Maximum Power Point Tracking using Adaptive Perturb and Observe Algorithm

A Project Report

Submitted by

Aurick Das	**111607002**
Suradha Iyer	**111607020**
Ruhshad Kasad	**111607029**
Tanay Kulkarni	**111607069**

Under the guidance of

Dr. S. P. Metkar

DEPARTMENT OF ELECTRONICS AND TELECOMMUNICATION ENGINEERING

COLLEGE OF ENGINEERING, PUNE

TABLE OF CONTENTS

ABSTRACT

Due to the severity of the global energy crisis and environmental pollution, the photovoltaic (PV) system has become one kind of important renewable energy source. Global energy demand projections show an increasing trend, with annual consumption predicted to reach around 778 Etta Joule by 2035. Global electricity demand in 2018 increased by 4%, or 900 TWh, growing nearly twice as fast as the overall demand for energy. This was also the fastest increase since 2010, when the global economy recovered from the financial crisis. Renewable Energy has been one of the sources to cope with the extra demand.

Fossil fuels are non-renewable and require finite resources, which are dwindling because of high cost and environmentally damaging retrieval techniques. So, the need for cheap and obtainable resources is greatly needed. An efficient and more feasible alternative option is solar energy. Solar energy is a more practical type of energy due to its plentiful availability.

One of the fields of application of solar energy is stand-alone Photovoltaic Systems. Such systems have far ranging applications. They can be utilized to power rural regions which have been isolated from the electric grid or at regions where access to the grid is difficult such as regions hit by natural disasters.

This study is aimed at developing a PV charging system for Li-ion batteries by integrating Maximum Power Point Tracking (MPPT) and charging control for the battery. Our work in this field is to validate new algorithms for Maximum Power Point Tracking and carry over the gains by using optimized hardware. Using low-cost and commercially available components to keep the cost down, we demonstrate a prototype for our MPPT topology. We simulate the system using Simulink and implement the topology using MSP430. A Cuk Converter is utilized to transform the DC-DC voltage.

The low-power MCU provides added gain and the integration of a battery pack provides a completely isolated, self-contained system capable of being portable and utilized in adverse environments.

INTRODUCTION

Solar energy is genesis for all forms of energy. This energy can be made use of in two ways:

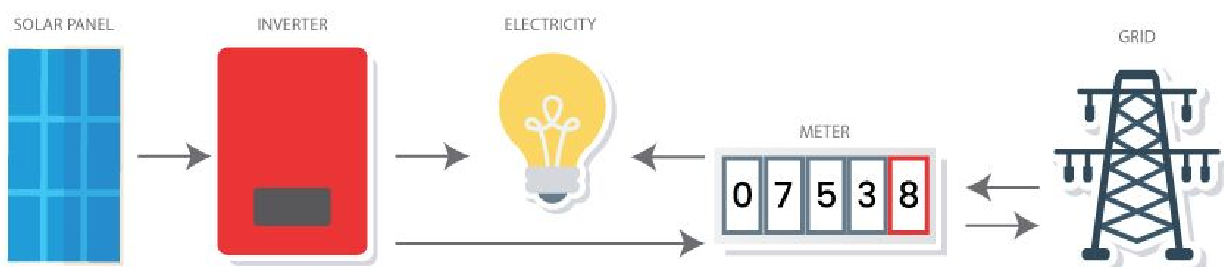
a. Thermal route i.e. using heat for drying, heating, cooking or generation of electricity, or
b. Photovoltaic route which converts solar energy into electricity that can be used for a myriad purposes such as lighting, pumping and generation of electricity. With its pollution free nature, virtually inexhaustible supply and global distribution- solar energy is a very attractive energy resource.

Remote/ stand-alone power systems are installed for the following reasons:

- Desire to use renewable – environmentally safe, pollution free. Combining various generating options available – hybrid power generation.
- Desire for independence from the unreliable, fault prone and interrupted grid connection. Available storage and back-up options.
- No overhead wires – no transmission loss.
- Varied daily activities: Lighting, Communication Systems,Cooking, Heating, Pumping, Small scale industry utilization, etc.
- Captive power generation is done mainly considering the replacement of diesel with solar.

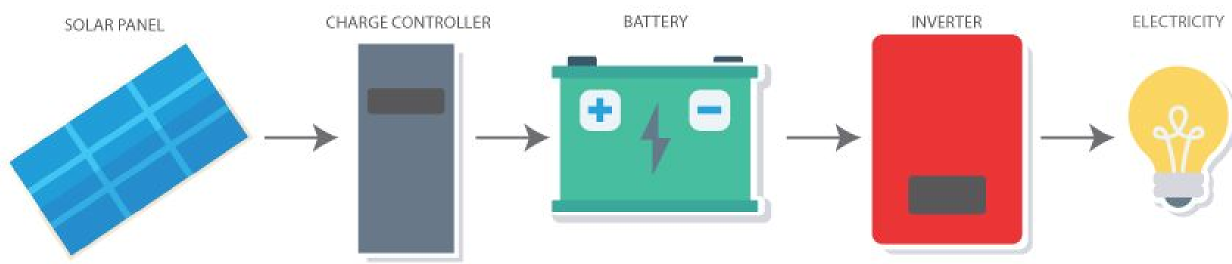
India's per capita power consumption is among the lowest in the world. Around 280 million people in the country do not have access to electricity.

GRID CONNECTED



A grid connect system is one that works in with the local utility grid so that when your solar panels produce more solar electricity than your house is using the surplus power is fed into the grid. With a grid connect solar power system when your house requires more power than what your solar panels are producing then the balance of your electricity is supplied by the utility grid. Obviously at night all of your electrical needs are supplied by the grid because with a grid connect system you do not store the power you generate during the day.

STANDALONE



With a stand alone solar system the solar panels are not connected to a grid but instead are used to charge a bank of batteries. These batteries store the power produced by the solar panels and then your electrical loads draw their electricity from these batteries. Stand alone solar power systems have been used for a long time in areas where no public grid is available. However, the real growth in solar power systems in the last 5 years has been in grid connect systems because most people live in areas that are connected to a public grid and stand-alone systems are much, much more expensive than grid connect systems because batteries are very expensive. It is my hope that in the future we will see a fall in battery prices and that stand alone systems will be used more.

The major disadvantages to using solar for grid connections:

- The weather may be cloudy or rainy, with little or no sun radiation. Hence, this makes solar energy panels less reliable as a solution for grid connected outputs.
- Only those areas that receive good amount of sunlight are suitable for producing solar energy.
- Solar panels also require inverters and storage batteries to convert direct electricity to alternating electricity so as to generate electricity. While installing a solar panel is quite cheap, installing other equipments becomes expensive.

In this project, we attempt to build a battery charger circuit for stand-alone applications/ MPPT fast charging preliminary circuit for 5-15V battery charging systems using a solar charger. It has various applications in

1. Providing connectivity safely in disaster-zones
2. Powering appliances in moving clinics
3. Charging backup reserves for computers/ mobiles/ refrigerators.

SECTION I: SOLAR PANEL

A photovoltaic (PV) module or solar electric panel is the smallest replaceable unit in a PV array. The module is an integral unit that provides support for a number of PV cells connected electrically and protected from the elements. The electrical output of the module depends on the size and number of cells, their electrical interconnection, and, of course, on the environmental conditions to which the module is exposed.

There are four factors that determine any solar electric panels output: efficiency of the photovoltaic cells, the load resistance, solar irradiance, and cell temperature. The solar cell efficiency is set by the manufacturing process; today's commercially available modules are from 3% to 17% efficient at converting the solar energy to electrical energy. The load resistance determines where the module will operate on the current and voltage (I-V) curve. The preferred operating point is where maximum power (power is calculated by multiplying the current times the voltage) is generated, called the peak power point.

