Analysis, Simulation and Experimental Implementation of Perturb and Observe Algorithm for PV Systems using Boost Converter

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Abstract: ***Energy and resources are limited whereas human wants are unlimited. Hence the need arises for the usage of renewable energy. Reliable electricity in recent days around the world is provided by renewable energy. The consequence of it is the evolution from dirty, coal-burning power generating plants that harm public health, causing imbalance in our ecosystem. We heed towards cleaner, more sustainable sources of electricity by utilizing the renewable energy. The world can pursue this clean energy transformation by the recent, modern technologies, while maintaining a dependable and inexpensive electricity system. The dispersion of PV systems as distributed generators in low-voltage grid has drawn enough attention. In addition, the need for overall grid efficiency and reliability has boosted the interest in the micro grid concept. High-efficiency PV-based microgrids require maximum power point tracking (MPPT) controllers to maximize the harvested energy due to the nonlinearity in PV module characteristics. Modified P and O MPPT technique helps in achieving adaptive tracking. There are no steady-state oscillations around the MPP and hence there is no need for predefined system-dependent constants. Resultant of it provides a generic design in providing a generic core design.***

Keywords: MPPT, Perturb & Observe method, microgrids, photo voltaics

1. Introduction

The increase of modern technologies has brought about in man a great change. Man is not satisfied with what he has. Electricity, which is the prime source of energy, has become his foremost want. The way to generate electricity is in turn depleting all our natural resources like coal, diesel and natural gas. In order to preserve fuels, prevent burnouts, disability of electronic communication, we have started using solar energy to meet the increasing demand of electricity. This decreases the expense of producing electricity and is a boon to mankind as it succeeds in saving our conventional source of energy from being depleted.

In order to generate electricity PV effect is used. Yet, the amount of solar energy that can be utilized will be very effective. Conversion of electrical energy from PV energy is therefore less too. Many ways have been used to increase the efficiency of conversion. The movement of sun has been tracked. The axis of the PV panel is rotated which gives better result than physical tracking. Software algorithms have been used to deliver the extreme power to the load from PV panel. These are none other than the MPPT algorithms. Here in this project perturb and observe MPPT algorithm with adaptive method has been applied to track MPP. Microcontroller has been used in the hardware.

2. Motivation

As power generation has become indispensible in our lives, we tend to use the conventional resources for its generation. The consequence of it is proving dangerous to our future generation as they are inevitable to get depleted in the coming days. To avoid such an outcome, a modern emerging power technology called Micro grid is expected to be a solution in the upcoming power system. Its innumerable advantages are truly commendable. To add to it the PV energy sector is also developing fast. In order to utilize the available energy in its best possible way it is needed to operate the system at it MPP.

3. Different methods of MPPT

The efficiency of a PV plant is affected by the following factors: the efficiency of the PV panel is found to be 8-15%, the efficiency of the inverter is found to be 95-98% and the efficiency of the maximum power point tracking (MPPT) algorithm is found to be 98%. The few MPP control algorithms are as follows:

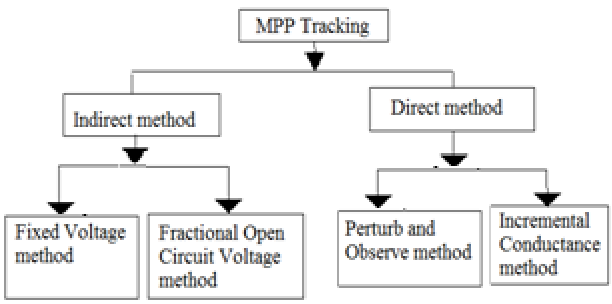

Figure 1: Different methods of MPPT

Fixed Voltage method

This technique is based on adjusting the operating voltage of the solar module only on a seasonable basis. This method is not so accurate. To increase the accuracy, this method is implemented in a place where minimal irradiance fluctuations are present on a particular day. Further this method can be clearly understood by the flow chart.

