RECURSIVE IDENTIFICATION OF MPP USING ADAPTIVE MPPT CONTROLLER FOR SOLAR PV SYSTEM

R.Durga Devi
Department of Electrical & Electronics Engineering, Veltech Dr.RR & Dr.SR University
Chennai, India, rdurgadevi@veltechuniv.edu.in

S.Nageswari
Department of Electrical & Electronics Engineering, A.C. College of Engineering & Technology
Sivagangai, India, nageswari@accet.edu.in

Abstract: *In this paper maximum power point of solar PV system is identified recursively using an adaptive maximum power point tracking (MPPT) method for improved dynamic performance. This adaptive controller modifies the behaviour of the system using certainty equivalence principle to maintain the load voltage as constant irrespective of the variation in solar insolation conditions. It also enhances the tracking speed of maximum power point by directly adjusting the duty cycle of the DC-DC converter based upon the system output voltage. Math Work Simulink environment is used for evaluating the performance of the entire system. The simulated results indicate enhanced dynamic performance with improved voltage gain.*

Key words: duty cycle, Insolation, Maximum Power Point (MPP), Maximum Power Point Tracking (MPPT), Parameter Estimation, Photovoltaic (PV) system, recursive identification, tracking error.

I.INTRODUCTION

Renewable energy resources gain their importance due to enormous power consumption and exhaustion of fossil fuel. Among several energy resources, the photovoltaic energy provides the solution for energy crisis and provides a sustainable environment. Energy provided by the sun in one hour is equal to the amount of energy required by the human in one year. The problems caused while harnessing solar energy using PV modules are varying due to changing environmental conditions such as varying insolation and temperature. Due to the non-linear characteristics of PV module, the changes caused by the varying insolation strictly affect the efficiency and output power of the PV modules. The PV module operating characteristics highly depend upon uncontrollable temperature & sun irradiation- as sun radiation varies throughout the day, the operating point of the module also varies throughout the day.

The optimum maximum operating point varies with the varying insolation and cell temperature, hence it is always necessary to track the maximum power point (MPP) of a PV array. The Maximum Power Point Tracking (MPPT) system consists of a power converter and controller circuit to maintain MPP. There are several methods for MPPT which vary in convergence speed, cost, and implementation complexity such as Perturb and Observe method (P&O) and Incremental Conductance (IC) method. P&O method is highly preferred because of its simplicity. P&O is the perturbation of operating voltage of PV array. However, P&O method cannot compare the array terminal voltage with the actual MPP voltage, since the change in power is due to perturbation of array terminal voltage [1]. Due to rapid fluctuation of weather conditions, P&O method loses its direction while tracking its optimal MPP [5] and takes more time to reach MPP [4]. Conversely Incremental Conductance method overrides the aforementioned problem, since array terminal voltage is always adjusted with MPP voltage [1] and it has higher gain and accuracy than P&O method [4]. However, IC method eliminates the fluctuation around MPP, it also has some drawbacks such as increased complexity and increased computational time. There are some MPPT such as fuzzy logic control and neural network algorithm methods which have to be specially designed and offer high accuracy. Though these methods provide good performance under varying atmospheric conditions, they require large amount of storage data and extensive computation along with the intense knowledge of the system [1-3].

The recursive identification of MPP using adaptive controller is proposed in this paper. This controller overrides the aforementioned problem and well suits for solving non-linear characteristics of solar PV system. In this method the array terminal voltage is always adjusted with optimal MPP voltage. It offers high accuracy under varying climatic conditions with simple implementation and reduced computational complexity.

The main objective of this paper is to improve the dynamic characteristics and to steadily track the MPP under varying insolation conditions. The feasibility of the proposed system is achieved by employing the Cuk Converter as the integral part of MPPT controller. In accordance with the adaptive controller, the pulse width modulation (PWM) signals are generated to control the duty cycle of the converter.

II.MATHEMATICAL MODELLING OF A PV CELL

The basic structural unit of a solar module is the PV cell. A solar cell converts energy in the photons of sunlight into electricity by means of the photoelectric phenomenon. The equivalent circuit model of a solar cell is shown in Fig. 1. It is modelled using a current source, a diode and two resistors. The diode is connected in parallel to current source; the photon energy incident on the PV cell generates current. The current source (I_L) is proportional to the amount of energy incident on PV cell.

