International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Volume 1 Issue 11 (November 2014) www.ijirae.com

ĆUK Converter Based Maximum Power Point Tracking for Photovoltaic System Using Incremental Conductance Technique

James Dunia
Department of Electrical Engineering
University of Dar es Salaam

Bakari M. M. Mwinyiwiwa
Department of Electrical Engineering
University of Dar es Salaam

Alex L. Kyaruzi
Department of Electrical Engineering
University of Dar es Salaam

Abstract— ***Photovoltaic (PV) energy is one of the most important energy resources since it is clean, pollution free, and sustainable. Maximum Power Point Tracking (MPPT) is used in photovoltaic (PV) systems to maximize the photovoltaic output power, irrespective of the temperature and radiation conditions. In MPPT system, the PV output power is fed directly to dc/dc converter and the output of MPPT control is used to control the dc/dc converter in order to operate at the maximum possible power point (MPP). In this paper it is proposed to track the MPP in PV module using incremental conductance algorithm. CUK converter is used as dc/dc converter to achieve the power/voltage level conversion. The MPPT system has been simulated using MATLAB/Simulink software to track the maximum output power from PV array and charge a battery bank. Simulation results show that the proposed MPPT system is capable of maximum power tracking of the PV array as desired.***

Keywords— ***Ćuk converter, PV cell, PV module, Maximum power point tracking (MPPT), incremental conductance***.

I. Introduction

The electrical energy supplied by national grid is not enough to meet demand. But human being needs electricity for sustainable development and poverty reduction. It affects practically all aspects of social and economic development including: livelihoods, water, agriculture, population, health, education, job creation and environmental concerns.

The world primary energy demand is expected to increase by 1.7% per year from the year 2002 and expending more than 50% in 2030 [1]. It is expected that the main global energy consumption will be continuously dominated by fossil fuel. Due to the awareness of global warming and climate change, nations are concerned of the planet's carbon emissions from fossil fuel used.

In order to meet these demands and at the same time to achieve sustainable development objectives on a global scale, conventional approaches to energy must be reoriented towards energy systems based on renewable energy and energy efficiency. Renewable energy is a natural energy which does not have a limited supply, can be used again and again, and will never run out. This paper presents an algorism for maximum power point tracking charger control system for solar power applications. The proposed design is expected to extract maximum power possible to be produced by PV modules, hence increase efficiency.

Solar power is an alternative energy technology that will hopefully lead a way from petroleum dependent energy sources. The major problem with solar panel technology is that, the efficiencies of solar power systems are still poor and the costs per kilo-watt-hour (kWh) are not competitive as compared to petroleum energy sources. Solar panels themselves are quite inefficient (approximately 30%) in their ability to convert sunlight to electrical energy. And PV maximum power point changes with the change of irradiance and temperature. PV module without MPPT cannot follow the maximum power point.

A. Overview of PV System Components and Parameters

PV Module: PV module is a type of equipment used to convert sunlight into electrical energy. It is formed by combination of many solar cells connected in series and parallel according to the required current and voltage. As sunlight strikes a solar cell, the incident energy is converted directly into electrical energy without any mechanical effort.

Equivalent circuit of PV module: Considering model of a single diode solar cell shown in figure 1 in this paper. This model offers a good compromise between simplicity and accuracy with the basic structure consisting of a current source and a parallel diode [2], whereby I_{ph} represents the cell photocurrent while R_{sh} and R_s are, respectively, the intrinsic shunt and series resistances of the cell.

Equations of a PV cell: PV cells are grouped in larger units called PV modules, which are further interconnected in a series and parallel configuration to form PV arrays. The following are the basic equations from the theory of semiconductors and photovoltaic [2] that mathematically describe the I-V characteristic of the photovoltaic cell and module.

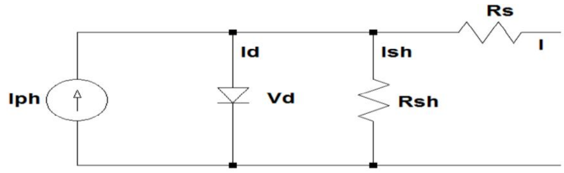

Fig 1 Schematic diagram of single diode solar cell.

Photo current: The PV cell photocurrent I_{ph} depends linearly on the solar irradiation and it is also influenced by the temperature according to (1).

$$I_{ph} = [I_{sc} + K_1 (T_c - T_{ref})]H \quad (1)$$

Where: I_{ph} is the nominal generated current at 25^0C and 1kW/m^2; I_{sc} is the cell's short-circuit current at a 25^0C and 1kW/m^2, K_1 is the cell's short-circuit current temperature coefficient (0.0017A/K), T_{ref} is the cell's reference temperature, and H is the solar insolation in kW/m^2.

Module reverse saturation current: Module reverse saturation current, I_{rs}, is given by (2).

$$I_{rs} = \frac{I_{sc}}{\left[\exp\left(\frac{qV_{OC}}{N_S kAT}\right) - 1\right]} \quad (2)$$

Where: q is the electron charge (1.6×10^{-19}C), V_{OC} is the Solar module open-circuit voltage (21.24V), N_s is the number of cells connected in series (36), k is the Boltzmann constant (1.3805×10^{-23} J/K), A is the ideal factor (1.6).

