International Journal on Advances in Engineering Technology and Science
Volume: 1, Issue: 2, December 2015, e-ISSN: 2455-3131

Design a Residential PV Power System with Battery Energy Storage

Krishnarajsinh A. Jadav

Department of Electrical Engineering, Atmiya Institute of Technology & Science,
Rajkot, Gujarat, India

krishnaraj.jadav@gmail.com

Abstract— **The system will be used to power a complex with 4-10 houses. The system can operate in standalone or grid-tied mode. When there is excessive power from the PV panels, the battery will be used to store energy. On the other hand, when there is an energy deficit, the energy stored will be released. All the components used in the system are commercially available. Cost estimation is also mention in this project. Maximum power point tracking (MPPT) technique is applied to photovoltaic (PV) system to extract maximum available power from it. Simulation results verify the effectiveness of the proposed PV system.**

***Keywords*— Bidirectional Converter, Battery Energy Storage, distributed generator (DG), photovoltaic (PV) system, maximum power point tracking (MPPT).**

I. Introduction

As electric distribution technology steps into the next century, many trends are becoming noticeable that will change the requirements of energy delivery. These modifications are being driven from both the demand side where higher energy availability and efficiency are desired and from the supply side where the integration of distributed generation and peak shaving technologies must be accommodated [1]. The transmission and generation system capabilities have been stressed by increase in power demand [2]. An overall power system with central plants is less efficient due to transmission and generation losses along with frequent power outages. These perplexities allow research to focus on fields that can respond to the increasing energy demands without adding new transmission lines. At first glance, integration of the distributed generation to the main grid can be a feasible solution [1]. The distributed energy generation field has its own problems that need to be solved [3].

II. Photovoltaic (PV) System

Complete system is presented in figure 2. Photovoltaic technology is the fastest growing technology used in current distribution systems [4]. PV utilizes sunlight to generate energy and it is an attractive alternate energy source because it is renewable, and harmless. PV system basic component is the PV cell which produces around 0.5V to 0.7V voltage on average [4]. Because of the low voltage generation in a PV cell, several PV cells are connected in series (for high voltage) and in parallel (for high current) to form a PV module for desired output [5]. The power produced by single module is not enough to meet the requirements of commercial applications, so modules are connected to form array to supply the load. The modules in a PV array are usually first connected in series to obtain the desired voltages known as string. Then these strings are connected in parallel as shown in figure 1 to allow the system to produce more current.

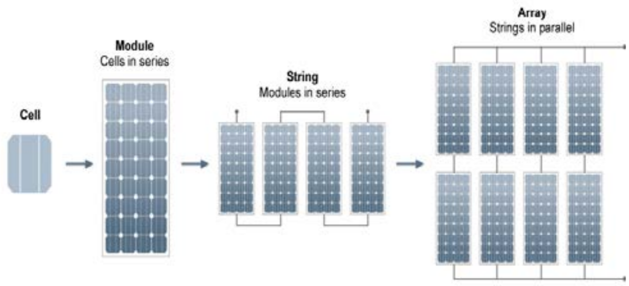

Fig. 1 PV array formation

A PV cell delivers different amount of current depending on the irradiation (or insolation), the PV cell temperature and where on the current-voltage curve the PV cell is operated. A PV cell behaves differently depending on the size/type of load connected to it. This behaviour is called the PV cell characteristics. The characteristic of a PV cell is described by the current and voltage levels when different loads are connected. When the cell is not connected to any load there is no current flowing and the voltage across the PV cell reaches its maximum. This is called open circuit voltage (Voc). When a load is connected to the PV cell, current flows through the circuit and the voltage goes down. When the two terminals are directly connected with each other maximum current will flow and the voltage is zero. The current in this case is called short circuit current (Isc). I-V and P-V characteristics are shown in figure 3.

