IJEW 国际工程期刊 International Journal of Engineering Works انجینئرنگ کاموں کا بین الاقوامی جرنل

International Journal of Engineering Works
ISSN-p: 2521-2419
ISSN-e: 2409-2770
Vol. 6, Issue 01, PP. 6-11, January 2019
https://www.ijew.io/

Modeling of Multi Junction Solar Cell and MPPT Methods

Rabia Bibi[1], Aftab Ahmad[2], Asfandyar Ali[3], Juveria Anwar[4], Tanvir Ahmad[5]
[1,3,4,5]USPCAS-E University of Engineering and Technology, Peshawar
[2]Pakistan Institute of Engineering and Applied Sciences
rabiakhan1294@yahoo.com[1]
Received: 06 December, Revised: 13 December, Accepted: 01 January

***Abstract*—** Multi Junction solar cells (MJSC) have gotten high attention in the concentrated PV systems because of its superior performance and high efficiency. MJSC have increased the concentration capacity of solar panels with a level greater than ever before. Compared to conventional silicon photovoltaic cell, MJSC have augmented 39.5% efficiency under similar atmospheric conditions. In this research work, two tasks have been performed, one is modeling and simulation of single, double and triple junction solar cell and the second one is modeling of MPPT methods. Graphical Results of MJSC modeling show approximately three times increase in power with using triple junction solar cell compared to conventional single junction solar cell. Constant voltage and perturb & observe maximum power point tracking (MPPT) techniques, that automatically adjust the switch duty cycle of converter are presented. Very simple and inexpensive analog PWM controllers are employed to continuously track the maximum power point of solar cell as the irradiance changes. The switch duty cycle is formed such that it automatically adjusts itself to produce maximum power as solar cell voltage changes. LTspice simulations are presented to demonstrate the effectiveness of proposed MPPT algorithms. Perturb & Observe method has a fast response, it takes 0.05s and gives smooth output initially. Constant voltage method takes 0.08s for simulation and it gives huge output initially. So perturb and observe method doubles the efficiency.

***Keywords*—**maximum power point tracking(MPPT); PWM; constant voltage; perturb & observe; multi junction solar cell;

I. Introduction

Renewable energy provides a better and clean alternative to fossil fuels. Solar energy is one of the most important renewable energy resources. It provides energy by capturing the solar radiation and converting it into electric energy by either running a steam turbine or by using photovoltaic cells. Photovoltaic cells are portable, easy assembly and flexible to suit most applications. Photovoltaic systems can be used in standalone and grid connected configurations [1]. Grid connected solar photovoltaic has reached 303 GW globally [2]. But photovoltaic systems also have some problems associated with it: Variability and lower efficiency. Electric power generated by solar arrays is continuously changing with weather conditions and solar irradiance and the V-I characteristic of photovoltaic panels have non linear dependence on irradiance and temperature [3]. In the V-I curve there is only one maximum power point and it changes continuously with the weather conditions. To extract maximum power from the solar panel the controller must set the panels to operate at this point thus increasing the efficiency of the system. These controllers are called maximum power point trackers (MPPTs). There are several techniques in literature to find the maximum power point for PV systems which include: incremental conductance method, perturb and observe method, fixed duty cycle method and constant voltage method [3]. If the MPPT controller could track the maximum power point accurately, the solar panels will be operating at its higher efficiency.

Perturb and observe, constant voltage and incremental conductance methods are the most commonly used algorithms used in MPPT controllers. Perturb and observe method employs the trial and error methodology and changes the terminal voltage and current of solar panels and compares the power output with the previous iteration. If the power increases it further changes the voltage and current in the directions otherwise it changes in the opposite direction until maximum power point is reached [4]. Constant voltage and constant current MPPT methods are simple and efficient.

Apart from MPPT, various issues also appear for solar cell itself like now, silicon the most prominent semiconductor due to its large vacancy in nature, cause it economical in designing and making the device. But, the silicon PV cell's efficiency is significantly low. Multi Junction solar cells (MJSCs) have gotten high attention in the concentrated PV systems because of its superior performance and high efficiency. MJSCs have increased the concentration capacity of solar panels with a level greater than ever before. Compared to conventional silicon photovoltaic cell, MJSC have augmented 39.5% efficiency under similar atmospheric conditions [5]. In this research work, two tasks have been performed, one is modeling and simulation of single, double and triple junction solar cell and the second one is modeling of MPPT methods.

