Design and Implementation of Cost Effective Controller for Solar PV Application

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Abstract: Growing pollution and depleting fossil fuel reserves have encouraged exploration and exploitation of non-conventional energy sources since oil crisis faced in late 1970. Among available renewable energy sources, photovoltaic (PV) generation is supposed to play major role in future energy scenario. High installation cost and low efficiency has been major challenges for its wide spread usage. This work focuses on reducing cost of generation from PV and enhances power tracking with low cost controller design module. Maximum power point tracking (MPPT) highly depends on atmospheric conditions and exposure of PV panel surface to solar radiation. So MPPT technique should be good enough in dynamic atmospheric conditions. Different algorithms are design in which the Perturb and Observer (P & O) and Incremental conductance (INC) are widely used MPPT techniques.

Present work focus to design the cost effective PV controller module. In the PIC technology C/C^{++} Coding is used to design the algorithm but the drawback of the PIC technology is the complex coding and debugging is much more difficult. Emphasizing on DsPIC30f4011, in which automatic C/C^{++} code for the algorithm generated in the MATLAB using simulation and can easily be dumped on the respected pins and for the completion of the coding MP-Lab IDE software is used which interface between the DsPIC chip and DsPIC hardware kit. For the compilation process complier XC16 and C30 complier is used.

Efforts have been made to design the cost effective and reliable operation of PV system using IGBT based boost converter and rectifier circuit thereby ensuring the minimum switching losses, reducing size and cost of controller. The new topology is well suited for drives and renewable energy applications.

Keywords: Solar PV, MATLAB, MPLAB, DsPIC30f4011, P&O Algorithm.

Introduction

Energy plays an important role in our daily life. With rise in dependence on electrical energy, new sources of energy need tobe explored and exploited in order to meet the energy demand. Most common sources of energy currently utilized world-wide for generating electricity includes coal (39.3%), petroleum (0.7%), natural gas (27.6%), nuclear (19.5%), hydro power (6.7%), wind (4.2%) and other renewable (2.1%) covers mainly geothermal, biomass & PV energy [1]. Fossil fuel based energy sources cause emission of carbon particle and harmful gases, causing severe environmental concerns. This has encouraged power system researchers to increase dependence on renewable energy based generation. Renewable energy is promising and inexhaustible in nature. Amongst the available natural sources, wind, solar and hydro energy are omnipresent in abundance around the globe. Wind energy is intermittent in nature, involves high initial installation cost and gets affected by the geographical condition. For terrestrial applications, solar energy has gained great attraction due to easy installation, high reliability and simplicity in design.

PV cells are used to convert solar energy into electrical energy with the help of power electronics based converters. Solar panel can easily be mounted on roof of houses, multi storage buildings and complexes. Besides these advantages, the drawback is that solar energy is not available during the night hours. So, auxiliary backup unit is necessary to assure continuous supply of electrical energy. Moreover atmospheric conditions like cloud, partial shadowed zone, dust, and snow reduces the overall efficiency of the PV cells. Kumar and Palwalia [1] discussed various MPPT algorithms used to track maximum solar power like perturb & observe (P&O), hill climbing, incremental conductance (Inc), etc [1]. In this work, a new cost effective and reliable microcontroller based P&O tracking has been implemented as MPPT. A MATLAB and MP-lab software tool has been used to obtain simulation results. The obtained results have been tested on real time environment with the help of hardware assembly and software platforms in order to design low cost and user friendly system.

Aim and Objective

PV panel installation cost is quite high due to low efficiency of conversion equipment. In order to encourage its usage, cost efficient design of the system should be used. Presented the cost efficient MPPT hardware for PV module and its compatibility has been investigated on software as well as hardware platform.

The main objectives of this dissertation can be summarized as –

- Investigate working of PV module (solar cell, connections) and its application in different area by recent & relevant literature survey.
- Inspect different MPPT techniques, algorithm and converter topology depending on area of application according to their need and advancement e.g. DC- DC converter.
- Study PIC micro-controller and DsPIC, and examine pin configuration of DsPIC Kit. Mark their advantage over sensors and other methodology used for implementation.
- Analyze PV system with PIC and DsPIC Microcontroller.
- Establish software compatibility via simulation of PWM and design algorithm in MATLAB toolbox.
- Generate C language code in MATLAB and obtain hex-code with the help of MP-Lab software platform, i.e. code compilation in DsPIC.
- Incorporate obtained code in micro-controller to obtain PWM gate pulse for IGBT module connected to PV system via DsPIC kit.

Motivation

In a developing country like India, energy demand has increased exponentially in the last few decades. Majority of power is generated by conventional sources like coal and petroleum. This has increased pollution and depletion of fuel reserves. Conventional sources can deplit in short duration and takes very long time to recover. This energy generation and consumption patterns have called upon need to increase dependence on green energy sources like wind, solar, hydro, etc. High initial installation cost of renewable energy modules, energy constraints and increasing per capita energy consumption have been challenging issues for energy authorities. This need to be coped up by encouraging research programs all over the country. India has vast energy reserve in form of conventional and non-conventional sources. Energy scenario in India has been shown in table 1.

Table 1: Energy Scenarios in India

S. No	Source	% Contribution
1.	Thermal	64.75%
2.	Hydro	21.73%
3.	Nuclear	2.78%
4.	Renewable & other Sources	10.73%

Grid connected (Capacities in MW)

Table 2: Capacity of grid connected power plants

Wind Power	1234.11
Solar Power	827.22
Bio-Power	132.00
Waste to Power	12.00
Total	2311.88 MW

Off-Grid connected (Capacities in MW)

Table 3: Capacity off grid connected power plant

Waste to Energy	0.50
Biomass	10.50
Biomass Gasifiers-Rural-Industrial	0.20 8.67
Hybrid systems	0.13
SPV Systems	46.50
Total	66.50 MW

To overcome the energy crises in power sector in last few decades, planning commission of India has set a new ministry called ministry of new and renewable energy (MNRE) with a motive to encourage use of non-conventional energy sources. MNRE has taken initiatives like Jawaharlal Nehru national solar mission (JNNSM) with an aim to install 20GW of grid connected solar system and 2 GW of off grid by year 2022. MNRE, in venture with Indian government, provides subsidy on PV module installation and provides extra benefits to people using maximum power m renewable sources.

Desgin of Photovoltaic Cell

Solar energy is the form of energy which is taken by the sun in the form of solar radiation. In other words we can define photovoltaic cells are those cells which convert solar energy direct into the electricity, using semi conductor material silicon or germanium. If we describe the background the word photo voltaic it comes from the Greek word which means "light " indicate to "photo" and "voltaic" indicate to "electrical". Efficiency of the solar cell is mainly 30 - 40%. Due to the low efficiency in the PV system different techniques are used to extract maximum power from solar panel like PIC, DSP, and FPGA & DsPIC.