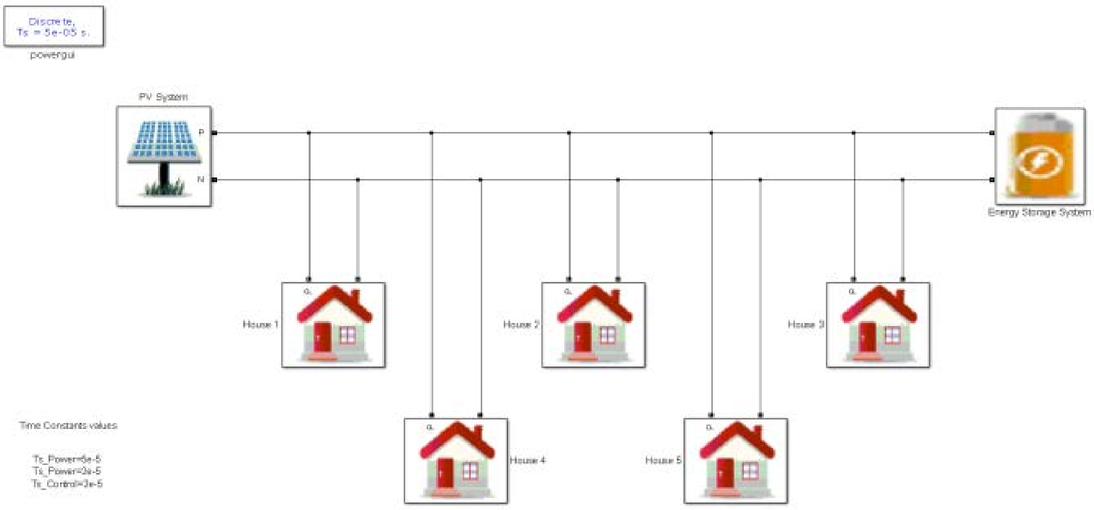

Fig.2 PV System with Energy Storage System

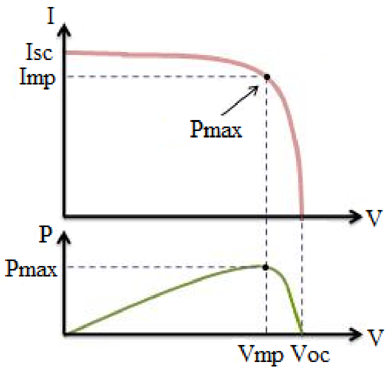

Fig. 3 I-V & P-V characteristics

The basic building block of PV arrays is the solar cell, which is basically a p-n junction that directly converts light energy into electricity. PV array is designed based on equivalent circuit of PV cell presented in figure 4. For modeling Mitsubishi PV-UD190MF5 Module data are used and it is taken from the NREL System Advisor Model (SAM 2014). The System Advisor Model (SAM) is developed by the National Renewable Energy Laboratory (NREL), which is operated by the Alliance for Sustainable Energy, LLC for the U.S. Department of Energy (DOE) and may be used for any purpose whatsoever [6].

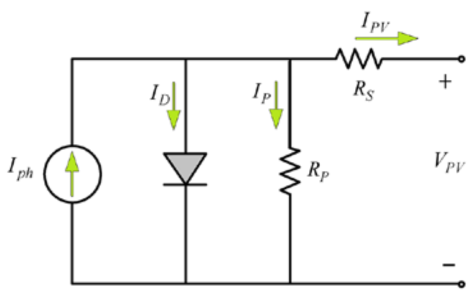

Fig. 4 Equivalent circuit of PV cell

Applying Kirchhoff's Current Law (KCL) to the node where I_{PH}, Diode, R_P and R_S meet, we get the following equation:

$$I_{PV} = I_{PH} - I_D - I_P \tag{1}$$

Where,

I_{PV} = PV module current (A)
I_{PH} = Photo-current (A)
I_D = Current through the diode of PV module (A)
I_P = Current through the parallel resistance of PV module (A)

Here, I_{PH} represent photo current generated by the solar irradiation and calculated using following equation:

$$I_{PH} = I_{SC} + k_i(T - T_r)\frac{\lambda_S}{1000} \tag{2}$$

Where,

I_{PH} = Photo current (A)
I_{SC} = Short circuit current (A)
k_i = Short circuit current temperature coefficient
T = Surface temperature of PV module (°C)
T_r = Reference temperature (°C)
λ_S = Solar radiation level (W/m^2)

The current I_D in equation 1 represent diode current and can be given by the Shockley's diode equation:

$$I_D = I_{SAT} \times [e^{(V_D/V_T)} - 1] \tag{3}$$

Where,

I_D = Current through the diode of PV module (A)
I_{SAT} = Diode saturation current of PV module (A)
V_D = Voltage across diode of PV module (V)
V_T = Thermal voltage (V)

Where, voltage across diode is calculated using following equation:

$$V_D = V_{PV} + I_{PV} \times R_S \tag{4}$$

Where,

V_D = Voltage across diode of PV module (V)
V_{PV} = PV module voltage (V)