Normally nowadays, the trend is towards microprocessor based tracking of MPPT which is expensive. In this paper, a simple, inexpensive and analog PWM controlling constant voltage and perturb & observe MPPT algorithms are developed in LTspice software.

II. General Scheme of Photovoltaic (PV)

Fig. 1 describes the process of PV system.

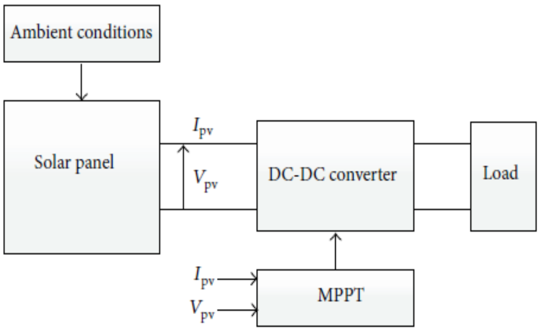

Fig. 1.General scheme of photovoltaic system

A. *Simulation of Solar Cell*

Solar cell model is simulated in LTspice as shown in fig. 2 to analyze its characteristics curves. Current-Voltage (I-V) and Power-Voltage (P-V) curves are called characteristics curves of PV cell. These curves are non linear in nature and shown in fig. 3. Results of simulation shows single junction solar cell gives maximum power of 2mW with V_{oc} of 0.31V and I_{sc} of 10mA.

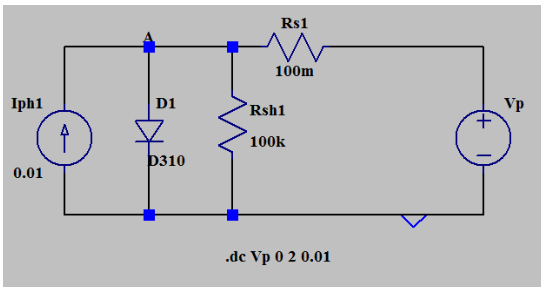

Fig. 2.LTspice model of solar cell

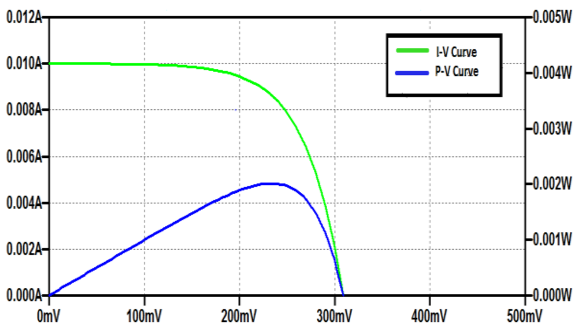

Fig. 3. I-V and P-V Curves of Solar Cell

B. *Simulation of Double Junction Solar Cell*

Fig. 4 shows circuit of double junction PV cell in which top layer is InGaP and bottom layer is InGaAs. The sub-cells are assembled in series with reduced energy gaps.

Table 1. Values of parameters for double junction InGaP/InGaAs solar cell

Parameter Value	**Top layer InGaP**	**Bottom layer InGaAs**
E_g(eV)	1.976	1.519
I_{sc}(mA)	6.5	7.8
N	1.97	1.75

Table 1 presents the values of parameters used in double junction solar cell modeling [5]. E_g is the activation energy or band gap energy of a diode and N is ideality factor. Fig. 5 shows that double junction of InGaP/InGaAs solar cell gives maximum power of 3.4mW with V_{oc} of 0.75V and I_{sc} of 6.5mA.