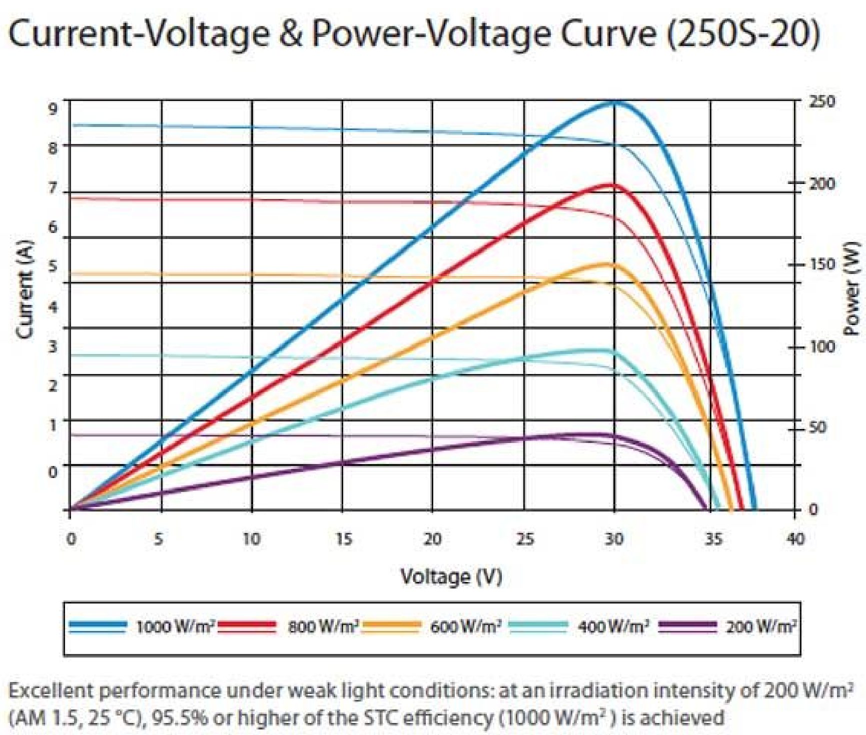


Fig.1.1: Current & Power vs Voltage of PV Array

Every model of solar panel has unique performance characteristics which can be graphically represented in a chart. The graph is called an “I-V curve”, and it refers to the module’s output relationship between current (I) and voltage (V) under prevailing conditions of sunlight and temperature.

Solar Array Parameters

- VOC = open-circuit voltage: – This is the maximum voltage that the array provides when the terminals are not connected to any load (an open circuit condition). This value is much higher than Vmp which relates to the operation of the PV array which is fixed by the load. This value depends upon the number of PV panels connected together in series.
- ISC = short-circuit current – The maximum current provided by the PV array when the output connectors are shorted together (a short circuit condition). This value is much higher than Imp which relates to the normal operating circuit current.
- MPP = maximum power point – This relates to the point where the power supplied by the array that is connected to the load (batteries, inverters) is at its maximum value, where MPP = Imp x Vmp. The maximum power point of a photovoltaic array is measured in Watts (W) or peak Watts (Wp).
- Percent efficiency – The efficiency of a photovoltaic array is the ratio between the maximum electrical power that the array can produce compared to the amount of solar irradiance hitting the array. The efficiency of a typical solar array is normally low at around 10-12%, depending on the type of cells (monocrystalline, polycrystalline, amorphous or thin film) being used.

Electrical Characteristics:

The industry standard against which all PV modules are rated and can be compared is called Standard Test Conditions (STC). STC is a defined set of laboratory test conditions which approximate conditions under which solar panels, or PV modules, might be used.

1. Irradiance (sunlight intensity or power), in Watts per square meter falling on a flat surface. The measurement standard is 1 kW per sq. m. (1,000 Watts/m2)
2. Air Mass refers to “thickness” and clarity of the air through which the sunlight passes to reach the modules (sun angle affects this value). The standard is 1.5.
3. Cell temperature , which will differ from ambient air temperature. STC defines cell testing temperature as 25 degrees C.

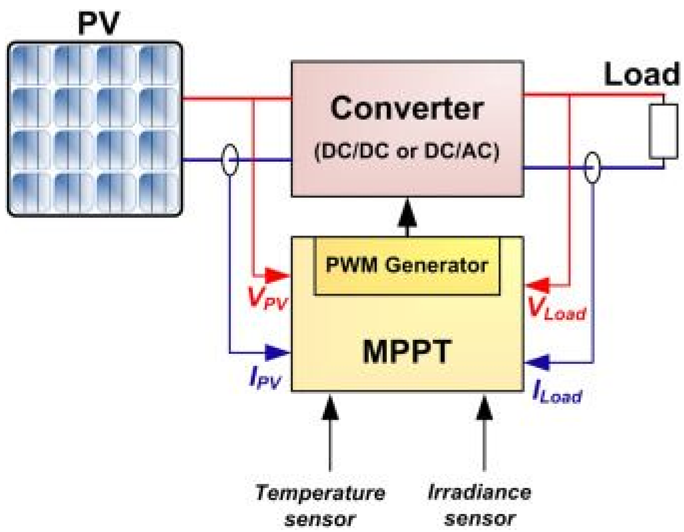


Fig.1.2: Block Diagram Schematic of MPPT setup

SECTION II: PERTURB & OBSERVE TECHNIQUE

Different MPPT algorithms can be deployed but for our small scale implementation & ADC parameters, we can only measure voltage. So we attempted the Perturb and Observe technique & improved it using the Adaptive technique. Here, we attempt to modulate pulse width to the converter (described in Section IV) and control the output.

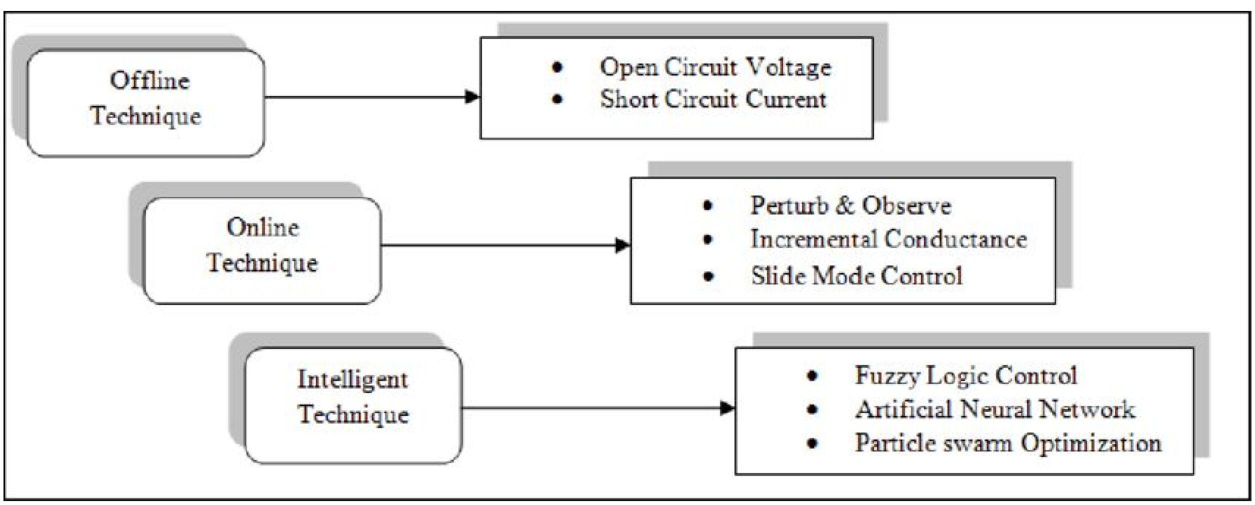


Fig.2.1: Types of MPPT Techniques

Maximum Power Point using P&O

In this method the controller adjusts the voltage by a small amount from the array and measures power; if the power increases, further adjustments in that direction are tried until power no longer increases. This is called the perturb and observe method and is most common, although this method can result in oscillations of power output. It is referred to as a hill climbing method, because it depends on the rise of the curve of power against voltage below the maximum power point, and the fall above that point. Perturb and observe is the most commonly used MPPT method due to its ease of implementation.

Perturb and observe method may result in top-level efficiency, provided that a proper predictive and adaptive hill climbing strategy is adopted.

