

DESIGN, SIMULATION AND IMPLEMENTATION OF MPPT CONTROLLED BUCK-BOOST CONVERTER EXTRACTING POWER FROM SOLAR PANEL FOR MICROGRID APPLICATIONS

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ABSTRACT

The work is dedicated to implementation of DC-DC converter for PV system in medium power Microgrid applications. Due to availability of flexible power management strategies along with effective cost, micro-grids are gaining immense popularity in present days. DC Microgrid mainly consists of PV system and battery system. Battery system plays very important role in improving dynamic response of the Microgrid. While designing power modulators for DC storage system, efficiency is a major concern. This paper proposes a method for modeling, simulation and hardware implementation of PV system and maximum power point tracking using Buck-Boost converter. Since PV cells have poor efficiency it is necessary to operate them at maximum power point using incremental conductance. The converter topology used here is Modified Buck-Boost Converter. All the simulations were carried out on MATLAB using variable parameters and the hardware results were verified on the PV arrays along with PV panel simulator.

Keywords: Buck-boost converter, Incremental conductance algorithm, Maximum power point tracking, PnO algorithm, PV system

Cite this Article: Pooja Ainapure, Pranav Kulkarni, Swapnil U. Patil and Atul Tiwari, Design, Simulation and Implementation of MPPT Controlled Buck-Boost Converter Extracting Power from Solar Panel for Microgrid Applications, *International Journal of Electrical Engineering & Technology*, 10(6), 2019, pp. 1-11.
<http://iaeme.com/Home/issue/IJEET?Volume=10&Issue=6>

1. INTRODUCTION

With the help of renewable sources like wind, solar along with the help of distributed generation system, effective power efficient and fairly reliable system can be established in the form of Microgrid. In order to satisfy the demand of DC load especially in DC Microgrid many sources are operating in parallel to supply power. Solar power plants, battery storage

systems are connected to DC bus via DC-DC converters. Solar PV is the main source of the energy in the system.[1][2] There are two main problems associated with the PV systems; one is the efficiency of conversion is very low 10%-17%. The change in the climatic conditions affects the irradiance and thus the solar power generated is also affected.

Secondly, the non-linearity of the V-I characteristics of solar panel makes the job difficult. It changes with the change in irradiance and temperature. To address this problem, On the V-I graph there is one point called maximum power point (MPP) where the power delivered is maximum. This point is tracked by search algorithms. Analysis of various algorithms is done and incremental conductance (InC) method is chosen for implementation because of the precise control under changing weather conditions and no oscillation around MPP and power loss due to oscillations at MPP is reduced [2][3]. The converter used is modified Buck-Boost converter. The factors leading to the DC-DC buck converter design are also discussed. Since most of the DC loads are operated at 48 V it is wise to use Buck mode. But in case of partial shading, voltage of PV panel may fall below certain limit so it is advisable to boost mode. It gives us the control as which mode to use depending on the weather conditions. In this work first the mathematical model of PV panel was studied and developed in the MATLAB [4]. Next the converter simulation was completed and InC algorithm was tested for buck and boost mode. The mode shifting was also verified in simulation. The simulation results were verified with the solar panel simulator of TERCAS and further the algorithm and converter were tested on actual PV panels.