Single solar cell can give only about 0.5 volt, using the solar for the terrestrial application such as home lighting, water pumping etc power generated by single solar cell is not enough. To increase the rating number of cell are connected in the series or parallel which is known as PV module. For obtaining the higher power PV panel should be connected in the array. Here the PV panels are the combination of PV modules. Series connections are responsible for increasing the voltage of the array whereas the parallel connection is responsible for increasing the current in the array.

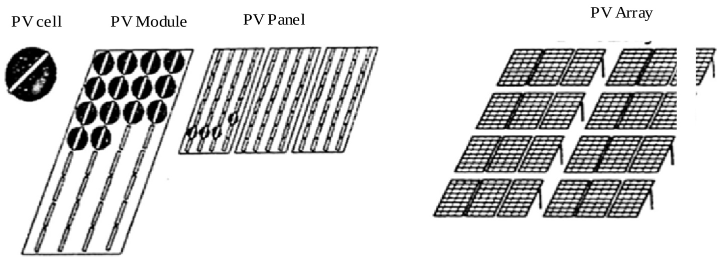

Fig 1: PV terms

The relationship between current and voltage may be determined from the diode characteristic equation that is:

$$I = I_{ph} - I_o(e^{qv/kt} - 1) \quad (3.1)$$

$$I = I_{ph} - I_d \quad (3.2)$$

Where q is the electron charge, k is Boltzmann constant, I_{ph} is the photo current, I_o is the reverse saturation current, I_d is the diode current and T is solar cell operating temperature (K).

An ideal source can be considered as a current source where the current produce by the solar cell is proportional to the solar irradiation falling on it. But the behavior of the ideal PV cell totally changes if we consider the practical circuit. Electrical

losses, optical losses are seen in the practical circuit. Modeling of the PV cell can be representation by the two type single diode model & double diode model .In the double diode model the optical losses are representation by the current sources .While the generated current I_L is directly proportional to the solar intensity. Two diode connected in the parallel representation the recombination losses. They are connected in the reverse because the recombination current flow opposite to the direction of the light generated current. Saturation current I_{S1} will flow in the diode J_{o1} due the diffusion and saturation current and Saturation current I_{S2} will flow in the diode J_{o2} due to the recombination of the space charge carrier. Electrical losses (ohmic loss) which occur due to series resistance Rs and shunt resistance R_{sh} .Series resistance offered the path to the current which is flowing in the solar cell. Shunt resistance indicate the leakage path of the current in a solar cell therefore it is represented in parallel with the current sources.
I-V equation of the solar cell is given by –

$$J = J_L - J_O(\exp\frac{qv}{KT} - 1) \qquad (3.3)$$

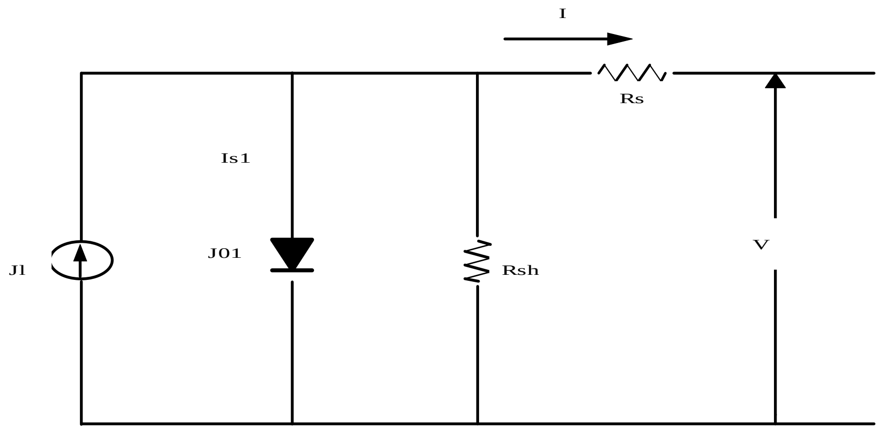

Fig 2: Single diode model

$$J = J_l - J_{O1}\exp(\frac{q(V+IR_s)}{KT}) - J_{02}\exp(\frac{q(V+IR_s)}{KT}) - \frac{V+IR_s}{R_{SH}} \qquad (3.4)$$

Equation (3.4) represented the two diode model equation. Term J_{01} represents the recombination in base and emitter region of cell &J_{02} represent the recombination of the space charge region.

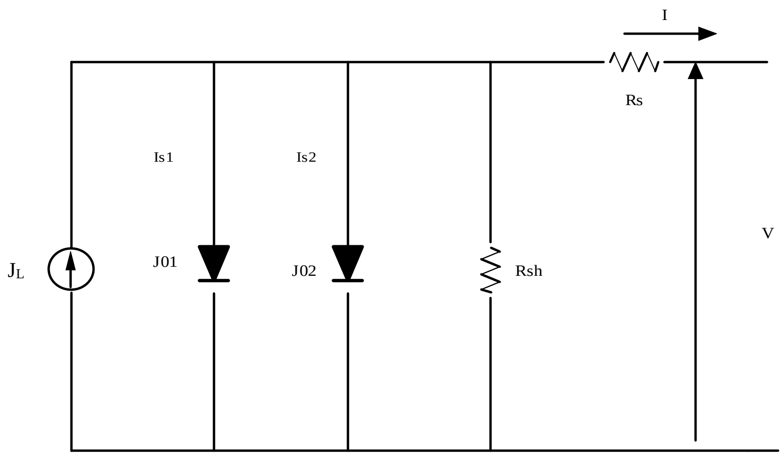

Fig 3: Double diode model

In the simple solar cell model J_{02} = 0.equation of the simple solar cell can be written as –

$$J = J_l - J_{O1}\exp(\frac{q(V+IR_s)}{KT}) - \frac{V+IR_s}{R_{SH}}$$

Here n is the diode ideality factor its value lie between 1 and 2 where 1 is for ideal diode and above equation represent the single diode model.

Ratings of 20w PV Module

The simulations are carried out using MATALB/SIMULINK package. The developed mathematical model of the PV array is used for the simulation studies. Various parameters of the PV array are determined and chosen. For the simulation work, we consider the solar panel model of rating 20 watt. Parameter ratings are taken from PV module datasheet

Table 4: Parameter of 20W Solar Module

Maximum Power	20 Watt
Open circuit voltage	1.2 V
Short circuit current	1.8 A
Ns	10
Np	2
Ideal factor	1.3
Band gap of semi conductor use in a cell	1.13 eV

Simulation results of 20W Solar PV Module

I-V curve of PV panel

I-V (Current-Voltage) curve originated from the equation (3.1) for particular value of the voltage .Current value we get and plot the curve this curve, shows what should be the current at a certain voltage. When the I_{pv}=0 we will get open circuit voltage (V_{oc}) of PV panel, when Voc=0we will get short circuit current (I_{sc}).In I-V curve represents the maximum power point corresponding voltage V_{mpp} and corresponding current I_{mpp}.