Module Saturation Current: The module saturation current I_o varies with the cell temperature and is given by (3).

$$I_0 = I_{rs} * \left(\frac{T}{T_r}\right)^3 * \exp\left[\left(\frac{(q * Ego)}{(A * k)}\right) * \left(\left(\frac{1}{T_r}\right) - \left(\frac{1}{T}\right)\right)\right] \quad (3)$$

Where: E_{go} is the band gap energy of the semiconductor ($E_{go} \approx 1.1$eV for the polycrystalline Si at 25^0C).

Module Output Current I_{PV}: The basic equation that describes the current output of PV module I_{PV} of the single- diode model presented in figure 1 is given by (4).

$$I_{PV} = N_P * I_{ph} - N_P * I_0 \left[\exp\left(\frac{q * (V_{pv} + I_{pv} * R_s Rs)}{N_s * A * k * T}\right) 1\right] - \frac{V_{pv} + (I_{pv} * R_s)}{R_{sh}} \quad (4)$$

Where: N_p is the number of parallel connection of cells (for referred module N_p = 1), N_S is the number of series connections of cells (for referred module N_s = 36), $V_{PV} = V_{oc}$ is open circuit voltage = 21.24V, R_s is the equivalent series resistance of the module, R_{sh} is the equivalent parallel resistance.

The effect of parallel resistance, when it is sufficiently small, is to reduce the open-circuit voltage and the fill factor [3]. The short-circuit current is not affected by it. The value of parallel resistance R_{sh} is generally high and hence neglected to simplify the model as given in (5). The series resistance R_s (0.1Ω) is the sum of several structural resistances of the PV module and its influence is stronger especially near the maximum power point region. Equation (4) for the current output of PV module can be simplified to give (5).

$$I_{PV} = N_P * I_{ph} - N_P * I_0 \left[\exp\left(\frac{q * (V_{pv} + I_{pv} * R_s Rs)}{N_s * A * k * T}\right) - 1\right] \quad (5)$$

II. MAXIMUM POWER POINT TRACKING (MPPT)

MPPT charger control: Maximum Power Point Tracking, frequently referred to as MPPT, is algorithm that includes an electronic system to operate the Photovoltaic (PV) modules in a manner which allows the modules to produce all the power they are capable of. MPPT is not a mechanical tracking system, it is fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power.

MPPT techniques: Maximum power point tracking (MPPT) technique is used to improve the efficiency of the solar panel. According to Maximum Power Transfer theorem, the power output of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load impedance.

There are different techniques used to track the maximum power point. Few of the most popular techniques are: Perturb and Observe, Incremental Conductance, Fractional short circuit current, Fractional open circuit voltage, Neural networks and Fuzzy logic. The choice of the algorithm depends on the complexity and time the algorithm takes to track the MPP and implementation cost

Selection of MPPT Control technique: There are large numbers of algorithms that are able to track MPPs. Some of them are simple, such as those based on voltage and current feedback like perturbation & observation (P&O) or the incremental conductance (IncCond) methods and some are more complicated. They mainly vary in complexity, sensor requirement, speed of convergence, cost, range of operation, popularity, ability to detect multiple local maxima, and their applications [4], [5]. Having a curious look at the recommended methods, IncCond and P&O [6] are algorithms that were in the centre of consideration because of their simplicity and ease of implementation. IncCond [7] is perturbation in the duty ratio of the power converter, and the P&O method [7] is perturbation in the operating voltage of the PV array. But P&Q fail to track MPP under rapidly changing atmospheric conditions [8] as shown in figure 2. In this paper incremental conductance (IncCond) method is used.

Incremental Conductance Technique: In incremental conductance technique the array terminal voltage is always adjusted according to the MPP voltage, it is based on the incremental conductance and instantaneous conductance of the PV module.

Figure 3 shows that the slope of the P-V array power curve is zero at the MPP, increasing on the left of the MPP and decreasing on the Right hand side of the MPP. The basic equations of this method are (6), (7) and (8) as follows.

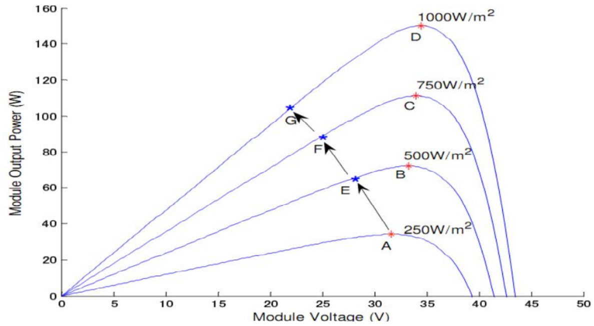

Fig. 2 Curve showing wrong tracking of MPP by P&O algorithm under rapidly varying irradiance [9]

$$\text{At MPPT } \frac{dI}{dV} = -\frac{I}{V} \quad (6)$$

$$\text{Left of MPPT } \frac{dI}{dV} > -\frac{I}{V} \quad (7)$$

$$\text{Right of MPPT } \frac{dI}{dV} < -\frac{I}{V} \quad (8)$$

Where I and V are PV module output current and voltage respectively. The left hand side of (6), (7) and (8) represents incremental conductance of PV module and the right hand side represents the instantaneous conductance.