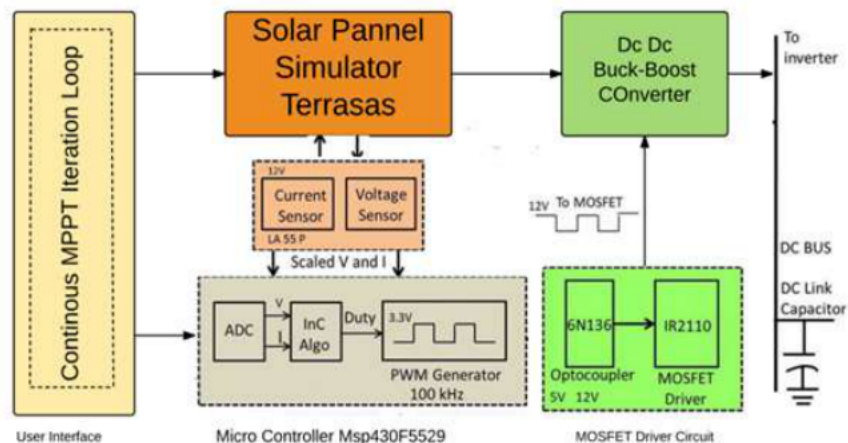


Figure 1.1 block diagram of overall system

2. MATHEMATICAL MODELLING OF PV PANEL AND SIMULATION

A solar panel is an array of solar cells arranged in series and parallel so as to obtain the desired current and voltage. The output of solar panel is nonlinear following a distinct current-voltage characteristic which varies according to the existing temperature, irradiance conditions also the load connected, the operating point varies accordingly. Modelling this device necessarily requires taking weather data (irradiance and temperature) as input variables and the output is non-linear V-I characteristics [2][5]. Any change in the input immediately changes the output, so we have to model the system correctly. A solar panel is thus simulated in MATLAB SIMULINK as in Fig(2.4). The panel is simulated with the help of the following equations [4]. Here we have considered the Single-Diode model of Photovoltaic cell as shown in Fig 2.1.

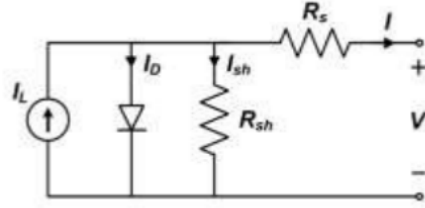


Figure 2.1 Single diode model of PV cell

R_{sh} and R_s are the shunt and series resistance and I_{sh} is Shunt current.

The panel is simulated with the help of following equations:

Thermal Voltage Equation:

$$V_T = \frac{k_B \times T_{opt}}{q}$$

Diode current equation:

$$I_D = N_p \times I_s \left[e^{\frac{(V + I R_s)}{N_s V_T}} - 1 \right]$$

Reverse current equation:

$$I_{RS} = \frac{I_{sc}}{e^{\left[\frac{q \times V_{oc}}{k_B \times T_{opt} \times C \times N} - 1 \right]}}$$

Photo current equation:

$$I_{ph} = [k_i (T_{opt} - T_{ref}) + I_{sc}] I_{RR}$$

Reverse saturation current equation:

$$I_s = I_{RS} \left[\frac{T_{opt}}{T_{ref}} \right]^3 \times q^2 \times \frac{E_g}{k_B \times N} \times e^{\left[\frac{1}{T_{opt}} - \frac{1}{T_{ref}} \right]}$$

Table 1 Constants and abbreviations used for PV panel modelling

V_T	thermal voltage(V)	I_s	Reverse saturation current of diode
k_B	Boltzmann constant(1.38×10^{-23} J/K)	I_{sc}	Short circuit current
C	cells in module	I	Cell output current
T_{ref}	reference operating temperature of cell(298K)	I_{ph}	photocurrent function of irradiance and temperature
k_i	current proportionality constant(2.2×10^{-3})	I_D	Diode Current
T_{opt}	operating temperature of cell	I_{RS}	Reverse current equation
N	ideality factor	I_{RR}	Irradiance factor
N_s	no. of cells in series	N_p	no. of cells in parallel