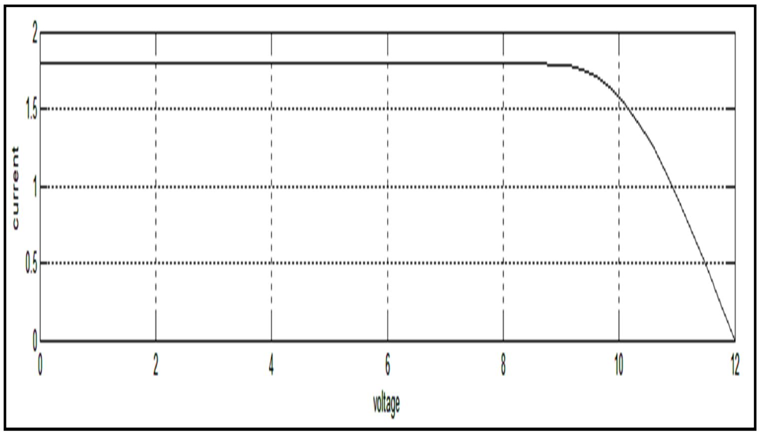

Fig 4: I-V cure at 1000W/m^2 irradiance

P-V curve of PV panel

Multiplication of output current and output voltage gives the output power, at particular value of Current (I_{mpp}) and voltage (V_{mpp}), will give maximum power P_{mpp}. Figure 5 shows P-V (Power-Voltage) curve of PV panel, point shows the maximum power point of the panel.

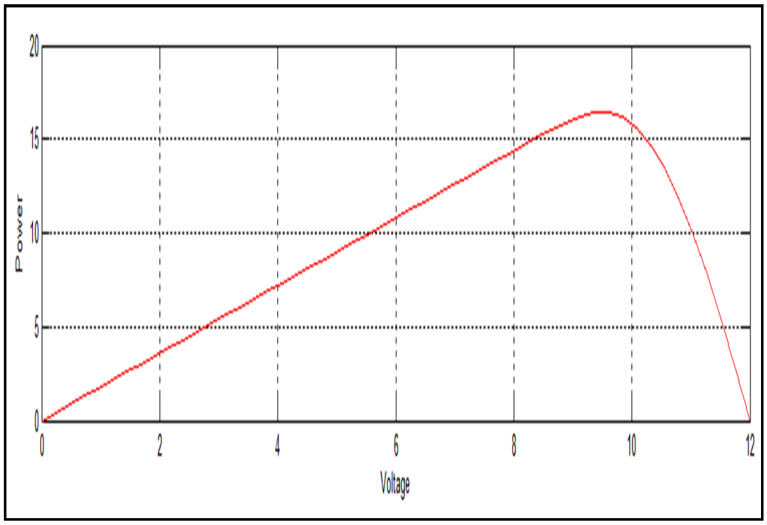

Fig 5: P-V cure at 1000W/m^2 irradiance

Varying insolation condition

Figure 6 shows the P-V curve in different insolation conditions

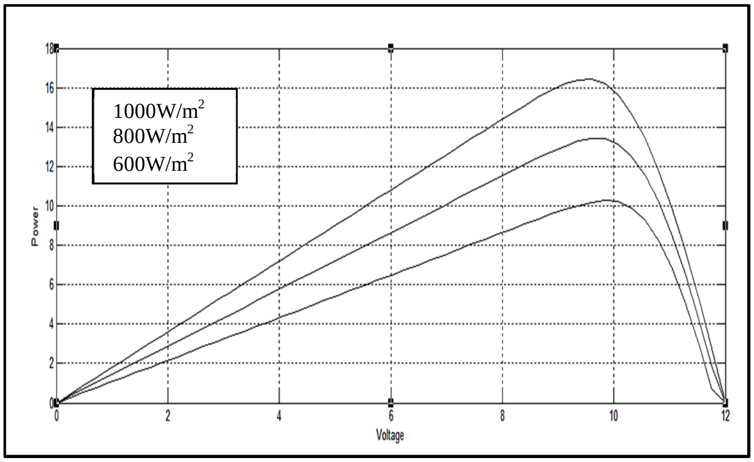

Fig 6: P-V curve at 1000W/m^2,800W/m^2,600W/m^2

Table 5: Power at different irradiance at constant temperature

Irradiance (W/m^2)	**Power (watt)**	**Temperature (^{o}C)**
1000	17.5	25
800	13	25
600	10	25

Varying temperature condition

Figure 7 & 8 shows the P-V and I-V curve in different temperature conditions, point shows peak power of each curve, as temperature increases peak power shifted downwards.

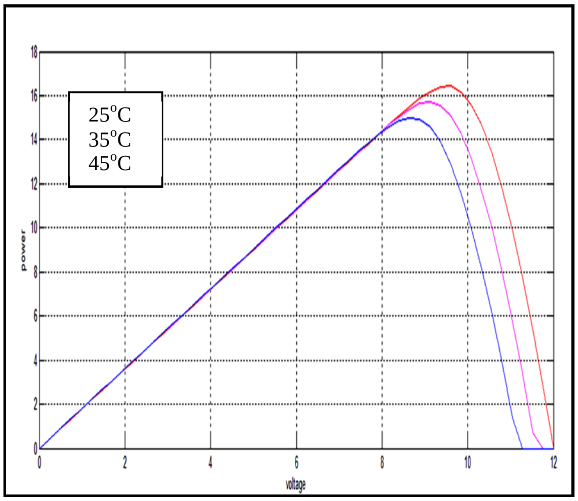

Fig 7: P-V Curve at temperature 25°C, 35°C, 45°C

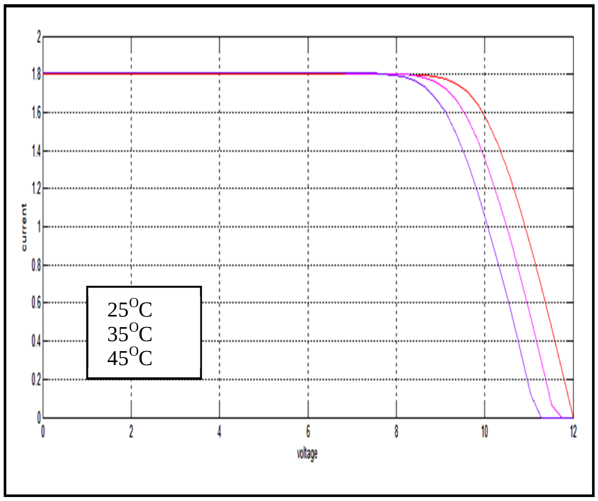

Fig 8: I-V Curve at temperature 25°C, 35°C, 45°C

Maximum Power Point Tracking

Output of the solar panel varies with respect to the sun position, temperature and insulation level. Out of these conditions there are two more conditions also which affect the output power of the PV system – cloudy day and partial shadings. As the efficiency of the PV panel is low i.e. ~ 10 – 25% and if the above condition occurs then the output power of the PV panel decreases. We cannot increase the efficiency of the PV panel but we can extract the maximum power from the panel and the point at which maximum power is extracted is known as MPPT. In other words, we can define controller which tracks the maximum power point locus of the PV array/panel & it is known as MPPT.

