PV System Simulation using Various Incremental Algorithms Applied in Maximum Power Point Tracking: A Comparative Study

M. Dev Anand, N. Ramasamy

Abstract--- ***Nowadays, PV plants have two main drawbacks, the high cost of cells production and their low energy conversion efficiency. Commercial modules are assembled with efficiency between 6 and 16% depending on their technology. Due to this poor efficiency, strongly dependent on solar radiation level and operating temperature, it is very important to achieve its maximum value. There are two main techniques to get good results. One is the use of electro-mechanical equipment. These equipments allow PV modules keep the best position to obtain the maximum solar-radiation level during the sunny interval of the day and are caller Solar Tracker. The other method is the use of control techniques, applied to a switching converter, that force the module to operate in the optimal operating point, that it's the Maximum Power Point Tracking (MPPT). The requirements of implementing maximum performance of a photovoltaic system are not only good weather conditions, but also with the appropriate MPPT method. If there is a good irradiance condition, the photovoltaic system can generate maximum power efficiently while an effective MPPT algorithm is used with the system. MPPT techniques considered for this project are fixed-step Incremental conductance, variable-step incremental Conductance and Variable Step size incremental Resistance. A lot of MPPT algorithms have been developed by researchers and industry delegates all over the world. In order to compare the accuracy and efficiency of the three MPPT algorithms selected in this work, The PV simulation system used in this workis set up under Matlab/Simulink environment. The model of PV modules used in PV simulation system is established according to the electrical specifications of the PV module. After accomplishing the model of PV modules, the models of DC-DC Cuk converter and MPPT systems are combined with it to complete the PV simulation system with the MPPT function. The accuracy and execution efficiency of each MPPT algorithm can be obtained by simulating them under different temperature.***

I. INTRODUCTION

The rapid increase in the demand for electricity and the gross changes in the environmental conditions such as global warming led to a need for a new source of energy that is cheaper and cause less pollution. Solar energy has offered promising results in the quest of finding the solution to the problem. The harnessing of solar energy using PV modules comes with its own problems that arise from the change in insulation conditions. These changes in insulation conditions severely affect the efficiency and output power of the PV modules. With free solar energy available, cutting down on electrical bills on industrial and home seems a possibility in the near future as the photovoltaic conversion into electrical energy. Large scale solar energy systems are being tested and might even be implemented in the coming years to cut down the emission of CO_2. Demand for photovoltaic energy will increase over the years as the breakthrough inthis new technology will sustain it at a lower cost. Solar cells are being seen as the fundamental power conversion unit of a photovoltaic system.Photovoltaic (PV) technology involves converting solar energy directly intoelectrical energy by means of a solar cell. A solar cell is typically made of semiconductor materials such as crystalline silicon. It will absorb sunlight and produces electricity through a process called the photovoltaic effect. The efficiency of a solar cell is determined by its ability to convert available sunlight into usable electrical energy and is typically around 10%-15%. Therefore, to produce significant amount of electrical energy, the solar cells must have large surface area. Certain appliances can be plug or connected directly as they operate on the dc level. Some devices might only work with a voltage adapter to adjust the voltage to make it useable or design it as an inverter to boost up the voltage and change it from dc to ac form. For the high power applications, it can be attained by using the parallel connected converters for electrical power. Temperature fluctuation, isolation and array voltage are important considerations in solar arrays power and hence it is necessary to draw out the peak voltage or maximum power of the solar array.

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II. PHOTOVOLTAIC CELL

2.1. History of Photovoltaic Cell

The solar panels or solar cells are devices that absorb the sunlight energy and convert the light energy into electricity. The PV cells or solar cells use the photovoltaic effect to store the solar energy which induces the current to flow between two opposite charge layers. The conversion efficiency of a solar cell is derived as the ratio of the solar energy that shines onto the cell and divided by the electrical energy output by the cell. The earliest PV device was invented in 1839, by the French physicist Edmond Becquerel, who was the first person who describes the effect of photovoltaic. Certain materials were found to produce electric current when they were exposed to the sunlight. The first material was tested by Heinrich hertz in the 1870s using a material called "selenium".

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These selenium photovoltaic cells only had an efficiency of one to two percent. During the 1940s and 1950s, photovoltaic cells was developed using the Czochralski process to come out with the crystalline silicone photovoltaic such that the efficiency improve to six percent. As of today, PV devices can give an efficiency of 7 to 17 percent conversion from light energy into electrical energy. The basic block diagram for MPPT is shown in Figure1.

2.2. Photovoltaic Cell Model Characteristic

The PV cells have the non-linear properties due to the semiconductor structure within the cells. The equivalent electrical circuit of an ideal solar cell can be treated as a current source parallel with a diode shown in Figure1.

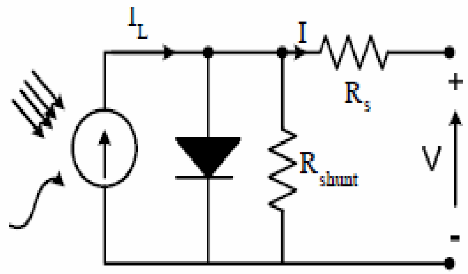

Figure 1: Circuit Diagram of Photovoltaic Cell

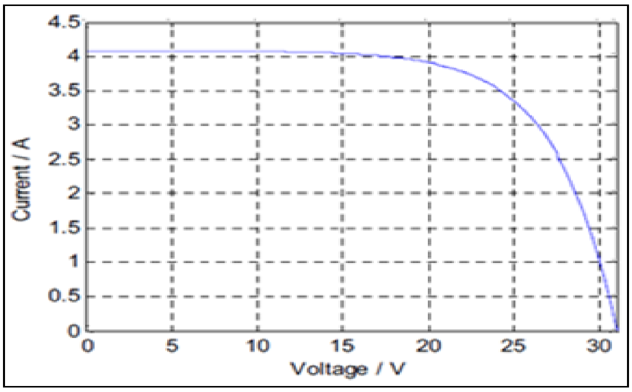

Figure 3: VI Characteristics of PV Cell

The (V-I) characteristics of solar cell is shown below in Figure2. The current will increases when the irradiance levels increase too. Therefore the maximum power point occurs at the highest peak point of the slope.Higher temperatures will show a reduction of the maximum PV power and the voltage at the peak point. The output current of PV cells is proportional to the state of irradiation and has been given in Figure3. By using a MTTP controller, the PV cell is efficiently utilized under changing atmospheric conditions.