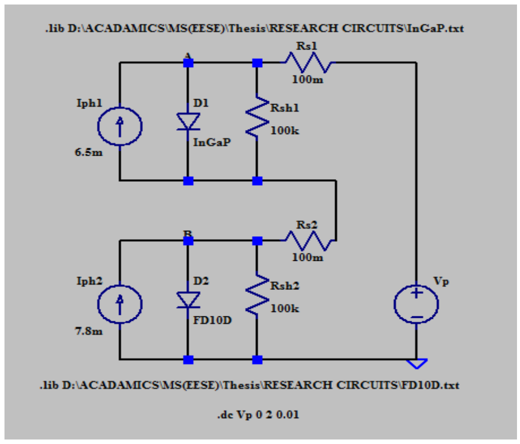

Fig. 4.LTspice model of double junction solar cell

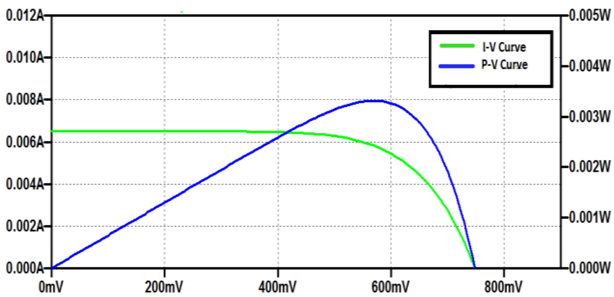

Fig. 5. I-V and P-V Curves of double junction Solar Cell

C. *Simulation of Triple Junction Solar Cell*

Bandgap variety isn't demonstrating the adequate decision. A perfect triple junction could deliver energy viably with composition of 1.976, 1.519 & 0.744 eV materials [5]. Consequently, AlAs is examined contain much big energy bandgap and could be replaced by InGaP. On account of that a three junctions PV cell designed by stacking InGaP, InGaAs, and Ge all together with measurement.

Table 2. Values of parameters for triple junction InGaP/InGaAs/Ge solar cell

Parameter Value	**Top/first layer InGaP**	**Second layer InGaAs**	**Third layer Ge**
E_g(eV)	1.976	1.519	0.744
I_{sc}(mA)	6.5	7.8	10.5
N	1.97	1.75	1.96

Fig. 6 shows spice model of this triple junction solar cell combination. Table 2 demonstrates the parameter's values utilized in triple junction cell modeling [5].

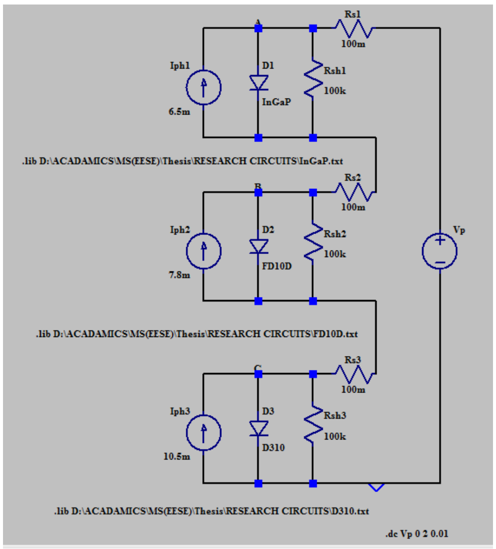

Fig. 6.LTspice model of triple junction solar cell

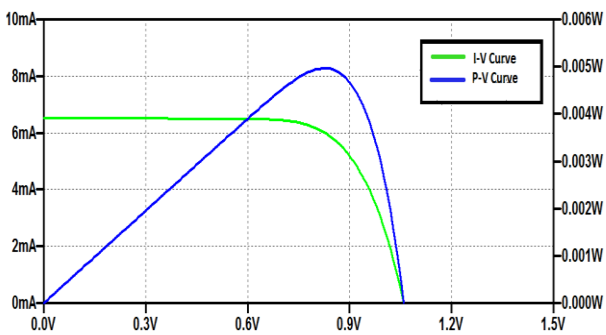

Fig. 7. I-V and P-V Curves of triple junction Solar Cell

Fig.7 shows that triple junction of InGaP/InGaAs/Ge solar cell gives maximum power of 5mW with V_{oc} of 1.05V and short-circuit current, I_{sc} of 6.5mA. This shows that power generated by triple junction solar cell is approximately three times greater than power generated by single junction solar cell.

III. MPPT METHODS

It is mandatory to get much accessible energy as could be expected from the PV cell to limit the energy price figure of PV system. An MPP tracker is utilized to discover the point when the MPP occurs. Various MPPT methods have been suggested by researchers but in this research, two widely used techniques are carried out for modeling.

A. Constant Voltage (CV) Method

This is the easiest MPPT method. The operating voltage of the panel is maintained close to a reference value, Vref. The value of reference voltage depends on the data provided by the manufacturer. In case of constant voltage method energy efficiency is increased as compare to no MPPT technique but it is used for optimization of only one ambient conditions. For other values of sun irradiance and temperature conditions, operational point will not overlap with maximum power point of IV curve. Thus by adjusting the duty cycle we can move operating point towards the MPP [6]. Fig. 8 shows block diagram of this method.