When the ratio of change in output conductance is equal to the negative output conductance, the PV module will operate at the maximum power point. This method exploits the assumption of the ratio of change in output conductance is equal to the negative output instantaneous conductance.

We have,

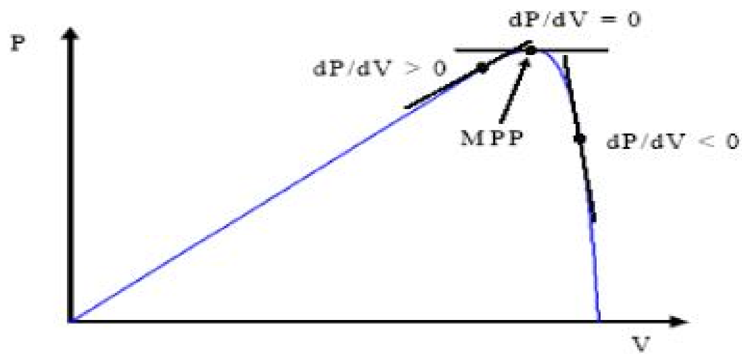

Fig 3 Basic idea of incremental conductance method on a P-V Curve of solar module.

$$P = V\,I \quad (9)$$

Applying the chain rule for the derivative of products of (9) yields (10) and (11).

$$\frac{\partial P}{\partial V} = \frac{\partial (VI)}{\partial V} \quad (10)$$

$$\text{At MPP} \quad \frac{\partial P}{\partial V} = 0 \quad (11)$$

Equations (10) and (11) can be simplified and written in terms of array voltage V and array current I as given by (12).

$$\frac{\partial I}{\partial V} = -\frac{I}{V} \quad (12)$$

The MPPT regulates the PWM control signal of the dc – dc converter until the condition of (13) is satisfied.

$$\left(\frac{\partial I}{\partial V}\right) + \left(\frac{I}{V}\right) = 0 \quad (13)$$

Flow chart of Incremental Conductance Algorithm: The flow chart in figure 4 shows step by step on how Incremental Conductance technique is operating. Generally it is following the PV curve as shown in figure 3. When the previous sensed power (current x voltage) is less than the present sensed power it increases the voltage and when the previous sensed power is greater than the present sensed power it decreases the voltage while if the previous sensed power is equal to the present sensed power it maintains the operating voltage.

III. DC–DC CONVERTER FOR PV APPLICATION

A DC-DC converter is an electronic circuit which converts a source of direct current (DC) from one voltage level to another. It can have two distinct modes of operation: Continuous conduction mode (CCM) and discontinuous conduction mode (DCM). In practice, a converter may operate in both modes, which have significantly different characteristics. Therefore, a converter and its control should be designed based on both modes of operation. DC-DC converter is normally used to control the PV voltage and current to the load.

A. Types of DC-DC Converter

There are many types of DC – DC converter, but the following are the most commonly used.

Buck Converter: Buck - Bust converter can convert a high voltage source into a lower regulated voltage

Boost Converter: Boost converter, can convert a low voltage source into a high regulated voltage.

Buck - Boost Converter: The buck–boost converter, can convert input voltage into greater than, equal or less than the input voltage magnitude.

ĆUK Converter: The Ćuk converter , can convert input voltage into greater than, equal or less than the input voltage magnitude. The Ćuk converter is obtained by using the duality principle on the circuit of a buck – boost converter.

The most important feature of this topology is the fact that a capacitor, instead of an inductor, is used as the primary means of storing and transferring energy from input to the output. This causes energy transfer to occur during both ON and OFF gated switch intervals.

B Selection of DC-DC converter

When proposing an MPP tracker, the major task is to choose and design a highly efficient converter, which is supposed to operate as the main part of the MPPT. There are several converter configurations such as Buck, Boost, Buck-Boost, SEPIC, ĆUK, etc. Buck and Boost configurations can only decrease and increase the output voltages respectively, while the others can do both functions. For Buck-Boost converter its output is inverted, discontinuous input current, high peak currents in power components, and poor transient response, make it less efficient. ĆUK and SEPIC convertors gives a desirable output although ĆUK converter gives inverted voltage output. They have become popular in recent years in battery-powered systems that must step up or down depending upon the charge level of the battery voltage. The simulation results for PV system with CUK and SEPIC converter shows that the power output of the PV system is stable and can find the maximum power point for both converter and algorithm of MPPT [9], [10]. In this research ĆUK converter is used because of its simplicity and low cost compared to SEPIC.