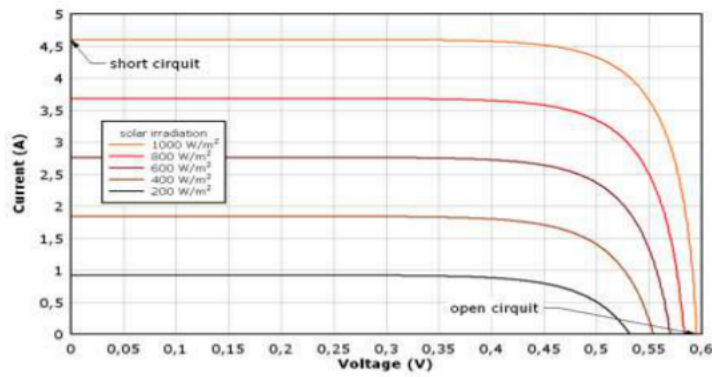


Figure. 2.2 VI characteristics of PV panel for varying Irradiance

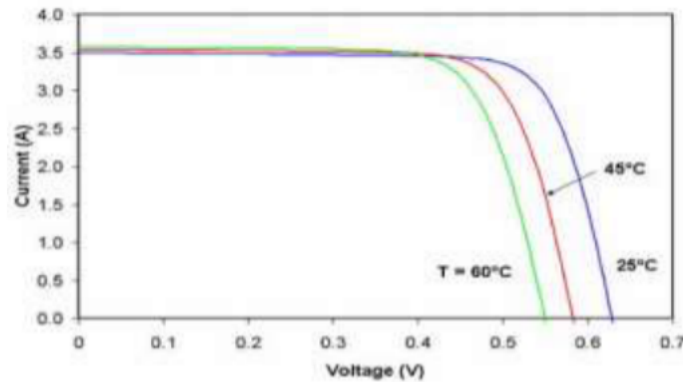


Figure 2.3 VI characteristics of PV panel for varying temperature

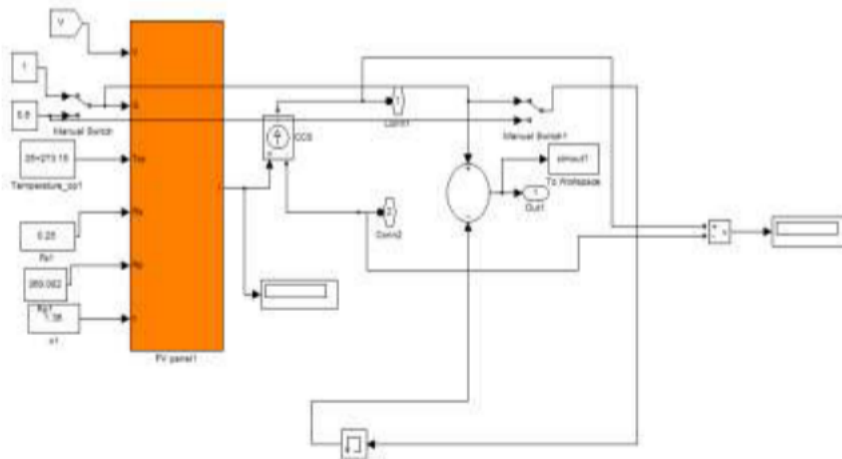
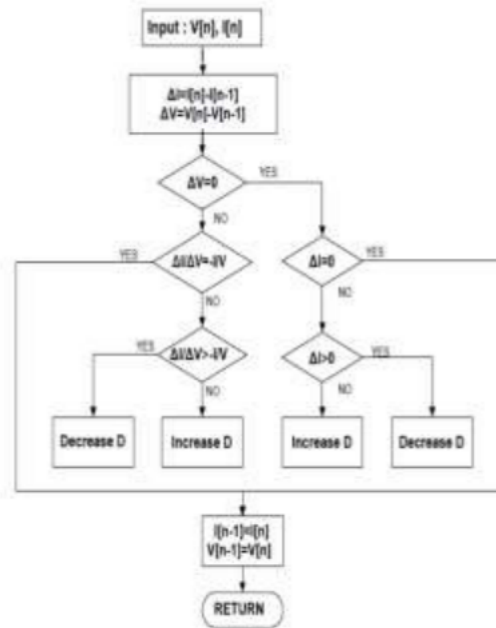


Figure 2.4 PV panel simulated in MATLAB

3. MPPT ALGORITHM

The MPPT is an electronic system that operates the PV modules in such a way that it allows the modules to produce all the power they are capable of it. It is done by various algorithms like fractional open circuit voltage or short circuit current, Perturb and Observe (PnO), Incremental Conductance (InC), Fuzzy Logic etc [2][5][6]. Here we are using InC algorithm because of its efficient work in varying weather conditions, better than PnO and less complicated than Fuzzy logic



The following equations govern the Incremental Conductance algorithm

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I + V \frac{dI}{dV} = 0 \quad \text{at MPP}$$

$$\frac{dI}{dV} = -\frac{I}{V}$$

4. SYSTEM DESIGNING AND COMPONENT SELECTION

In order to convert the power available at the panel output to suitable form DC-DC converters are required. There are various converter topologies like Buck, Buck-Boost, Cuk, Sepic converter [7]. By considering pros and cons of the every converter topology it is observed that Buck-Boost have following advantages over other topologies.

