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A DISSERTATION REPORT
ON

Design & Implementation of Solar PV MPPT Device

Submitted in the Partial Fulfilment of the requirements for the Degree of Master of Technology in Solid State Electronics and Materials

Submitted by

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CANDIDATE'S DECLARATION

I hereby declare that the work which is presented in this thesis, entitled, "**Design & Implementation of Solar PV MPPT Device**", submitted in partial fulfillment of the requirement for the award of the degree of **Master of Technology** in **"Solid State Electronic Materials"** in **Department of Physics, Indian Institute of Technology Roorkee**, is an authentic record of my own work carried out during the period from May 2017 to April 2018 under the supervision and guidance of **Professor Dr. Rabindra Nath and Satpal Chaudhary, Chief Engineer (E&T) ONGC**.

I also declare that I have not submitted the matter embodied in this report for award of any degree.

Date: 07.05.2018

Place: Roorkee

(Gaurav Sharma)

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ONGC, Tripura Asset, Agartala.

Abstract

An innovative practice to effectively make use of the sunshine is with transportation powered by photovoltaic (PV) energy. Railroads, subways, buses, planes, cars and even roads can all be powered by solar, and solar transit is becoming a popular offering in the renewable energy sector .

Maximum Power Point Tracking (MPPT), in this we use Buck-Boost converter . First Proteus software is used to model the photovoltaic cell. Then MPPT interfacing is done with Arduino Microcontroller. All simulations have been done in Proteus and programming software is Arduino.

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Chapter 1

INTRODUCTION

1.1 The need for Renewable Energy

The various sources of renewable energy are tides, sunlight, rain, geothermal energy and wind. These resources can be naturally replenished and never go out of stock. Generally the prime source of energy these days come directly or indirectly from fossil fuels which are slowly getting exhausted from the earth storage unlike these renewable resources which are inexhaustible in nature. With time and development people around the world have been searching for nonconventional sources for long term fulfilment of their basic energy demand. With rapidly increasing population and growing consumption of fossil fuel the pollution caused to the environment also increases , hence there is a urgent need of Clean and Green Mechanisms which are now popularly adopted by nations throughout the world. The clean and no pollution consumption of these renewable energy is what attracted the current globe and hence a huge capital is investment is being done for harvesting these resources.

1.2 Solar power

The rising power demand of day to day life cannot only be maintained by using conventional energy recourses due to its unavailability. Along with conventional systems the demand for renewable sources has increased to meet the energy demand. Renewable sources like solar energy and wind energy are the prime energy sources which are being utilized in this regard. The continuous use of fossil fuels has drastically affected the environment depleting the biosphere and causing global warming.

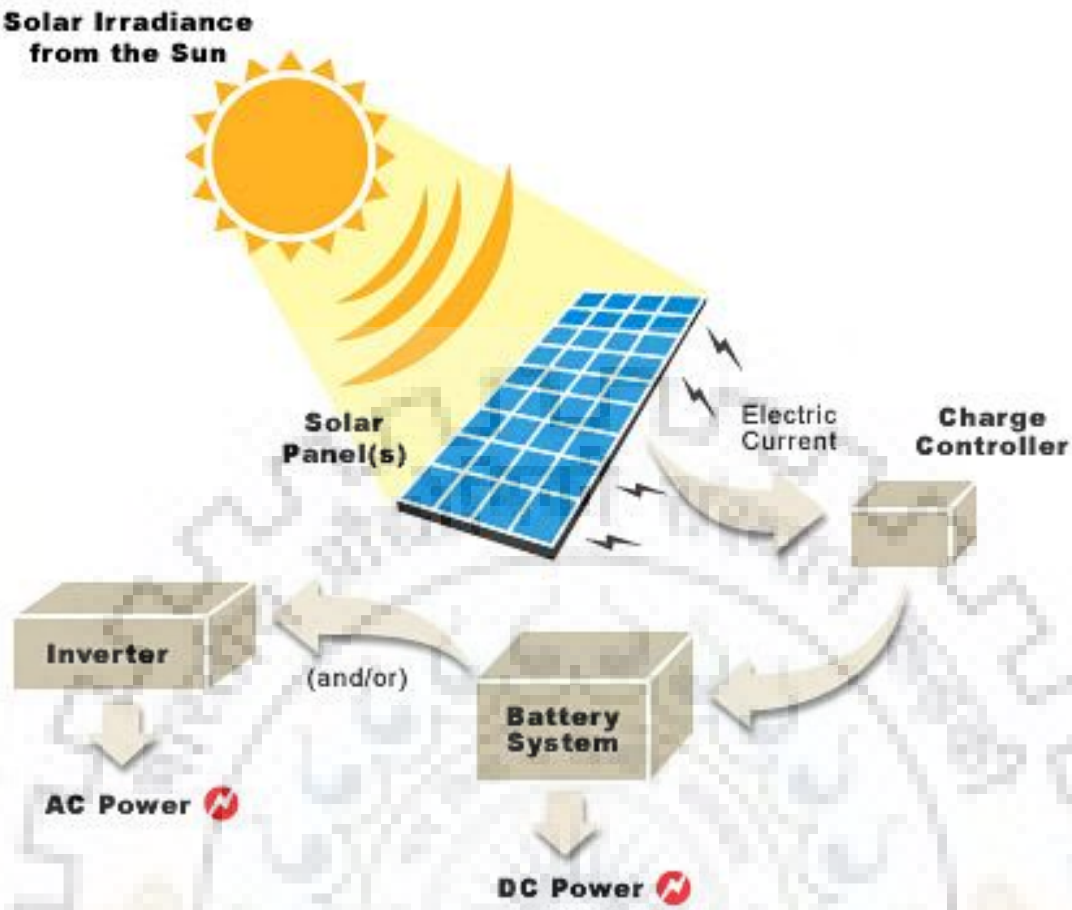
Harvesting Solar energy is possible because of it's abundantly availability. Solar energy can be a standalone generating unit or can be a grid connected generating unit depending on the availability of a grid nearby. Since the availability of grid is very low at rural areas the use of renewable sources is maximum over there. Another importance of using solar energy is the portable operation, can be used everywhere as per the necessity.