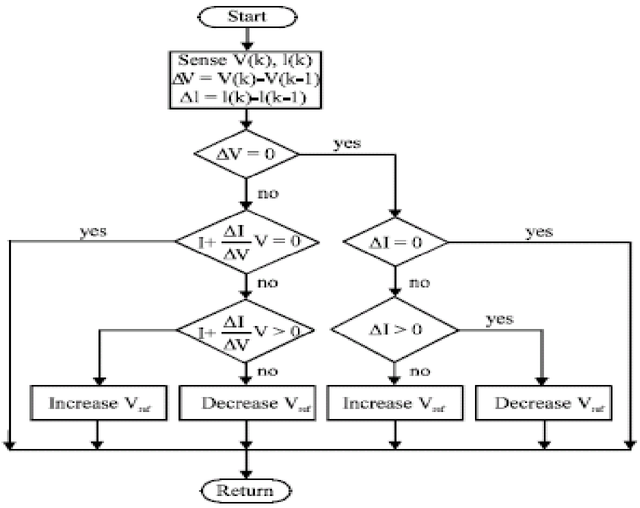

Fig. 4 Flowchart of Incremental Conductance algorithm for MPPT control.

C. Proposed MPPT charger control for PV application

The proposed system shown in figure 5 comprises of MPPT charger control which is used to track MPP on the PV system and Ćuk converter is used for charge control.

Modelling of PV cell: The modelling of the single-diode PV cell as shown in figure 1 is done according to (5) which has been derived from (1), (2) and (3).

Photocurrent: The module photocurrent I_{ph} of PV cell depends linearly on the solar irradiation and is also influenced by the temperature as shown in (1) and is modelled as shown in figure 6.

Module Reverse Saturation Current: Module reverse saturation current, I_{rs}, is given by (2) and its Simulink model is shown in figure 7. Module reverse saturation current also varies with temperature.

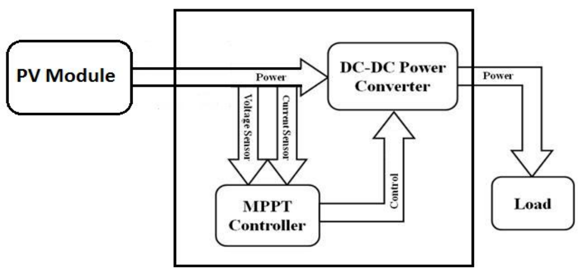

Fig. 5 Block Diagram of the proposed system of MPPT.

Module Saturation Current I_0.: The module saturation current I_0 is given by (3) and its detailed Simulink model is shown in figure 8. Module saturation current also varies with temperature.

*Module Output Current I_{PV}.:*Is the basic equation that describes the current output of PV cell. I_{PV} of the single- diode model presented in figure 9 is given by (4) and simplified to (5). The solution of this involves iteration and requires solving of algebraic loop in Simulink.

To avoid this problem, the functional models are used for modelling of PV module. All the above four circuits are interconnected to get Simulink model of I_{PV}.

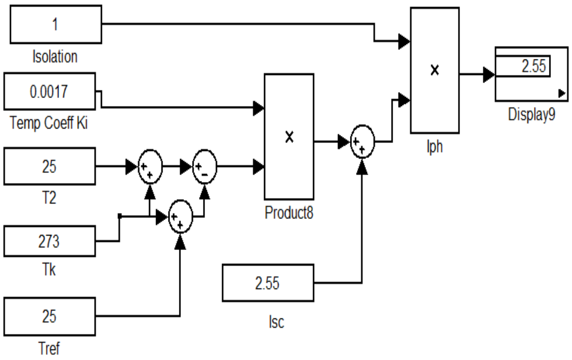

Fig. 6 Simulink Model of PV photocurrent.

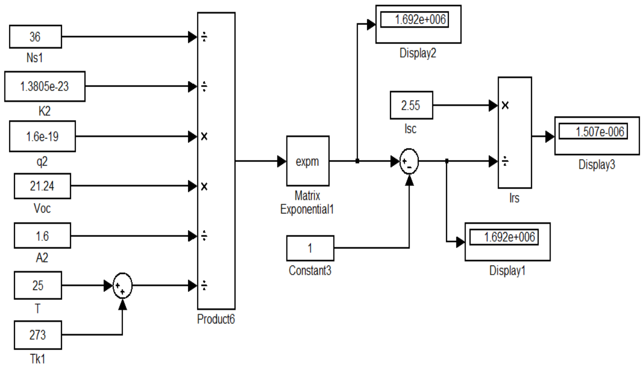

Fig. 7 Simulink Model of PV reverse saturation current.

D. *General Simulink Model representation of PV module*

This model takes insolation and temperature as inputs and calculates I_{PV} as shown in figure 10. And it is simulated with the PV of Ns=36 and Np=1 at standard temperature of 25^0C and irradiation of 1000W/m^2. The I-V and P-V characteristics are as shown in figure 11 and 12 respectively.

E. *Maximum Power Point Tracking (MPPT) System*

The Maximum power point tracking comprises of two parts: DC-DC converter and MPPT control. The DC-DC converter is used as interface between PV system and load. It is the one which play part on extracting maximum power by changing the load as seen by PV module due to change in switching pulses. Also play parts in giving output required voltage level by either increasing or decreasing voltage level. MPPT control is the brain of the system, it track the maximum power possible to be delivered by PV module. It is implemented by the use of algorithm shown in figure 4 which tracks voltage and current with which the PV module can deliver its maximum power.