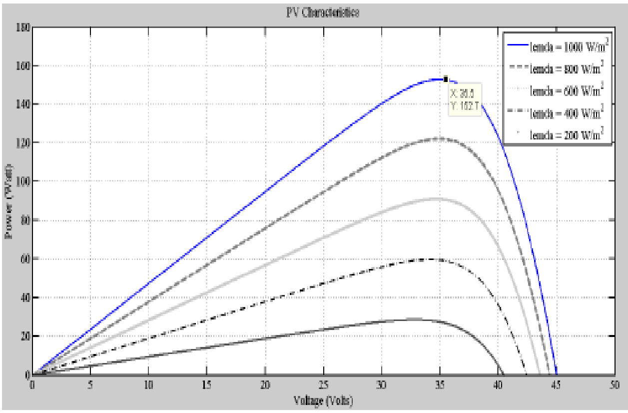

Figure 1: PV Characteristics of Photovoltaic Cell

The V-I characteristics of the equivalent solar cell circuit can be determined by following equations.

The current through diode is given by:

$$ID = IO\,[\exp (q\,(V + I\,RS)/KT)) - 1](1)$$

While, the solar cell output current:

$$I = IL - ID - Ish$$

$$I = IL - IO\,[\exp (q\,(V + I\,RS)/KT)) - 1] - (V + IRS)/\,Rsh$$

Where:

I: Solar cell current (A)

IL: Light generated current (A) [Short circuit value assuming no series/ shunt Resistance]

IO: Diode saturation current (A)

q: Electron charge ($1.6\times10\text{-}19$ C)

K: Boltzman constant ($1.38\times10\text{-}23$ J/K)

T: Cell temperature in Kelvin (K)

V: solar cell output voltage (V)

Rs: Solar cell series resistance (Ω)

Rsh: Solar cell shunt resistance (Ω)

III. MAXIMUM POWER POINT TRACKING METHODS

Since the photovoltaic array usually relies on the performance of isolation, temperature and cell voltage, maximum power point tracking is important in extracting the maximum available power form the arrays. Many MPPT methods have been proposed and discussed in the past years. So far the most common and recent incremental methods to achieve MPPT are by (1) fixed Incremental conductance method, (2) Variable step Incremental conductance and (3) Variable and fixed step Incremental resistance method. The incremental conductance method may perform well under fast changing atmospheric conditions, but it required at least four sensors for computation purpose. The basic block diagram for MPPT is shown in Figure 4.

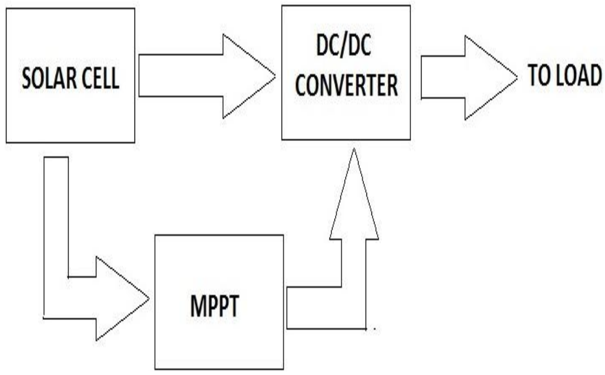

Figure 4: Basic Block Diagram of MPPT

3.1. Incremental Conductance Method INC (Fixed Step Size)

This method works by using the slope of the derivative of the current with respect to the voltage so as to obtain the maximum power point. The dI/dV must be equal to –I/V as shown in Figure 5.

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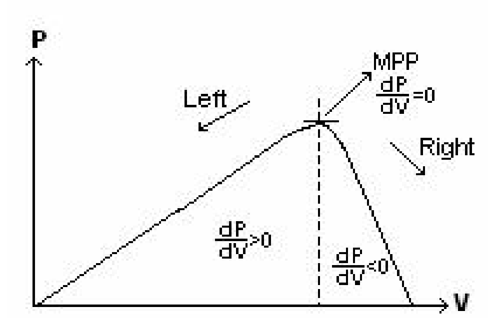

Figure 2: Incremental Conductance Method

When the voltage is at its largest or smallest value, if there is variation being applied, the power value will be affected. Hence, to increase power, the voltage can be applied in the same direction, if not, in the opposite direction. This method has a higher accuracy than the P&O as it can track rapidly increasing and decreasing irradiance conditions. Oscillations can also occurs in this MPP due to noise and errors, increasing computational time and slower sampling frequency from the algorithm. The slope of the PV array powercurve is zero at the MPP, positive on the left of the MPP, and negative on the right, as given by;

$\frac{dP}{dV}$= 0, at MPP

$\frac{dP}{dV}$> 0, left of MPP(3)

$\frac{dP}{dV}$< 0, right of MPP.