The present energy crisis can be tackled by developing power efficiently and can be extracted from the incoming solar radiation. The power conversion techniques have been greatly reduced in the past few years. To withstand the high power demand the development in

power electronics and material science has helped technicians to come up very brief but powerful systems. The increased power density is the major disadvantage of these systems. Trend has set in for the use of multi-input converter units that can effectively handle the voltage fluctuations. But due to high production cost and the low efficiency of these systems they can hardly compete in the competitive markets as a prime power generation source.

The constant increase in the development of the solar cells manufacturing technology would definitely make the use of these technologies possible on a wider basis than what the scenario is presently. The use of the newest power control mechanisms called the Maximum Power Point Tracking (MPPT) algorithms has led to the increase in the efficiency of operation of the solar modules and thus is effective in the field of utilization of renewable sources of energy.

The conversion of solar energy was originated by the British astronomer John Herschel who famously used a solar thermal collector box to cook food during an expedition to Africa. Solar energy has two major applications. Firstly, the captured heat can be used as solar thermal energy, with applications in space heating. Another alternative is the conversion of incident solar radiation to electrical energy, which is the most usable form of energy. This can be achieved with the help of solar PV cells or with concentrating solar power plants.



1.3 MOTIVATION

Photovoltaic power control is one of the modern research fields in these days. Researchers have given their best to develop better solar cell materials and efficient control mechanisms. The modern day challenge of the project and the latest technology study were the motivations behind the project.

1.4 OBJECTIVE

The primary focus will remain on the effect of Maximum Power Point Tracking and load matching and its successfully implement using the Proteus. For obtaining the maximum power point operation, the modelling the PV module, buck- boost converter, design of the model and circuitry in Proteus and interfacing of these with the MPPT algorithm with the help of Arduino would be of prime importance of the work.

Chapter 2

LITERATURE REVIEW

While a solar panel has the capacity to convert only 30-40% of incident energy on it to useful electrical energy experiment show that the efficiencies of various types and makes of solar panel varies from 3%(amorphous grade silicon solar cells) to 25 % (single crystal silicon solar cells) . Therefore in order to increase the power output of the PV system there is a need of various algorithms and tracking systems. There are different techniques for MPPT such as Hill climbing method (P&O), Fractional Short Circuit Current, Incremental conductance, Neural Network Control, Fractional Open Circuit Voltage, etc. The simplicity of implementation and short duration of operation makes Perturb and observe (P&O) and Incremental conductance algorithms popular .Economic factors also play a major role for using P&O because they are cheaper. Incremental Conductance has an advantage over P&O algorithm that is when there is an unusual change in weather or Insolation level ie when the Maximum power point changes in continuous basis P&O calculates the wrong value of MPP because it detects it as a perturbation change which is avoided to a large extent in IC method because two samples of voltage are taken. But, counterbalancing the higher efficiency factor of IC & its high complexity as compared to P&O boost the implementation cost by a visible margin. Complexity and efficiency has to be settled for a compromising balance. Another notable thing is that the type of converter used also affects the efficiency to a large extent. buck type topology staying at the top of the list, followed by buck-boost converter and boost topology residing at the lower end. While making the grid connection one has to also take care of the inverter and load requirement and the type of source connected to avoid losses and harmonics which may damage the PV system itself. Solar energy capture and harvest has been the topic of research since Einstein discovered the Photoelectric effect and won noble prize in physics 1905. The material he used in his experiment was primarily selenium coated with thin gold layer. But after that a lot of researchers have been putting together their nights and days for further technological improvement in the field solar energy worldwide.

From silicon solar cells to gallium arsenide, Cadmium sulphide- Cadmium telluride have been used for manufacturing purpose. Apart from the hardware improvement researchers have also come up with advance electronics and logical operations for increasing the overall efficiency. Hence MPPT algorithms were developed which not only enhanced the efficiency but also gave a very effective control mechanism to the whole system.

Chapter 3

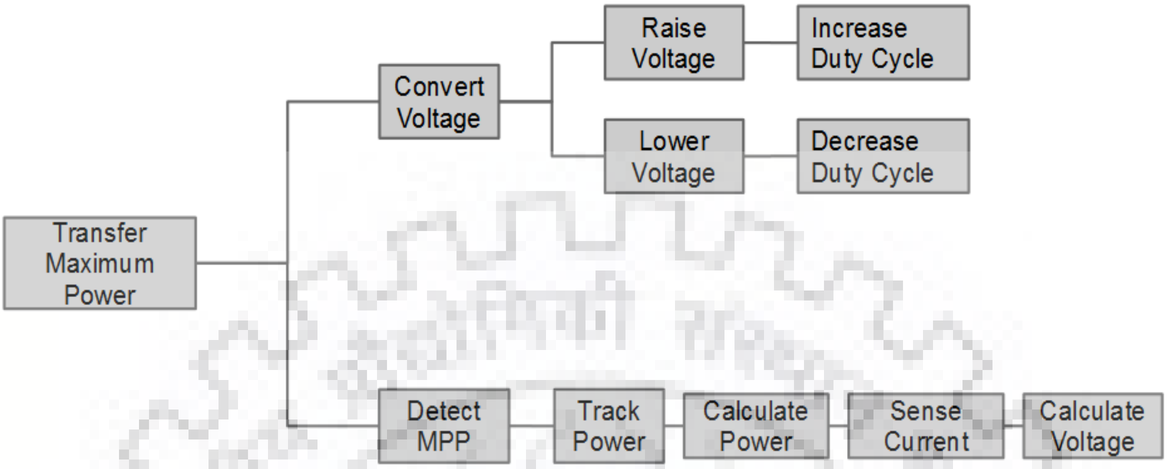
Maximum Power Point Tracking (MPPT)

An MPPT, or maximum power point tracker is an electronic DC to DC converter that optimizes the match between the solar array (PV panels), and the battery bank or utility grid. To put it simply, they convert a higher voltage DC output from solar panels (and a few wind generators) down to the lower voltage needed to charge batteries.

