storage system fed by a bidirectional DC-DC converter is shown in Fig: 11. DC-DC bidirectional converter is used for charging and discharging of battery storage system [7]. Photovoltaic energy can be generated and transferred to the DC-DC bidirectional converter for storage of the power. When the sun light is not available stored the solar electrical energy stored in battery. Thus it can be reused when the sun light is not available.

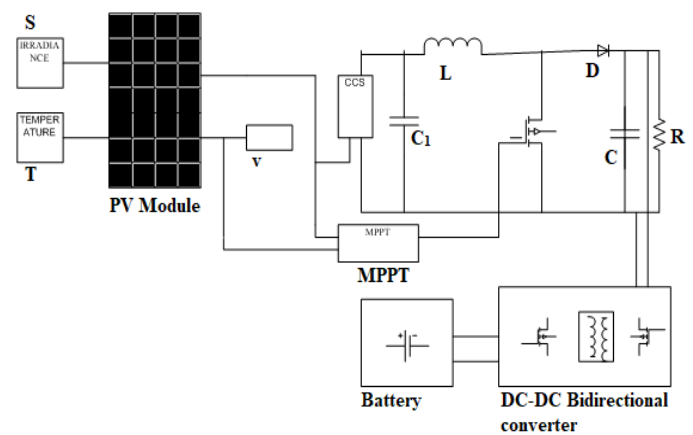The total system is simulated in MATLAB SIMULINK software. Corresponding results are shown in Fig: 12 to19.

Fig: 11. Simulation model of proposed system

The Figs. 12 & 13 show the I-V and P-V characteristics at constant temperature of 25 ^{0}C for different irradiances 600, 800 and 1000 W/m^2.

And Fig. 14 & 15 show the I-V and P-V characteristics at constant Irradiance of 1000 W/m^2 for different temperatures at 25, 30 and 60^{0}C.

The output voltage of Boost converter for the given input voltage of 36.4V is as shown in Fig: 6.Fig.16& 17 depicts the output voltage, current and power of the boost converter with solar energy an input with out and with P&O controlled MPPT algorithm respectively.

DC –DC Bidirectional converter output with 24 V storage battery is shown in Fig: 18.At Maximum power point tracking (MPPT),the Output power, Current and voltage of the system connected with solar energy is shown in Fig: 19.
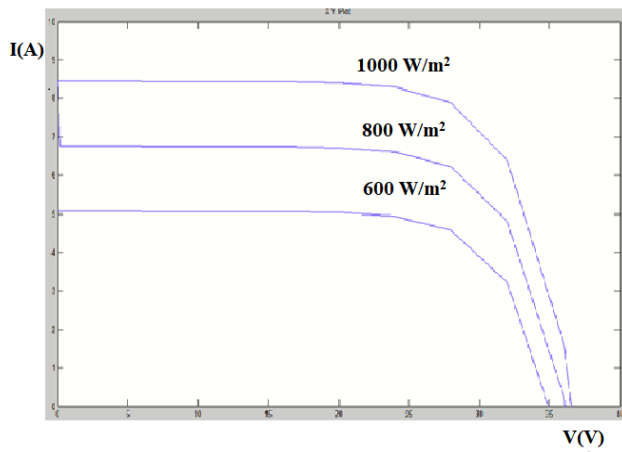
Fig: 12. I-V Characteristics of solar panel at constant Temperature =25^{0}C with different Irradiance 600, 800,1000W/m^2
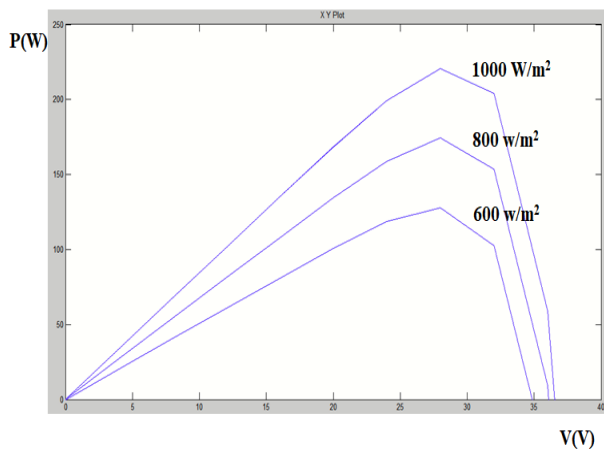

Fig: 13. P-V Characteristics of solar panel at constant Temperature =25^{0}C with different Irradiance 600, 800,1000W/m^2
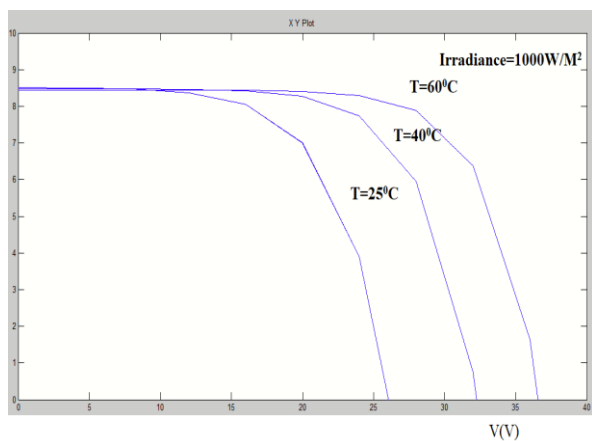