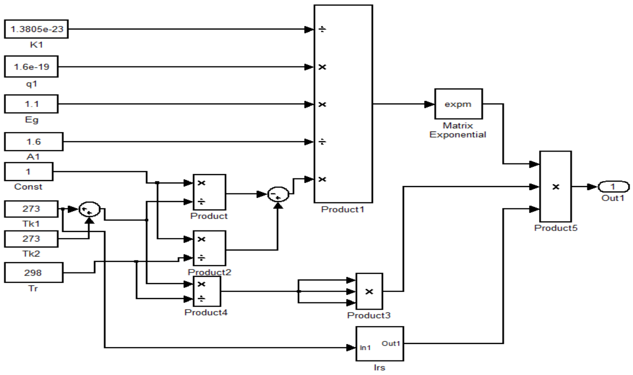

Fig. 8 Simulink Model of PV saturation current.

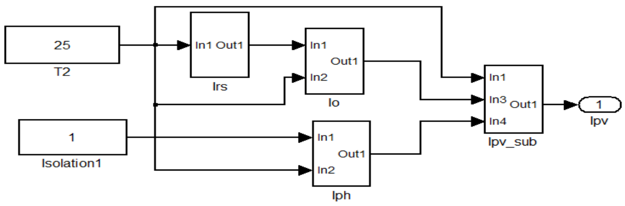

Fig. 9 Simulink Model of PV current output.

Ćuk Converter Parameters: Ćuk converter used has the following parameters: V_{out} = 24V, f_s = 50 KHz, T = 20μs, L_1 min = 6mH, L_2 min = 12mH, C_1= 218.75pF, C_2= 5.86mF.

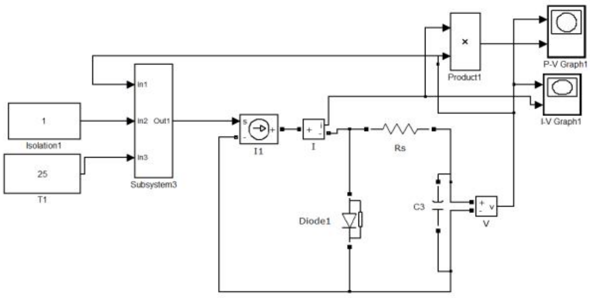

Fig. 10 Simulink Model of PV module.

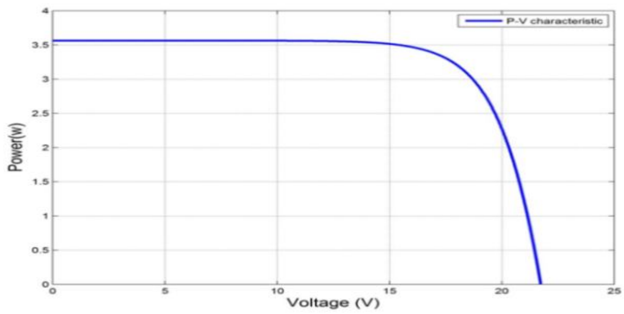

Fig. 11 Graph showing I-V characteristic.

Modelling of Ćuk Converter: Ćuk converter is modelled by the use of Matlab/Simulink software according to the circuit of figure 13 using all parameter values listed above.

Modelling of MPPT Control: The MPPT control is moulded according to Incremental conductance algorithm as shown in figure 4. The current and voltage of the PV model are measured and fed as input signals to the control. The differential of each signal are obtained by delaying their corresponding input signals (V and I) and subtracting it to the signal value that was sampled at the input obtaining ΔV and ΔI signals. The memory block was initialized to zero for the initial computation.

The first switching block compares the value of ΔV to zero, and splits the algorithm in an upper and lower half.

The upper half corresponds to the case when the value of ΔV is equal to zero. The next comparison is regarding the current values. If the variation of ΔI is zero then the "adjust" signal passes without any modification meaning the MPPT point has been reached.

If the variation is any value but not zero the signal gets directed to a signal comparison of ΔI. If ΔI is positive, then the "adjust" signal is incremented by 0.01, if the value is negative then the "adjust" signal is decreased by the same amount. This calculation is a linear approximation to the slope of the Current-Voltage characteristic near the MPPT point. When the condition of (6) is satisfied the MPPT has been reached and the system stops oscillating. Figure 14 shows the complete MPPT control.

Combined simulated circuit: This circuit comprises PV module, MPPT charger control and the proposed load as shown in figure 15. This is the final system which its results will be discussed in the next part.

Comparison with and without MPPT system: Figure 16 shows the system modelled in such a way to compare the system with MPPT and the system without MPPT. The system without MPPT uses PWM control system. The two systems are exposed under the same conditions (Temperature and irradiation) and also have the same parameters (PV parameters, DC-DC converter and load)

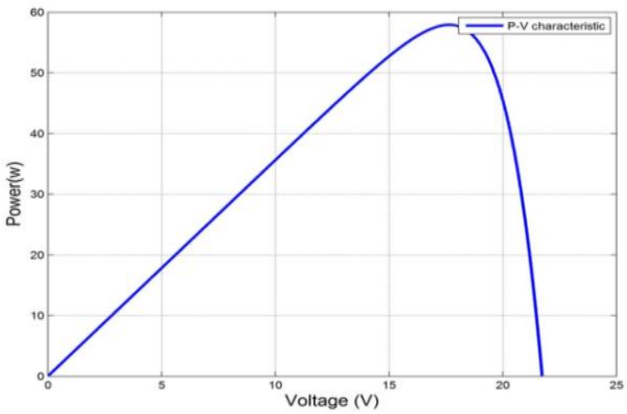

Fig. 12 Graph showing P-V characteristic.