Maximum Power Point Tracking is electronic tracking - usually digital. The charge controller looks at the output of the panels and compares it to the battery voltage. It then figures out what is the best power that the panel can put out to charge the battery. It takes this and converts it to best voltage to get maximum AMPS into the battery. (Remember, it is Amps into the battery that counts). Most modern MPPT's are around 93-97% efficient in the conversion. You typically get a 20 to 45% power gain in winter and 10-15% in summer. Actual gain can vary widely depending weather, temperature, battery state of charge, and other factors.

How a Maximum Power Point Tracker Works:

The Power Point Tracker is a high-frequency DC to DC converter. They take the DC input from the solar panels, change it to high-frequency AC, and convert it back down to a different DC voltage and current to exactly match the panels to the batteries. MPPT's operate at very high audio frequencies, usually in the 20-80 kHz range. The advantage of high-frequency circuits is that they can be designed with very high-efficiency transformers and small components. The design of high-frequency circuits can be very tricky because of the problems with portions of the circuit "broadcasting" just like a radio transmitter causing radio and TV interference. Noise isolation and suppression becomes very important.



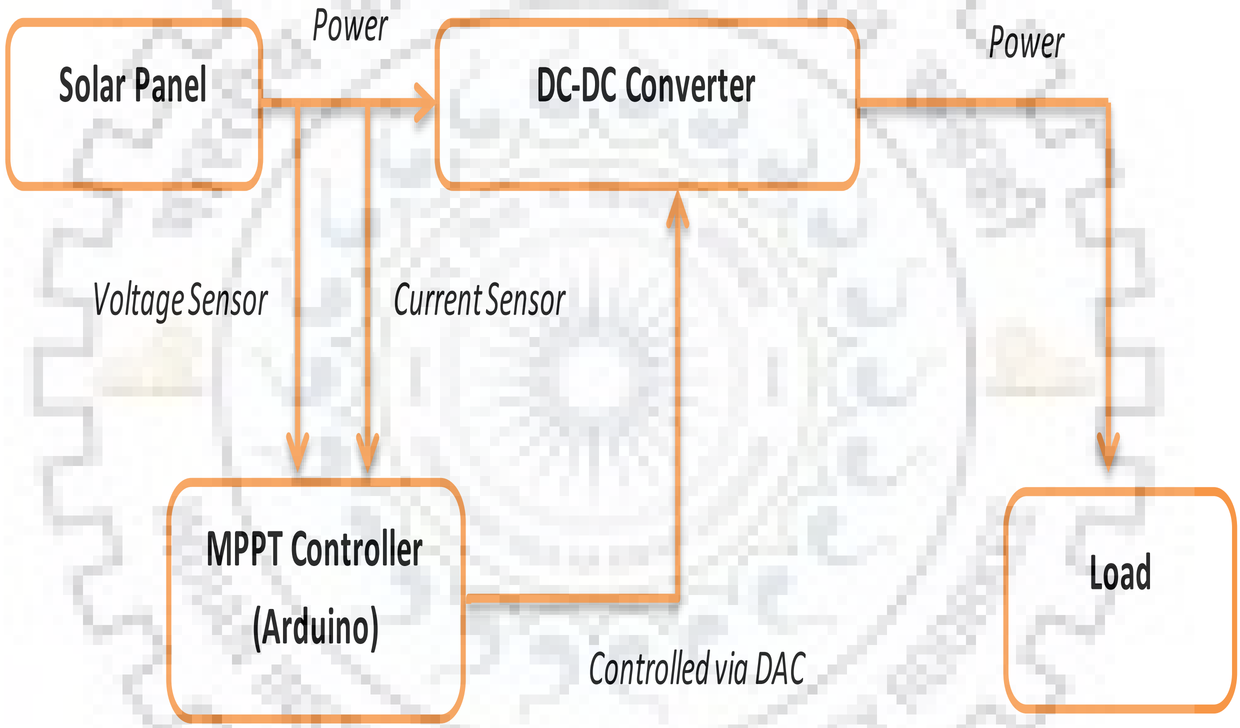
There are a few non-digital (that is, linear) MPPT's charge controls around. These are much easier and cheaper to build and design than the digital ones. They do improve efficiency somewhat, but overall the efficiency can vary a lot - and we have seen a few lose their "tracking point" and actually get worse. That can happen occasionally if a cloud passed over the panel - the linear circuit searches for the next best point but then gets too far out on the deep end to find it again when the sun comes out. Thankfully, not many of these around anymore.

The power point tracker (and all DC to DC converters) operates by taking the DC input current, changing it to AC, running through a transformer (usually a toroid, a doughnut looking transformer), and then rectifying it back to DC, followed by the output regulator. In most DC to DC converters, this is strictly an electronic process - no real smarts are involved except for some regulation of the output voltage. Charge controllers for solar panels need a lot more smarts as light and temperature conditions vary continuously all day long, and battery voltage changes.