Since

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} \cong I + V\frac{\Delta I}{\Delta V} \quad (4)$$

Equation (1) can be rewritten as

$\Delta I/\Delta V = -I/V$, at MPP

$\Delta I/\Delta V > -I/V$, left of MPP(5)

$\Delta I/\Delta V < -I/V$, right of MPP

The MPP can thus be tracked by comparing the instantaneous conductance (*I/V*)to the incremental conductance ($\Delta I/\Delta V$) as shown in the flowchart given in Figure 6. *Vref*is the reference voltage at which the PV array is forced to operate. At the MPP, *Vref* equals to *VMPP*. Once the MPP is reached, the operation of the PV array is maintained at this point unless a change in ΔI is noted, indicating a change in atmospheric conditions and the MPP. The algorithm decrements or increments *Vref*to track the new MPP.The increment size determine how fast the MPP is tracked. Fast tracking can be achieved with bigger increments but the system might not operate exactly at the MPP and oscillate about it instead; so there is a tradeoff. A method is proposed to bring the operating point of the PV array close to the MPP in a first stage and then uses IncCond to exactly track the MPP in a second stage. By proper control of the power converter, the initial operating point is set to match a load resistance proportional to the ratio of the open-circuit voltage (*VOC*) to the short-circuit current (*ISC*) of the PV array. This two-stage alternative also ensures that the real MPP is tracked in case of multiple local maxima. A linear function is used to divide the *I–V* plane into two areas, one containing all the possible MPPs under changing atmospheric conditions. The operating point is brought into this area and then IncCond is used to reach the MPP. A less obvious, but effective way of performing the IncCond technique is to use the instantaneous conductance and the incremental conductance to generate an error signal

$$e = \frac{I}{V} + \frac{dI}{dV} \quad (6)$$

From (1), it's known that e goes to zero at the MPP. A simple proportional integral (PI) control can then be used to drive e to zero. Measurements of the instantaneous PV array voltage and current require two sensors.

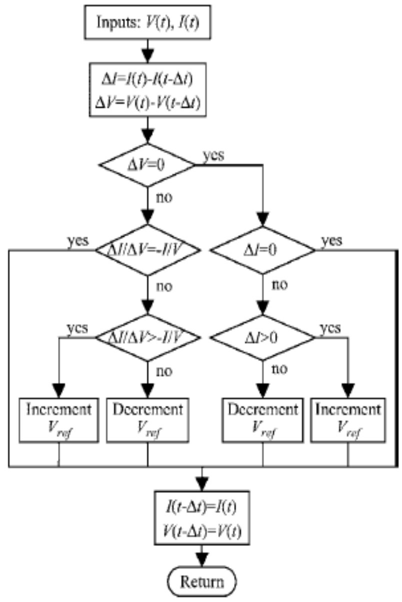

Figure 3: INC Algorithm (Fixed Step Size)

3.2. Variable Step Size INC MPPT Method

The step size for the INC MPPT method is generally fixed. The power drawn from the PV array with a lager step size contributes to faster dynamics but excessive steady state oscillations, resulting in a comparatively low efficiency. This situation is reversed while the MPPT is running with a smaller step size. Thus, the MPPT with fixed step size should make a satisfactory tradeoff between the dynamics and oscillations. Such design dilemma can be solved with variable step size iteration. In this project, modified variable step size algorithm for the INCMPPT method which is dedicated to find a simple and effective way to improve tracking accuracy as well as tracking dynamics are used.

In most applications, the MPP tracker is achieved by connecting a dc-dc converter between the PV array and load. The PV output power is used to directly control the power converter duty cycle to reduce well the complexity of the system. The flowchart of the modified variable step size INC MPPT algorithm is shown in Figure7, where the converter duty cycle iteration step size is automatically tuned. The PV output power is employed to directly control the converter duty cycle, contributing to a simplified control system. Note that V (k) and I (k) are the PV array output voltage and current at time k. In addition, D (k) and step are the duty cycle and change of duty cycle (step size), respectively. The variable step size adopted to reduce the problem mentioned above is shown as follows:

$$D(k) = D(k-1) \pm N * \left|\frac{dP}{dV}\right| \quad (7)$$

Where coefficient N is the scaling factor which is tuned at the design time to adjust the step size.

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The variable step size can also be realized from the slope of the P–D curve in for P&O MPPT as

$$D(k) = D(k-1) \pm N * \left|\frac{\Delta P}{\Delta D}\right| \quad (8)$$

Where $\Delta D$is the step-change in duty cycle in the previous sampling period. The derivative of power to voltage (*dP/dV)*of a PV array can be employed herein to determine the variable step size for the INC MPPT algorithm. The update rule for duty cycle can be obtained as follows:

$$D(k) = D(k-1) \pm N * \left|\frac{P(K)-P(K-1)}{V(K)-V(K-1)}\right| \quad (9)$$

Scaling factor *N* essentially determines the performance of the MPPT system. Manual tuning of this parameter is tedious and the obtained optimal results may be valid only for a given system and operating condition. A simple method to determine the scaling factor is proposed here. Comparatively large step size ΔDmaxfor fixed step size MPPT operation is initially chosen. With such value, the dynamic performance is good enough, while the steady-state performance may not be satisfactory. The steady-state value instead of dynamic value in the startup process of the derivative of PV array output power to voltage can be evaluated under the fixed step size operation with ΔDmax, which will be chosen as the upper limiter as the variable step size INC MPPT method. It is known that $|dP|/|dV|$ is almost at its lowest value around the PV MPP. To ensure the convergence of the MPPT update rule, the variable step rule must obey the following:

$$N * \left|\frac{dP}{dV}\right| \text{fixed step} = \Delta D_{max} < \Delta D_{max} (10)$$

Where$|(dP/dV)|$fixed step=ΔDmax is the $|dP|/|dV|$ at fixed step size operation of ΔDmax. The scaling factor can therefore be obtained as

$$N < \Delta D\text{max} / \left|\frac{dP}{dV}\right| \text{fixed step} = \Delta D\text{max} (11)$$

If the above equation cannot be satisfied, the variable step size INC MPPT will be working with a fixed step size of the previously set upper limiter ΔDmax. Above equation provides a simple guidance to determine the scaling factor *N* of the variable step size INC MPPT algorithm. With the satisfaction of above equation, larger *N* exhibits a comparatively faster response than a smaller *N*. The step size will become tiny as *dP/dV*becomes very small.