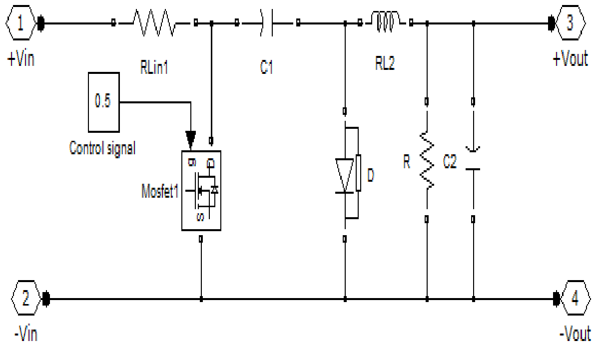

Fig. 13 Simulink Model of Ćuk Converter.

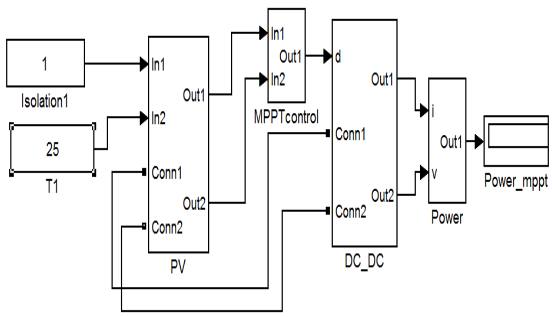

Fig. 15 Simulink Model for MPPT charger controller.

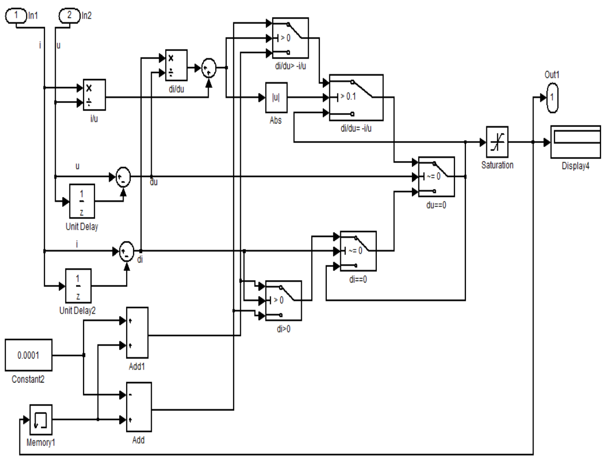

Fig. 14 Simulink Model of Incremental conductance control circuit.

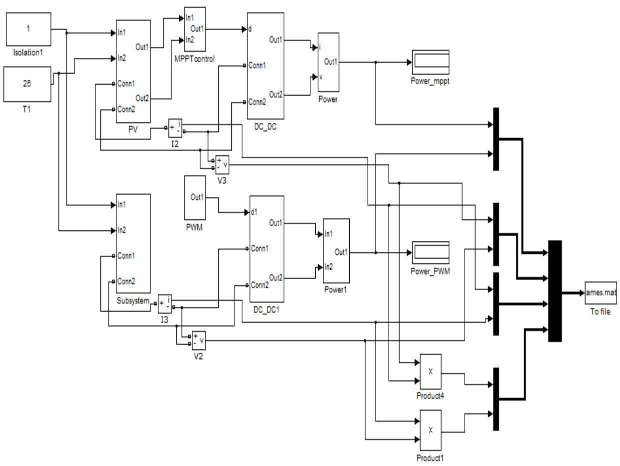

Fig. 16 Simulink Model for comparison between the systems with and without MPPT control.

IV. ANALYSIS AND DISCUSSION OF SIMULATION RESULTS

A. Analysis of Simulation Results

Modelling and simulation of PV module and MPPT charger control was performed using MATLAB/Simulink software. Uniform irradiance and temperature is assumed for the PV module simulation. The simulation is analysed at two points, output of PV module and at the load terminal with changes of two input factors, Temperature and Irradiance. To have clear understanding of the advantages of using MPPT charger control the system was also compared with the system without MPPT (using regular PWM). The simulation results show that the system with MPPT gives better results as shown in figures 17 through 24.

B. Simulation Results for Output Terminal of PV module:

Simulation results for Output Terminal of PV module are shown in figures 17 through 22. The results give comparison of PV system with and without MPPT controller.