Methods of MPPT

Algorithms of MPPT are of various types and are implemented for obtaining the maximum power. Algorithms are used in the DsPIC to implement the maximum power tracking. Different MPPT techniques are given below –

- Hill climbing/ P & O Method
- Incremental conductance Method
- Fractional open circuit voltage/ short circuit current
- Fuzzy and neural network
- dP/dV or dP/dI feedback control

Hill climbing/ P & O Method

The P & O algorithm is widely accepted algorithm due to its simplicity and easy implementation. This algorithm is also known as Hill Climbing (HC) Algorithm. The difference between the two is that only P & O algorithm will work on the PV array voltage and PV array current & hill climbing algorithm work on the concept of Duty Ratio. Although Hill climbing and P & O method are used to obtain MPP but the concept is same. In the P&O algorithm, from the I-V characterizes and conclude that the operating on the left of MPP, when there is increase in voltage then there is increase in the power while on the right hand side if voltage decreases power also decreases. Therefore with increase in power perturbation should be same to reach the desired MPP and if the power is decreased then perturbation should be positive.

Modeling of PV Module with P & O and Boost Converter

The Simulink model of the required solar cell and boost converter system is as shown. This is for the P&O method. Here the solar cell is represented by a block named ‘Photovoltaic cell’. Boost converter, which consists of a 0.001H inductor and a 1F capacitor. This boost converter is used to step up the voltage to the required value. The gating signal to the boost converter is generated by comparing the signal generated by the MPPT algorithm to a repeating sequence operating at a high frequency. The load is a 10 ohm resistance P&O algorithm is applied to track MPP. Data sheet is taken from- Energy PV module 285PC8.