- Simple in construction
- Small values of L and C required for given operation
- Less settling time
- Output is not inverted

The converter used is a modified Buck-Boost converter so that the output voltage polarity is not reversed. It consists of two MOSFETs, two freewheeling Diodes, one inductor and two capacitors for input and output.

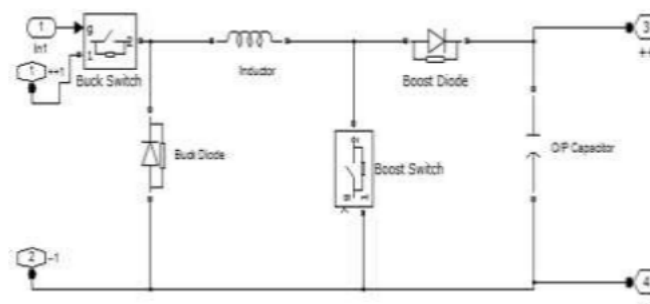


Figure 4.1: Schematic of Buck-boost converter

The switching frequency used for both MOSFETs is 100 kHz. It brings down the values of the Inductor and Capacitor, so the circuit becomes less bulky. The converter operates in one mode at a time. If it is buck then normal buck equations hold and if it is boost normal boost equation holds [8].

$$V_{out} = D * V_{in} \quad \text{.....Buck equation}$$

$$V_{out} = \frac{V_{in}}{1-D} \quad \text{.....Boost equation}$$

4.1. Design Specification

- Short circuit current of panel : 3 Ampere
- Maximum voltage at MPP : 16.25 Volt
- Open circuit voltage of panel : 19.12 Volt

Let's assume efficiency of converter is 80% hence to achieve output power of 500 Watts min, required input power will be 643 Watts. We have fixed output voltage of converter to 48 V.

$$I_{max} = \frac{514.4}{48} = 10.716 \text{ A max}$$

4.2. Sizing of Inductors and Capacitors

Inductor: $V_{in(min)} = 60 \text{ V}$ and $V_{in(max)} = 130 \text{ V}$

Assuming MOSFET voltage drop across it as 0.3 Volt

$$D_{max} = \frac{V_{out}}{V_{in(min)} - V_{mosfet}}$$

$$= \frac{48}{60 - 0.3} = 0.8$$

$$D_{min} = \frac{V_{out}}{V_{in(max)} - V_{mosfet}}$$

$$= \frac{48}{130 - 0.3} = 0.37$$

$$dI(\text{ripple current}) = 0.2 \times I_{out}$$

$$= 0.2 \times 10.716 = 2.1432 \text{ A}$$

$$dV(\text{output voltage ripple}) = 300 \text{ mV}$$

$$L(\text{inductor value}) = \frac{(V_{in(min)} - V_{out}) \times D_{max}}{dI \times f}$$

$$= \frac{(60 - 48) \times 0.8}{2.1432 \times 10^5} = 0.04479 \text{ mH}$$

The calculations of inductance and capacitance are done for the largest range so as to get largest value as possible. The switching device used is MOSFET IRFP 250N having V_{ds} of 200 V and pulsed drain current of 30 A. As the switching frequency is 100 kHz so as to minimize loss in energy storing components, but at the same time recovery period is expected to be very less and hence diode used is fast recovery diode. The fast recovery diode used is MUR3060 having peak reverse voltage rating of 1200 V and a recovery time of 85 ns.

For MPPT algorithm sensor needs to be very precise and accurate. Therefore current sensor used is ACS721 having sensitivity of 185 mV/A and current measuring range from -5 A to 5 A. The output of sensor in form of voltage is given to ADC of the microcontroller.

Similarly for voltage sensing isolated voltage signal is obtained by potential divider arrangement which applied to ISO 124U which is unity gain IC whose output is given to ADC of microcontroller.

4.3. Microcontroller and Driver for Switching Application

The driver circuit is used to drive the MOSFET switch at threshold voltage. The Buck-Boost converter have both high side and low side switches. Hence this circuit consists of an opto-coupler 6N136, driver IC IR2110. The isolation of the microcontroller from the power circuit is provided by the opto-coupler. The microcontroller used is Texas Instruments MSP 430F5529. It has a clock frequency of 25 MHz which makes PWM control more precise. It has 5 ePWM channels and 16 ADC channels. The programming is done through Code Composer Studio.