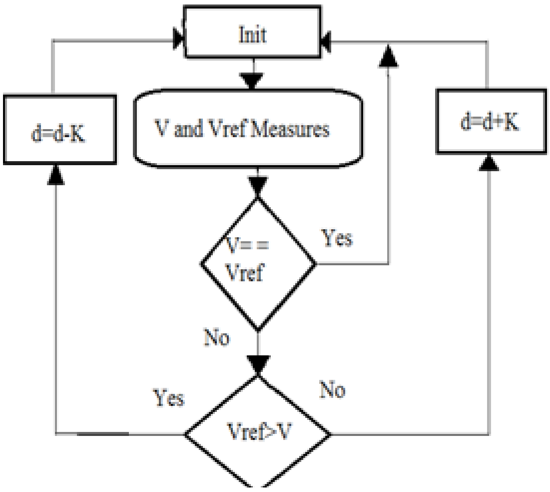

Figure 2: Flow chart of the Fixed Voltage Method

Fractional open circuit voltage method

The most common MPPT technique in direct method is the fractional open circuit voltage method. This method exploits the fact that the good approximation of Vmpp is given by the constant 'K' multiplied by the open circuit voltage i.e.

Vmpp=K*Voc, where, K=0.7 to 0.8 in practice.

In general K is based on the PV technology and the kind of solar cell used. This method is easy to implement. As the value of K is just an approximation, this technique does not hold for MPP. Here the temperature and irradiance impacts are neglected; hence it is not very effective.

Perturb and observe method

In this type of technique direct measurements of voltage, current and power is possible. It is more accurate and has faster response. This method is also classified as hill climbing method. In this technique, perturbation is provided to the PV module for array voltage. This would translate to increase or decrease in power. Increase in voltage leads to an increase in power, this means that the operating point is situated to the left of the MPP and hence voltage perturbation is required towards the right to reach the MPP. Conversely if the increase in voltage leads to decrease in power, this means that the current operating point is to the right of the MPP and hence voltage perturbation is required towards the left to reach the MPP. In this way the algorithm converges to several perturbations. This technique is more understood with the following flow chart.

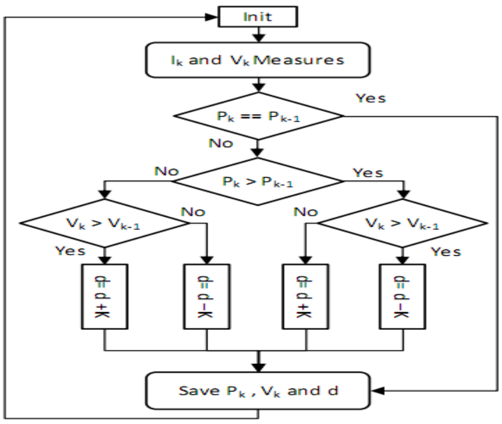

Figure 3 : Flow chart of P and O method

Incremental Conductance Method

To understand the Incremental Conductance method, it is important to know the meaning of conductance and incremental conductance. Conductance is the ability for electricity to flow a certain path whereas incremental conductance of the PV helps to determine an optimum operating current for the maximum output power. This method offers good performance under rapid change of atmospheric conditions.

Conductance, G = $\frac{I}{V}$

Power, P = V * I

On differentiating power with respect to voltage V, we get

$$\frac{dP}{dV} = \frac{d(I*V)}{dV}$$

$$\frac{dP}{dV} = \text{I} + \frac{V*dI}{dV}$$

$\frac{\Delta I}{\Delta V} = -\frac{I}{V}$. This refers that the point is at MPP.

$\frac{\Delta I}{\Delta V} > -\frac{I}{V}$. This refers that the point is of to the left of MPP and then the Vref has to be increased

$\frac{\Delta I}{\Delta V} < -\frac{I}{V}$. This refers that the point is of to the right of MPP and then the Vref has to be decreased.