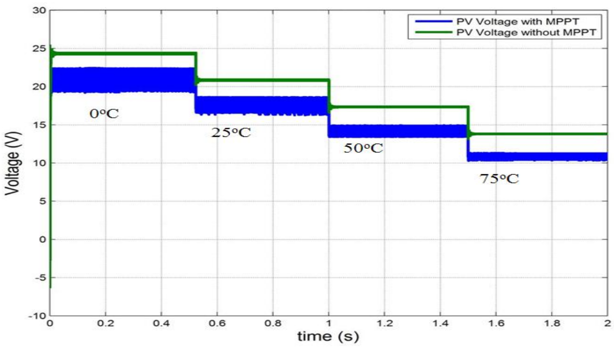

Fig. 17 PV module with and without MPPT output voltage with variation of temperature

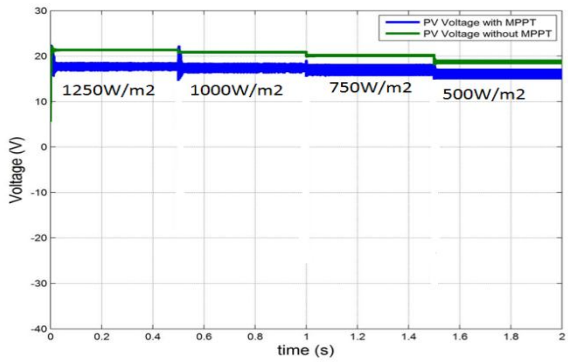

Fig.18 PV module with and without MPPT output voltage with variation of irradiance.

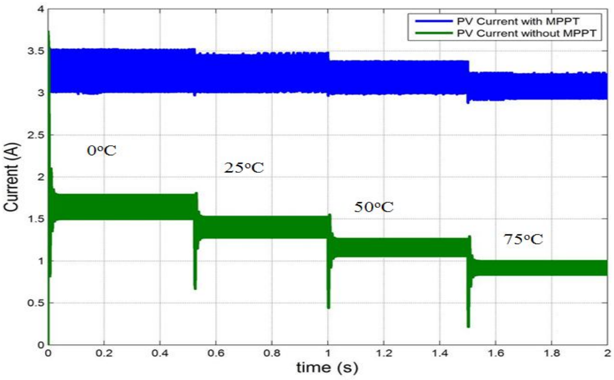

Fig. 19 PV module with and without MPPT current with variation of temperature

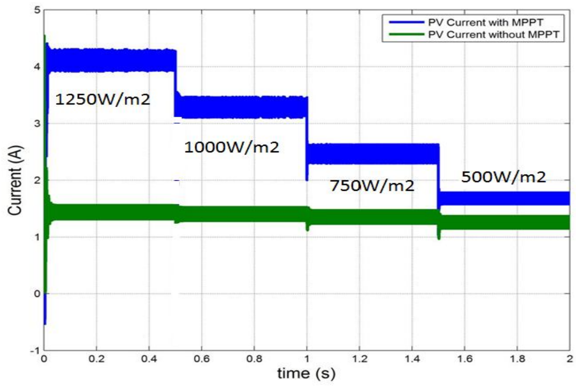

Fig. 20 PV module with and without MPPT current with variation of irradiance

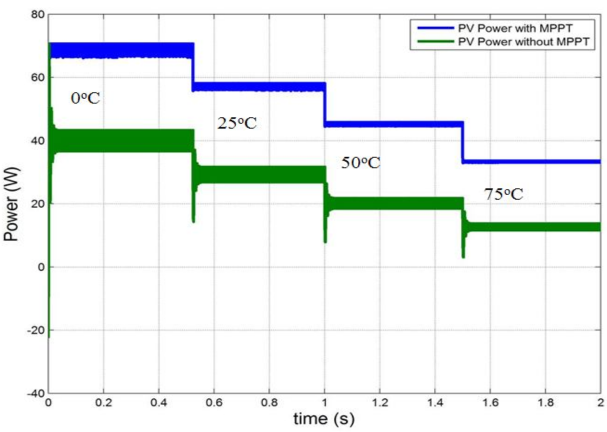

Fig. 21 PV module with and without MPPT power with variation of temperature.

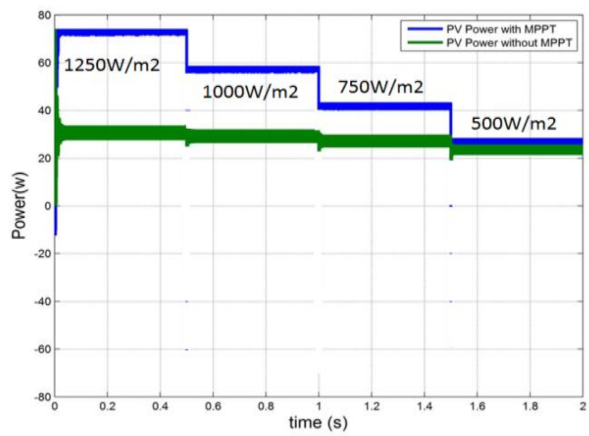

Fig. 22 PV module with and without MPPT power with variation of irradiance.

Simulation Results for Load Terminal of PV module: Simulation results for Load Terminal of PV module are shown in figures 23 through 24. The results give comparison of PV system with and without MPPT controller.

