INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
Ballaji A. et.al., Vol.9, No.1, March, 2019

Energy Efficient Perturb and Observe Maximum Power Point Algorithm with Moving Average Filter for Photovoltaic Systems

Adithya Ballaji*, B.P. Divakar*, Mr.Nagaraj Hediyal**, Dr. Rajashekar P Mandi***, K Narayan Swamy****

*Assistant Professor, School of Electrical xand Electronics Engineering, REVA University

*School of Electrical and Electronics Engineering, REVA University

**M/s eNLiven Technologies, Bangalore

***Director, School of Electrical and Electronics Engineering, REVA University

****Associate Professor, School of Electrical and Electronics Engineering, REVA University

(adithyaballaji@reva.edu.in, divakar@reva.edu.in)

(Adithya Ballaji, REVA University, India, +91-9738827023)

Received: 18.12.2018 Accepted: 25.01.2019

Abstract: Utilization of renewable energy resources is gaining more importance due to improved rate of returns on investment and the technology. Solar energy is the main resource at present to receive wide spread acceptance due to the maturity of the technology among all renewable energy resources. The power production from the solar source largely depends upon the irradiance and the temperature and hence requires complex control strategies for better utilization of energy. Many researchers have been working on improving the solar power extraction by way of maximum power point tracking and other means. This paper presents the modified Perturb and Observe (P&O) algorithm with Moving Average Filter (MAF) to extract the maximum power from the solar for photovoltaic systems. The paper also presents a buck converter controlled by the modified algorithm to charge the battery of a photovoltaic system. The proposed system is simulated and implemented in hardware. The simulation and experimental results show a good performance of the modified algorithm and its suitability for photovoltaic applications.

Key Words: *Renewable energy, Solar, MPPT, Irradiation, Algorithm, MAF, P & O.*

1. Introductıon

The fast depletion of the fossil fuel resources and their negative impact on the environment are the cause for concern in meeting the demand for energy. This rapid demand for energy can only be fulfilled with renewable energy resources. The use of renewable energy resource not only improves the supply and demand ratio of power but also avoid the global warming. Thus the world moves towards green energy era as these renewable energy resources do not contribute to greenhouse gases. The solar renewable energy is the most sought resource due to the devices used to extract power from the source has simple structure and ease of use.

India is endowed with a vast solar energy potential. India receives one of the highest global solar radiations of about 5,000 trillion kWh per year as per the global study. Most part of India receives solar irradiance of about 4.5 kWh /m^2 per day. Enormous amount of power can be extracted from solar but is limited by the conversion efficiency of the available technology. The maximum efficiency of the currently available technologies is less than 22.2% as per the literature done. However, recent information indicates that the multi junction cell technology has efficiency slightly greater than 40.7% as claimed by U.S Department of energy (courtesy Google).

The maximum power point tracking techniques are employed to harvest maximum power from solar. The most popular MPPT techniques are Perturb & Observe (P&O), Incremental Conductance (INC). These techniques suffer from certain drawbacks. The P & O technique is simplest and easy to implement but has an issue of oscillations. INC has better efficiency than P & O but it is complicated. In order improve the efficiency and remove the noted drawbacks of P & O technique, the paper presents the work on modified P & O algorithm for photovoltaic systems.

The paper is arranged in such a way that the section 2 describes the related work done in the past, section 3 details the problem overview, section 4 deals with the proposed work, section 5 presents the simulation, experimental models along with results and analysis of the proposed work and section 6 presents the conclusion.

2. Related Work

In the past many techniques have been proposed by researchers on the MPPT. In [1], the evaluations of P & O, INC have been presented with the extended operating conditions. At varied temperature and different operating conditions, the performance of these techniques is studied and tabulated. The study has revealed that the P & O has a faster dynamic performance over a distinct wide range of operating conditions compared to its sibling incremental conductance technique. In [2], the buck boost and buck converters are used along with P & O to improve the performance of PV system. The study shows that the performance of the PV system with buck converter controlled by P & O has better over buck-boost controlled by P & O. It has been observed that the performance of the buck and buck-boost converters had an effect with sudden change in operating conditions like temperature irradiance etc. In [3], the performance study of INC MPPT with boost converter has been presented using MATLAB/SIMULINK model. It was only a simulation model. In [4], a Simulink model and experimental models have been developed to study the performance of the PV system with boost converter controlled by the P & O and INC MPPT techniques. As per the authors the performance of the system with boost converter controlled by INC MPPT technique is 3 times faster than that controlled by P & O MPPT. In [5], [6] the performance study of Photovoltaic (PV) systems with P & O MPPT are presented. The results indicate that the drift and instability was observed due to change in irradiance and temperature. In [7] to [15], the basic MPPT techniques P & O, INC have been subjected to various operating conditions by employing Buck Converter, Buck-Boost Converter, Boost Converter, CUK converter, in conjunction with PID controller and other means. The performance study by all these researchers have indicated that these techniques suffer from instability, drift, cumulative errors, speed etc. The performances of these systems have also had an effect on the applications as well.