I_{PV} = PV module current (A)
R_S = PV module series resistance (Ω)

And thermal voltage is calculated using following equation:

$$V_T = \frac{K \times T}{q \times N_{CELL} \times Q_D} \quad (5)$$

Where,
V_T = Thermal voltage (V)
K = Boltzmann constant = $1.3806e^{-23}$ JK^{-1}
T = Cell temperature = 298 K
q = Electron charge = $1.6022e^{-19}$ C
Q_D = Diode quality factor of PV module= 1.25
N_{CELL} = No. of series connected cells per module = 50

Current passing through the parallel resistance I_P is calculated by applying KVL in equivalent circuit of PV cell.

$$I_P = \frac{V_{PV} + I_{PV} \times R_S}{R_P} = \frac{V_D}{R_P} \quad (6)$$

Where,
I_P = Current through the parallel resistance of PV module (A)
V_{PV} = PV module voltage (V)
I_{PV} = PV module current (A)
R_S = PV module series resistance (Ω)
R_P = PV module parallel resistance (Ω)
V_D = Voltage across diode of PV module (V)

PV system is designed for 100 KW using Mitsubishi PV-UD190MF5 Module and parameters of module are listed in Table I.

TABLE I
MITSUBISHI PV-UD190MF5 MODULE PARAMETERS

No.	Parameter	Temperature (°C)			
		0°C	25°C	75°C	100°C
1	I_{PH}	8.17	8.25	8.49	8.67
2	I_{SAT}	1.08×10^{-6}	3.80×10^{-8}	1.01×10^{-5}	9.56×10^{-5}
3	V_T	1.4703	1.6049	1.8742	2.0088
4	R_S	0.22154	0.2231	0.25351	0.28829
5	R_P	760.17	1011.15	953.25	1044.70

PV array design configuration parameter is listed in Table II.

TABLE II
PV ARRAY DESIGN CONFIGURATION PARAMETERS

No.	Parameters	Values
1	P_{MPP_ARRAY}	100.5 KW
2	N_{SER}	16
3	N_{PAR}	33
4	V_{MPP_ARRAY}	395.1984 V
5	I_{MPP_ARRAY}	254.5198 A

A. *Perturb and observe algorithms for MPPT*

In this algorithm a slight perturbation is introduced in the system. The power of the module changes due to this perturbation. If the power increases due to perturbation then the perturbation is continued in that direction. When power attains its peak point, the next instant power decreases and so also the perturbation reverses. During the steady state condition the algorithm oscillates around the peak point as shown in figure 5. The perturbation size is kept very small to keep the power variation small. It is examined that there is some power loss because of this perturbation and also it fails to track the power under fast varying atmospheric conditions. But still this algorithm is very popular and simple.