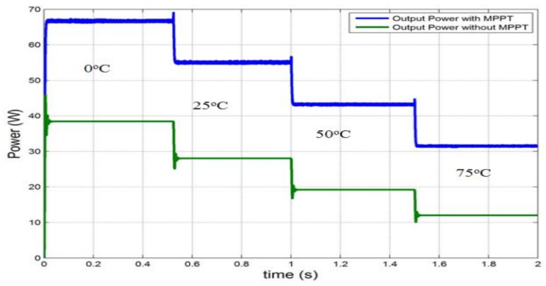

Fig. 23 Output power at load terminal with and without MPPT with variation of temperature.

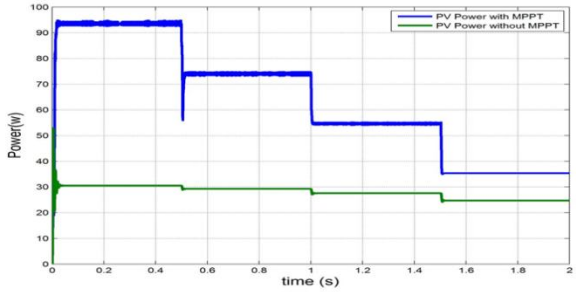

Fig. 24 Output power at load terminal with and without MPPT with variation of irradiation

C. Discussion of Simulation Results

The simulation results above show that: The voltage at a terminal of PV module without MPPT is greater than that with MPPT figure 17 and figure 18. Also, the current at the terminal of PV module without MPPT is less compared to that with MPPT figure 19 and figure 20, this is because the system with MPPT is operating at the voltage that deliver maximum power to the load and not depending on the load voltage so it is balancing between the voltage and current to get maximum power. Hence the power at the PV module with MPPT is greater compared to that module without MPPT as shown in figure 21 with variation of temperature and figure 22 with variation of irradiance. Finally the output power to the system with MPPT is greater compared to that of the system without MPPT with all temperature variation and irradiance variation as shown in figures 23 and 24 respectively.

V. CONCLUSIONS

This study presents a simple but efficient MPPT battery charging control system for photovoltaic module. MATLAB/Simulink software has been used to simulate the system. The results show that the system increases the efficiency of PV model by extracting maximum power from the PV module to the load. The system tracks the point of voltage that delivers maximum power capable to be delivered by the PV module.

Simulations perform comparative tests for the two configurations. One is with MPPT control and the other is without MPPT control. The one with MPPT control delivers more power than the one without MPPT control hence increased efficiency of PV module. In this research work, simulation of the proposed system has been performed and verifies the benefits of MPPT system as compared to the system without MPPT. The results confirm that the proposed MPPT can significantly increase the efficiency of energy production from PV module.

ACKNOWLEDGMENT

The authors are grateful for financial support provided by Sida from Sweden.

REFERENCES

[1] M. R. Islam, R. Saidur, N. A. Rahim, and K. H. Solangi, “Usage of solar energy and its status in Malaysia,” *Engineering e-Transaction*, Vol. 5, No. 1, 2010, pp. 6-10.

[2] Aeronautics and Space Administration, (NASA-CR-149364) National, Solar Cell Array Design Handbook, Vol.1, Jet Propulsion Lab, 1976.

[3] K. Nishioka, N. Sakitani, Y. Uraoka, and T. Fuyuki, “Analysis of multi-crystalline silicon solar cells by modified 3-diode equivalent circuit model taking leakage current through periphery into consideration,” S*olar Energy Materials and Solar Cells*, Vol. 91, No. 13, 2007, pp. 1222–1227.

[4] T. Esram and P. L. Chapman, ― Comparison of photovoltaic array maximum power point tracking techniques,” *IEEE Trans. Energy Conver*sion, Vol. 22, No. 2, June 2007, pp. 439–449.

[5] G. Petrone, G. Spagnuolo, R. Teodorescu, M. Veerachary, and M. Vitelli,” Reliability issues in photovoltaic power processing systems”, *IEEE Trans. Ind. Electronics*, Vol. 55, No. 7, July 2008, pp. 2569–2580.

[6] C. Hua, J. Lin, and C. Shen, ― Implementation of a DSP-controlled photovoltaic system with peak power tracking,” *IEEE Trans. Ind. Electronics*, Vol. 45, No. 1, Feb. 1998, pp. 99–107.

[7] N. Femia, D. Granozio, G. Petrone, G. Spagnuolo, and M. Vitelli, Predictive & adaptive MPPT perturb and observe method,” *IEEE Trans. Aerosp. Electron. Syst*., Vol. 43, No. 3, July 2007, pp. 934–950.

[8] K. H. Hussein, I. Muta, T. Hoshino, and M. Osakada, “Maximum photovoltaic power tracking: An algorithm for rapidly changing atmospheric conditions,” *Proc. Inst. Elect. Eng., Generation, Transmission. Distribution*, Vol. 142, No. 1, January 1995, pp. 59–64.

[9] Akihiro Oi “Design and Simulation of Photovoltaic Water Pumping System,” Masters Thesis, California Polytechnic State University, San Luis Obispo, September, 2005.

[10] Muhammad Syafei Gozali, “Comparison of ĆUK and SEPIC Converter Applied in Maximum Power Point Tracking for PV System,” *IJEERI*, Vol. 2, No. 1, March 2013.