Flowcharts for P&O and Adaptive P&O:

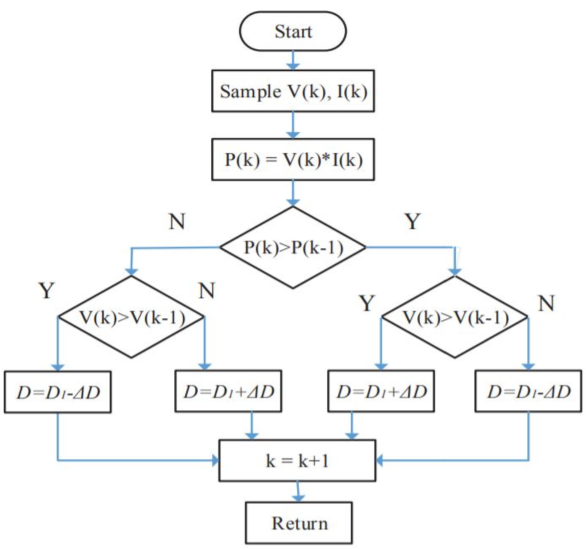


Fig.2.2: Flowchart for Perturb and Observe Method

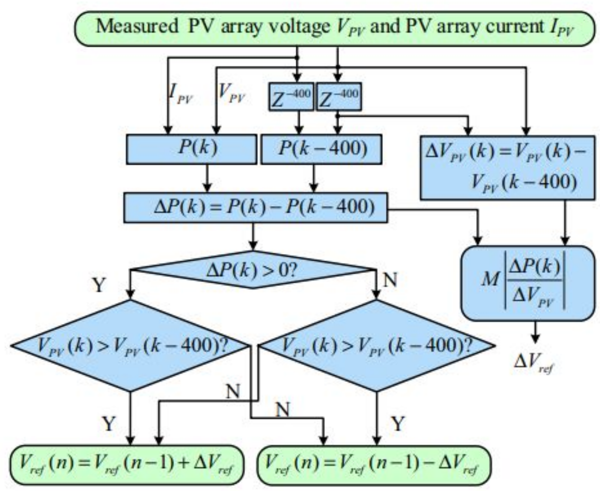


Fig.2.3: Flowchart for Adaptive Method

SECTION III: MSP430F5529 LAUNCHPAD

Fig.3.1: MSP430F5529 Launchpad

In order to supply the PWM to the Switch (MOSFET in our design), we must use a microcontroller of the low power variety.

From the product description, we can identify the core features of the specific microcontroller:

- The TI MSP430™ family of ultra-low-power microcontrollers consists of several devices featuring peripheral sets targeted for a variety of applications. The architecture, combined with extensive low-power modes, is optimized to achieve extended battery life in portable measurement applications. The microcontroller features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally controlled oscillator (DCO) allows the devices to wake up from low-power modes to active mode in 3.5 µs (typical).

- The MSP430F5529, MSP430F5527, MSP430F5525, and MSP430F5521 microcontrollers have integrated USB and PHY supporting USB 2.0, four 16-bit timers, a high-performance 12-bit analog-to-digital converter (ADC), two USCIs, a hardware multiplier, DMA, an RTC module with alarm capabilities, and 63 I/O pins.

The specific features of this family that make it ideal for adaptive Perturb & Observe applications:

1. 12-Bit Analog-to-Digital Converter (ADC) With Internal Reference, Sample-and-Hold, and Autoscan Feature; for accuracy in converting input & reference
2. Flexible Power-Management System; for automatic power savings in energy deficient environments
3. Wake up From Standby Mode in 3.5 µs (Typical)
4. 16-Bit RISC Architecture, Extended Memory, up to 25-MHz System Clock; enough to handle fast computation within sampling time

MSP Coding Environment: Energia

Energia is an open source & community-driven integrated development environment (IDE) & software framework. Based on the Wiring framework, Energia provides an intuitive coding environment as well as a robust framework of easy-to-use functional APIs & libraries for programming a microcontroller. Energia supports many TI processors, primarily those available in the LaunchPad development ecosystem.

Features:

a. Simple & easy-to-use code editor & compiler with built-in Serial Monitor/terminal
b. Features a robust framework of intuitive functional APIs for controlling microcontroller peripherals (i.e. digitalRead, digitalWrite, Serial.print, etc)

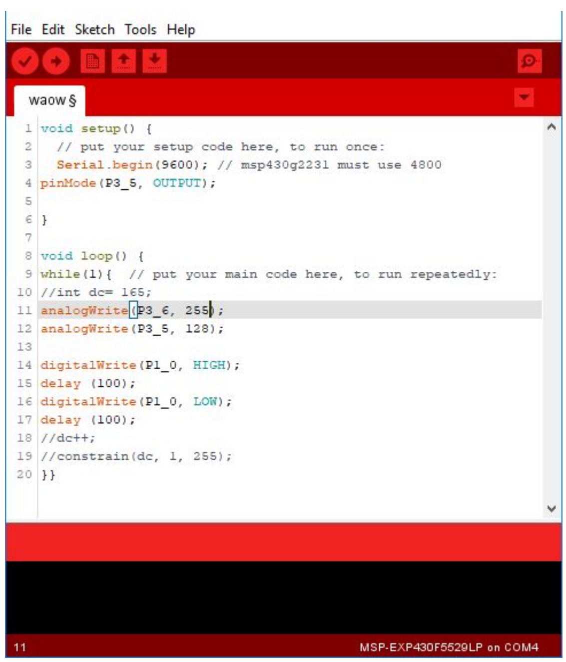


Fig.3.2: Energia Interface with Setup and Loop functions for simple codes

Code in Energia:

```
/*
 * Adaptive MPPT converter control code
  Hardware Required:
  * MSP-EXPF5529 LaunchPad
  * Voltage Divider ccts
  * Power supply or solar module
  * added converter ccts to feed PWM signal to
*/
const float M= 13; // ~0.05 DC variation
float V1;
float exV;
float exI;
float delV;
float I;
float Pnow;
float exP;
float Vref;
float delVref;
int PWM= P3_5; // DIGITAL output pin
int dc=127; // 50% DC assumed initially

// the setup routine runs once when you press reset:
void setup() {
  V1= 0;
  exV=0;
  exI=0;
  I= 0;
  exP= 2.5;
  Pnow= 0;
  delVref= 0;
  Vref= 1.5;
  dc= 127;
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600); // msp430g2231 must use 4800
  pinMode(A3, INPUT); // analog pins to be fed into the ADC
  pinMode(A4, INPUT);
  pinMode(PWM, OUTPUT);
}

// the loop routine runs forever:
void loop() {
  // read the voltage input on analog pin A3, current on pin 6_3:
  //int VADC = analogRead(A3);
  int VADC = 490;
  delay(200); // 20ms delay between sampling
```

```
 //int IADC = analogRead (A4);
 int IADC = 103;
 // Convert the analog reading (which goes from 0 - 1023) to a voltage (0 - 3V): and find Power
// for current iteration
 float voltage = VADC * (3.0 *7 / 1023.0); // step down vtg divider of 7:1
 float current = IADC * (3.0/ 1023.0); // both current and voltage input normalized by the same
                                       // factor in the hardware
 constrain (voltage, 0.1, 7);
 constrain (current, 0.1, 3);
 Pnow= voltage* current;

float delP= Pnow- exP;
delV = voltage- exV;
delVref= M * (delP/ voltage- exV);

if (delP > 0){

if (delV > 0)
    Vref= Vref + delVref;

else
    Vref = Vref - delVref;
 }

 else
{
if (delV < 0)
    Vref= Vref + delVref;

else
    Vref = Vref - delVref;
 }

//modulating duty cycle
 dc= dc + (Vref * M);
constrain (dc, 0, 255);
analogWrite(PWM, dc);
 Serial.println("\n");
 Serial.println(delP );
 Serial.println("DUTY CYCLE :" );
 Serial.println(dc);
  exV= voltage;
 exI= current;
 exP= exV* exI;
 VADC = VADC+10;
 delay(100);
}
```

SECTION IV: CONVERTER DESIGN

1. PV Module:

Temp. (°C)	Voltage (V)	Current (A)	Power (W)
100	11.4785	0.58719	6.7401
50	15.121	0.59181	8.9488
25	17	0.59	10.03
0	18.9057	0.5859	11.0768

Fig.4.1: Ratings for PV Module from Solar City

2. Cuk Converter:

CuK converter is actually the cascade combination of a boost and a buck converter.It is essentially a boost converter followed by a buck converter with a capacitor to couple the energy.

It has the following advantages:

- Continuous input current.
- Continuous output current.
- Output voltage can be either greater or less than input voltage.