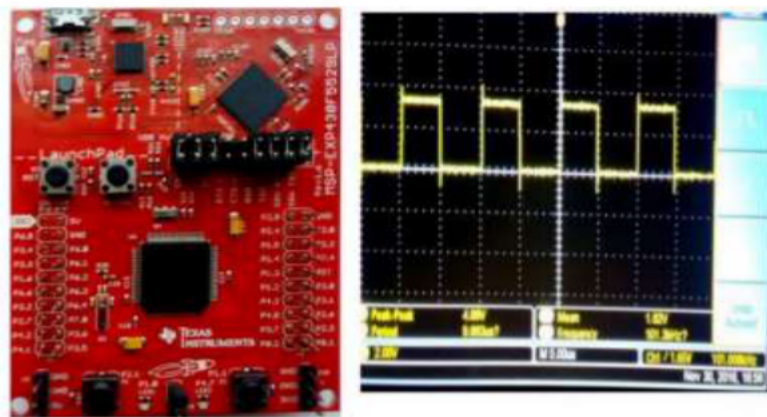


Figure 4.2 MSP 430F5529 and waveform observed on DSO

5. SIMULATION RESULTS

The first simulation was carried out with mathematical model of PV having open circuit voltage as 100 V and short circuit current as 10 A and constant irradiance of 1000 W/sq. m and constant resistive load of 2 Ohms [1][6].

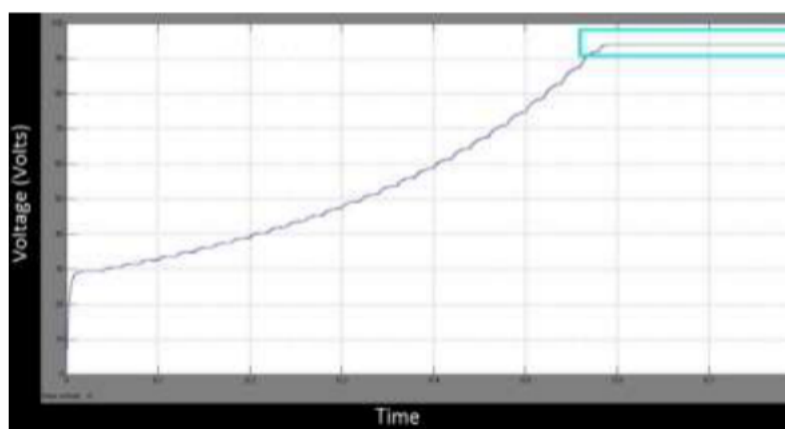


Figure 5.1 Voltage waveform for constant resistive load and constant irradiance

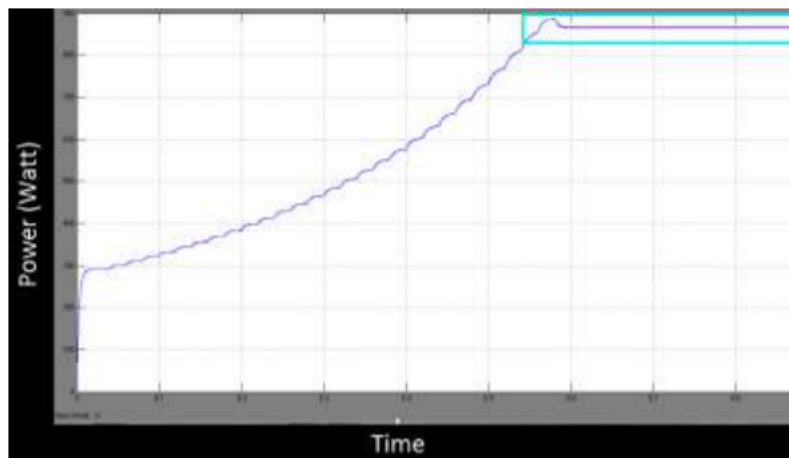


Figure 5.2 Power waveform for constant resistive load and constant irradiance

The second simulation was carried out with changing irradiance from 1000W/sq m to 600W/sq m