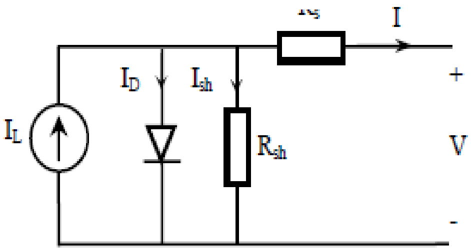


Fig.1. Equivalent Circuit Model of a Solar Cell

The I-V characteristics of the equivalent solar cell model can be determined by the equations (1) to (3). The current through diode is given by:

$$I_D = I_{sat}\left[\exp(q(V + IR_s)/KT) - 1\right] \quad (1)$$

While, the solar cell output current is given by:

$$I = I_L - I_D - I_{sh} \quad (2)$$

And,

$$I = I_L - I_{sat}\left[\exp(q(V + IR_s)/KT) - 1\right] - (V + IR_s)/R_{sh} \quad (3)$$

Where,

$$I_{sat} = CT^3[\exp(\text{-}Egap / KT)] \quad (4)$$

$$I_L = I_{L,stc}\cdot\frac{G}{G_{stc}}[1+\alpha[T\text{-}T_{stc}] \quad (5)$$

Where:

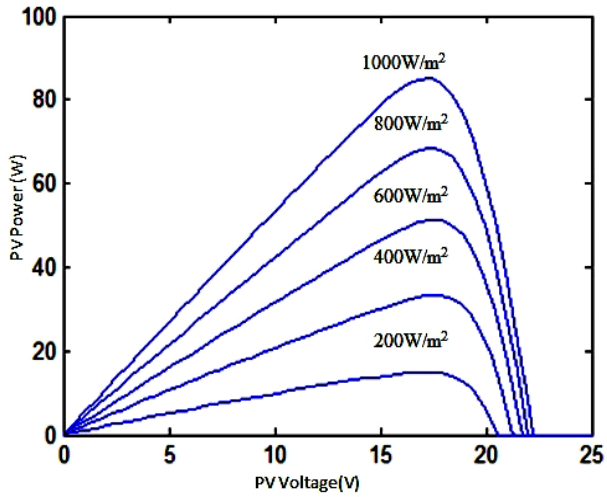
I: Solar cell current (A)
I_L: Light generated current (A)
I_D: Current across Diode (A)
I_{sat}: Diode saturation current (A)
q: Electron charge (1.6×10^{-19} C)
C: Temperature Coefficient (^{0}C)
α: Current Coefficient (^{0}C)
E_{gap}: Band gap of semiconductor material (J)
K: Boltzmann constant (1.38×10^{-23} J/K)
T: Cell temperature (^{0}C)
T_{stc} : Cell temperature under standard testing conditions (25 ^{0}C)
G: Irradiation level (W/m^2)
G_{stc}: Irradiation level under standard testing conditions (1000W/m^2)
V: Solar cell output voltage (V)
R_s: Solar cell series resistance (Ω)
R_{sh}: Solar cell shunt resistance (Ω)
$I_{sh:}$ Current flowing through shunt resistance.
The electrical specifications are listed in Table I.

TABLE I

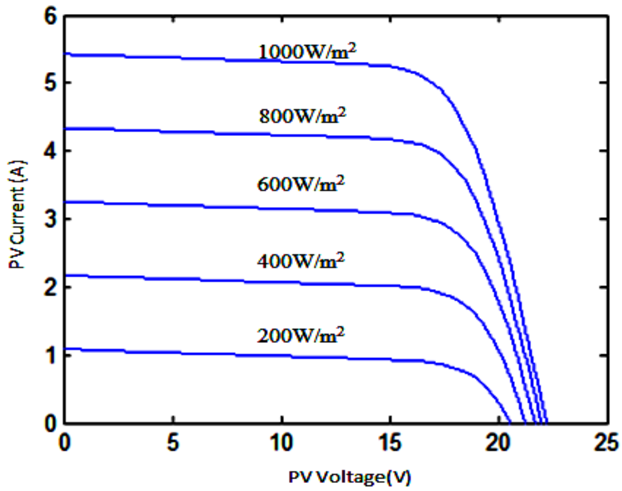
ELECTRICAL SPECIFICATIONS OF SOLAR PV SYSTEM

Short Circuit Current (Isc)	5.45A
Open Circuit Voltage (Voc)	22.2V
Voltage at Pmax (Vmpp)	17.2V
Current at Pmax(Impp)	4.95A
Maximum Power (Pmax)	85W

The resultant curves for varying insolation are shown in Fig. 2.