It is the latest approximation technique in different MPPT techniques. This method is very efficient. It is more complex when it comes to hardware implementation. The operation of this technique can be better understood by the following flow chart.

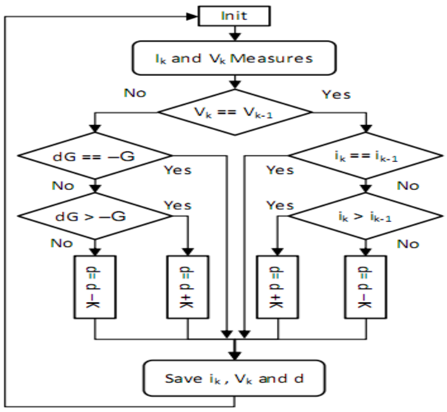

Figure 4: Flow chart of Incremental Conductance method

4. Fundamentals of PV panel

Photovoltaic system:

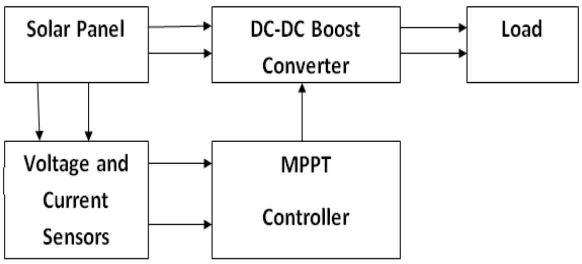

Figure 5: Block diagram of photovoltaic system

The block diagram of PV system consists of the solar panel, DC-DC Boost converter, load, voltage and current sensors and the MPPT controller. The voltage and the current output of the solar panel are fed to the DC-DC Boost converter through which the power is supplied to the load. The voltage and current from the panel is also given to the MPPT controller as input through the sensors. Then the MPPT algorithm processes these inputs. The MPPT controller is a microcontroller or any other embedded system on which a tracking algorithm is implemented.

The current or voltage is sensed based on the type of algorithm implemented. In perturb and observe algorithm both current as well as voltage is sensed. The DC-DC Boost converter will act as the variable impedance between the solar panel and the load. Here, the current and the voltage of the solar panel changes when the duty cycle of the converter changes. The duty cycle of the converter is changed as per the implemented MPPT algorithm to technique achieve the MPP of solar panel. Hence the MPPT along with photovoltaic system is a feedback control system where the duty cycle of the DC-DC converter is changed to track MPP based on the climatic conditions.

5. Modelling of solar panel

A solar cell or a photovoltaic cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. The operation of solar cell requires the following basic attributes: **a)** the absorption of light, generating either electron-hole pairs commonly called as excitons**. b)** The separation of change carriers of opposite types. **c)** The separate extraction of those carriers to an external circuit.

The solar cell can be modelled by using various methods either in a MATLAB/Simulink or using any programming languages. It is modelled either of the single diode model, single diode with series and shunt resistance, double diode model with series and shunt resistance model. If we see the power voltage (PV) and current voltage (IV) characteristics of a solar cell it is noticed that the characteristics is nonlinear.

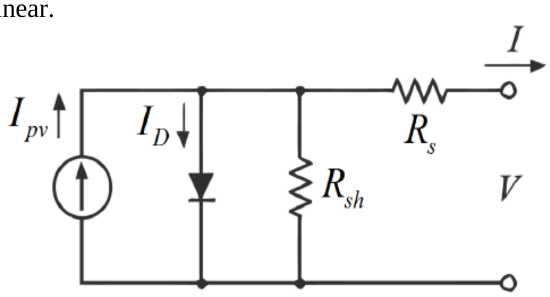

Figure 6 : Equivalent circuit of a solar cell

$\boldsymbol{I} = I_{pv} - I_D - I_{sh}$

$$I_D = I_S \left[e^{q\left(\frac{V}{N_S}+\frac{IR_S}{N_p}\right)} - 1 \right]$$

$$I_{pv} = [I_{sc} + K_i(T - T_r)] * \frac{\lambda}{1000}$$

$$I_s = I_{rs} \left(\frac{I}{T_r}\right)^3 e^{\frac{qE_g}{AK}\left(\frac{1}{T_r}-\frac{1}{T}\right)}$$