3. Problem Overvıen

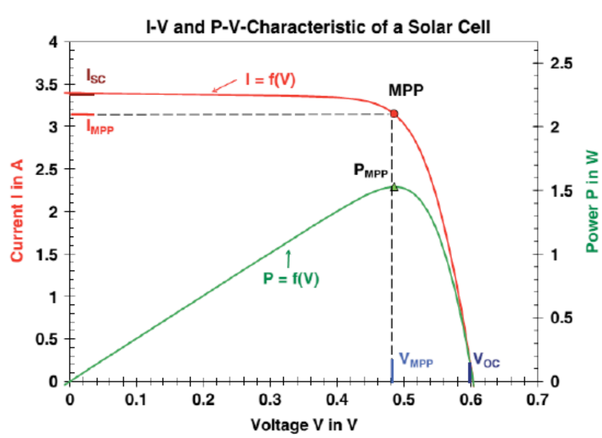

Fig.1. (a) I–V and (b) P –V characteristics of PV panel at different Irradiance and Temperature conditions [16]

The I-V and P-V characteristics of a photovoltaic cell are shown in figure 1 which shows that selection of appropriate operating points can only lead to extraction of maximum power from the source. This is possible through MPPT tracker. The MPPT tracker automatically ascertains the voltage and current to reach their peak values i.e. (V_{MPP}) & (I_{MPP}) for certain temperature and irradiance and hence the maximum power output (P_{MPP}). Perturb and observe method is one of the popular algorithms owing to its simplicity. However, in Perturb and Observe algorithm, the operating point swings at the MPP which leads to reduced efficiency affecting the charging process of battery leading to poor life expectancy of battery.

From Figure 1 it is clear that the change in irradiance has an effect on the maximum power point.

It has been noted from the work presented in the past by the research community, the drift, instability and oscillations of the operating point is the main concern in achieving the highest efficiency. The problems mentioned here could be eliminated by employing the Moving Average Filter (MAF) in conjunction with P & O control algorithm.

4. Proposed Modified P & O Technique with MAF

The proposed MPPT algorithm has P & O as the basic algorithm and MAF as the extension algorithm to improve the efficiency by eliminating the oscillations and drift in the operating point and thus forms the modified P & O MPPT technique. The flow chart of the basic P & O algorithm is shown in Figure 2.

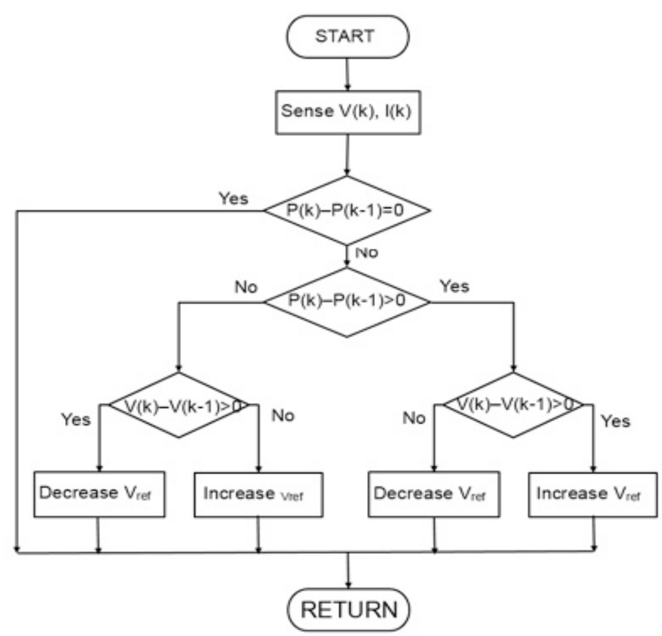

Fig.2. Flow chart of P & O algorithm

Moving average filter is used in almost all applications where mean values and precision is most important. It is also known as running average technique and mostly applied in financial transactions with unweighted values. However, it assumes most significance in noise elimination within communications systems. The MAF can be simple or weighted depending upon the application. In the proposed system, it is a weighted MAF, since each value has a multiplying factor to represent changing weights at different positions within the simple window. The MAF can be better understood from the Figure 3.