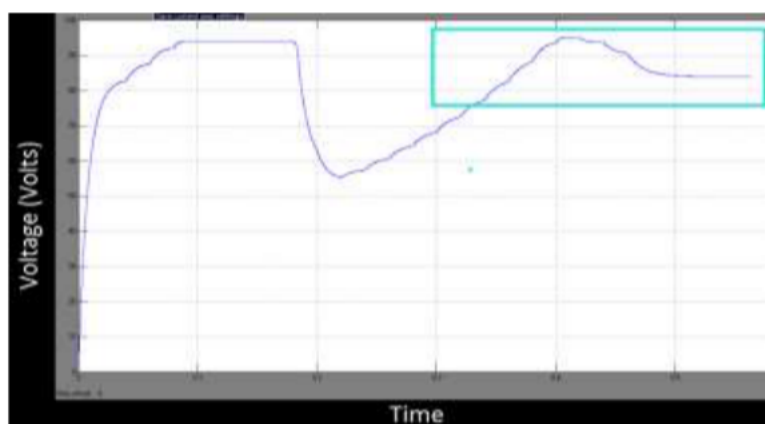


Figure 5.3: Voltage waveform for constant resistive load and changing irradiance

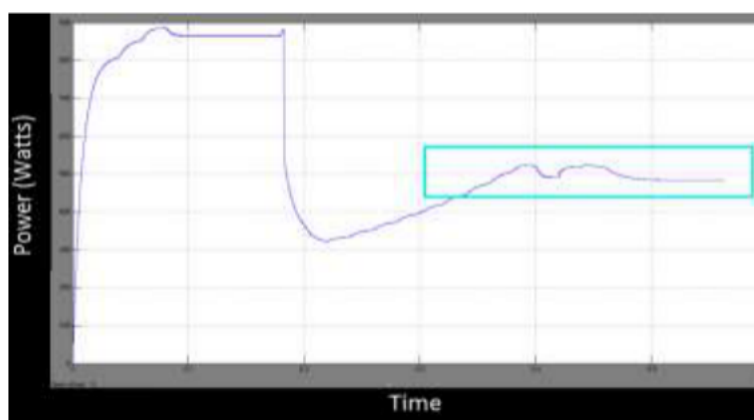


Fig 5.4: Power waveform for constant resistive load and changing irradiance

6. HARDWARE IMPLEMENTATION

Before going to the testing on actual solar panels, the MPPT algorithm was verified and hardware was tested on the solar panel simulator. The Elgar PV simulator is a programmable digital power source designed to simulate the electrical behaviour of terrestrial photovoltaic arrays [8]. The simulator provides a turnkey hardware and software solution to deliver all functionality required to test the MPPT characteristics. It is controllable through a PC. It uses

LAN as a communication protocol. All the hardware components like driver circuit, sensors, and converter are firstly designed in PCB design software and later printed on PCB. The microcontroller is initially burned with the program from Code Composer Studio. Then various VI curves loaded via visual interface to the simulator, while in runtime, the ultimate control over the entire system is governed by GUI.

The sequential flow of the MPPT system runs as shown in Fig.6.1. Initially curve of particular open circuit voltage and short-circuit current is loaded. The power supply for power circuit as well as for auxiliaries is initialized. Initially duty ratio is set to 40% and ADCs are initiated. For higher accuracy the ADCs are sampled a number of times and for stable value and higher accuracy average of samples is consider for the Incremental conductance algorithm. By following the algorithm the duty cycle is calculated and changed accordingly. For the next iteration voltage and current changed accordingly as per changed in output impedance seen by the converter and this is how cycle continues.