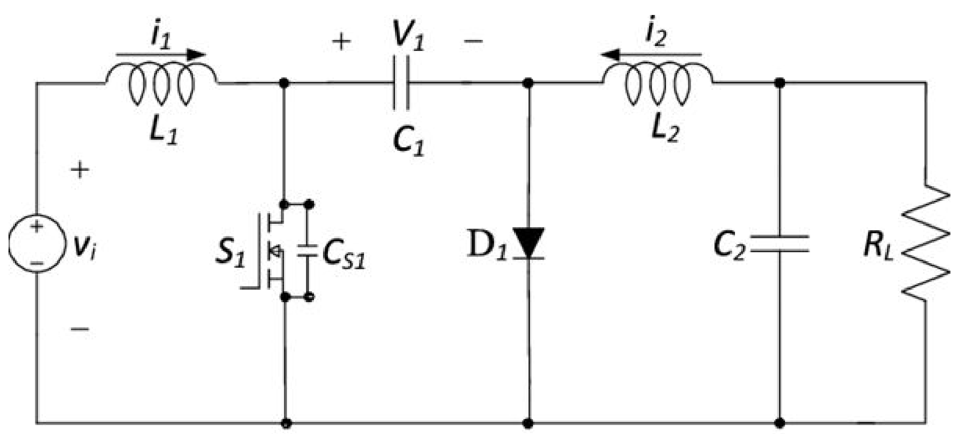


Fig.4.2: Cuk Converter Schematic

Design Considerations:

V_{out} = 17V
I_{out} = 0.57A

$V_{in(min)}$ = 5V
$V_{in(max)}$ = 21V

$V_{out} = V_{in}(D/1-D)$, where D is the Duty Cycle
D_{max} = 0.772
D_{min} = 0.447

For Continuous Conduction Mode

Assuming ripple factor $r_1 = r_2 = 0.2$

Switching Frequency (f_s) = 500Hz

Inductor $L_1 = V_i*(1-D)/f_s*r_1*I_o$
L_1 = 5*(1-0.77)/500*0.2*0.57
= 20mH

Inductor $L_2 = V_i*(D)/f_s*r_2*I_o$
L_2 = 5*0.77/0.2*500*0.57
= 68mH

$I_{1, L(max)} = I_oD/(1-D) + V_i*D/2*f_s*L_1$
= 0.57*0.772/0.228 + 5*0.77/(2*500*20m)
= 0.195+1.93
= 2.125A

$I_{2, L(max)} = I_o + V_i*D/2*f_s*L_1$
= 0.57+ 5*0.77/(2*500*68m)
= 0.598A

Coupling Capacitor,
$C_c = I_o*(1-D)/f_s*D$
= 0.57*(1-0.77)/500*0.77
= 330uF

Diode Current(I_f) $= I_{1, L(max)}+I_{2, L(max)}$
= (2.125+0.598)
= 2.723A

Output Capacitor, C_o $= I_o*r_2/8*f_s*V_{o(ripple)}$

$= 0.57*0.2/8*500*0.1$

$= 280uF$

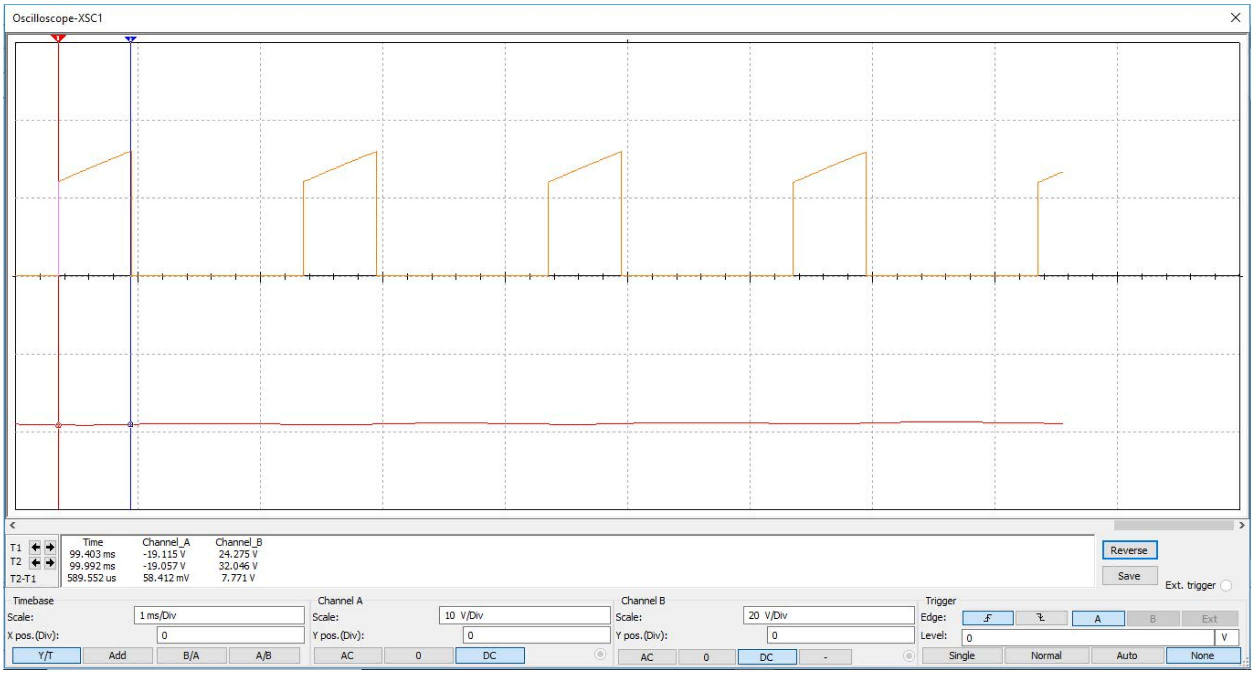


Fig.4.3: Output Voltage:19V Input Voltage:9.24V D=70%

Orange Curve:MOSFET Drain Source Voltage

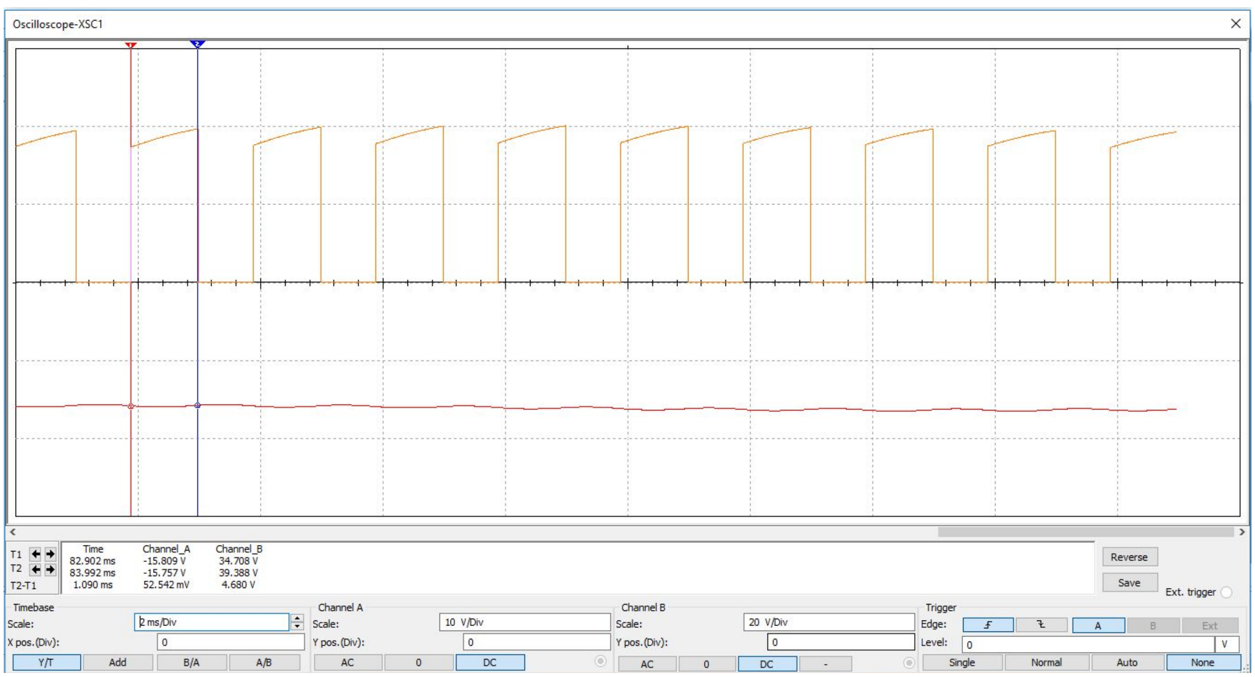


Fig.4.4: Output Voltage:17V Input Voltage:21V D=45%

Orange Curve:MOSFET Drain Source Voltage

3. MOSFET: IRFZ44N

The MOSFET switch requires 10V of gate-source voltage to reliably trigger. The output voltage from the pin of MSP430 is 3.3V. To provide the necessary voltage we utilise an inverting drive circuit. 9V battery is used to bias the BJT driver circuit.