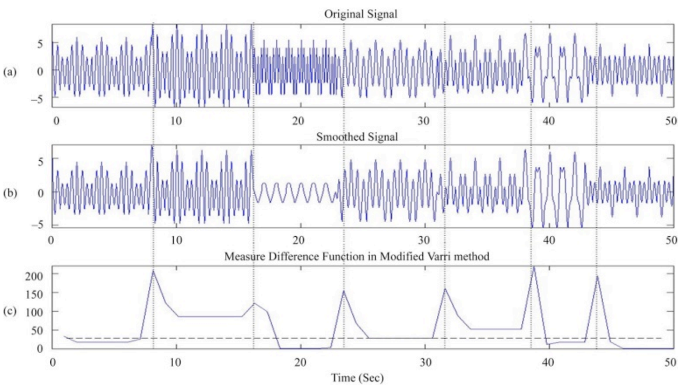

Fig.3. MAF explained [Courtesy Google]

The MAF depends upon the number points (step size) to average the values. Mathematically, MAF is given by given

$$y[i]=\frac{1}{M}\sum_{j-0}^{m-1}x[i=j] \qquad (1)$$

Where *x [ ]* is the input signal and *y [ ]* is the output signal and M is the number of points in the moving average.

Figure 4 shows the flowchart of proposed modified perturb and observe technique using moving average filter.

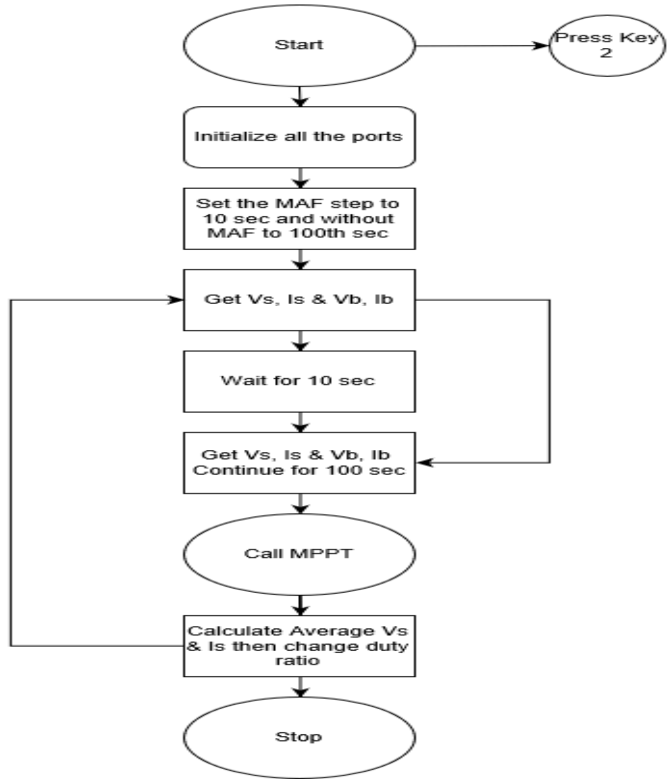

Fig.4. Flow chart of P&O using MAF

4.1 The Simulation results

The simulation and experimental models of the proposed system and associated results are discussed in this section. Figure 5 shows the schematic representation of the PV cell model to obtain I-V characteristics. The simulation is carried out with a variable load to obtain the I-V characteristics of the solar panel.

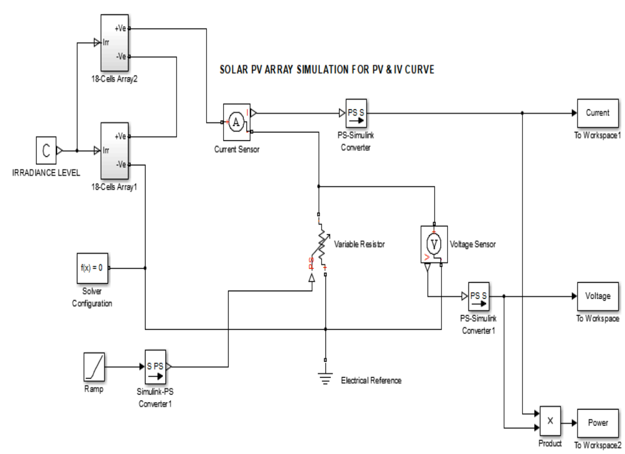

Fig.5. Simulation model of 20W Panel (36 cells)

Figure 6 and 7 show the I-V and P-V characteristics of the selected 36 cells polycrystalline type solar panel.