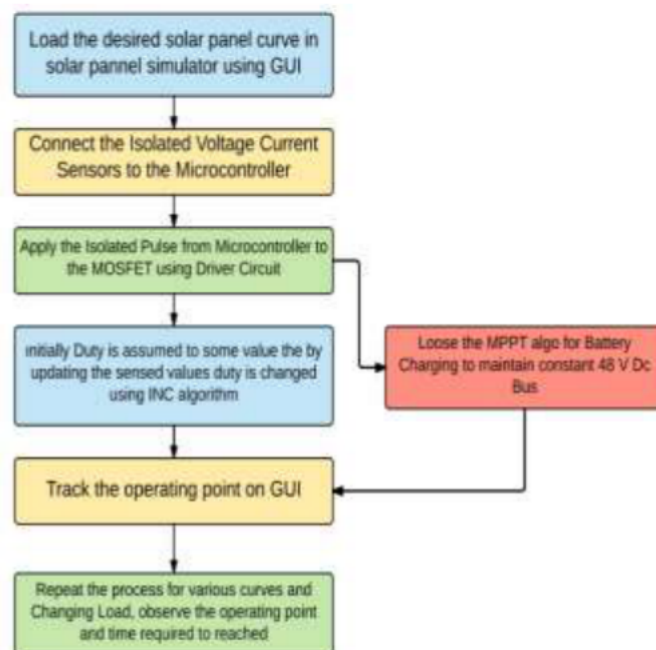


Figure 6.1 Sequential flow of MPPT system



Figure 6.2 Hardware implementation of MPPT converter

7. RESULTS

The MPPT algorithm was successfully tested and verified on the solar panel simulator with changing irradiance and variable load. The following results were obtained for fixed load and variable curve (V_{oc} and I_{sc} variable). After that the system was tested on actual solar panels. As per the availability of solar panel 5 panel were connected in series having total open circuit voltage as 92.1 V and short circuit current was 3 A. The MPPT algorithm was successfully tested with V_{mpp} as 72 V and I_{mpp} as 2.96 A. Fig 7.1 shows that for a particular open circuit voltage and short circuit current, maximum power point achieved. And by changing input we can affirmed the accuracy and proper working of converter at MPP.

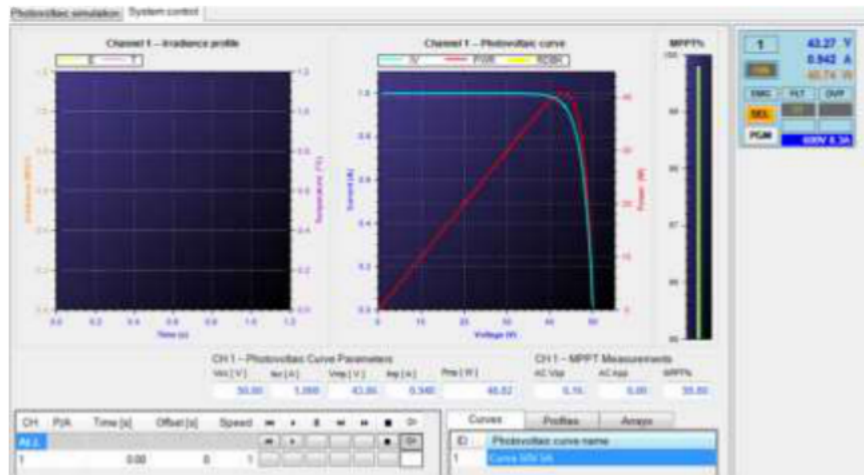


Figure 7.1 Visual interface for tracking MPP

Table 2 Output for changing curves obtained by simulator

No	Output voltage(V)	Output current(A)	Power(W)	Input voltage	Input current	Efficiency (%)
1	85.3	5.45	464.885	88.39	5.49	95.8
2	80.4	5.77	463.9	88.39	5.49	95.5
3	76.4	5.85	446.94	88.39	5.49	92.1
4	73.4	5.97	438.2	88.39	5.49	90.4
5	70.2	6.07	426.11	88.39	5.49	87.81
6	50	7.15	358.95	88.39	5.49	74.01
7	45.3	7.58	343.37	88.39	5.49	70.8

8. CONCLUSION

The approach presented in this paper is to work efficiently for simulated conditions. Intricacies of solar panel, DC-DC converters, MPPT algorithm were analysed, designed and implemented. The system was tested at steady power output of 600W using solar panel simulator and up to 300 W using solar panels working satisfactorily for changing irradiance conditions. The future scope will include to make system more robust, to provide cooling system for MOSFET and to increase the speed of operation by using high precision sensors. On a clearer and specific knowledge of working conditions, more complex algorithms of fuzzy logic based MPPT, neural networks etc. can be studied and implemented on this system.

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