Main features of MPPT solar charge controller

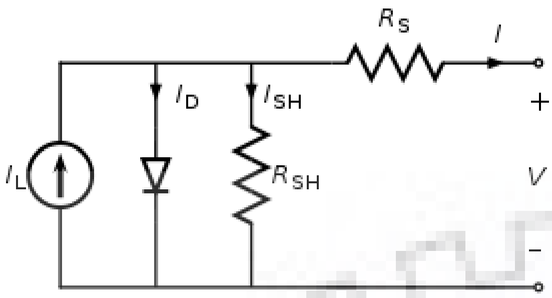
- In any applications which PV module is energy source, MPPT solar charge controller is used to correct for detecting the variations in the current-voltage characteristics of solar cell and shown by I-V curve.
- MPPT solar charge controller is necessary for any solar power systems need to extract maximum power from PV module; it forces PV module to operate at voltage close to maximum power point to draw maximum available power.
- MPPT solar charge controller allows users to use PV module with a higher voltage output than operating voltage of battery system. For example, if PV module has to be placed far away from charge controller and battery, its wire size must be very large to reduce voltage drop. With a MPPT solar charge controller, users can wire PV module for 24 or 48 V (depending on charge controller and PV modules) and bring power into 12 or 24 V battery system. This means it reduces the wire size needed while retaining full output of PV module.
- MPPT solar charge controller reduces complexity of system while output of system is high efficiency. Additionally, it can be applied to use with more energy sources. Since PV output power is used to control DC-DC converter directly.
- MPPT solar charge controller can be applied to other renewable energy sources such as small water turbines, wind-power turbines, etc.

3.1 SYSTEM MODEL COMPONENTS



3.2 PROTEUS MODEL OF SOLAR CELL

Equivalent circuit of a solar cell



To understand the electronic behavior of a solar cell, it is useful to create a model which is electrically equivalent, and is based on discrete electrical components whose behavior is well known.

Characteristic equation

From the equivalent circuit it is evident that the current produced by the solar cell is equal to that produced by the current source, minus that which flows through the diode, minus that which flows through the shunt resistor:

$$I = I_L - I_D - I_{SH}$$

where

- I = output current (amperes)
- I_L = photogenerated current (amperes)
- I_D = diode current (amperes)
- I_{SH} = shunt current (amperes).

The current through these elements is governed by the voltage across them:

$$V_j = V + IR_S$$

where

- V_j = voltage across both diode and resistor R_{SH} (volts)
- V = voltage across the output terminals (volts)

- I = output current (amperes)
- R_S = series resistance (Ω).

By the Shockley diode equation, the current diverted through the diode is:

$$I_D = I_0 \left\{ \exp\left[\frac{qV_j}{nkT}\right] - 1 \right\}$$

where

- I_0 = reverse saturation current (amperes)
- n = diode ideality factor (1 for an ideal diode)
- q = elementary charge
- k = Boltzmann's constant
- T = absolute temperature
- At 25°C, $kT/q \approx 0.0259$ volts.

By Ohm's law, the current diverted through the shunt resistor is:

$$I_{SH} = \frac{V_j}{R_{SH}}$$

where

- R_{SH} = shunt resistance (Ω).

Substituting these into the first equation produces the characteristic equation of a solar cell, which relates solar cell parameters to the output current and voltage:

$$I = I_L - I_0 \left\{ \exp\left[\frac{q(V + IR_S)}{nkT}\right] - 1 \right\} - \frac{V + IR_S}{R_{SH}}.$$

An alternative derivation produces an equation similar in appearance, but with *V* on the left-hand side. The two alternatives are identities; that is, they yield precisely the same results. In principle, given a particular operating voltage *V* the equation may be solved to determine the operating current *I* at that voltage. However, because the equation involves *I* on both sides in a transcendental function the equation has no general analytical solution. However, even without a solution it is physically instructive. Furthermore, it is easily solved using numerical methods. (A general analytical solution to the equation is possible using Lambert's W function, but since Lambert's W generally itself must be solved numerically this is a technicality.)

Since the parameters I_0, n, R_S, and R_{SH} cannot be measured directly, the most common application of the characteristic equation is nonlinear regression to extract the values of J_0 = reverse saturation current density (amperes/cm^2)

3.3 BUCK-BOOST CONVERTER

Need of DC/DC converter

A dc/dc converter is an integral part of any MPPT circuit system. Without dc/dc converter no any MPPT circuit can be designed.

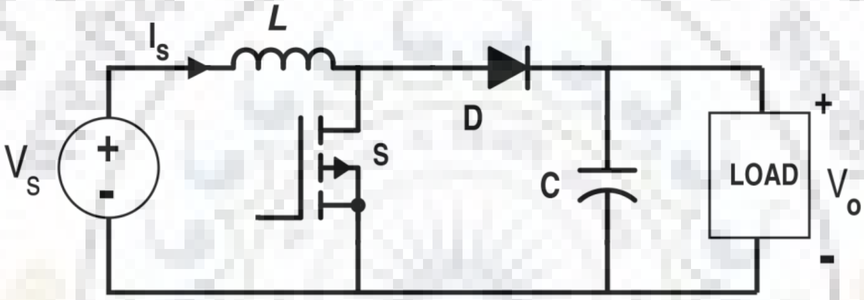
When a direct connection is carried out between the source and the load, the output of the PV module is irregularly shifted away from the maximum power point. It is necessary to overcome this problem by adding an adaptation circuit between the source and the load. . A MPPT controller circuit with a DC-DC converter circuit is used as an adaptive circuit.

For maximum power transfer from source to load an extra circuit is required to support the load to match the impedance with source impedance.