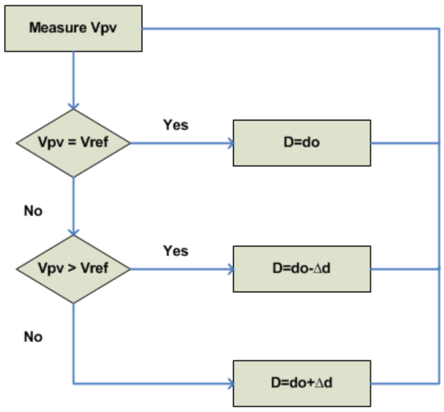

Fig. 8.*Block diagram of CV method*

1) LTspice model of CV method

Fig. 9 shows spice model containing solar cell, constant voltage MPPT method and boost converter with a resistive load.

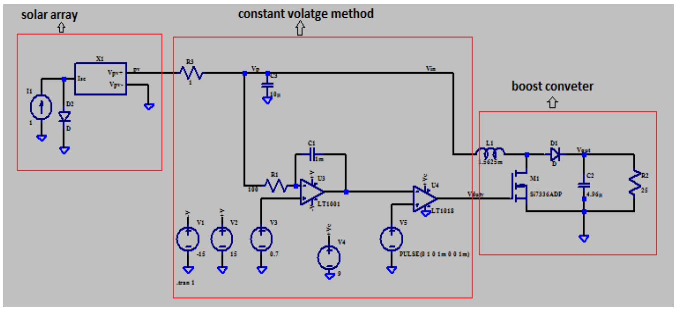

Fig. 9.*LTspice model of CV method*

In this method, PV cell output goes to boost converter as well as to integrator. Op-amp being used as an integrator holds the PV voltage. Capacitor in an integrator, initially charges and then supply voltage to the comparator, which is further compared with sawtooth signal to gives pulse width modulation (PWM) signal for the MOSFET gate switch present in boost converter. As PV voltages is changed, Duty cycle of PWM is changed and this set maximum power to the load.

2) Simulation Results

Constant voltage method model is simulated in LTspice. Simulation results shows variation of current and voltages of boost converter which include PWM, inductor current, input and output voltages.

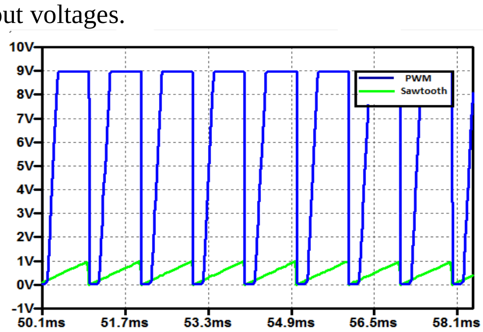

Fig. 10.*Generating PWM for switch with constant voltage method*

PWM generation is shown in fig. 10. When PV voltage is higher than saw tooth, comparator gives high and when low than it gives 0. Output voltage from solar array is shown in fig. 11 which is 1V while fig. 12 shows output of boost converter which is initially 5V and then goes to steady state which is 3.5V. The simulation time taken by constant voltage method is 0.08s. Fig. 13 shows inductor current of boost converter which works in CCM because does not go to zero.