$$I_{rs} = \frac{I_{sc}}{e^{N_S AKT} - 1}$$

Where, *I*=output current of PV model
Ipv = light generated current of the PV model
ID = PV model saturation current
Ish = current through the shunt resistance
Is = current through the series resistance
q = electron charge i.e. $1.6*10^{-19}$C
V = output voltage of the PV panel
Ns = number of cells connected in series
Np = number of cells connected in parallel
Isc = PV model short circuit current
Ki = short circuit temperature co-efficient at Iscr=0.0013 A/o_C
T = module operating temperature in Kelvin
Tr = 25 + 273=298
Eg = band gap of Si =1.12eV
A = ideality factor=1.3
K = Boltzmann constant=1.3805 $*10^{23}\,{}^{J}/_{K}$

The two important points of current and voltage characteristics of solar panels are firstly the open circuit voltage and the short circuit current. One important thing of these characteristics is that at both the points the power generated is zero. The maximum power generated is where the product of voltage and current is maximum.

6. PV module efficiency

The PV module efficiency can be calculated by taking an example of crystalline silicon solar PV module of a HHV SOLAR COMPANY of 300-310 WATT.

Assuming the ideal conditions, consider the irradiance as 1000 ${}^{W}/_{m^2}$

The dimension of the panel is 1968 mm * 987 mm (from data sheet).

Expected output = length * breadth of the panel
= 1.9m * 0.987m
= 1875.3W
Panel actual rating (from data sheet) = 300 W
Therefore PV module efficiency = $\frac{Actual\ output}{Expected\ output} * 100$
= $\frac{300}{1875.3} * 100$
= 15.9% ~ 16%
In the data sheet it is mentioned as 15.44- 15.69%.

7. PV characteristics of a solar panel

The PV characteristics of a solar panel are simulated at 1000 ${}^{W}/_{m^2}$ with 10^0 C,25^0 C and 40^0C. If the temperature increases then the power supplied is less.