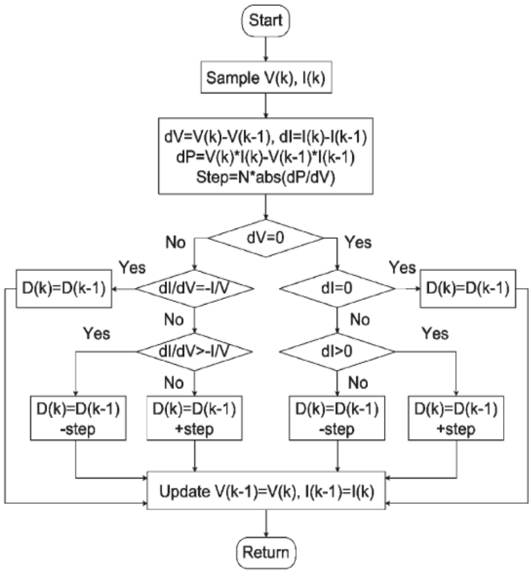

Figure 4: INC Algorithm (Variable Step Size)

3.3. Variable Step-Size INR MPPT Algorithm

The step size for the INC MPPT determines how fast the MPP is tracked. Fast tracking can be achieved with bigger increments, but the system might not run exactly at the MPP but instead oscillate around it; thus, there is a comparatively low efficiency. This situation is inverted when the MPPT is operating with a smaller increment. Therefore, a satisfying tradeoff between the dynamics and oscillations has to be made for the fixed step-size MPPT. The variable step-size iteration. The derivative of power to voltage (*dP/dV)*of a PV array was introduced as a suitable parameter for regulating the variable increment for the INC MPPT algorithm in.The derivative of power to current (*dP/dI*) as shown in Fig. 8, is employed to determine the variable increment for the INR MPPT algorithm which has a duality relation with the INC MPPT.

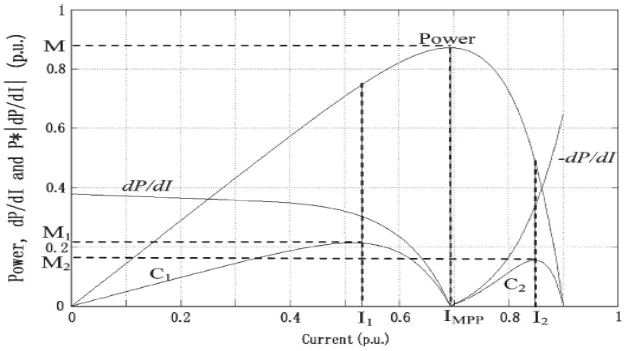

Figure 5: Slope of Power Vs Current for INR

The variable step-size method introduced to solve the problem discussed earlier is given as follows:

$$D(k) = D(k-1) \pm N * \left|\frac{dP}{dV}\right| = D(k-1) \pm N * \left|\frac{P(k)-P(k-1)}{V(k)-V(k-1)}\right| (12)$$

Where *D* (*k*) is the duty cycle and coefficient *N* is the scaling factor adjusted at the sampling period to regulate the step size. In addition, the step size is the change of duty cycle. The variable step-size algorithm can also be implemented according to the slope of the P–D curve for P&Q MPPT as

$$D(k) = D(k-1) \pm N * \left|\frac{\Delta P}{\Delta D}\right| (13)$$

Where ΔD is the step variety of the duty cycle in the former sampling period. The performance of the MPPT system is essentially decided by the scaling factor *N* for the variable step-size MPPT algorithm. Manual adjusting of this parameter is slow and tedious, and the acquired optimal values may be just suitable for a given system and certain operating conditions. A simple method is to determine the scaling factor. To guarantee the convergence of the MPPT update rule, the variable step rule must meet the following inequality:

$$N * \left|\frac{dP}{dV}\right| < \Delta D\text{max} (14)$$

Where ΔDmaxis the largest step size for fixed step-size MPPT operation and is chosen as the upper limit for the variable step size INC MPPT method. Therefore, the scaling factor can be obtained as

$$N < \Delta D\text{max} / \left|\frac{dP}{dV}\right| (15)$$

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Equation (15) provides a simple guidance to determine the scaling factor N of the variable step-size INCMPPT algorithm. If equation (15) cannot be satisfied, the variable step-size INC MPPT will be working with a fixed step size ΔDmax. However, the fixed scaling factor decided by this simple way cannot satisfy the requirement of the MPPT system while irradiation or temperature condition is varying enormously or quickly. The scaling factor N almost cannot make the system realize the variable step size MPPT algorithm for $P1$ because $\Delta D\max/N$ ($>|dP/dV|$) is so small that the fixed step size ΔDmaxis too large to make the following step size within the variable step-size range.

In this project, an improved variable step-size algorithm for the INR MPPT method is used and is devoted to obtain a simple and effective way to ameliorate both tracking dynamics and tracking accuracy. The primary difference between this algorithm and the others is that the step-size modes of the INR MPPT can be switched by extreme values/points of a threshold function which is the product (C) of the exponential of the PV array output power (P^n) and the absolute value of the PV array power derivative ($|dP/dI|$) as

$$C = P^n * |dP/dI| \quad (16)$$

Where n is an index. The product of the first-degree exponential (n = 1) of the PV array power (P) and its derivative ($|dP/dI|$) is applied to control the step size for the INR MPPT. The product curve has two extreme values/points ($M1$ and $M2$) corresponding to two current values ($I1$ and $I2$) at the two sides of MPP. The INR MPPT is in the variable step-size mode when the PV array output current is between I1and $I2$. Otherwise, it is in the fixed step-size mode.