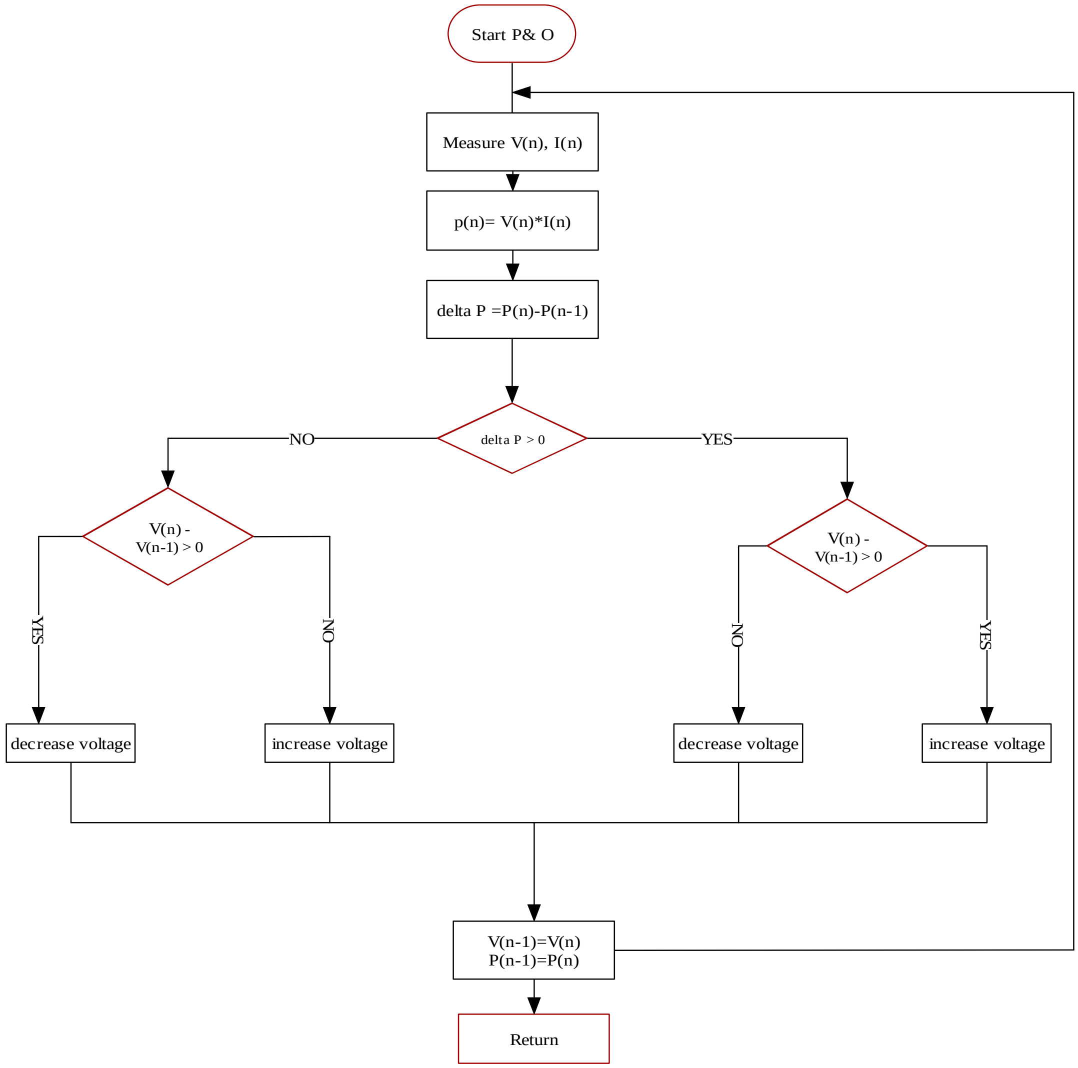

Fig 9: Flow chart of P&O Algorithm

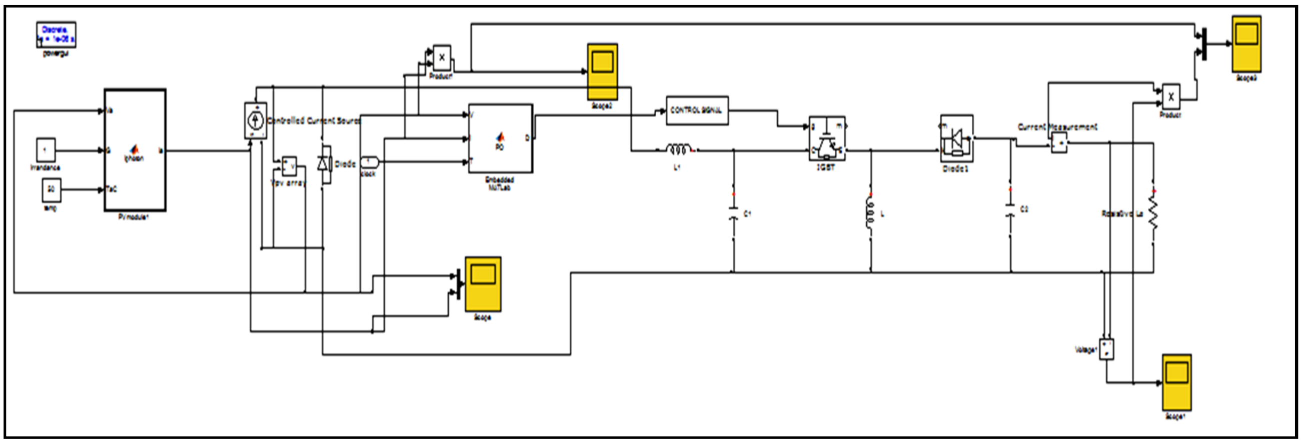

Fig 10: Simulation of PV system

Table 6: PV module 285PC8

Voltage at V_{max} (V_{mp})	35.9 V
Current at I_{max} (I_{mp})	7.95 A
Maximum Power	276 Watt
Open circuit voltage V_{oc}	44.5 V
Short circuit current I_{sc}	8.56 A
Module efficiency	14.37 %

Simulation result

PV module is simulated with MPPT with boost converter and output voltage, output power curve is plotted. Figure 11-16 shows input and output power.