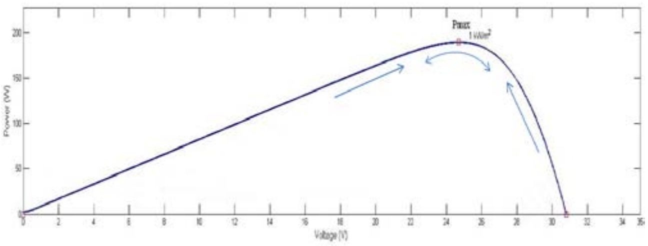

Fig. 5 Perturb and Observe (P&O) algorithm

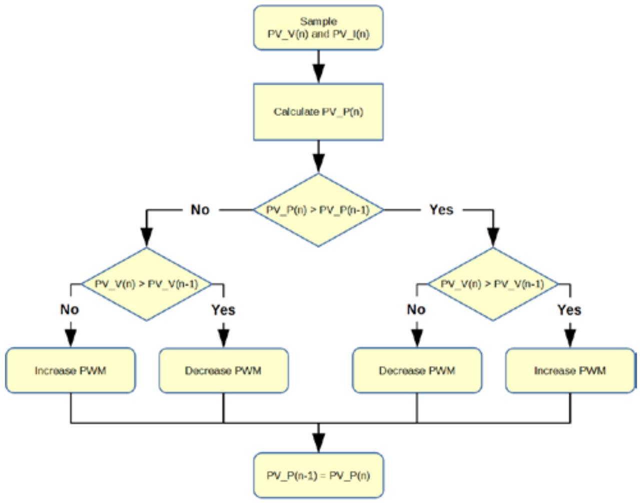

Fig. 6 Perturb and Observe (P&O) algorithm flowchart

Figure 6 represent flowchart of P&O algorithm. Here a reference duty cycle is set 0.5 corresponding to the peak power point of the module. The value of current and voltage can be obtained from the solar PV module. From the measured voltage and current power is calculated. The value of voltage and power at n instant are stored. Then values at n+1 instant are measured again and power is calculated from the measured values. The power and voltage at n+1 instant are subtracted with the values from n instant. If change in power is positive then next perturbation is positive and if change in power is negative then next perturbation is reversed. This algorithm is used for maximum power point tracking in simulation. By changing duty ratio of the boost converter system is operate at maximum power point.

III. MODELING AND SIMULATION RESULTS

A system whose parameters and design are given in section III is simulated using MATLAB/SIMULINK environment. The operation is carried out for isolated mode. Along with the DC, the performance of the photovoltaic system is also analyzed. The solar irradiation and cell temperature are also taken into consideration for PV system design. The performance analysis is done using simulated results which are found using MATLAB. PV system block consist PV Array and Boost converter.

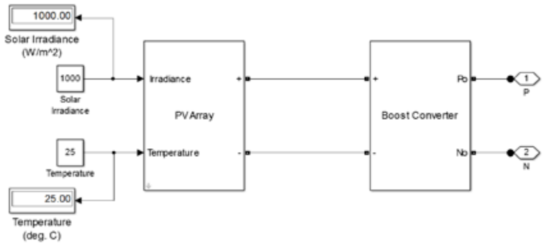

Fig. 8 PV system

PV array is designed using equivalent circuit of PV cell presented in figure 4. It includes 3 subsystems, which are presented in figure 9.

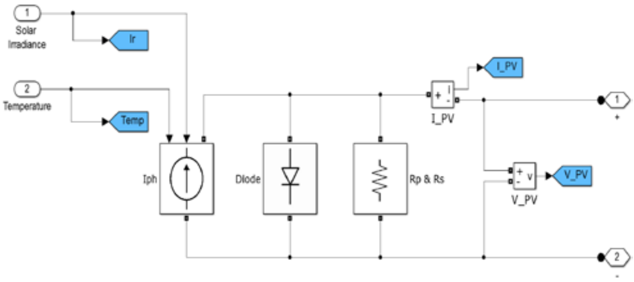

Fig. 9 PV array subsystem

I_{PH} block represents photo current produced by solar irradiation. It is modelled using equation 2.

$I_{PH\ ARRAY}$ represents lookup table and contain data of photo current calculated in Table III.

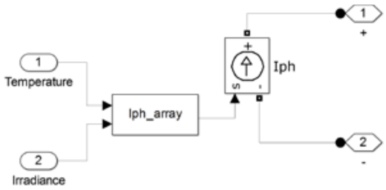

Fig. 10 I_{PH} subsystem

Diode block in figure 9 represents PV cell diode characteristic and modelled using Shockley's diode eq. 3.

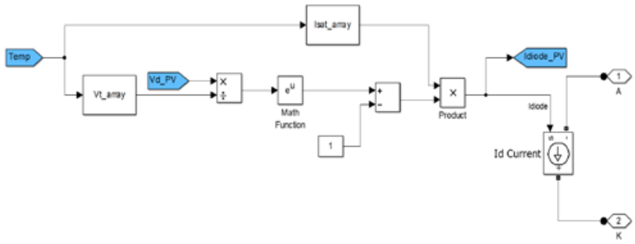

Fig. 11 Diode subsystem

In figure 11 $I_{SAT\ ARRAY}$ and $V_{T\ ARRAY}$ are saturated current and thermal voltage of PV array that contains lookup table's data calculated in Table III. From eq. 6 R_p and R_s effect is modelled and presented in figure 12.