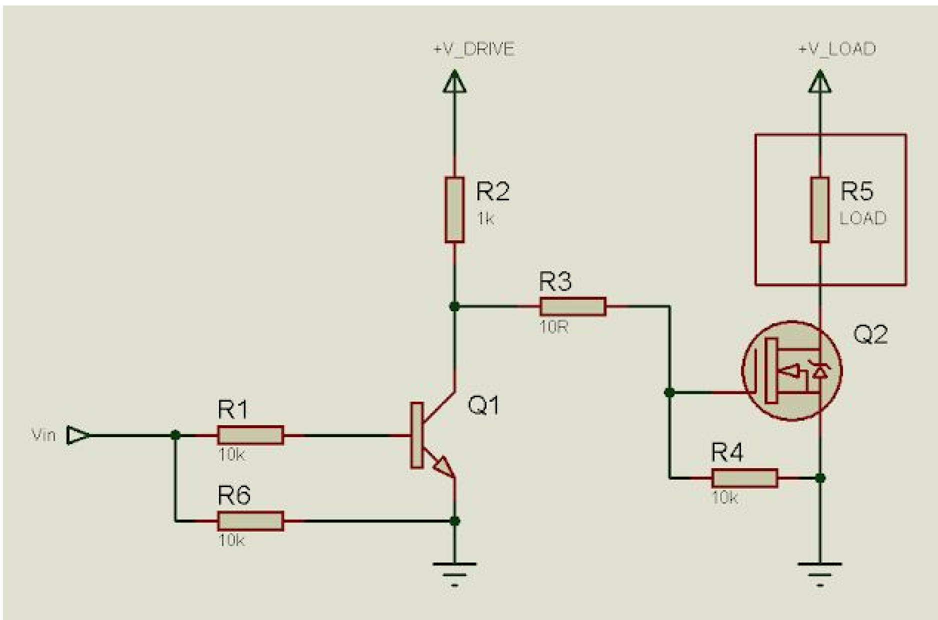


Fig.4.5: Current & Power vs Voltage of PV Array

SECTION V: TESTING

Software Implementation

For our project, it was chosen to implement the preliminary software simulation on MATLAB and Simulink, both of which are software widely used at the educational and industrial level. While Simulink allows for easy and user friendly modeling of otherwise complex circuits, MATLAB allows for even more customization via user-defined functions and an extensive Standard Library of functions. Thus, it was possible to focus on refining the simulation, and comparing between the chosen algorithms.

Simulation Overview

Simulink allows the user to model any circuit as a multitude of connected "blocks", which can be chosen from their vast library, or defined uniquely. The simulation circuit consisted of three basic subparts – one block to represent the PV module, one to act as a buck-boost converter for the input received from the PV module, and a final block to actually perform the MPPT algorithm. Aside from these, we had a dummy output resistor across which output was measured, and multiple display/scope blocks to observe the values of the individual components of the circuit. Each block is further talked about in detail below.

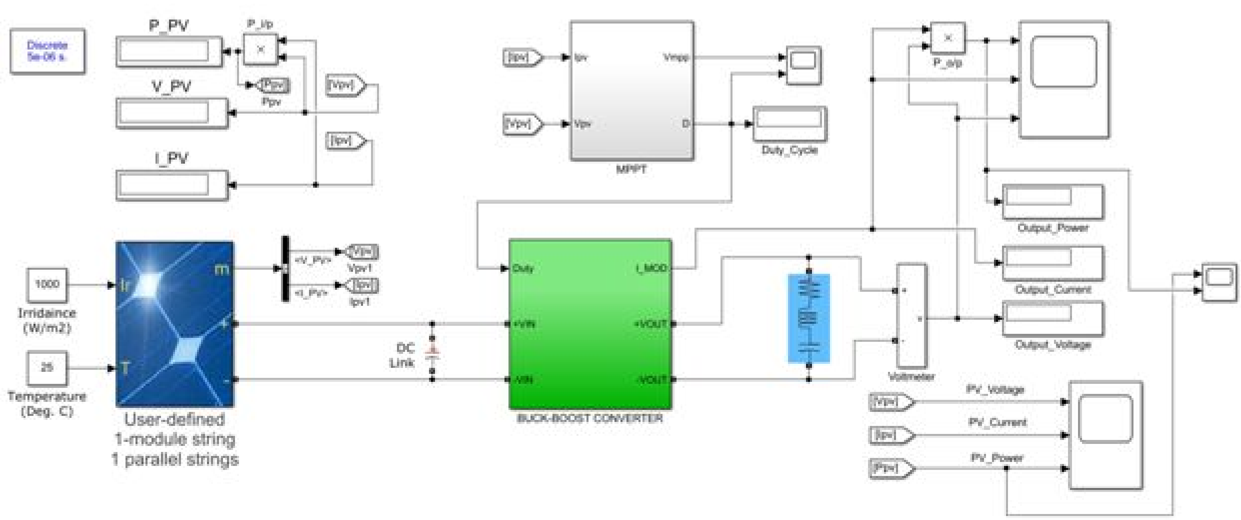


Fig.5.1: Simulation Circuit for MPPT setup

Modeling of Circuitry Blocks on Simulink

Modeling of the PV array

The Simulink "PV Array" block implements an array of photovoltaic (PV) modules. This block is available in their library. The array is built of strings of modules connected in parallel, each string consisting of modules connected in series. For this usage, only one individual module was used. However, multiple modules can be arranged in a cascade manner for higher output levels.

The PV Array block is a five parameter model using a current source I_L (light-generated current), diode (I_0 and n_I parameters), series resistance R_s, and shunt resistance R_{sh} to represent the irradiance – and temperature-dependent I-V characteristics of the modules. The PV Array block used in this case was user-defined, and based on the Sun Factory 10W 12V Standard Poly Crystalline Solar Panel Module, obtained commercially online.

The output of the PV module varies with parameters such as solar irradiance (G) and temperature (T) associated with the panel. This is in accordance with the true Power-vs-Voltage and Current-vs-Voltage characteristics of a PV module. Thus we also have a maximum power point which is to be tracked.

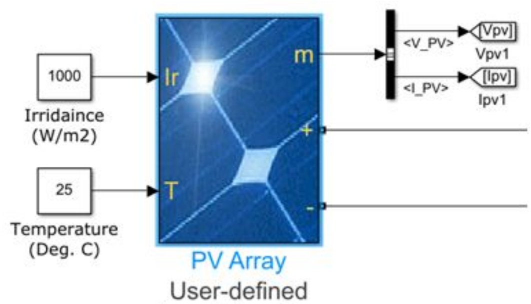


Fig.5.2: PV Array Simulink Block

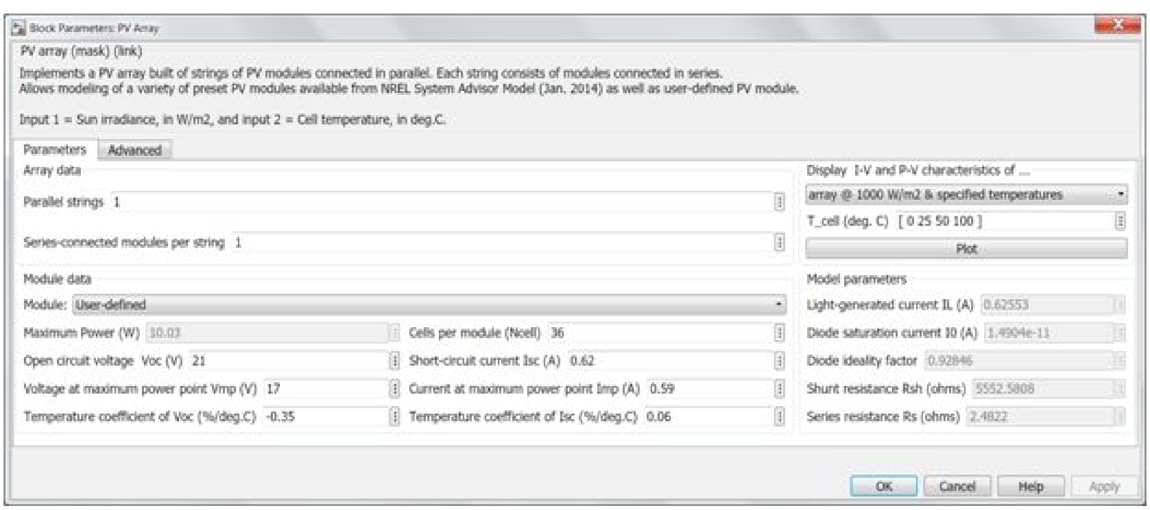


Fig.5.3: Modifiable Characteristics of PV Array Block

Modeling of the Buck-Boost Converter

The buck-boost controller block required for adjusting the input from the PV module and interfacing with the load has been implemented in Simulink within a single subsystem. The implementation has been achieved by selecting and routing the appropriate components as shown in the figure below. The values of the capacitors, the inductors, as well as the tolerance limits of the switching device and diodes have been calculated to suit the desired operating conditions.