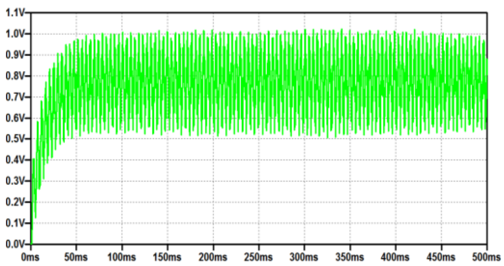

Fig. 11.*Output voltage from solar cell*

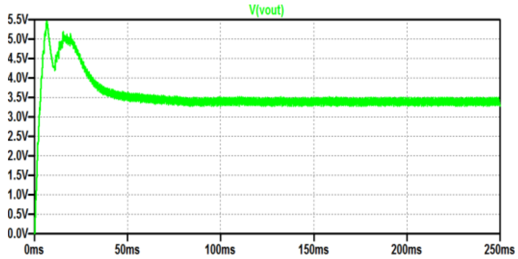

Fig. 12.*Output voltage from boost converter*

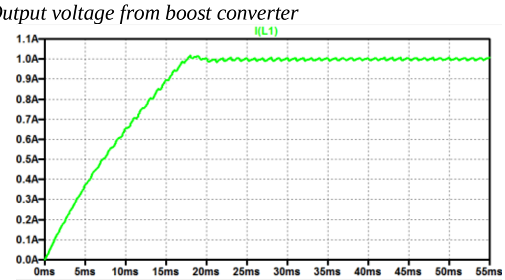

Fig. 13.*Inductor current of boost converter*

B. Perturb and Observe (P&O) Method

The algorithm starts by setting the computed maximum power P_{MAX} to an initial value (usually zero). Then at specific intervals, the actual PV current and voltage are measured and the current value of PV power, P_{ACT} is calculated. Then P_{ACT} and P_{MAX} are compared. If P_{MAX} is less than P_{ACT}, it is stored in the P_{MAX} as the new value. At every moment the P_{ACT} is computed, and the comparison is constantly carried out. The point when both are equal will be the point at which maximum power can be delivered to the load. The input impedance should be equal to the load impedance for maximum power transfer across the load. Fig. 14 shows block diagram of this method.

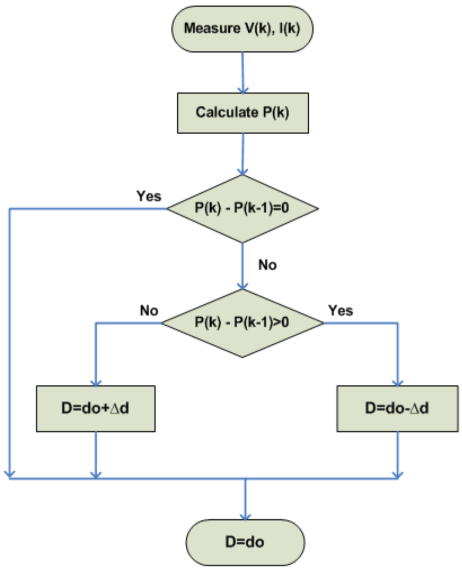

Fig. 14.*Block diagram of P&O method*

1) LTspice model of P&O method

Fig. 15 shown is spice model of Perturb and Observe MPPT method. In this method, Solar cell gives voltage Vp to boost converter and also Vp and Ip goes to M2 MOSFET which gives product of these two called power. After that this power goes to hold circuit which holds the previous value and then comparator compares the past and present value of power. The comparator output goes to circuit which determine the direction of power that either it is increasing or decreasing. It produces signal CNT which goes to Switches that produces the PWM signal for boost converter and it controls the power to a maximum level.

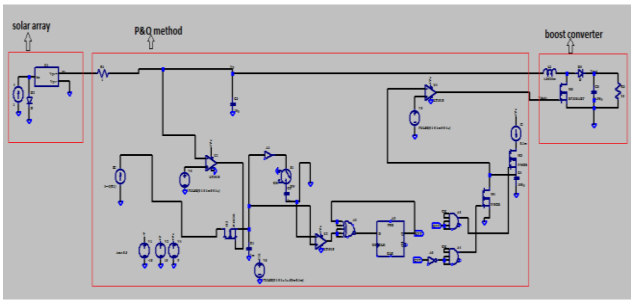

Fig. 15.*LTspice model of P&O method*

2) Simulation Results

Following waveforms are the simulation results of perturb and observe MPPT method. Fig. 16 shows the PWM signal which is the result of comparison of PV signal and sawtooth waveform. Fig. 17 shows output voltage of boost converter which shows that P&O method gives smooth output and takes less time, 0.05s which is approximately half of the time taken by CV method. Fig. 18 shows the variation in inductor current used in boost converter. One drawback is that this method adds oscillation to the inductor current.