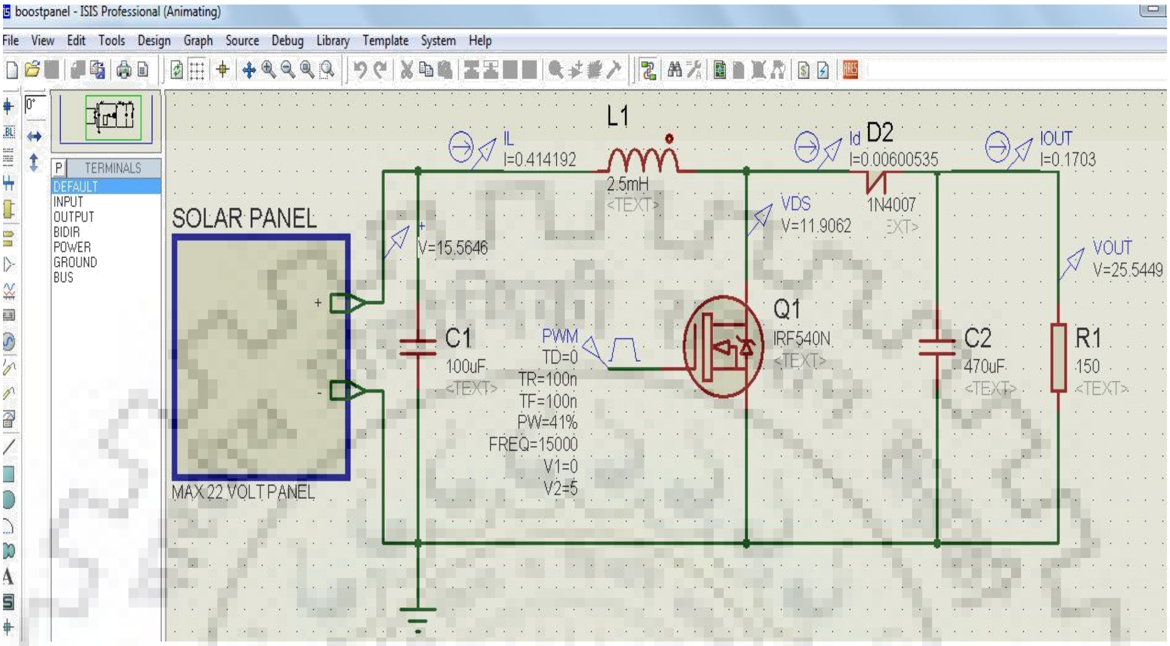
Boost Converter

In a boost converter or regulator output voltage of the converter is greater than input voltage of the converter circuit that means it boosting the input voltage that's way its name is "BOOST" regulator.

The boost circuit consist a energy storing element inductor, a capacitor, a diode, a load and a switching device like Mosfet BJT etc. Circuit diagram of boost converter is shown in figure below.



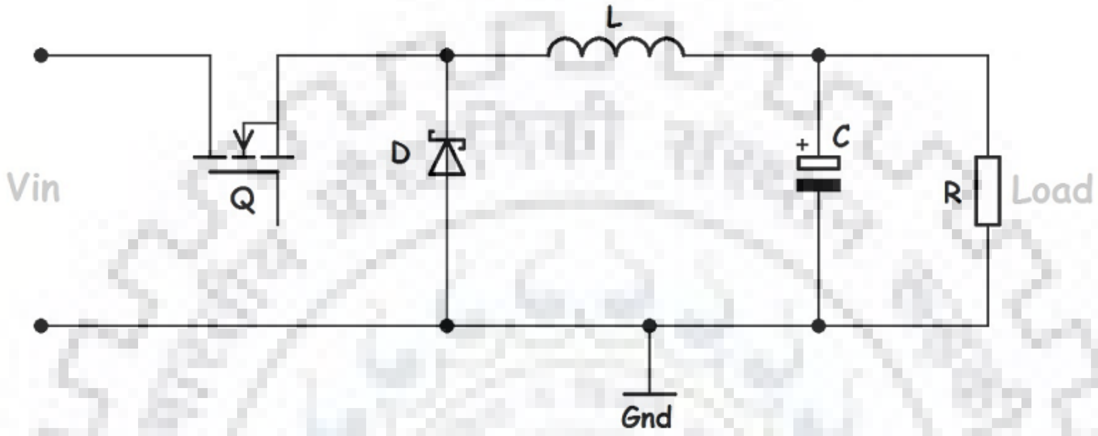
<u>Proteus design of Boost converter</u>