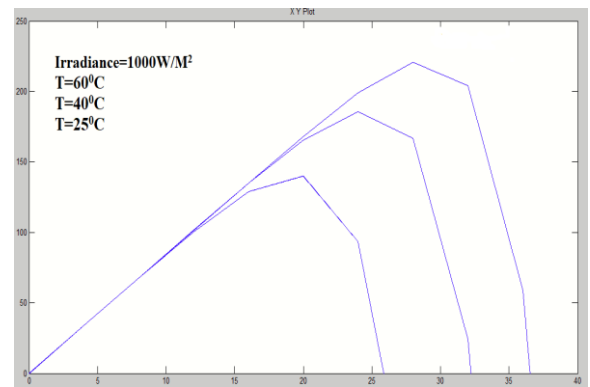Fig: 14. I-V characteristics of solar PV panel at constant Irradiance with different Temperature =25, 40 and 60^{0}C

Fig: 15. P-V Characteristics of solar panel at constant Irradiance=1000W/m^2 different Temperature =25, 40 and 60^{0}C
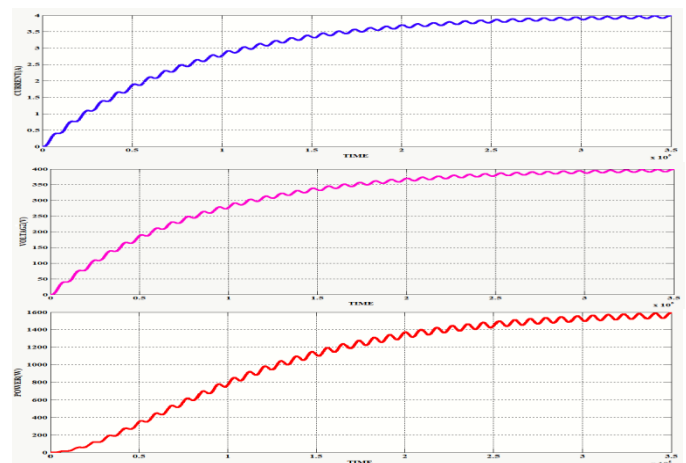

Fig: 16. Output voltage, current and power of DC-DC Boost converter with solar module input without MPPT
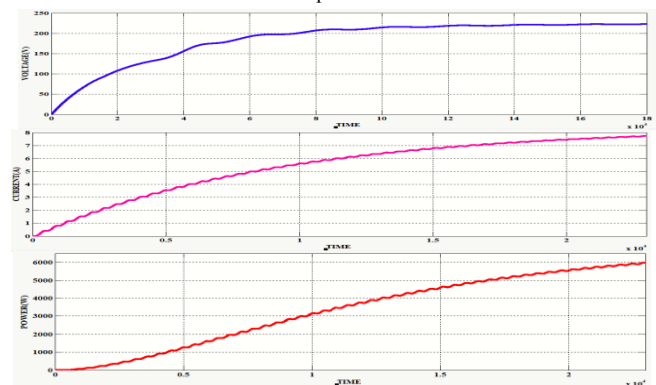

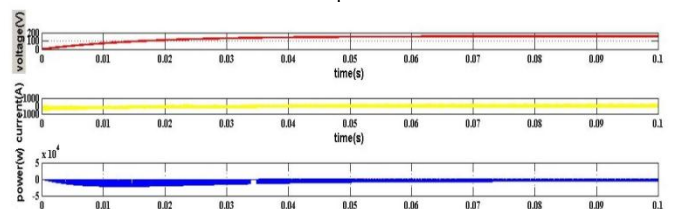Fig: 17. Output voltage, current and power of DC-DC Boost converter with solar module input with MPPT

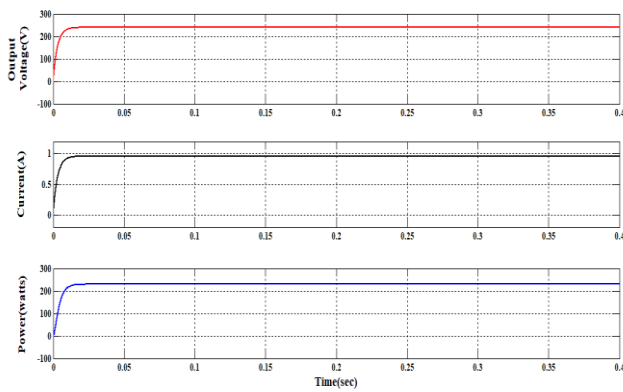Fig:18. DC –DC Bidirectional converter output voltage, current, power

Fig.19. Voltage, Current and Power of boost converter with solar energy as input With MPPT

VI. CONCLUSION

The proposed system presents mathematical modeling and design of solar PV system, developed in MATLAB SIMULINK environment. The characteristics and behavior of the PV module are obtained by changing the irradiance and temperature. Maximum power from the panel is extracted by using the maximum power point tracking (MPPT) P&O controlled algorithms for PV based boost converter with a Bidirectional converter storage system. Implementation of solar Photovoltaic based DC microgrid is viable for unelectrified rural regions. And it is a way for more effective democratic improving the quality of solar based DC microgrid for further generations.

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