The inputs to the defined subsystem are $+V_{in}$ and $-V_{in}$ (from the PV module), and Duty Cycle (from MPPT algorithm); while the outputs of the converter are $\pm V_{out}$ and I_{mod}. The switching element governs the output voltage and current based on the Duty Cycle input it receives from the MPPT algorithm. The output voltage and current from this block are further used to calculate net output power.

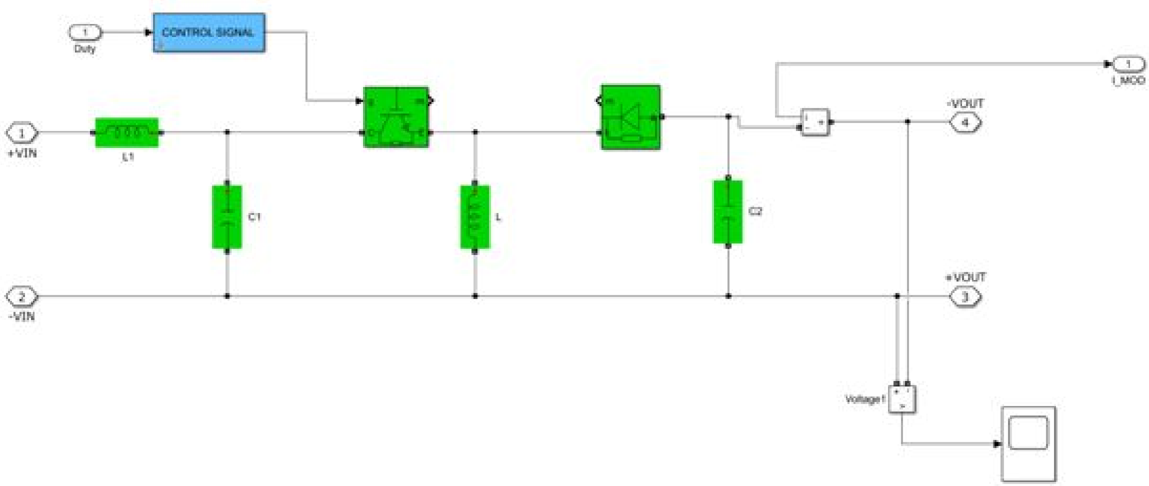


Fig.5.4: Buck-Boost Converter Implementation (Subsystem)

Modeling of the MPPT block

Among all the possible MPPT algorithms, the ones we have chosen to implement are the P&O and Adaptive methods, which have been discussed previously. Their Simulink implementations and simulation results are further discussed below.

Modeling of Perturbation and Observation Method

Similar to the buck-boost modeling, the P&O block was made as a subsystem. The inputs to this block are the input-side current (I_{pv}) and the input-side voltage (V_{pv}) taken directly from the PV module block. These inputs are sampled, and their product (input-side power) is found. The difference between the present and previous values of power and voltage are calculated, which are then used to determine whether their respective values have increased or decreased. This is used to modify the output Duty Cycle by either adding or subtracting a fixed step amount to it. Thus the tracking of power progresses with the Duty Cycle controlling the Buck-Boost block, and hence the output power by proxy.

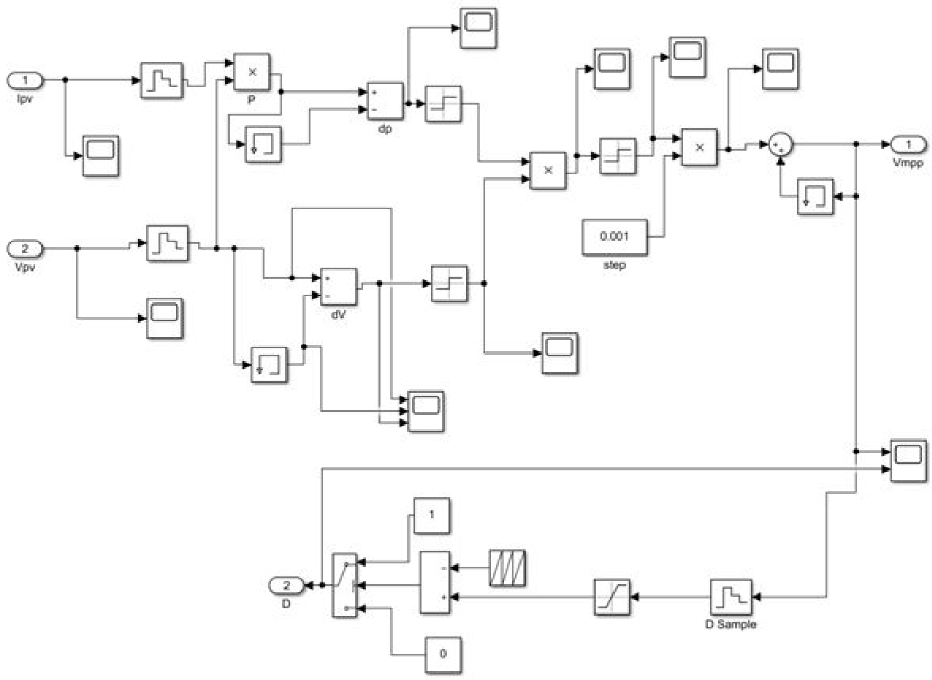


Fig.5.5: Perturb and Observe Implementation (Subsystem)

Modeling of Adaptive Perturb and Observation Method

For better tracking efficiency, Adaptive P&O method is preferred. Rather than implementing a Simulink equivalent as done for ordinary P&O, it was preferred to define a MATLAB function block. This block takes inputs and gives outputs similar to P&O, however the internal working is purely a MATLAB code function. This block takes current (I_{pv}) and voltage (V_{pv}) directly from the PV module block, as well as a clock cycle (that which the microcontroller provides). These inputs are sampled, and power is found. Again, the difference between the present and previous values of power and voltage are calculated, and it is determined whether their respective values have increased or decreased. Now, the (adaptive) step size is calculated for this iteration, and is used to modify the output Duty Cycle by either adding or subtracting to it. Thus the tracking of power progresses much more efficiently than ordinary P&O.

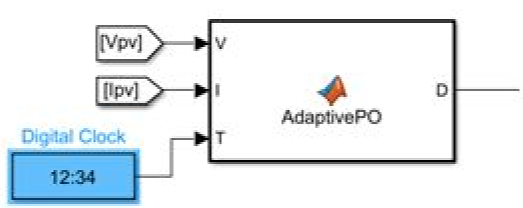


Fig.5.6: Adaptive P&O: MATLAB Function Block

MATLAB code for Adaptive P&O:

```
function D = AdaptivePO(V,I,T)
persistent exV exI exP Vref n dc

if isempty(V)
        V=0;
end
if isempty(I)
        I=0;
end
if isempty(exV)
        exV=0;
end
if isempty(exI)
        exI=0;
end
if isempty(exP)
        exP= 2.5;
end
if isempty(Vref)
        Vref= 1.5;
end
if isempty(n)
        n = 1;
end
if isempty(dc)
        dc = 0.5;
end
Pnow = 0;
delVref = 0;
M = 9;

%%%%%%%%%%%%%% Working %%%%%%%%%%%%%%%
if (T>n*0.001)
        n = n+1;
        Pnow = V * I;
        delP = Pnow- exP;
        delV = V - exV;
        delVref= M * (delP/(V - exV));

        if (delP > 0)
        if (delV > 0)
        Vref= Vref + delVref;
        else
        Vref = Vref - delVref;
```

```
        end
        else
        if (delV < 0)
        Vref= Vref + delVref;
        else
        Vref = Vref - delVref;
        end
        end

        dc= dc + ((Vref * M)/V);
        exV= V;
        exI= I;
        exP= exV * exI;
end
D = dc;
if D<0.1
        D=0.1;
else
        if D>0.9
        D=0.9;
        else
        end
end

end
```

Simulation Results

Perturbation and Observation (P&O) Method:

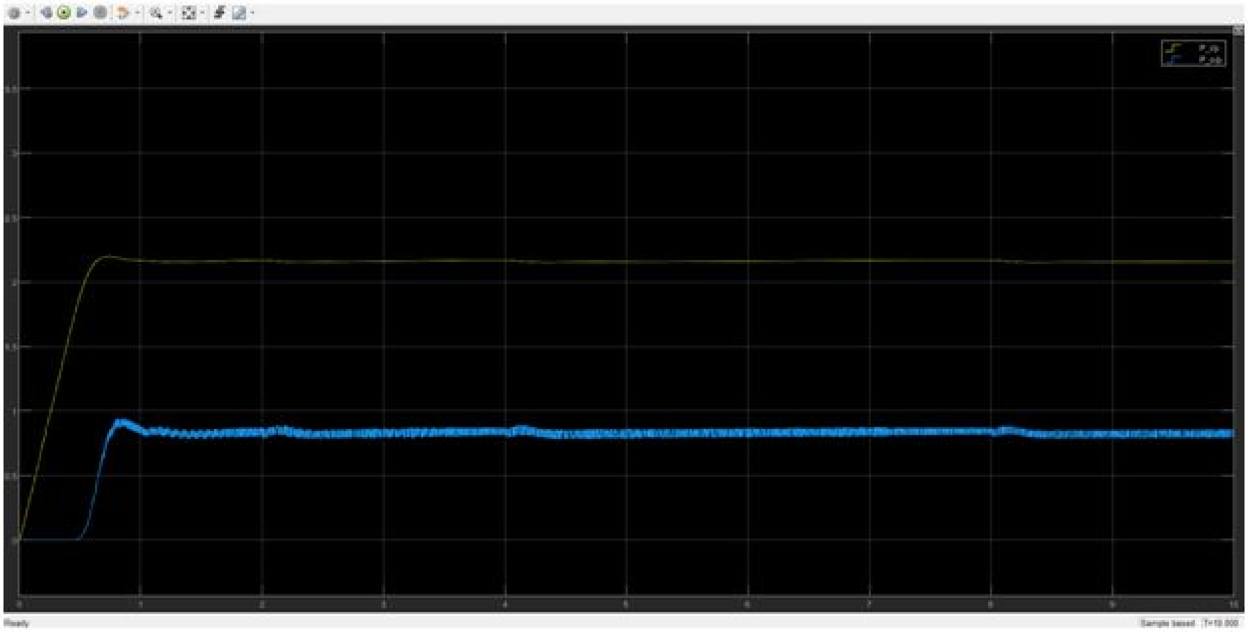


Fig.5.7: Input-side Power (yellow) and Output-side Power (blue) vs Time, for Perturb and Observe

Adaptive P&O Method:

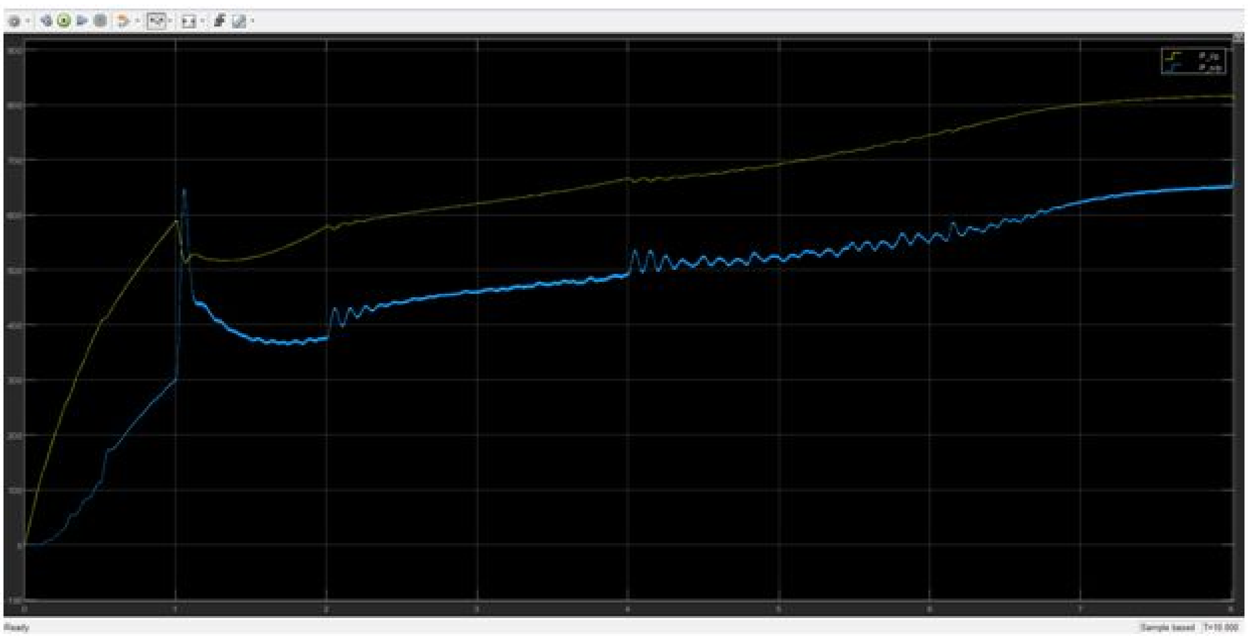


Fig.5.8: Input-side Power (yellow) and Output-side Power (blue) vs Time for Adaptive P&O

As seen from the above output plots, the output power is tracking the input power. This is evident from the fact that they have similar shapes. However, the Adaptive Method output power is closer to the input power than that of the ordinary P&O Method, which is an indication of better efficiency. By the reference [4], the improved efficiency in the adaptive technique is >96%.

SECTION VI: RESULTS AND OBSERVATIONS

1. A constant regulated voltage of 17V was maintained by supplying a viable duty cycle.
2. The prototype in its current stage requires 9V to function, this necessity can be overcome with the use of a Li ion Cell in the future.
3. The prototype size is minimal and can be adapted into a portable unit.
4. The Cuk converter (design calculations explained in Section 3) gives better output current than a buck-boost block.