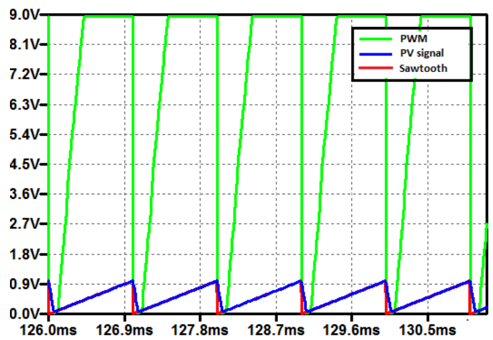

Fig. 16.*Generating PWM for switch with P&O method*

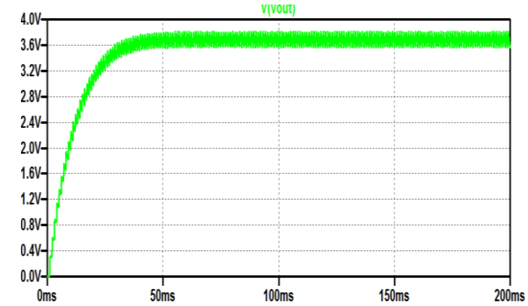

Fig. 17.*Output voltage from boost converter*

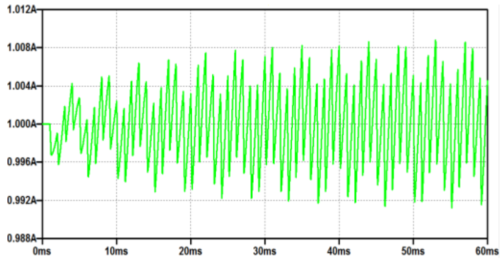

Fig. 18.*Inductor current of boost converter*

CONCLUSION

In this paper, two widely used MPPT methods, Constant Voltage and Perturb & Observe MPP algorithms were simulated in LTspice software. A simple and analog model of these algorithms is developed which is inexpensive compared to microprocessor based which are often expensive. Constant voltage method is easy to implement but reference voltage needs to be changed automatically. Perturb and Observe method is fast, accurate, medium implementation but it adds oscillations to the output. Perturb & Observe method has a fast response, it takes 0.05s and gives smooth output initially. Constant voltage method takes 0.08s for simulation and it gives huge output initially. So perturb & observe method increases the efficiency two times.

Apart from MPPT, the output power of triple junction PV cell is compared with single junction conventional silicon solar cell. Comparison shows approximately three times increase in power delivered from conventional silicon cell. This gigantic rise in output energy of Photo-voltaic verifies the supremacy of suggested technique that will be translated to significant cost depletion of the produced kWh.

ACKNOWLEDGMENT

A part of this work was carried out at Arizona State University (ASU) in the United State under the supervision of Dr. Bertan Bakkaloglu. The authors would like to acknowledge the efforts of the team at ASU who gave time to this research work. Also to USAID who funded this research work.

REFERENCES

[1] Kaundinya, D.P., P. Balachandra, and N. Ravindranath, “Grid-connected versus stand-alone energy systems for decentralized power—A review of literature”. Renewable and Sustainable Energy Reviews, p. 2041-2050, 2009. **13**(8):

[2] Sawin, J.L., et al., “Renewables 2017 Global Status Report”, 2013.

[3] Rezk, H. and A.M. Eltamaly, “A comprehensive comparison of different MPPT techniques for photovoltaic systems”, Solar energy, **112**: p. 1-11,2015.

[4] Femia, N., et al., “Optimization of perturb and observe maximum power point tracking method”, IEEE transactions on power electronics, **20**(4): p. 963-973, 2005.

[5] H. Rezk and E.-S. Hasaneen, “A new matlab/simulink model of triple-junction solar cell and mppt based on artificial neural networks for photovoltaic energy systems,” *Ain Shams Engineering Journal*, vol. 6, no. 3, pp. 873–881, 2015.

[6] Liu, B., et al. “Analysis and improvement of maximum power point tracking algorithm based on incremental conductance method for photovoltaic array”, Power Electronics and Drive Systems, PEDS'07. 7th International Conference on. 2007. IEEE,2007.

[7] Mohamed A. El-Sayed, Steven Leeb, “Evaluation of maximum power point tracking algorithms for photovoltaic electricity generation in Kuwait”, international conference on renewable energies and power quality (icrepq’14), April 2014.

[8] A. M. Atallah, A. Y. Abdelaziz, and R. S. Jumaah, “Implementation of perturb and observe mppt of pv system with direct control method using buck and buckboost converters,” Emerging Trends in Electrical, Electronics & Instrumentation Engineering: An international Journal *(EEIEJ)*, vol. 1, no. 1, pp. 31–44, 2014.

[9] Kennedy A. Aganah, Aleck W. Leedy, “A Constant Voltage Maximum Power Point Tracking Method for Solar Powered Systems”, March 2011.

[10] Bibi Rabia, “ Design of multi junction solar cell MPPT controller in LTspice”, MS thesis.