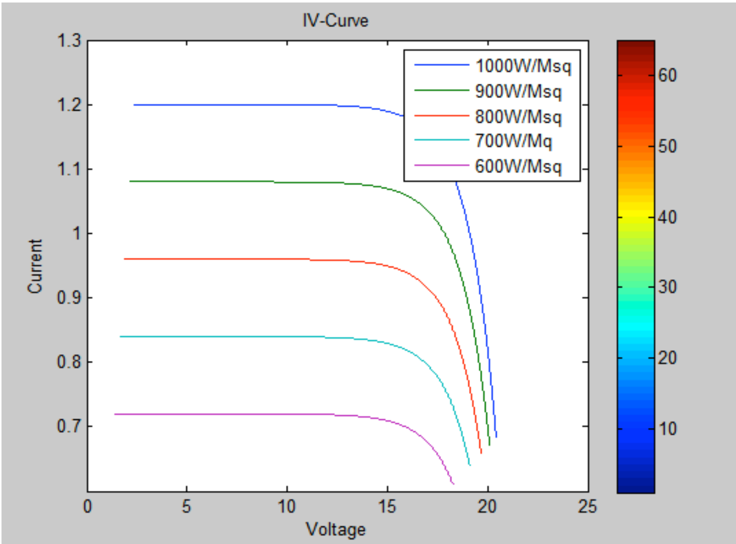

Fig.6. I-V characteristics of 20W Solar panel

In Figure 6, the panel current verses panel voltage characteristics at different irradiance of 600 w/m^2 to 1000 w/m^2 are plotted.

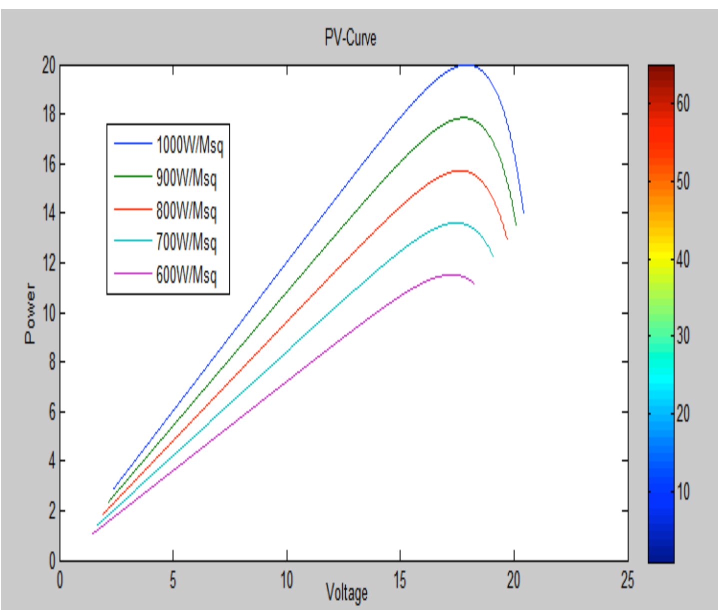

Fig.7. P-V characteristics of 20W Solar panel

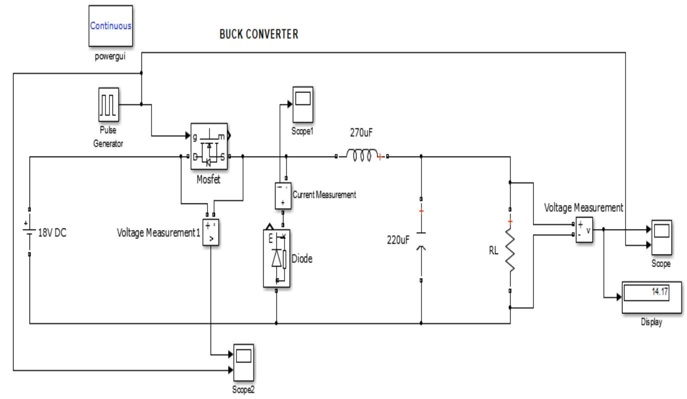

Fig.8. Simulink model of Buck converter

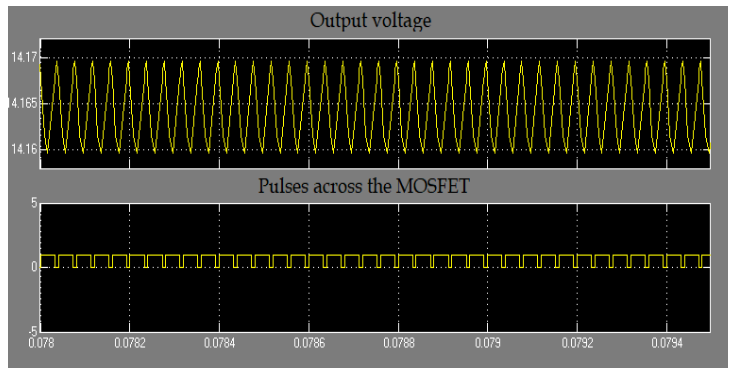

Fig.9. Simulated output of Buck converter

Figure 7 above shows the P-V curves for various irradiances.