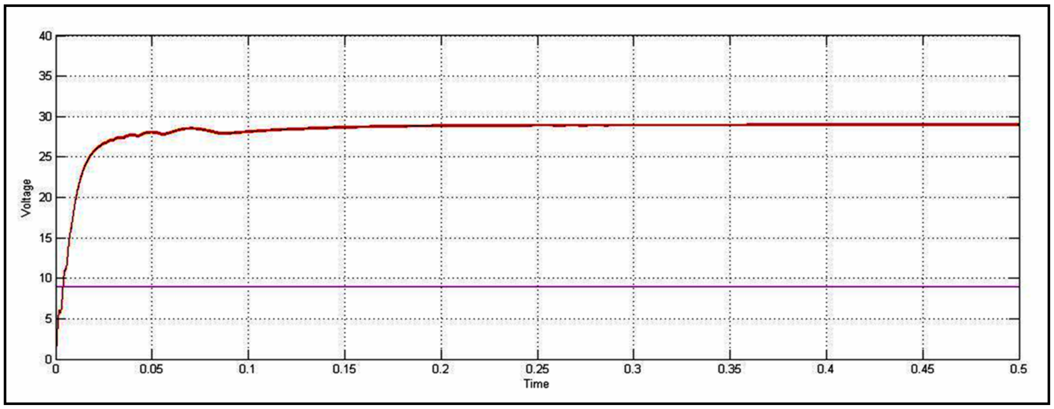

Fig 11: Input voltage 26V before boost converter

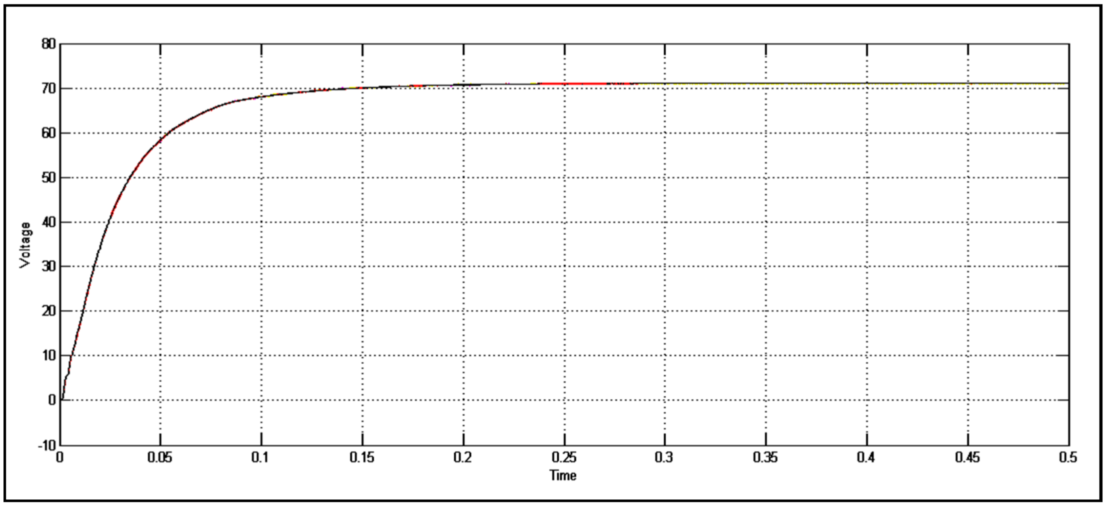

Fig 12: Output voltage 70V after boost converter

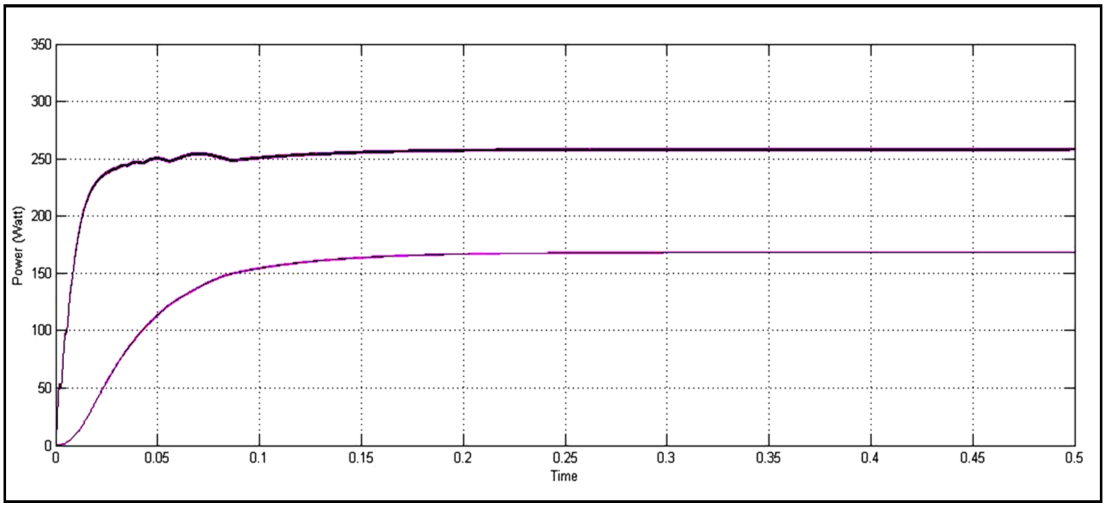

Fig 13: Output and input power at 1000W/m^2

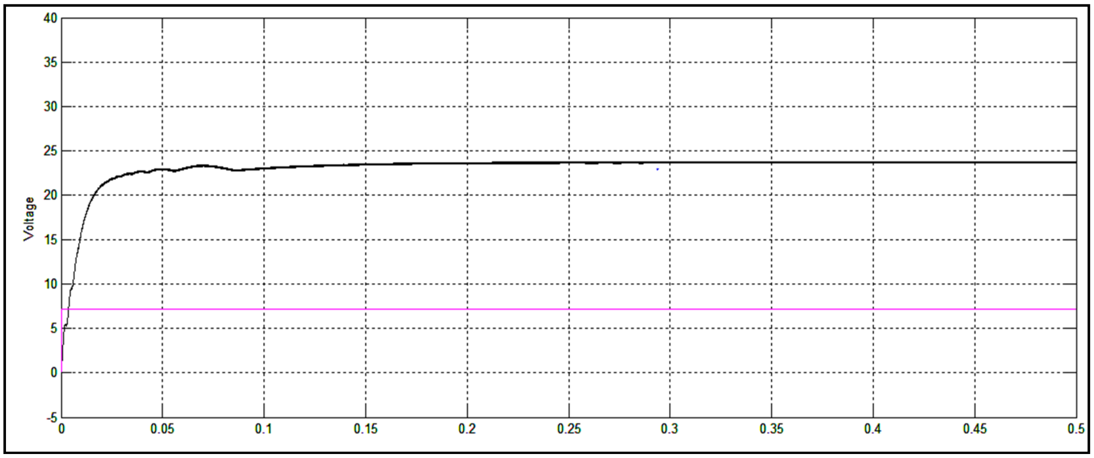

Fig 14: Input voltage 21V before boost converter

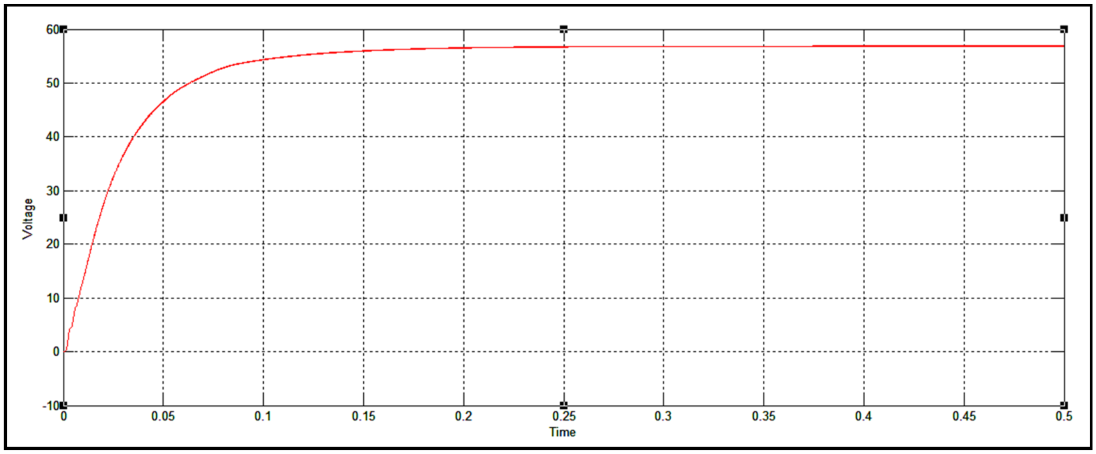

Fig 15: Output voltage 55V after boost converter

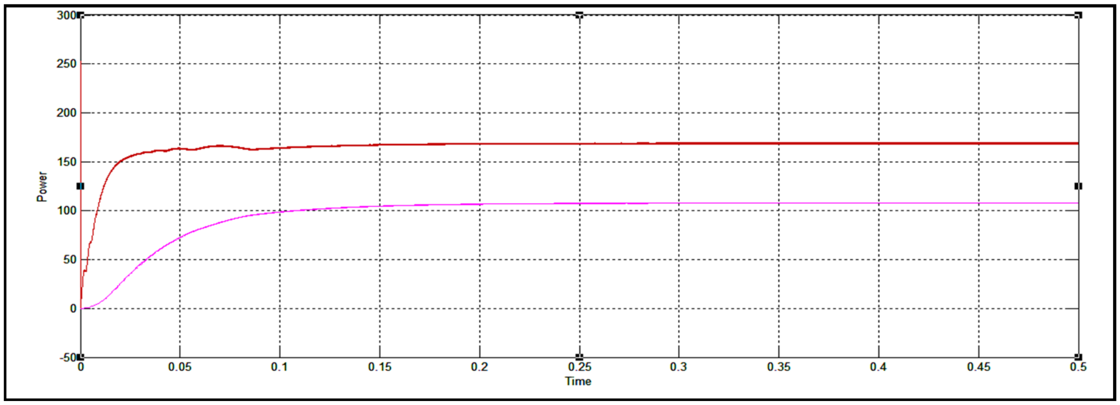

Fig 16: Input and output power at 800 W/m^2

Table 7: Simulation result

Irradiance	Input voltage	Output voltage	Input power before MPPT	Output power after MPPT
1000W/m^2	26 V	70V	150 W	250W
800W/m^2	21 V	55V	90W	150W

Harware Simultion Results

With the advantage of automatic generated code its gives another benefit of a low price which is very economical to the industry purpose. MPP is tracked using P & O Algorithm, for tracking this algorithm different medology used to track MPP and to extract the maximum power form the PV module. DsPACE, FPGA, Sensors & PIC are the different mode to track the MPP but these modules have some disadvantage which is higher cost, complex, and not user friendly system. If we consider the DsPACE and FPGA module they are they are costly and difficult to implement on the large scale. In the PIC family 18, 24 c coding is to be done in this configuration it is very difficult to find the error and error line is not shown in the system we have to find the error by checking all the line which will make very complex and lengthy. Microchip has developed a unique configuration DsPIC30F4011 which contains all the parameter to make the system low cost, easy and reliable.DsPIC30F4011 has a six PWM channel which can be utilized in the converter and automatic C/C++ code can be generated and easily dumped on the chip using MPLab. In this error finding is very simple if the simulation has some error then built will not success and error in the line can be shown in red color. This makes system easier and reliable.