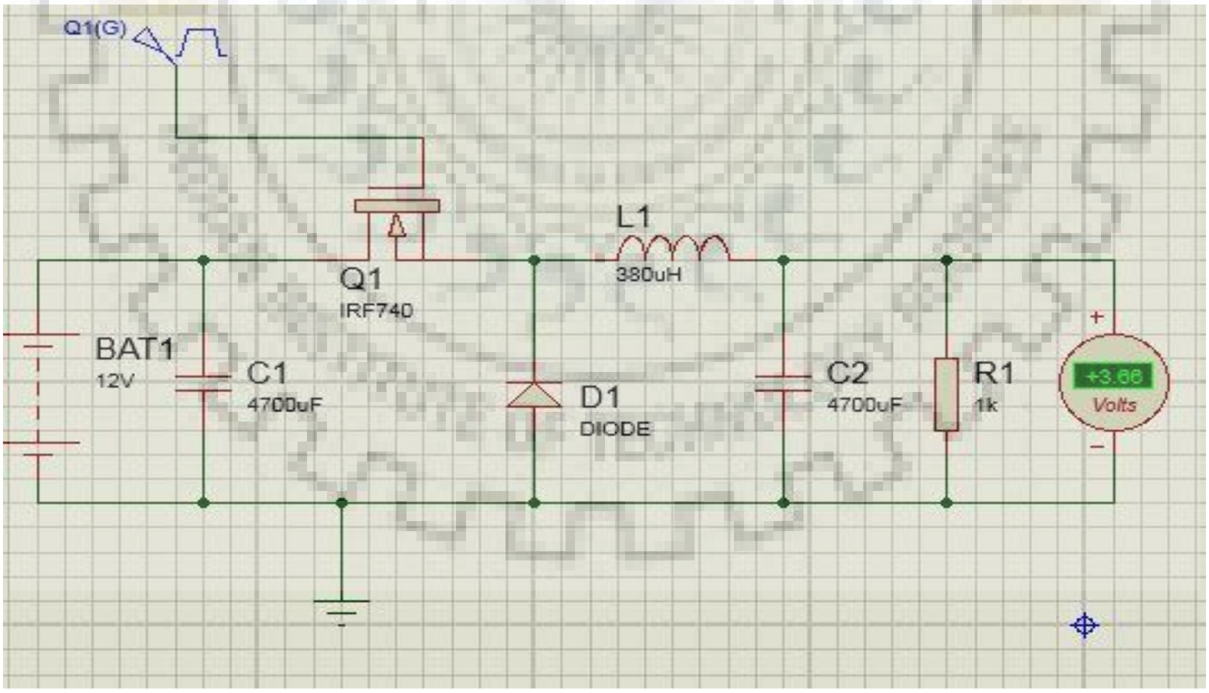


Buck Converter

Heart of MPPT is the Buck Converter

A buck converter is basically a small DC to DC converter. The main principle at work in a buck converter, is the tendency for an inductor to resist changes in current. A buck converter output voltage will always be lower or the same as the input voltage.





Proteus design of Buck converter

3.4 Maximum Power Point Tracking Algorithms

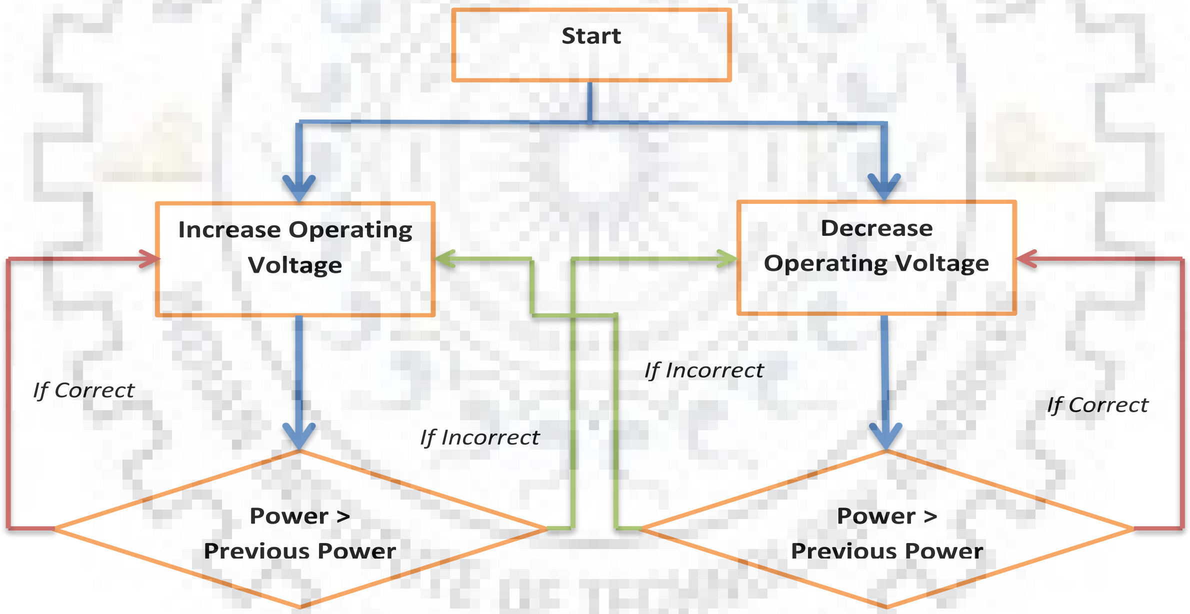
An overview of MPPT

The efficiency of Solar PV module is measured to be not more than 30%. As seen from the Power vs Voltage curve the module has to operate at specific range of voltage values in order to extract maximum power thus improving the efficiency. The Max Power Transfer Theory says that maximum power can be extracted from source when the load impedance matches the source impedance (Thevenin equivalent impedance). There are basically three methods to derive peak power operation electrically. The first method is by measuring dV/dI i.e the dynamic impedance by injecting periodic signal current (small magnitude) and increasing operating voltage until it equals the static impedance V/I. The second method is by increasing the operating voltage until dP/dV ie (slope of the P vs V curve) is positive . In most of the cells ratio between the maximum power voltage and open circuit voltage is maintained and experimentally found to be near 0.72 in the third method this idea is key for MPPT . From the above method what we can infer is that our basic motive can be achieved by matching the impedances by duty cycle alteration of buck-boost converter switch and obtain higher value of output voltage.