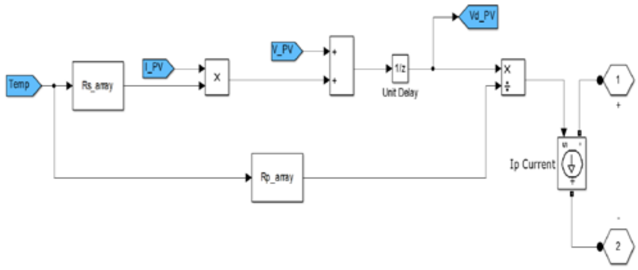

Fig. 12 R_p & R_s subsystem

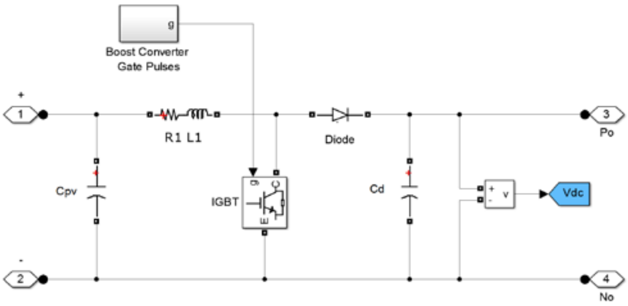

Fig. 13 PV boost converter

PV Boost converter is presented in figure 13. MPPT algorithm is implemented in MATLAB function block that allows program execution in Simulink model. By measuring V_PV and I_PV output of PV array maximum power point is obtained using P&O algorithm as presented in figure 6.

TABLE III

PV ARRAY CALCULATED PARAMETERS

No	Parameter	Calculation	Temperature (°C)				
			0°C	**25°C**	**50°C**	**75°C**	**100°C**
1	I_{PH_ARRAY}	$I_{PH\_ARRAY} = I_{PH} \times N_{PAR}$	269.80	272.53	276.02	280.38	286.12
2	I_{SAT_ARRAY}	$I_{SAT\_ARRAY} = I_{SAT} \times N_{PAR}$	3.59×10^{-8}	1.25×10^{-6}	2.54×10^{-5}	3.35×10^{-4}	3.15×10^{-3}
3	V_{T_ARRAY}	$V_{T\_ARRAY} = V_T \times N_{SER}$	23.52	25.67	27.83	29.98	32.14
4	R_{S_ARRAY}	$R_{S\_ARRAY} = R_S \times \frac{N_{SER}}{N_{PAR}}$	0.107	0.108	0.112	0.122	0.139
5	R_{P_ARRAY}	$R_{P\_ARRAY} = R_P \times \frac{N_{SER}}{N_{PAR}}$	368.56	490.25	446.14	462.18	506.52

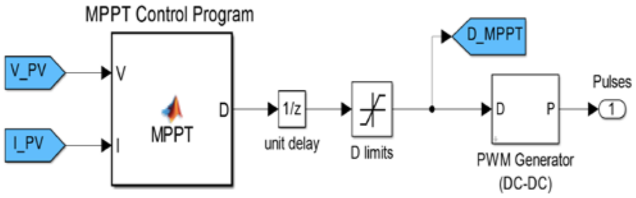

Fig. 14 MPPT based boost converter gate pulses subsystem

Figure 15 shows waveforms of change in duty ratios as per MPPT, PV system voltage and power deliver by the PV system. It is clear from the waveforms that MPPT will operate PV system at its maximum power point and delivers maximum power that is 100KW.

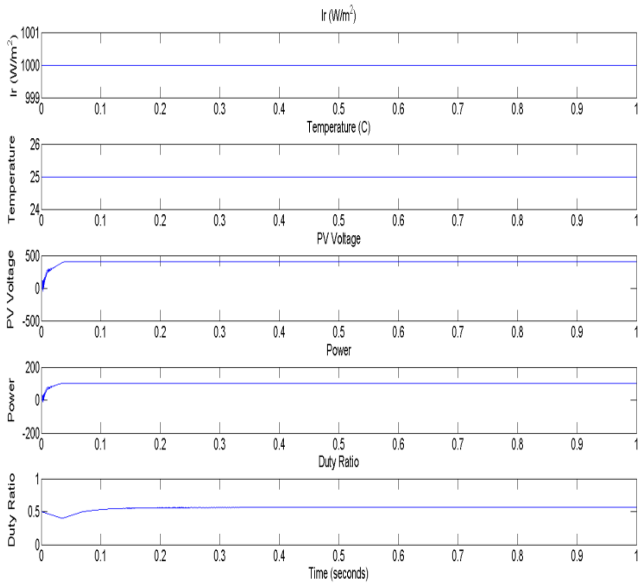

Fig. 15 Waveforms of (1) Irradiation, (2) Temperature, (3) PV voltage, (4) PV output power and (5) Duty ratio of boost converter

Figure 16 and 17 represents I-V, P-V, characteristics with variation in solar irradiation. The nonlinear nature of PV cell is noticeable as shown in the figures, i.e. the output current and power of PV cell depend on the solar irradiation. As the solar irradiation increase output current and power is increases.