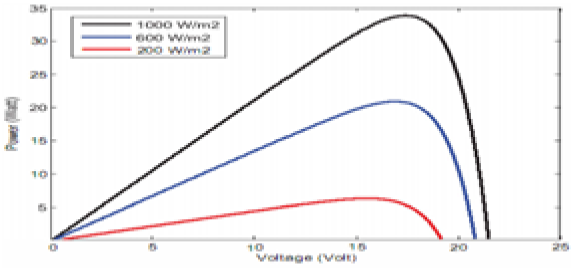

Figure 7: PV characteristics at different radiations

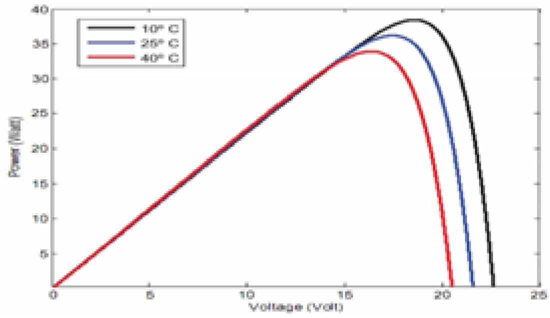

Figure 8: PV characteristics at different temperatures

8. DC-DC boost converter

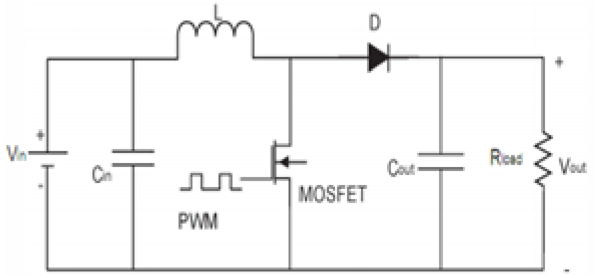

Figure 9: Electrical circuit of the DC-DC boost converter

The DC-DC Converter used in this project is Boost Converter. The main purpose of using boost converter for MPPT is because in grid tie inverters first stage is boost which gives the bus voltage for inverter. The boost converter receives the input voltage from the solar panel of 12 V and steps up the voltage to 24V and supplies it to the load. The active switch used here is MOSFET and the passive switch as diode. The Gate pulses to the MOSFET are given from the microcontroller. The converter is assumed to be working in Continuous Conduction Mode and Steady State. The duty cycle is taken as 50% where Ton=Toff period.

9. Working principle of the complete system:

Solar panel works on the principle of photo voltaic. When light of a particular wave falls on a cell then voltage is generated and when the load is connected to this unit, we are converting solar power to electrical power. When we model a solar panel we can observe that it is a current source with a parallel and series resistance. When light falls on it a constant current is generated which is a function of illumination. We know that source will deliver maximum power to load when load resistance is equal to source resistance. This is the main aim of MPPT. The output voltage of solar panel is given as input to DC-DC converter, the boost converter steps up the voltage and supplies it to the load. The maximum power is obtained so that the output efficiency is more. This is done by MPPT; here we use Microcontroller LPC2148 Arm Processor for controlling. The circuit diagram of the complete system is as shown below:

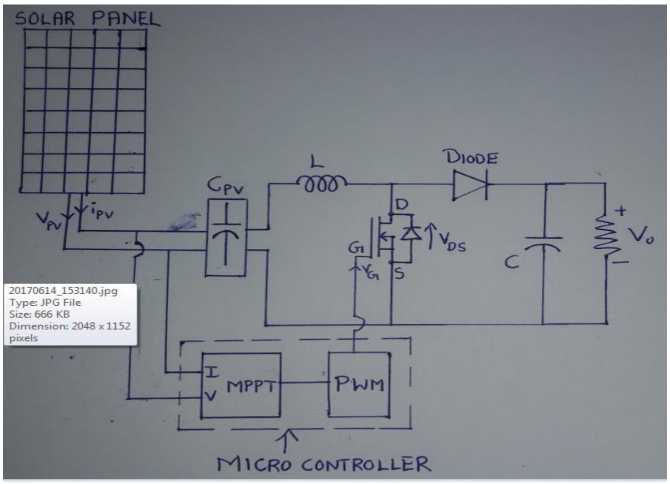

Figure 10: Circuit diagram of the complete system

10. Perturb and observe MPPT algorithm

Among various MPPT technique the most commonly used and more efficient technique is the perturb and observe MPPT technique. However, it is pointless to use more expensive or more complicated method if with a simpler and less expensive one similar results can be obtained. This is why some of the techniques are not used. The perturb and observe MPPT method is easy to implement and usually called as hill climbing technique because of the shape of the power voltage curve.

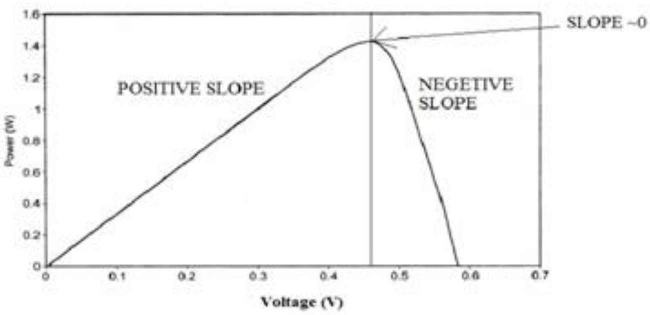

Figure 11: PV Curve

dv = V_f - V_i

where, dv = change in voltage

V_f = *Final voltage*

V_i = *initial voltage*

The perturb and observe algorithm can be explained by the following tables:

Perturbation in panel voltage (dV)	Effect on power(dP)	Conclusion for next perturbation panel voltage
Positive	Positive	Positive
Negative	Negative	Positive
Negative	Positive	Negative
Positive	Negative	Negative

Positive refers to increase in the value and negative refers to decrease in the value.