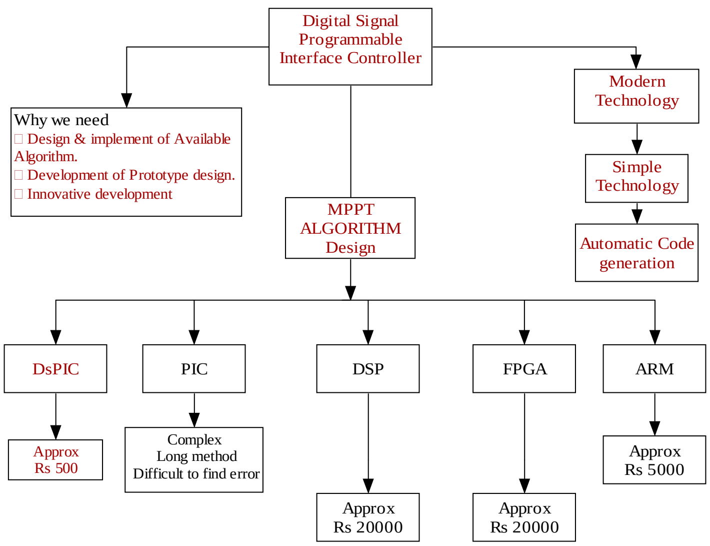

Fig 17: Flow chart showing advantage of DsPIC controller

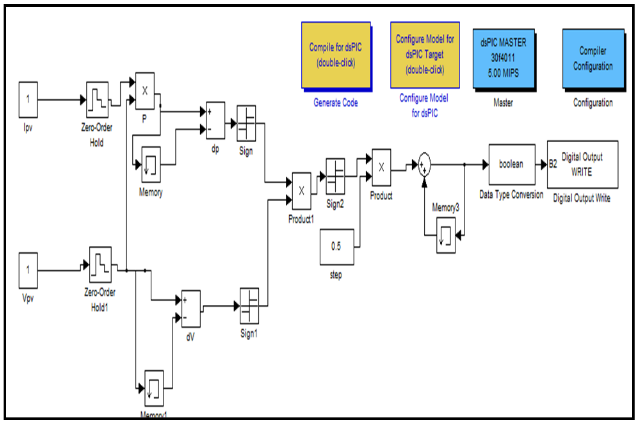

Fig 18: Simulation of P&O Algorithm using DsPIC Patch

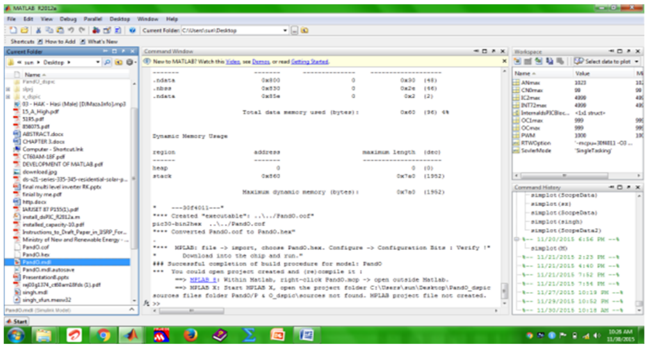

Fig 19: Successful build for P&O Algorithm

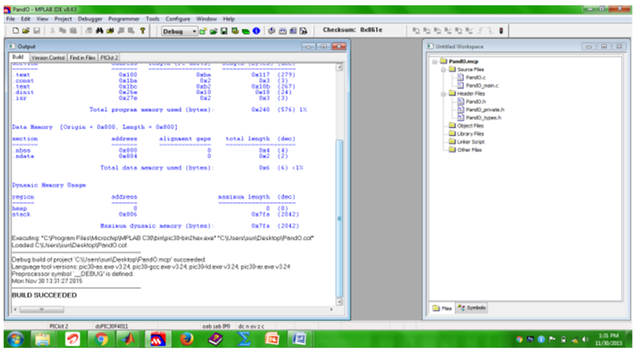

Fig 20: Successful build of code in MP Lab

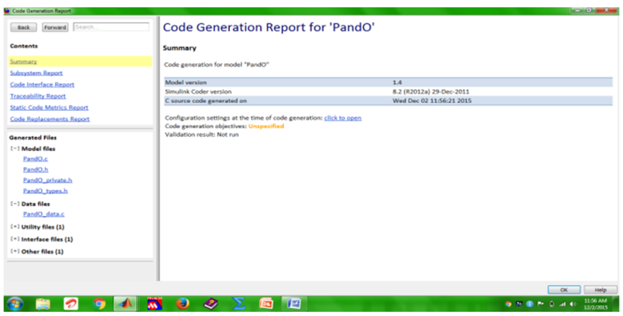

Fig 21: C Code generated report for P&O Algorithm

Hardware Implementation for Pv System

Hardware design of PV system is done using DsPIC30F4011. Flow chart describing the theme of the hardware.

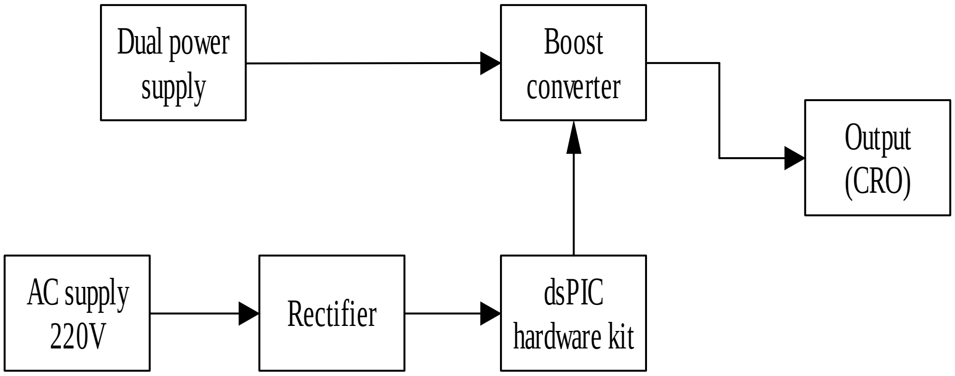

Fig 22: Block diagram showing PV system hardware

Dual power supply is used to vary the dc voltage and dual power supply act as PV module in this 9V is boost up to 24V dc using DsPIC30f4011. In the PV module as the voltage vary w.r.t to temperature and irradiances. Similarly experiment is performed by varying the voltage. Single integrated diagram is shown below-