Figure 8 shows the schematic of the buck converter whose specifications are: V_{in} = 18V; V_{out} = 14.17V; f_s =25 KHz; L = 270uH; C = 220uF; Load = 7W 12V DC LED Bulb.

Figure 9 shows the steady state output voltage with ripple of less than 10 mV.

4.2 Experimental prototype

The experimental model of the proposed system is shown in Figure 10 depicting sensor circuits and microcontroller.

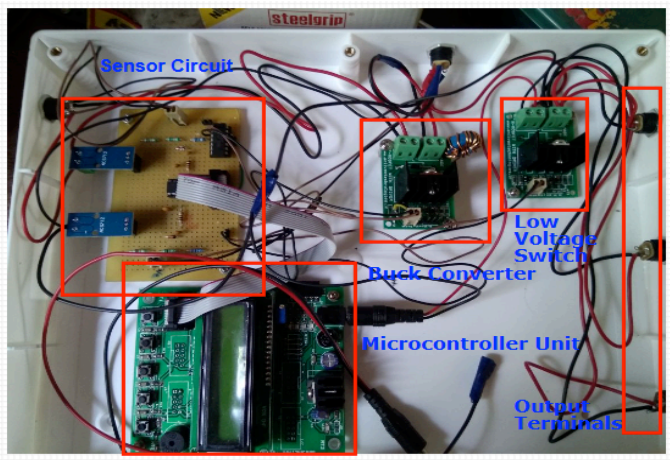

Fig.10. Experimental prototype of the buck converter

The schematic representation of the proposed system is shown in Figure 11.

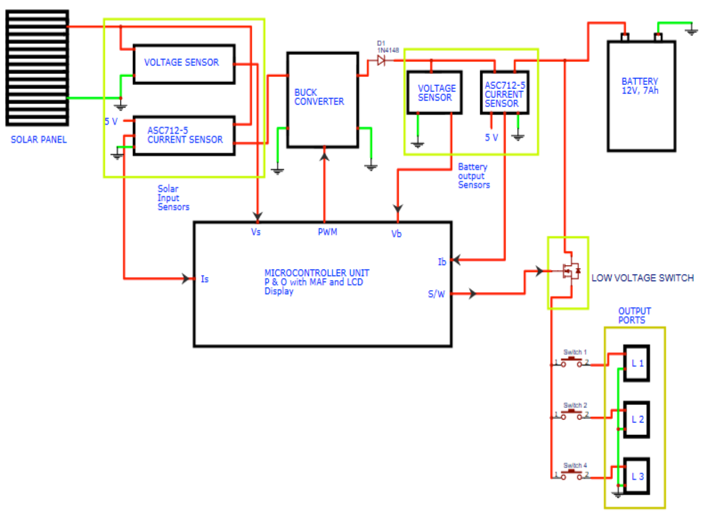

Fig.11. Schematic representation of the system proposed.

The MPPT algorithm requires information of voltage and current. Hence to acquire the solar voltage and load voltage a signal conditioning circuit is designed around LM358 a dual operational amplifier device along with passive components. The schematic of the same is shown in Figure 12.

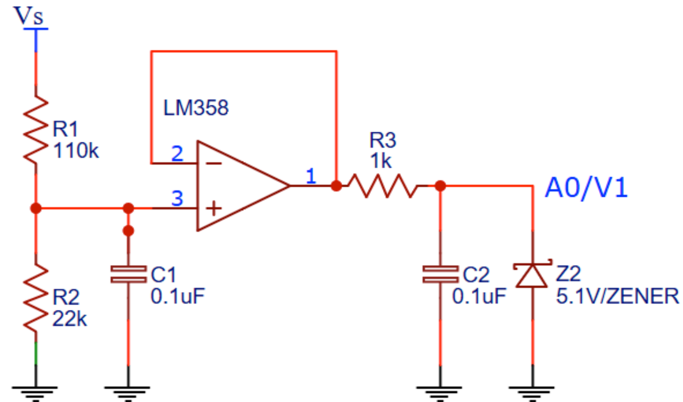

Fig.12. Signal conditioning circuit for voltage acquisition.