Table 1: Working of P AND O algorithm

Perturbation in Duty cycle (d)	Perturbation in voltage 'V_c'
Negative	Negative
Negative	Negative
Positive	Positive
Positive	Positive

Some important points:

a) If dP * dV =Positive, then the control voltage is positive.
b) If dP * dV =Negative, then the control voltage is negative.
c) If duty cycle is increased then the ratio $\frac{T_{ON}}{T}$ decreases.
d) If duty cycle is decreased then the ratio $\frac{T_{ON}}{T}$ increases.
e) By controlling the duty cycle we can either increase or decrease perturbation.

11. Simulation modelling of perturb and observe MPPT algorithm

Defining the values of boost converter in matlab:

```
k_boost_model.m
1 -    L=4e-3
2 -    C=10e-3
3 -    CMT=1e-3
4 -    R=5
```

Figure 12: Boost converter values given in MATLAB

First step in modeling a P and O MPPT in MATLAB is to assign the values for boost converter and running it.

Defining the values of pv model in mat lab:

```
k_pv_model.m
1  -    q = 1.6022*10^-19;
2  -    A = 1.3;
3  -    k = 1.3807*10^-23;
4  -    Voc = 20;
5  -    ISC = 10;
6  -    NS = 36;
7  -    NP = 1;
8  -    Ki = 0.0017;
9  -    Tr = 25+273;
10 -    Eg = 1.1;
11 -    RS = 0.0111;
12 -    Rsh = 1000;
```

Figure 13: PV model values given in MATLAB

Second step is to assign the values of PV module and running it.

12. Simulating the complete mppt system:

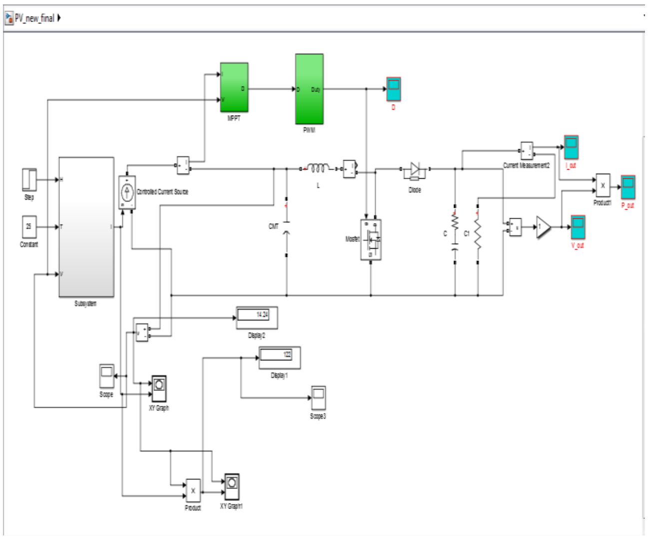

Figure 14: MATLAB simulation of the complete model

13. Simulation results of output current

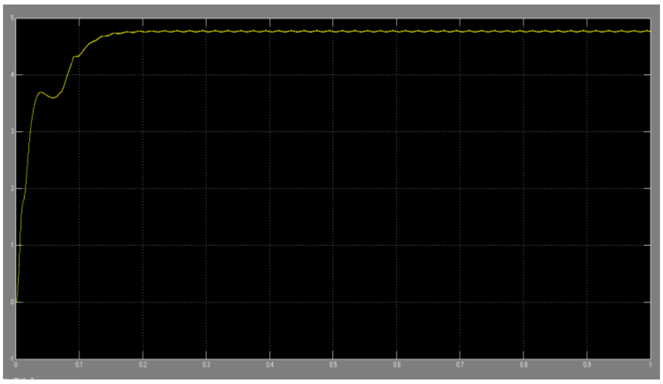

Figure 15: Waveform of output current

The output current is found to be around 5A.