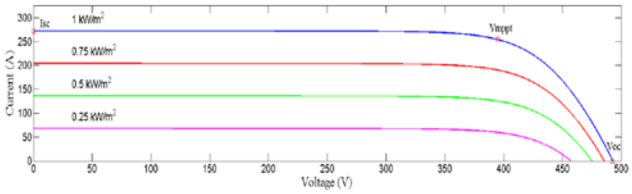

Fig. 16 I-V output characteristics of PV array for different irradiation

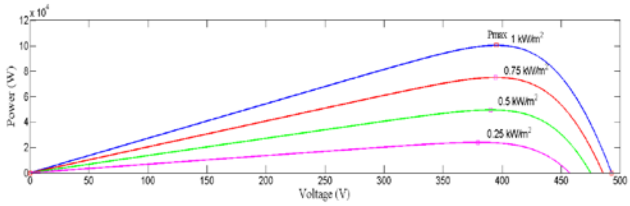

Fig. 17 P-V output characteristics of PV array for different irradiation

Figures 18 and 19 verify that with increase of cell's working temperature, the current output of PV module increases, whereas the maximum power output reduces. Since the increase in the output current is much less than the decrease in the voltage, the total power decreases at high temperatures.

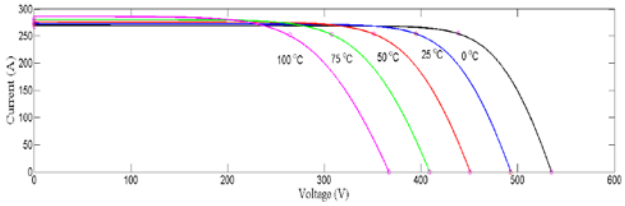

Fig. 18 I-V output characteristics of PV array for different temperatures

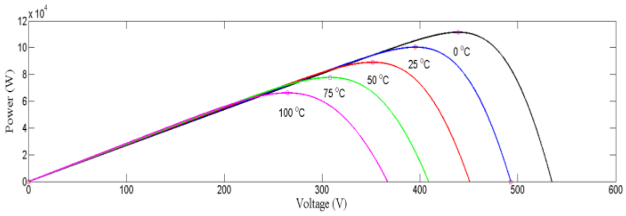

Fig. 19 P-V output characteristics of PV array for different temperatures

Battery charging configuration is presented in figure 20. The constant current and constant voltage charging strategy is used to charge battery.

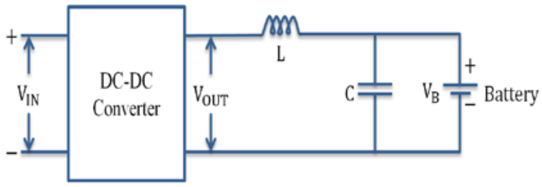

Fig. 20 Electric Vehicle Battery Charging (EVBC) configuration

Battery charging and discharging is implemented and presented in figure 21. Battery voltage is used to control charging.

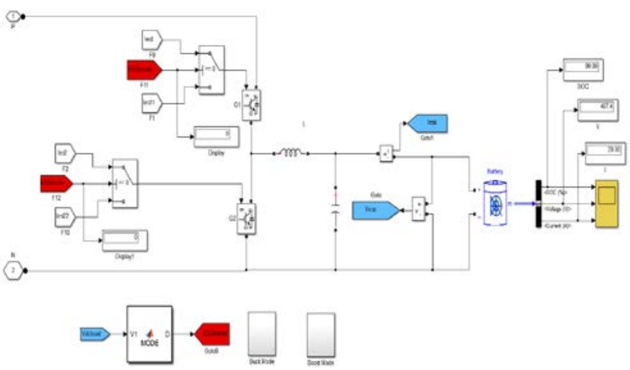

Fig. 21 Electric Vehicle Battery Charging (EVBC) Subsystem

Lithium-Ion battery of 350 V and 60 Ah of capacity is used in simulation. Initial SOC is taken as 100%. In constant current control, when battery voltage is reached to a design charging voltage, the control method changed to constant voltage control method to make the charging voltage stable, and the charging current amount of flowing current is getting decreased simultaneously .