From the above figure:

The voltage at pin 3 and 1 of LM358 is given by:

$$V_1 = V_s * \frac{22k}{100k + 22k} \tag{2}$$

$$V_1 = V_S * 0.167 \tag{3}$$

$$V_S = \frac{V_1}{0.167} \tag{4}$$

Further, the relation between the analog input and digital output of the analog to digital converter is given by:

$$V_{adc} = ADCcount * \frac{5}{1023} \tag{5}$$

$$V_{adc} = ADCcount * 0.00488 \tag{6}$$

Therefore, the input from solar V_1 is equal to V_{adc}

And hence from (4) and (6)

$$V_S = ADCcount * \frac{0.00488}{0.167} \tag{7}$$

$$V_S = ADCcount * 0.0293 \tag{8.}$$

Similarly the load side voltage is determined.

Next current is acquired by using a Hall Effect current sensor (ACS712-05A). The typical circuit of the ACS712-05 sensor is shown in Figure 13.

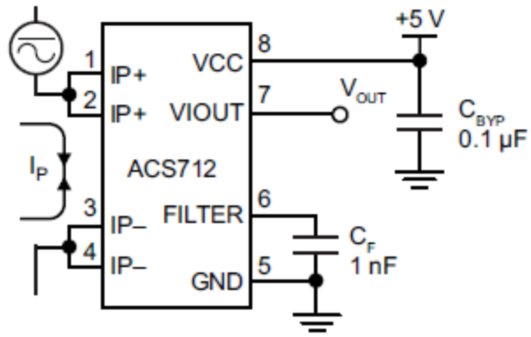

Fig.13. Hall effect current sensor ACS712-05A [Data Sheet]

The ACS712-05A has a sensitivity of 185mV/A and the offset voltage of 2.5V. The operating voltage is 5V.

The output voltage of this sensor is fed to ADC, therefore:

The input of the A to D given by:

$$V_{adc} = \frac{V_{cc}}{2} + 0.185 * I \tag{9}$$

$$V_{adc} = \frac{5}{2} + 0.185 * I \tag{10}$$

From (6) and (10)

$$I = (ADCcount - 512) * 0.0264A \tag{11}$$

The schematic of the buck converter is shown in Figure 14.

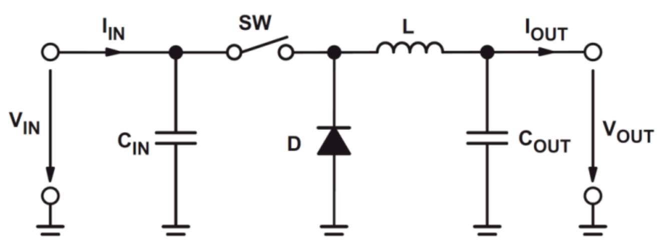

Fig.14. Buck Converter Power stage.

The circuit parameters of the buck converter are:
Input voltage V_{IN}= 18V DC,
Output voltage V_{OUT} = 15.2V DC,
Output Current I_O= 1A, DC
Maximum Duty ratio D_{MAX}= 0.85
Inductor L= 270µH,
Output Capacitance C_O = 220µF,
Input Capacitance C_{IN} =47µF.
Switching frequency f_{SW} = 25 kHz.
Ripple Voltage ΔV = 50mV.

The specifications of solar panel, Battery and load used in the experiment are:
The solar panel specifications:
Open circuit voltage= 21.2V
Short circuit current of= 1.13A
Optimum voltage = 17.71V
Optimum current = 1.2A

Battery specifications:
Nominal voltage=12V
Capacity= 7.2Ah
Type: Lead acid
Load= Up to 20W any DC load.

Load specifications:
7W LED bulb was used as load in the experiments.
System has 3 slots to connect load.

4.3 Experimental results

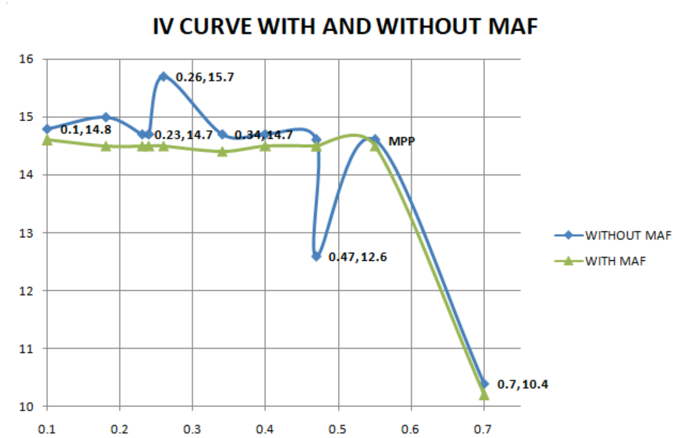

Fig.15. I vs V characteristics of the PV system

The microcontroller generates the gate signals as per the modified P&O algorithm by sensing voltages and currents. The experimental results with and without MAF algorithms were recorded and plotted in Figure 15.