The aforementioned idea can be formulated by

$\Delta C/\Delta I \geq 0$, fixed variable step-size mode (left of MPP)
$\Delta C/\Delta I < 0$, Variable step-size mode (left of MPP)
$\Delta C/\Delta I > 0$, *Variable* step-size mode (right of MPP)
$\Delta C/\Delta I \leq 0$, *fixed* variable step-size mode (right of MPP)

Where$\Delta C/\Delta I$ is the increment of the threshold function. The fixed and variable step-size modes are thus switched by above expression which will determine the response speed and the stable-state performance for the variable step-size INR MPPT method. The two extreme points of the threshold function are closing to the peak power point as the index n becomes larger. Thus, the larger the index n is, the faster the system response is, and vice versa. Moreover, in theory, this method adapts to almost all irradiation or temperature conditions. With index n = 3, the threshold-function curves under different ambient conditions .Furthermore, the proposed variable step-size INR method is also based on the fact that the slope of the PV array power curve is zero at the MPP, positive at the left of the MPP, and negative at the right, as given by

$dP/dI = 0$, at MPP
$dP/dI > 0$, left of MPP(17)
$dP/dI < 0$, right of MPP.

Since

$$\frac{dP}{dI} = \frac{d(IV)}{dI} = V + I\frac{dV}{dI} \cong V + I\frac{\Delta V}{\Delta I} \quad (18)$$

Above equation can be rewritten as

$\Delta V/\Delta I = -V/I$, at MPP
$\Delta V/\Delta I > -V/I$, left of MPP (19)
$\Delta V/\Delta I < -V/I$, right of MPP.

The MPP can thus be tracked by comparing the instantaneous resistance (V/I) with the INR ($\Delta V/\Delta I$), as shown in the flowchart. Irefis the reference current at which the PV array is forced to operate. At the MPP, Irefis equal to IMPP. Once the MPP is reached, the operation of the PV array is maintained at this point unless a change in ΔV is noted, indicating a change in atmospheric conditions at the MPP. The algorithm decreases or increases Irefto track the new MPP. The PV array output power is employed to directly control the converter output current reference which is also the output current reference of the PV array, contributing to a simplified control system. $V(k)$, $I(k)$, and $C(k)$ are supposed to be the PV array output voltage, current, and the proposed threshold function at time k. In addition, Iref(k) and ΔIref(k) are the output current reference and its change (step size) at time $r$espectively.

A scaling factor N was applied to ensure the convergence of the variable step-size MPPT algorithm which produces a dead band. To avoid the dead band mentioned earlier for the scaling factor, a novel and simple method is proposed to realize the variable step size and make the INR MPPT system convergent in this paper. As shown in Fig. 9, $dP/dI$is the slope of power versus current, and $|dP/dI|$ can be expressed as;

$|dP/dI| = |\tan\theta|, -90^\circ < \theta < 90^\circ$

Since

$\sin\theta = \tan\theta/1 + \tan 2\,\theta.$

Thus

$0 < \sin\theta = |dP/dI|/\sqrt{1 + |dP/dI|^2} < 1$

Comparatively, the large step size (ΔIref) max is initially selected for the fixed step-size MPPT operation. With such a value, the steady-state performance may be unsatisfactory, while the dynamic performance is fairly good. With (ΔIref max chosen as the upper limit for the variable step-size INR MPPT method,the variable step rule can be given by

$Sk = (\Delta I\text{ref})\max * \sin\theta k$, $k = 0, 1,$
$Sk = (\Delta I\text{ref})\max * \sin\theta k < (\Delta I\text{ref})\max$

Where Sk ($k = 0, 1, \cdots$) is the variable step-size at time k. Function above provides a simple and effective variable step size algorithm. The step size Skwill become very tiny as sin θk becomes very small around the MPP. For the left side of MPP, if $\Delta C/\Delta I \geq 0$, the proposed variable step-size INR MPPT will be working with the fixed step size which is the previously set upper limit (ΔIref)max, and if $\Delta C/\Delta I < 0$ in satisfaction of above function, the system will operate in variable step size mode. For the right side of MPP, the situation is reverse.

IV. DC-DC CONVERTER

A dc/dc converter serves the purpose of transferring maximum power from the solar PV module to the load. A dc/dc converter acts as an interface between the load and the module. DC-DC Converter which I used in this project is CUK Converter.

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4.1. CUK Converter

The Ćuk converter is named for Slobodan Ćuk of the California Institute of Technology. It is the result of applying the duality principle to the buck-boost converter to use a capacitor instead of an inductor as the primary energy storage device.

Circuit operation can be divided in to two modes. In Mode1- transistor is ON and current through inductor L1 rises, at the same time voltage of the capacitor C1 reverse biases diode and turn it off. The capacitor C1 discharges its energy to the circuit formed by C1, C2 the load and L2. In mode2 transistor is off, the capacitor C1 is charged from the input supply and the energy stored in the inductor L2 is transferred to the load. The diode and transistor provide synchronous switching action. The capacitor C1 is the medium for transferring energy from the source to load. Assuming that the current of inductor L1 rises linearly in time t1.