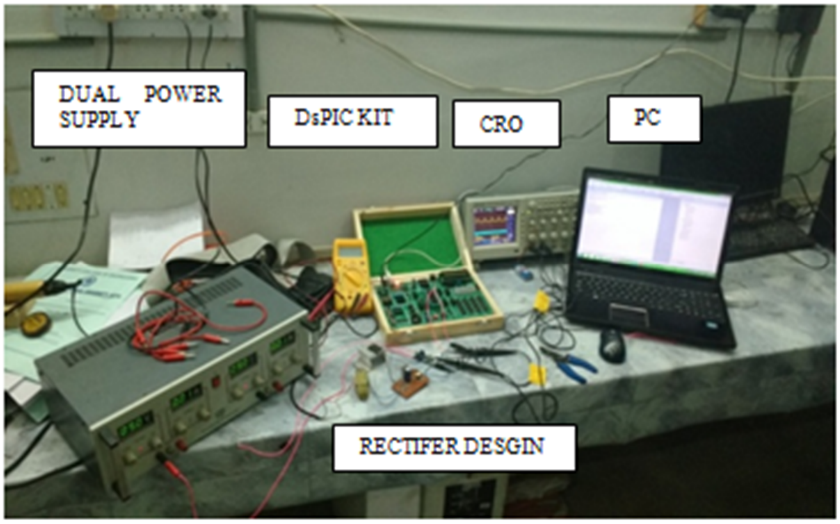

Fig 23: Hardware set up

Table 8: Components Rating

Components	Rating	Numbers
Capacitor	100uF	1
Transformer	220V-15V	1
IGBT	CT60AM-18F	1
TPL-250	3V/15V	1
IC-7825	15V	1
DsPIC30F	4011,6 Channels PWM	1
Boost converter	5V-35V	1
Resistor		2
Hardware kit		1
Diodes		4

Output waveform

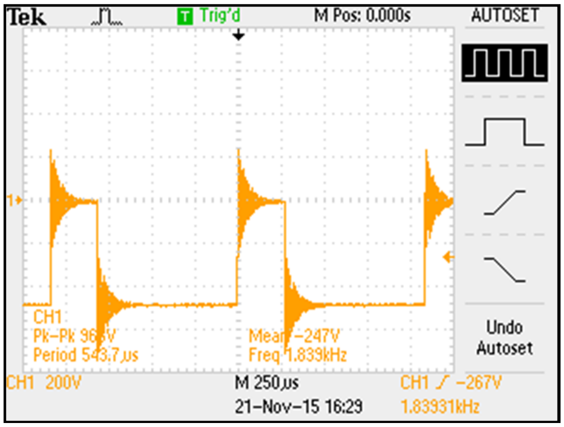

Fig 24: Boost voltage 9V to 24V using P&O Algorithm

Conclusion

Solar PV is a technology that offers a solution for a number of problems associated with fossil fuel. It is clean and continuously imports the energy from the sources. Round the globe India placed in the top which has highest solar irradiances. PV cell covert solar into electricity with a specified irradiance but due to partial shading irradiances goes lower and output power of the PV panel decreases. To get the better output Maximum Power Point (MPP) is track by designing different algorithm and we have designed controller based hardware using P&O algorithm of low cost and reduce complexity due to the automatic code generated in the MATLAB. Simulation and hardware result are successfully obtained.

Future Work

Designed low cost solar PV system can be installed in the small town, residential buildings etc.

The designed model can be used or implemented as a-

- Standalone unit.
- Design for the charge controller.
- Combination of the series and parallel connection can be explored.
- Cope up with the higher non linearity fuzzy algorithm to obtain MPP.
- For the larger PV system they can be implemented with the multi level inverter.
- Design of buck/boost algorithm can also be done to make the system reliable

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Code Generated For P&O Algorithm

```
 * PandO.c
 *
 * Code generation for model "PandO".
 *
 * Model version              : 1.4
 * Simulink Coder version: 8.2 (R2012a) 29-Dec-2011
 * C source code generated on: Mon Nov 30 13:30:34 2015
 *
  * Target selection: dspic.tlc
  * embedded hardware selection: 16-bit Generic
  * Code generation objectives: Unspecified
  * Validation result: Not run
  */
#include "PandO.h"
#include "PandO_private.h"

/* Real-time model */
RT_MODEL_PandO PandO_M_;
RT_MODEL_PandO *const PandO_M = &PandO_M_;
static void rate_monotonic_scheduler(void);

/*
 * Set which subrates need to run this base step (base rate always runs).
 * this function must be called prior to calling the model step function
 * in order to "remember" which rates need to run this base step.  The
 * buffering of events allows for overlapping preemption.
 */
void PandO_SetEventsForThisBaseStep (boolean_T *eventFlags)
{
  /* Task runs when its counter is zero, computed via rtmStepTask macro */
  eventFlags[1] = ((boolean_T)rtmStepTask(PandO_M, 1));
}

/* rate_monotonic_scheduler */
static void rate_monotonic_scheduler (void)
{
  /* Compute which subrates run during the next base time step.  Subrates
   * are an integer multiple of the base rate counter.  Therefore, the subtask
   * counter is reset when it reaches its limit (zero means run).
   */
  (PandO_M->Timing.TaskCounters.TID [1]) ++;
  if ((PandO_M->Timing.TaskCounters.TID [1]) > 1) {/* Sample time: [0.002s, 0.0s] */
    PandO_M->Timing.TaskCounters.TID [1] = 0;
  }
}

/* Model output function for TID0 */
void PandO_output0(void)              /* Sample time: [0.001s, 0.0s] */
{
  {                            /* Sample time: [0.001s, 0.0s] */
    rate_monotonic_scheduler();
  }
}

/* Model update function for TID0 */
void PandO_update0(void)              /* Sample time: [0.001s, 0.0s] */
{
  /* (no update code required) */
}

/* Model output function for TID1 */
void PandO_output1(void)              /* Sample time: [0.002s, 0.0s] */
{
  /* (no output code required) */
}

/* Model update function for TID1 */
 void PandO_update1 (void)                   /* Sample time: [0.002s, 0.0s] */
{
  /* (no update code required) */
}

void Pando output (int_T tid)
{
  switch (tid) {
   case 0:
    PandO_output0 ();
    break;

   case 1:
    PandO_output1();
    break;

   default:
    break;
  }
}

void Pando update (int_T tid)
{
  switch (tid) {
   case 0:
    PandO_update0();
    break;

   case 1 :
    PandO_update1();
    break;

    default:
     break;
   }
 }

 /* Model initialize function */
voids Pando initialize (void)
 {
   /* Registration code */

   /* initialize real-time model */
   (void) memset((void *)PandO_M, 0,
```

```
        sizeof(RT_MODEL_PandO));

/* S-Function "dsPIC_MASTER" initialization Block: <S1>/Master */
/* Solver mode : Multitasking */
/* CONFIG TIMER 1 for scheduling steps          */
ConfigIntTimer1 (T1_INT_PRIOR_1 & T1_INT_ON);
T1CON = 0x8000;                /* T1_PS_1_1      */
PR1 = 4999;

/* Configuration TRIS */
/* Configuration ADCHS */
ADPCFG = 0U;
}
```