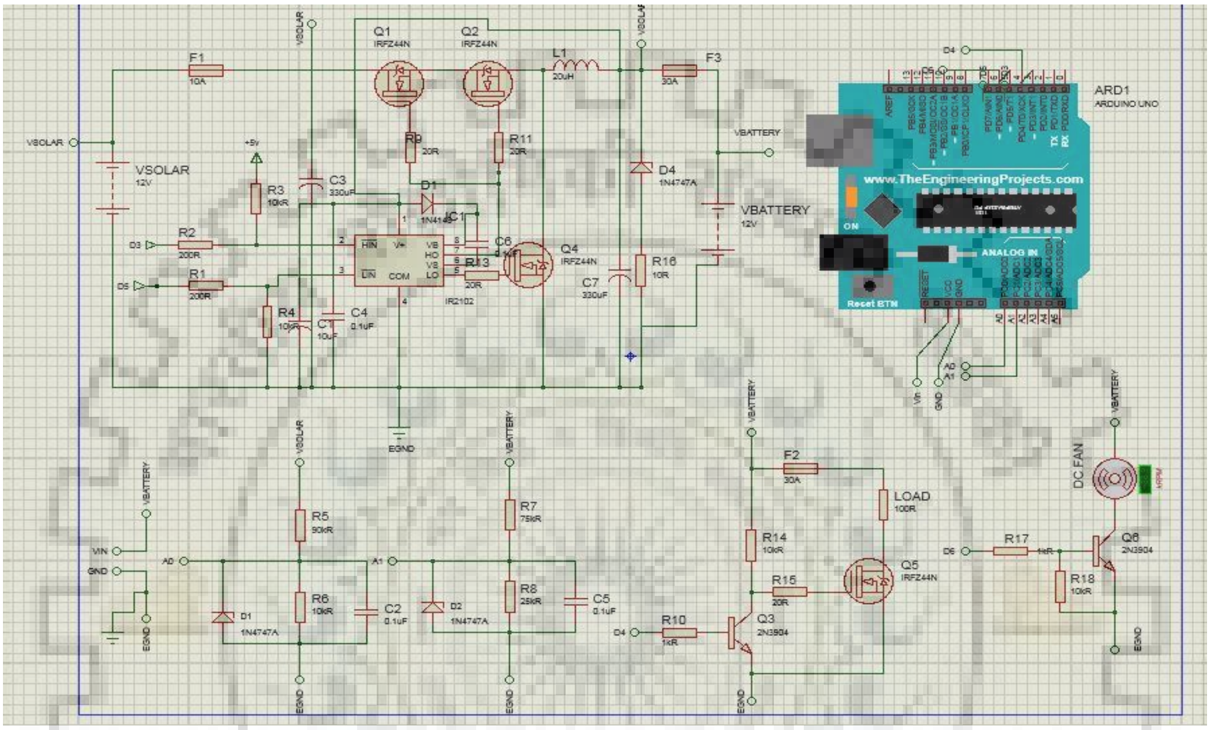
3.5 Perturb & Observe

Perturb & Observe (P&O) is one of the simple technique that uses a voltage sensor, to sense the voltage of Photovoltaic array voltage which reduces the implementation cost and hence easy to operate. The of this algorithm has a very less time complexity but when it reaches close to the maximum power point it perturbs on both the directions without stopping. An appropriate error limit is to be set or a wait function can be added when MPP is reached thus increasing the time complexity of the algorithm.

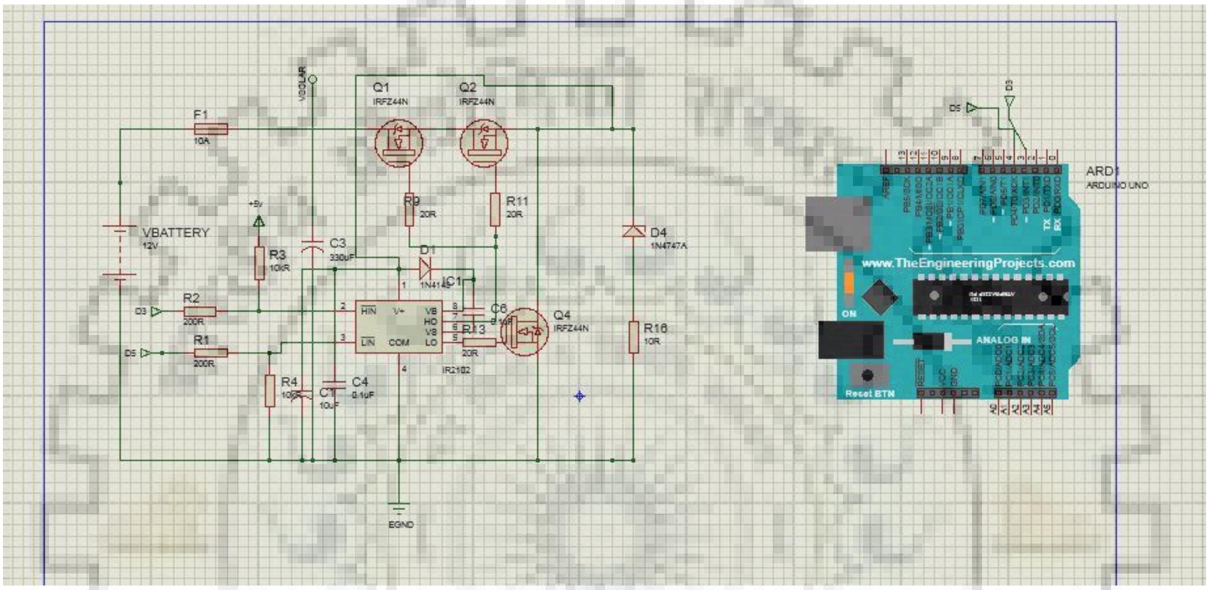
Flow chart for Perturb & Observe (P&O) algorithm:-