From figure 15, it is clear that, the output of the PV system has drift and oscillations without the application of MAF and has an almost smooth curve with MAF. The P & O sampling time is 100 s while that of MAF 10. Figure 16 shows the power vs voltage of the PV System with and without MAF.

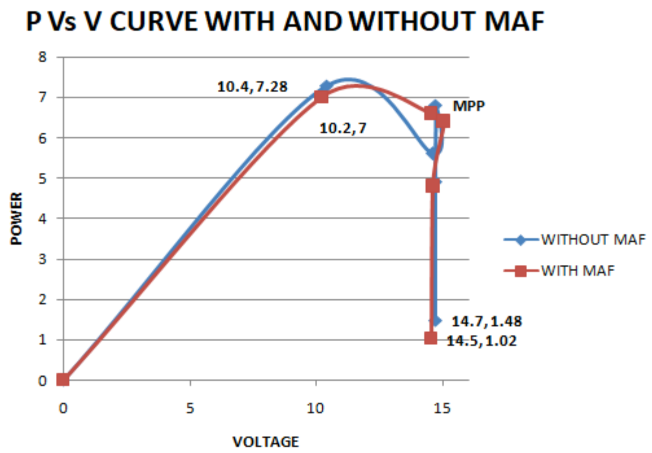

Fig.16. P vs V characteristics of the PV system.

It is observed that, the proposed algorithm with MAF has no drift in power extraction as compared to the system without MAF. The estimated efficiency of the system is well above 90% with operating condition 33 degree Celsius and 1080W/m^2

5. Conclusıon

Maximum power extraction is possible through various MPPT algorithms and one of the popular methods is P&O algorithm. The main limitation of it is the wide drift in the extracted power due to the oscillations introduced inherently by the algorithm. To overcome the power drift, the basic P & O algorithm was modified with MAF algorithm to improve the performance of the PV system. The drift and the oscillations present in the basic P & O algorithm were completely eliminated by MAF as evident from the results obtained experimentally. The location of the maximum point near the peak is evidence of good performance of the proposed technique. A buck converter designed and developed for the experiment was able to deliver the intended performance by extracting the expected output. The output of the buck converter was used to charge the battery and the load. The experiments results confirm the better performance of the P & O with MAF technique for the maximum power point tracking of the solar PV system. Further work is in progress to test the system under variable temperature and irradiance.

Acknowledgment

The authors wish to thank REVA University for providing the facilities to carry out the research.

References

[1] Saleh Elkelani Babaa, Matthew Armstrong, Volker Pickert, “Overview of maximum power point tracking control methods for PV Systems”, Journal of Power and Energy Engineering, 2014, 2, 59-72

[2] Ahmed M. Atallah, Almoataz Y. Abdelaziz, and Raihan S. Jumaah, “Implementation of Perturb and Observe MPPT of PV system with direct control method using buck and buck – boost converter” Emerging Trends in Electrical, Electronics & Instrumentation Engineering: An international Journal (EEIEJ), Vol. 1, No. 1, February 2014

[3] S.Gomathy, S.Saravanan, Dr. S. Thangavel “Design and Implementation of Maximum Power Point Tracking (MPPT) Algorithm for a Standalone PV System” International Journal of Scientific & Engineering Research Volume 3, Issue 3, March -2012 1 ISSN 2229-5518

[4] Anmol RatnaSaxena, Shyam Manohar Gupta “Performance Analysis of P&O and Incremental Conductance MPPT Algorithms Under Rapidly Changing Weather Conditions” Journal of electrical Systems, 10-03—2014, 292-304

[5] S. Kolsi1, H. Samet, M. Ben Amar, “Design and analysis of DC-DC Converters connected to a photovoltaic generator and controlled by MPPT for optimal energy transfer throughout a clear day”
Journal of Power and Energy Engineering, 2014, 2, 27-34

[6] Adel A. Elbaset, Hamdi Ali, Montaser Abd-El Sattar, “ A modified Perturb and observe Algorithm for maximum power point tracking of photovoltaic system using buck – boost converter” Journal of engineering sciences Assiut University Faculty of Engineering Volume 43. No.3, May 2015, PP 344-362.