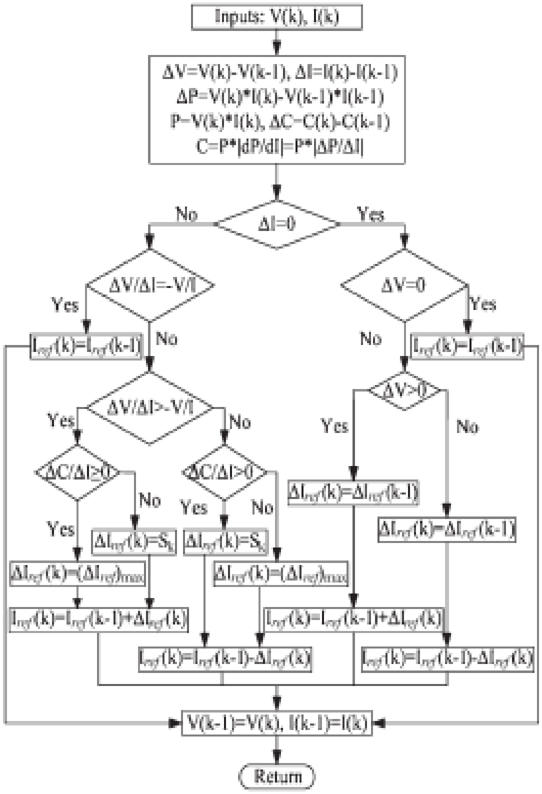

Figure 6: Incremental Resistance Algorithm

$$Vs = L1\frac{\Delta I1}{t1} \qquad (20)$$

and due to the charged capacitor C1, the current in inductor L1 falls in time t2

$$Vs - Vc1 = -L1\frac{\Delta I1}{t2} \qquad (21)$$

The average voltage of capacitor C1,

$$Vc1 = Vs/(1-D) \qquad (22)$$

The average output voltage

$$Va = \frac{DVs}{1-D} \qquad (23)$$

The switching period T can be found by

$$T = \frac{1}{f} = \frac{-\Delta I1 L1\, Vc1}{Vs(Vs - Vc1)} \qquad (24)$$

An advantage of the Ćuk converter topology is that the current pulsing occurs within the converter itself and both the input and output currents are not pulsed. Furthermore, if integrated magnetics are used, the input or output current can (theoretically) be nullified as the ripple is transferred to the other side of the converter. Because only one capacitor suffers the losses associated with (internal) current pulsing, the Ćuk converter is more efficient than a filtered Buck-Boost converter.

The voltage across the primary energy transfer capacitor is the sum of the input and output voltages in the Ćuk converter, but the difference between them in the SEPIC. This means that a lower capacitance can be used in the Ćuk converterwhile maintaining continuous electrification, but that a lower voltage capacitorcan be used in the SEPIC. The specific application will determine which is ofgreater value.Ćuktopology should be used, because it maintains continuous input and output current (requiring less filtering and thus leading to greater efficiency and controllability. With switching period of T and duty cycle of D is considered. During the continuous conduction mode of operation, the state space equations are as follows; these equations are implemented in Simulink.

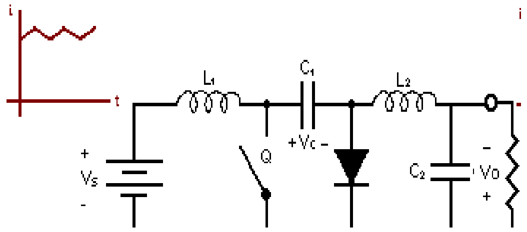

Figure 7: CUK Converter Circuit Representation with Input and Output Current Waveform

$$\begin{cases} \dfrac{di_{L1}}{dt} = \dfrac{1}{L_1}(v_{in}) \\ \dfrac{dv_c}{dt} = \dfrac{1}{C_2}(-i_{L2}) \\ \dfrac{di_{L2}}{dt} = \dfrac{1}{L_2}(-v_o + v_c) \\ \dfrac{dv_o}{dt} = \dfrac{1}{C_1}(i_{L2} - \dfrac{v_o}{R}) \end{cases} , \quad 0 < t < dT \quad , \quad Q:ON$$

When the switch is OFF the state space equations are represented by

$$\begin{cases} \dfrac{di_{L1}}{dt} = \dfrac{1}{L_1}(v_{in} - v_o) \\ \dfrac{dv_c}{dt} = \dfrac{1}{C_2}(i_{L1}) \\ \dfrac{di_{L2}}{dt} = \dfrac{1}{L_2}(-v_o) \\ \dfrac{dv_o}{dt} = \dfrac{1}{C_1}(i_{L2} - \dfrac{v_o}{R}) \end{cases} , \quad dT < t < T \quad , \quad Q:OFF$$

V. BATTERY

In photovoltaic systems, battery is needed to replace functional of PV array when PV array cannot be functional or at night and cloudy day. Battery or storage battery can be divided into two categories, primary and secondary battery.

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Primary battery is the battery that can store and deliver electrical energy, but cannot be recharged. While secondary battery can store and deliver electrical energy and also can be recharged. Thus, PV system uses secondary battery. The major functions of a storage battery in a PV system are:

a. Energy Storage Capacity
b. Voltage and Current Stabilization:
c. Supply Surge Currents

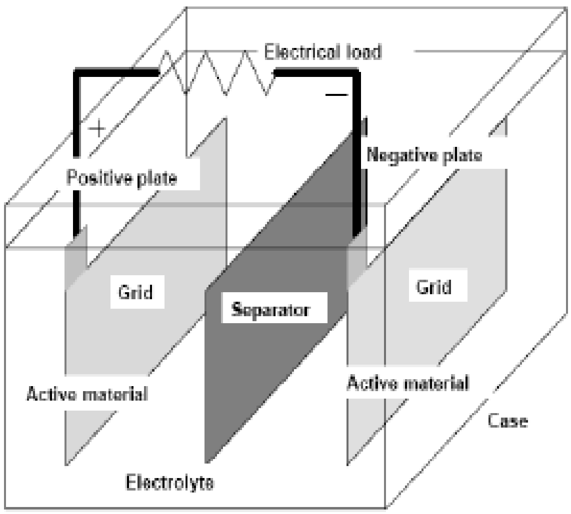

Figure 8: Battery Cell Composition

There are two types of battery, primary and secondary. Primary battery can store and deliver electricity. But it cannot be recharged and not used in PV system. While, secondary battery can store and deliver electricity. It can also be recharged by passing current through it in opposite direction to the discharge current. Several types of batteries of importance to PV systems designers are floodedlead-acid (PbH2), captive electrolyte lead-acid (VRLA) and nickel-cadmium (NiCd). The requirements for an effective battery for a photovoltaic system include:

1. Low self-discharge
2. High charge or discharge efficiency
3. Long life under cyclic charging or discharging
4. Ease of transport
5. Low maintenance

The battery is generally the weakest part of the photovoltaic system and particular care is needed in its selection and sizing. Although alkaline batteries may be used for photovoltaic systems but they are in general expensive and so their use is restricted to certain specialist applications. Lead-acid batteries give a satisfactory performance provided that they are specified and applied correctly. The widely available automotive starter batteries are not suitable as they have a very limited cycle life.