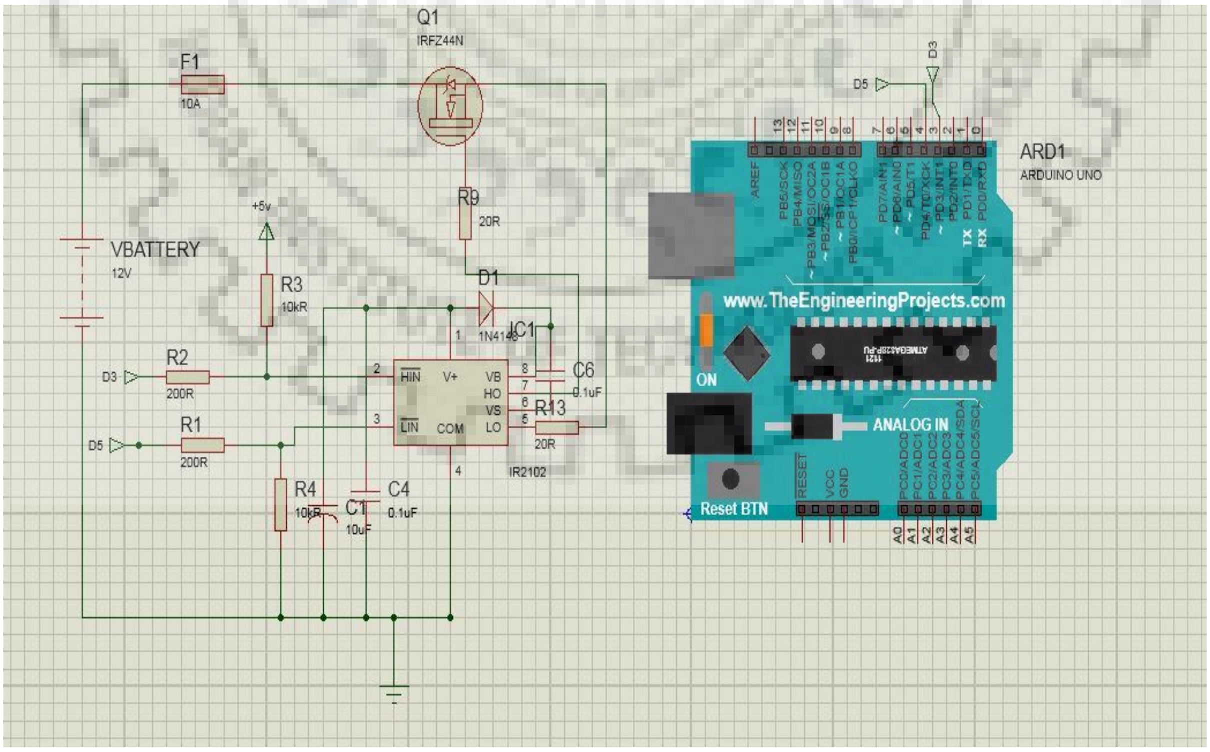


Proteus design of complete circuitry

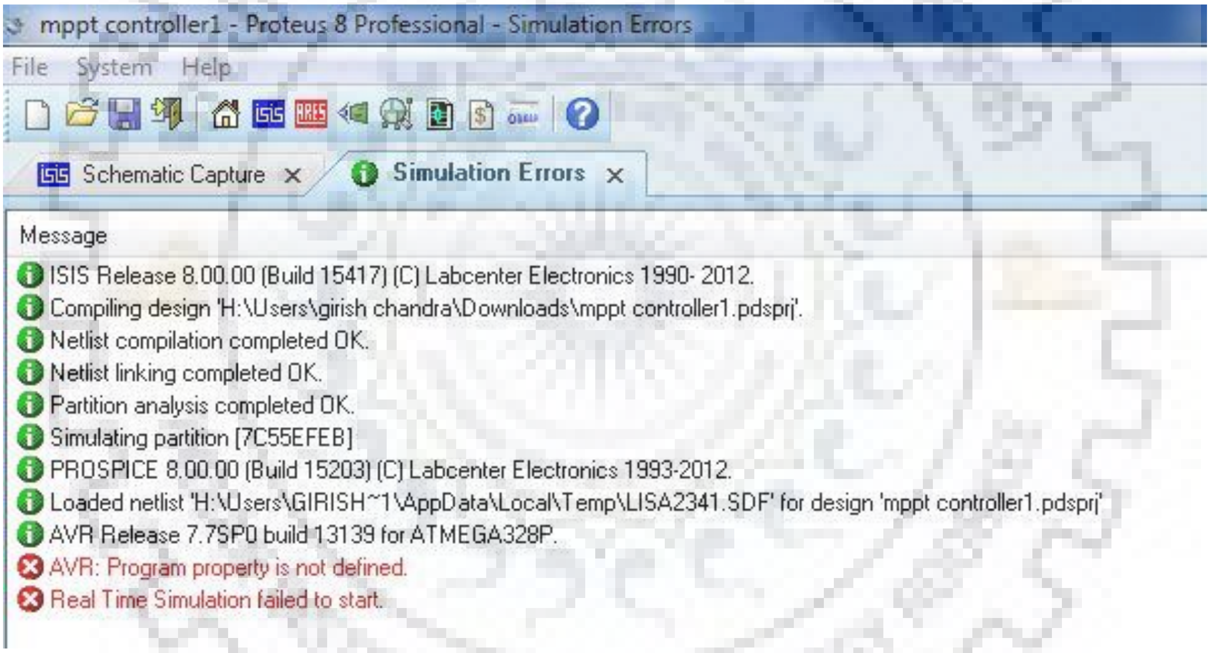


Proteus designs of components of circuitry





Simulation Result



4.2 FUTURE WORK

Future work to this project will include the removal of harmonics in the grid connection system as well as operation of the PV system in variable environmental and physical conditions like change in solar irradiation or sudden altering in atmospheric temperature. Further improvement can be made by enhancing the energy exchange with the local electrical grid in order to stabilise the energy curve. Design of more generalised solar cell with variable inputs of incident solar radiation and atmospheric temperature can be designed using Proteus instead of predefined constant values.

Solar Converters work as best renewable power sources for charging battery or operation of appliances. Studies could be made prior to analyse efficiency and determine losses in converters. Design and development of advanced lossless converters with appropriate duty cycle can be considered for further research in varying panel sizes .