[7] Emmanuel Kwaku Anto, Johnson A. Asumadu, Philip Yaw Okyere, “PID based P&O MPPT Controller for offgrid Solar PV Systems using Ziegler – Nichols tuning method to step, ramp, and Impluse Inputs” Journal of Multidisciplinary Engineering Science Studies (JMESS) ISSN: 2458-925X Vol. 2 Issue 7, July – 2016

[8] Deepti Singh, RiaYadav, Jyotsana, “Perturb and Observe method MATLAB Simulink and design of PV System using buck boost converter” International Journal of Science, Engineering and Technology Research (IJSETR), Volume 3, Issue 6, June 2014

[9] P. C. M. Bernardo, Z. M. A. Peixoto and L.V. B. Machado Neto, " A high efficient micro- controlled buck converter with maximum power point tracking for photovoltaic systems" International Conference on Renewable Energies and Power Quality (ICREPQ'09)Valencia (Spain), 15th to 17th April, 2009

[10] Ting-Chung Yu, Yu-Cheng Lin "A Study on Maximum Power Point Tracking Algorithms for Photovoltaic Systems" A Study on Maximum Power Point Tracking Algorithms for Photovoltaic Systems.

[11] Samia Latreche, Mabrouk Khemliche, Mohammed Mostefai, "Design of MPPT in PV System Based on PIC18F4550 Microcontroller" CIER-2014, Proceedings of Engineering and Technology – PET, Copyright - IPCO 2015

[12] Fangrui Liu, Shanxu Duan, Fei Liu, Bangyin Liu, and Yong Kang, "A Variable step size INC MPPT Method for PV System" IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 55, NO. 7, JULY 2008

[13] Kannabiran Kanimozhi1, Bagarudeen Raja Mohamed Rabi, "Development of Hybrid MPPT Algorithm for Maximum Power Harvesting under Partial Shading Conditions" Circuits and Systems, 2016, 7, 1611-1622

[14] Mohammed A. Elgendy, Bashar Zahawi, Senior Member, IEEE, and David J. Atkinson, "Assessment of Perturb and Observe MPPT Algorithm Implementation Techniques for PV Pumping Applications" IEEE transactions on sustainable energy, vol. 3, no. 1, january 2012

[15] Subhransu Padhee, Umesh Chandra Pati, Kamalakanta Mahapatra, "Design of photovoltaic MPPT based charger for lead acid batteries" ©2016 IEEE

[16] Emad Talib Hashim, Akram Abdulameer Abbood, "Temperature Effect on Power Drop of Different Photovoltaic Modules" Number 5, Volume 22, May 2016, Journal of Engineering

[17] Abdellah Ziouh , Ahmed Abbou, "Fuzzy-Super Twisting Sliding Mode MPPT Control for Three-Phase Grid-Connected PV" INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH A. Ziouh and A. Abbou , Vol.8, No.4, December, 2018

[18] Yuwei Sun, Xinping Yan, Chengqing Yuan, Hu Luo and Qizhen Jiang, "The I–V characteristics of solar cell under the marine environment: Experimental research," *2015 International Conference on Renewable Energy Research and Applications (ICRERA)*, Palermo, 2015, pp. 403-407.doi: 10.1109/ICRERA.2015.7418445

[19] E. Kabalci, Y. Kabalci, R. Canbaz and G. Gokkus, "Single phase multilevel string inverter for solar applications," *2015 International Conference on Renewable Energy Research and Applications (ICRERA)*, Palermo, 2015, pp. 109-114. doi: 10.1109/ICRERA.2015.7418459

[20] Youcef Soufi,Mohcene Bechouat,Sami Kahla, Kais Bouallegue, " Maximum Power Point Tracking using fuzzy logic controller for Photovoltaic System" 3rd *International Conference on Renewable Energy Research and Applications (ICRERA)* Milwakuee, USA19-22 Oct 2014

[21] Ahmed Ali, Ali N Hasan, Tshilidzi Marwala,"Perturb and Observe based on fuzzy logic controller Maximum Power Point Tracking (MPPT)" 3rd *International Conference on Renewable Energy Research and Applications (ICRERA)* Milwakuee, USA19-22 Oct 2014

[22] G Graditi, G Adinolfi, A Del Giudice,"Experimental Performance of a DMPPT Multitopology converter" 3rd *International Conference on Renewable Energy Research and Applications (ICRERA)* Milwakuee, USA19-22 Oct 2014