The captive electrolyte lead-acid battery is the most popular for PV applications because of it is spill proof and easily to transport. This battery type requires no water additions making it ideal for remote applications. Thus, this battery maintenance is infrequent or maybe unavailable. It is also less susceptible to freezing compared to flooded battery. However, the use of this battery type in PV systems, commonly failure in excessive overcharges mode and loss of electrolyte which is accelerated in warm climates. For this reason, it is essential that the charge controller regulation set points are adjusted properly to prevent overcharging. The recommended charging algorithm is constants voltage withtemperature compensation of the regulation voltage required to prevent overvoltage.

VI. SIMULINK MODEL AND RESULTS

6.1.Software Used

The MATLAB/SIMULINK software is used for the modeling and simulation purposes. This software prepares all the electrical and mathematical blocks that needed in the project under Power System Block set, Signal Routing and Math Operations (Simulink).This software is easy to use as it is more on graphical user interface pertaining to building or modeling any circuits or mathematical equations. Model for the PV Cell, MPPT, DC-DC converter (CUK Converter) are shown below. The modeling was done by stages.

6.2.Simulink Model for PV Cell

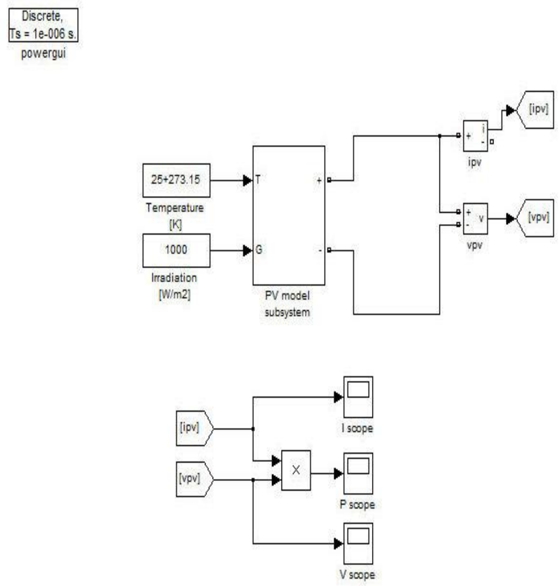

Figure 9: Simulink Model of PVcell

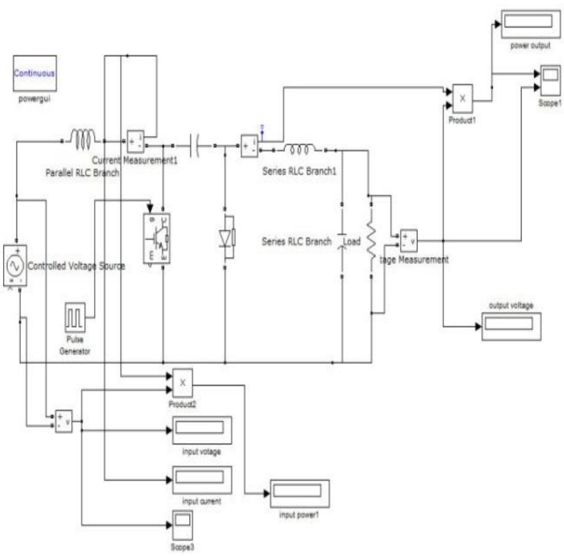

Figure 10: Simulink Model of Cuk Converter

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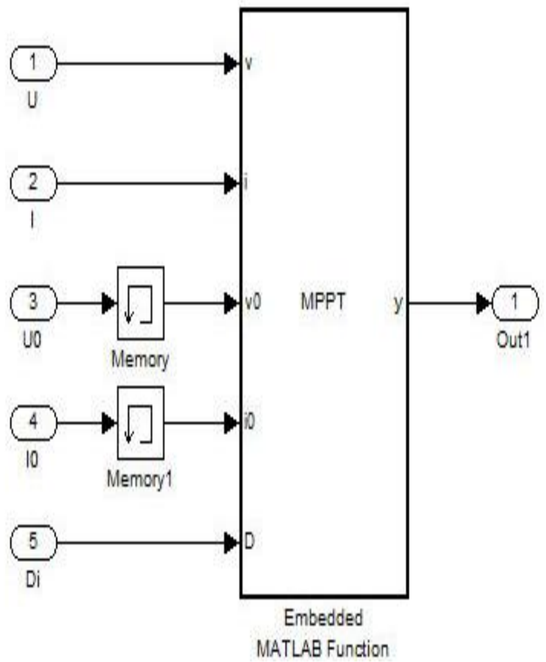