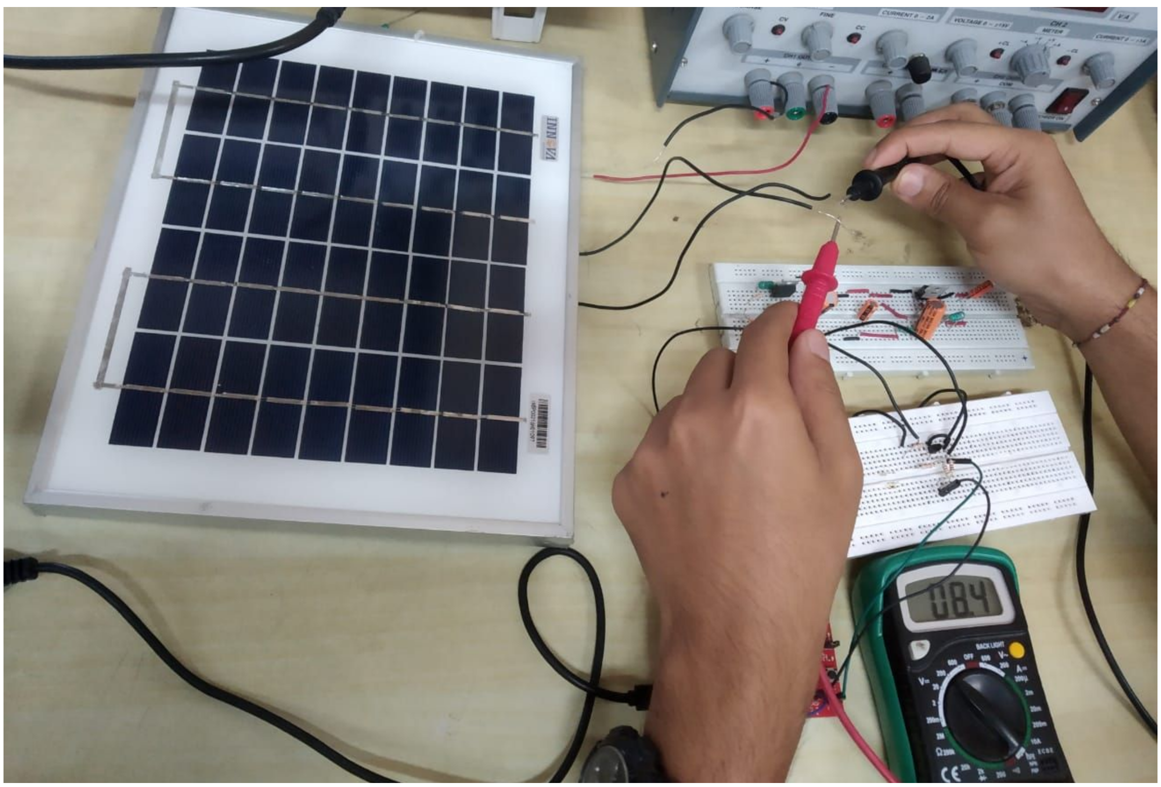


Fig.6.1: Output Voltage of PV module in ambient light

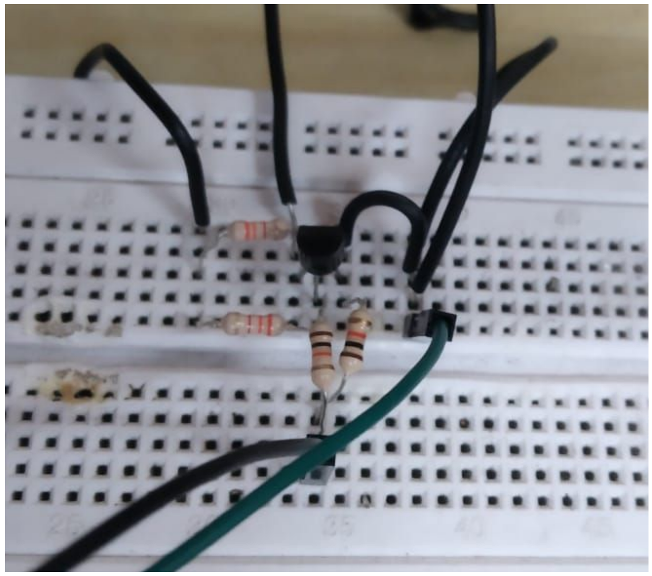


Fig.6.2: Driver circuit (PWM amplifier) with BJT

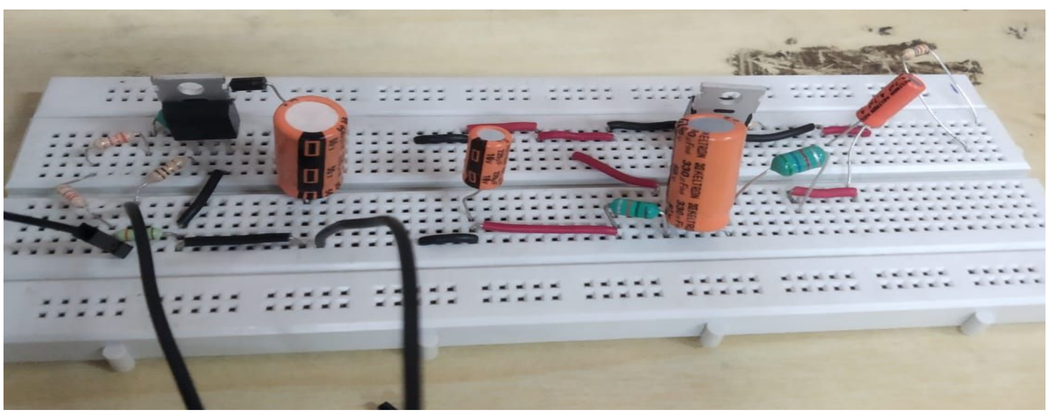


Fig.6.3:

Left Half: Boost circuit for ambient lighting conditions only

Right Half: Cuk Converter topology for full range of output

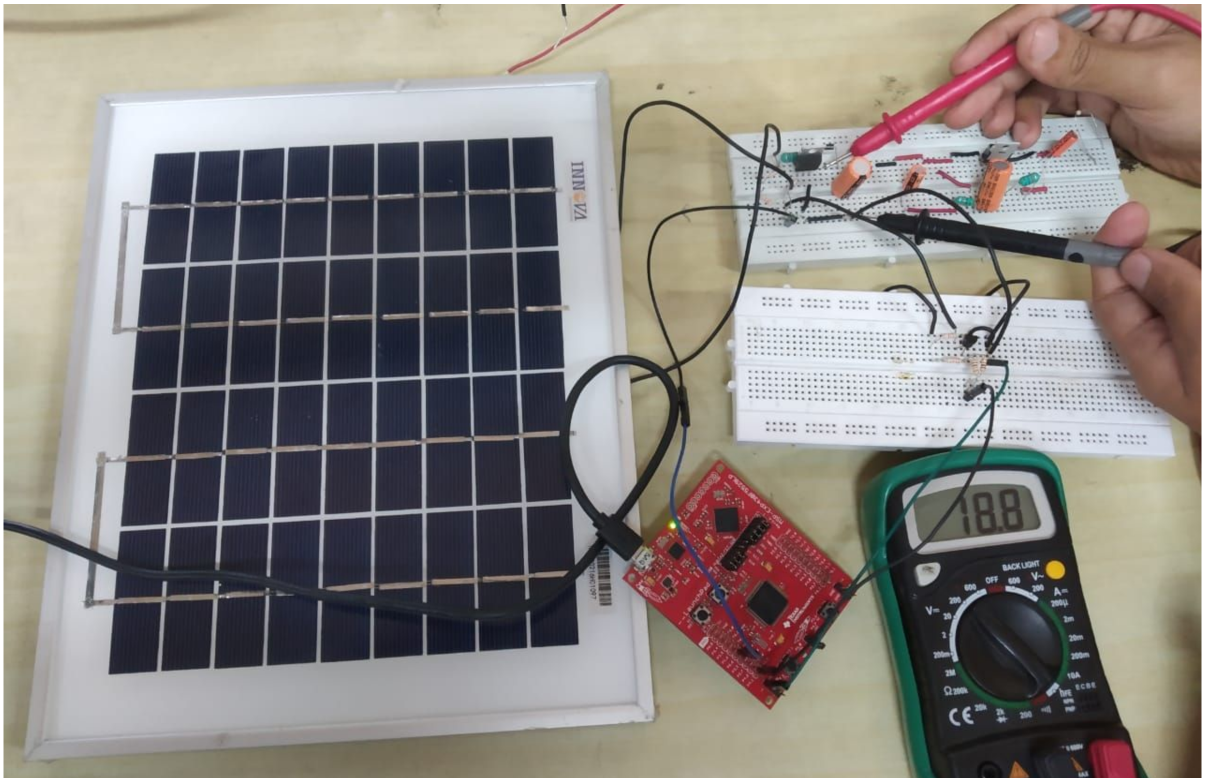


Fig.6.4: Output Reading (with Boost converter) in Ambient Light

SECTION VII:

CONCLUSIONS AND FUTURE SCOPE

After testing the Cuk converter with the Adaptive P&O algorithm, we arrived at the following conclusions:

a. The MPPT at room temperature (25-30 deg Celcius) is 17-19V and is being tracked consistently in moderate environments.

b. The adaptive model tracks the input curve closer than the simple P&O algorithm.

c. While the Cuk converter is being tested with MOSFET IRFZ44, there is need for driving circuit (Fig 5. 3). An alternative would be to use IRLZ44/ IRLZ530 (datasheet attached) that can be driven by the MCU directly. The use of the current switching MOSFET requires us to use a battery to bias the BJT (in the driver cct), which can be eliminated in areas that are energy deficient.

d. The 17-19V output can be used to charge two 5V batteries with the remaining power converted to current.

e. The entire module can be made into a self sufficient drive when power can be provided to the MSP continuously and reliably, ie, from the battery itself.

f. The loss of energy between input and output can be further improved by using circuits with higher frequency switching which is currently constrained by the MSP430 & Energia environment. Using a lower level coding will allow us to modulate the Timing control registers.

The possible proposals for future research work that assure further improvements in extension:

1. To improve the robustness of the PV system during environmental disturbances, fuzzy and neural controllers can be incorporated.
2. The present research work can be extended to multilevel inverters for AC appliances. This can be used in higher power grid connected systems as well.
3. The PV system with multilevel inverter based on fuzzy and neural controllers can be implemented through digital controllers.

SECTION VIII:

BIBLIOGRAPHY:

1. Singh, Prof Bharat Raj & Singh, Onkar. (2016). Future Scope of Solar Energy in India.. SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology. 8. 10.18090/samriddhi.v8i1.11408.

2. https://www.solarreviews.com/blog/grid-connect-solar-power-systems

3. Yong, Yang & Wen, Huiqing. (2018). Adaptive P&O MPPT with current predictive and decoupled power control for grid-connected photovoltaic inverters. Journal of Modern Power Systems and Clean Energy.

4. David Sanz Morales, Maximum Power Point Tracking Algorithms for Photovoltaic Applications

DATASHEETS:

1. TI MSP430F5529 Launchpad
   http://www.ti.com/document-viewer/MSP430F5529/datasheet/absolute-maximum-ratings-slas5906560#SLAS5906560

2. IRFZ44 (Switching MOSFET)
   https://www.vishay.com/docs/91291/91291.pdf

3. IRLZ44 (Logic level MOSFET)
   https://www.vishay.com/docs/91328/sihlz44.pdf

4. RHRP 3060 Hyperfast Diode
   https://www.onsemi.com/pub/Collateral/RHRP3060-D.PDF

5. 2N2222A Amplifier BJT
   https://www.onsemi.com/pub/Collateral/P2N2222A-D.PDF