14. Simulation results of output voltage

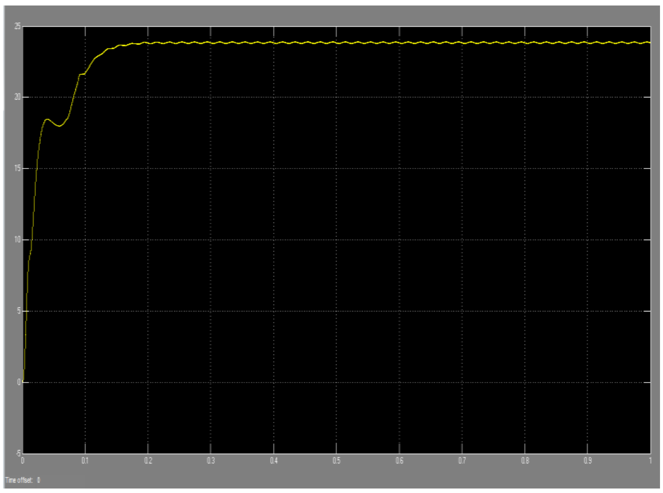

Figure 16: Waveform of Output voltage

15. Simulation result of output power

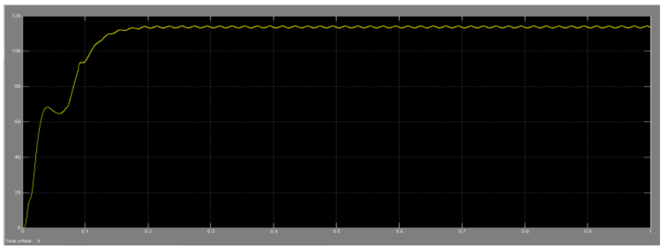

Figure 17: Waveform of output power in MATLAB

16. Hardware implementation and results

List and ratings of the components

Table 2: Components list

S No	Part Description	Rating
1	Micro Controller (LPC 2148 Arm Processor)	32 Bit
2	MOSFET IRF 245	14A and 13A, 275V and 250V, 0.28 and 0.34 Ohm, N-Channel Power MOSFETs
3	CD4047 IC	3V-15V
4	Resistors	220 Ohm
5	Variable Resistor	100 Kilo Ohm
6	Electrolytic Capacitor	10 Micro Farad
7	Ceramic Capacitor	
8	Inductor	4.7mH
9	Diode	2A
10	LED	1A
11	Step-Up Transformer	12-0-12V,3A

17. Conclusion

The hardware results are matching with the simulation results. The oscillations are less compared to other MPPT methods. The system is simple to implement as the maximum power is obtained with less cost controllers. The tracking of the power is also faster when compared to other methods.

The P&O MPPT method is implemented with MATLAB SIMULINK for simulation. The MPPT method simulated in this paper is able to improve the dynamic and steady state performance of the PV system simultaneously. Through simulation it is observed that the system completes the maximum power point tracking successfully despite of fluctuations. When the external environment changes suddenly the system can track the maximum power point quickly. The boost converter have succeeded to track the MPP and is much more effective specially in suppressing the oscillations produced due the use of P&O technique.

18. Future Scope

The present project system consists of only adaptive perturb and observe MPPT method, in future it can be merged with the conventional method so that the efficiency of the system increases as well as the difference between both the methods can be understood. Features can be developed to work the system under climatic changes also.

Currently MPPT is used for low power capacity; it can be developed for high power capacity by selecting the higher ratings of the components.

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