Two control blocks are used for the control buck mode and boost mode. Buck mode will step down the voltage from 400 V DC bus voltage to battery voltage. Boost mode will step up the voltage of battery to DC bus voltage. MATLAB function consist of program that will decide the mode of operation of the charging or discharging.

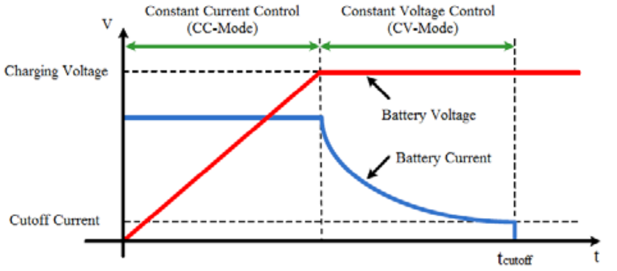

Fig. 22 Constant Current (CC) and Constant Voltage (CV) control of the battery charging

Gate pulses for buck converter are generated using PI loops. The control block diagram is presented in figure 23.

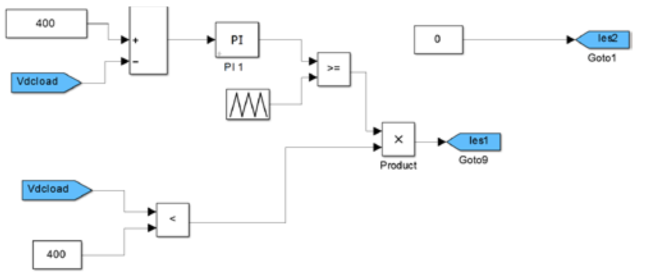

Fig. 23 Pulse generator for charging subsystem

Two PI controllers $K_p + \frac{K_i}{s}$ are used for to CC control and CV control. CV control is composed of battery voltage $V_{Charging}$, battery voltage reference V_{ref}, two PI-controller and limiter. A difference in values between battery voltage and reference voltage is passed through PI controller which generates reference I_L. State of charge is increased from its initial value 50% as shown in figure 24.

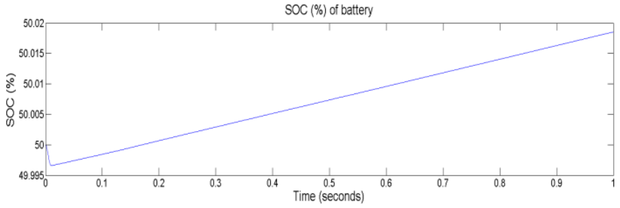

Fig. 24 Battery state of charge and Battery voltage

IV. CONCLUSIONS

The modeling of PV system with battery charging and discharging is presented MATLAB/SIMULINK environment. The models are developed for all the converters to maintain stable system operation under various source conditions. Effect of solar irradiation and temperature on PV system is used in this project. Maximum Power Point Tracking (MPPT) algorithm is used to harness maximum power from PV system. Simulation results of MPPT control verified that it is tracking maximum power point and accordingly it changes duty ratio of boost converter. The bus voltage is maintained stable at setting value. Project estimation cost is mention in below tables.

REFERENCES

[1] G. Pepermansa, J. Driesenb, D. Haeseldonckxc, R. Belmansc, W. D'haeseleer, "Distributed Generation: definition, benefits and issues", ELSEVIER Energy Policy 33, pp. 787-798, 2005.

[2] D. J. Hammerstrom, "AC Versus DC Distribution Systems Did We Get it Right?" in IEEE Power Engineering Society General Meeting, pp. 1-5, 2007.

[3] R. H. Lasseter, P. Paigi, "Microgrid: A conceptual solution," in PESC'04 Aachen, Germany, IEEE, pp. 4285-4290, 2004.

[4] Wang Panbao, Wang Wei, Xu Dianguo, Liu Guihua, Li Ming, "An Autonomous Control Scheme for DC Micro-Grid System", Industrial Electronics Society, IECON 2013 - 39th Annual Conference of the IEEE, pp. 1519 - 1523, 2013.

[5] Kumars Rouzbehi, Arash Miranian, Jose Ignacio Candela, Alvaro Luna, Pedro Rodriguez, "Intelligent Voltage Control in a DC Micro-Grid Containing PV Generation and Energy Storage", T&D Conference and Exposition IEEE PES, pp.1-5, 2014.

[6] System Advisor Model (SAM) of National Renewable Energy Laboratory (NREL) (https://sam.nrel.gov).