Figure 11: Subsystem for MPPT

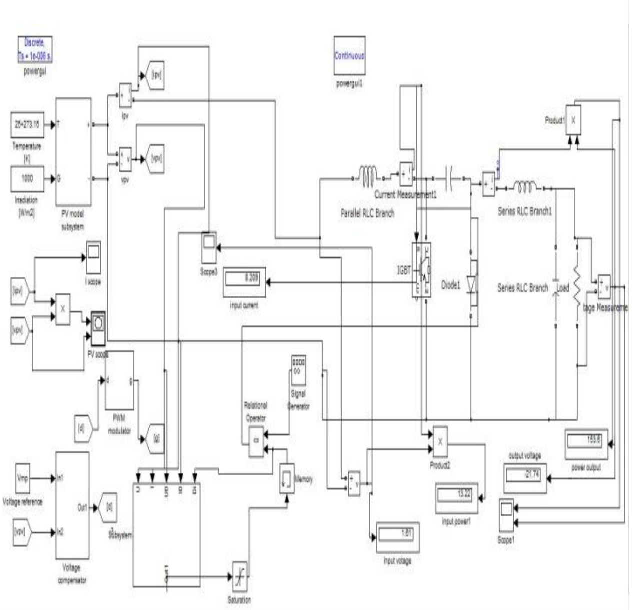

Figure 12: Simulink Model for PV Cell with MPPT

6.3. PV Cell Output

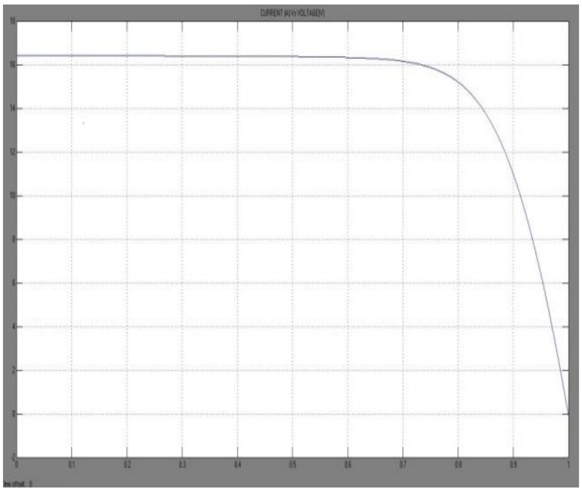

Figure 13: VI Output of PV Cell

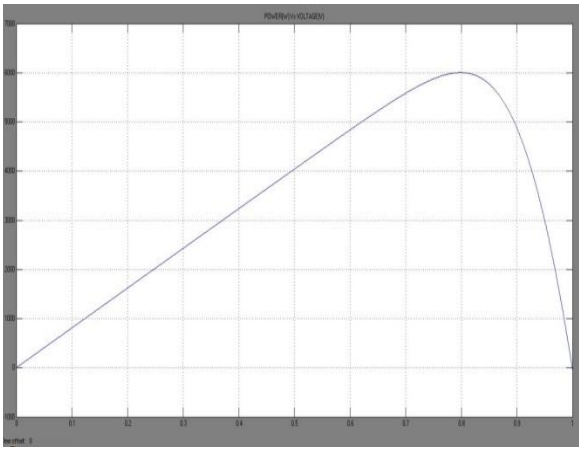

Figure 14 : PV Output of PV Cell

6.4.Output of CUK Converter

6.4.1.Output of CUK Converter with and without MPPT

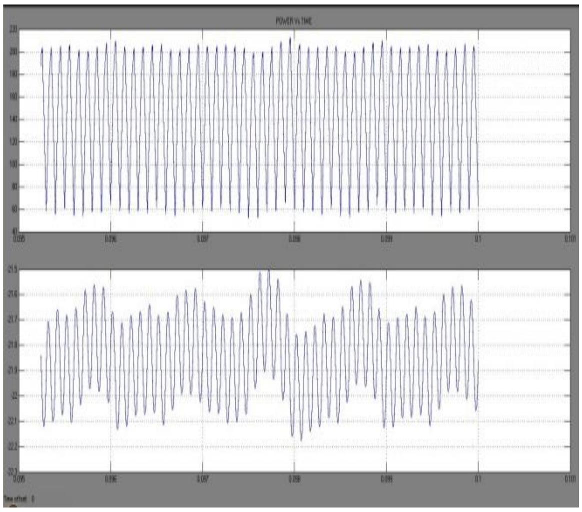

Figure 15: Output of Cuk converter without MPPT

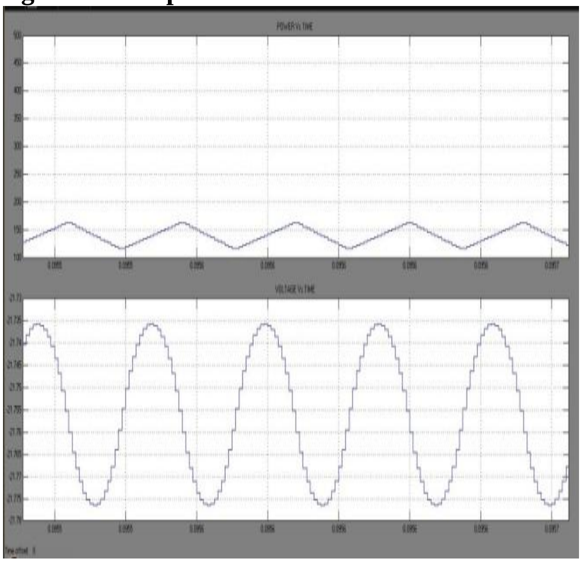

Figure 16: Output of Cuk converter with MPPT

For insolation of 1000W at 25°C temperatures the output power of PVcell was found to be 13.22W without MPPT. When MPPT is introduced as shown in figure15 the output power of PVcell is increased to 153.6W.

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VII. CONCLUSION AND FUTURE WORK

7.1. Conclusion

This project has presented a comparison of three most popular MPPT controller, Incremental Conductance fixed step and Variable step size with Incremental Resistance Controller. This project focus on comparison of three different controller with CUK converter which will connected with the controller. One simple solar panel that has standard value of insolation and temperature has been included in the simulation circuit. In project phase -1 incremental Conductance with fixed step size controller is simulated using Matlab Simulink. This controller gives a better output value for Cuk converter.

The simulation of remaining incremental algorithm as stated above will be carried out using MATLAB Simulink software in Project Phase-2 and an analytical and comparative study will be made considering criteria such as simplicity of implementation and capability to follow irradiance variations.

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