(a)



(b)

Fig.2. Characteristic Curve of Solar PV Cell for varying Insolation Condition
(a)P-V Characteristics of a Solar Cell
(b) I-V Characteristics of a Solar Cell

III.MODELLING OF CUK CONVERTER

It is always necessary to select a highly efficient power converter which offers high voltage gain with low duty cycle, which is supposed to operate as the main part of the MPPT [9]. A Cuk converter is a single-switch converter, which consists of a cascade of a boost converter followed by a buck converter.

The Cuk converter combines the desirable input properties of boost converter and desirable output properties of buck converter and performs general conversion function (increase or decrease of input voltage) of a conventional buck-boost converter with highest efficiency where the conversion ratio M =Vo/Vi varies with the duty ratio D of the switch. The basic schematic of cuk converter and its operation is shown in Fig. 3 & Fig.4 (a) & (b).

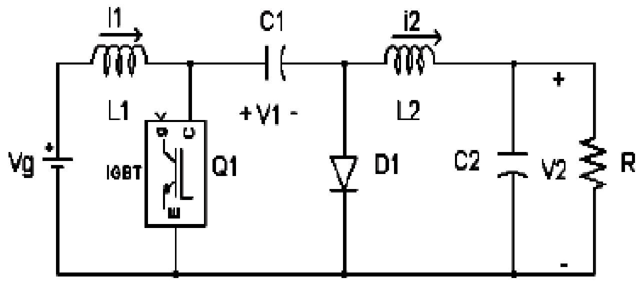


Fig.3. Circuit Diagram of Cuk Converter

The Cuk converter operates in two modes with respect to the inductor current. During mode 1 the switch Q1is turned on, the current flows through the inductor L1 and the diode D1 is reverse biased due to polarity reversal of capacitor C1.During mode 2 the switch Q1 is turned off, the capacitor C1 will charge from the input supply and the energy stored in the inductor L2 is transferred to the load [15].

When the switch is turned on,

$$Vg = V_{L1} \tag{6}$$

$$V_o + V_1 = L2\frac{di_2}{dt} \tag{7}$$

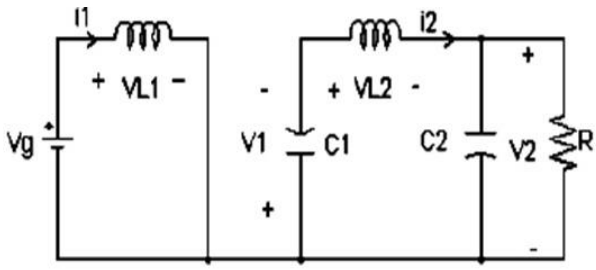


Fig.4 (a) Operation of Cuk converter when switch is on

When the switch is turned off,

$$Vg + L1\frac{di_1}{dt} = V_1 \tag{8}$$

$$V_o = V_{L2} \tag{9}$$

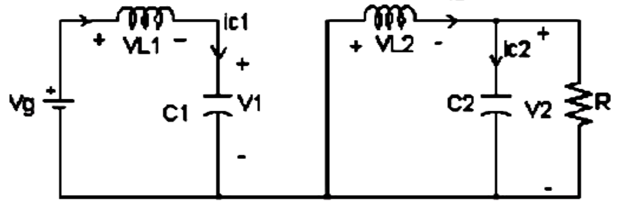


Fig.4 (b) Operation of Cuk converter when switch is off

From the above equations, the average output voltage of the converter is given by,

$$V_o = \left(\frac{-D}{1-D}\right)Vg \tag{10}$$

The average input current is given by,

$$I_s = \left(\frac{D}{1-D}\right)I_o \tag{11}$$

The peak to peak ripple current of inductor L1 is given by,

$$\Delta I_{L1} = \frac{DV_s}{fL1} \tag{12}$$

Where f is the switching frequency of the converter.

The peak to peak ripple current of inductor L2 is given by,

$$\Delta I_{L2} = \frac{DV_s}{fL2} \tag{13}$$

The main advantage of using Cuk converter is the continuous current at both the input and output of the converter due to the presence of inductor both at the input and the output terminals. Due to the capacitor energy transfer mechanism, it ensures good efficiency with reduced ripples.

IV.ADAPTIVE MPPT CONTROLLER FOR MPP IDENTIFICATION

The proposed adaptive MPPT controller mainly aims to solve the MPPT controller design at every instance of time since it mainly depends upon the varying insolation condition. If PV array feeds a load, the intersection of load characteristics and the I-V curve of the PV array curve cannot always occur in MPP, so, power lower than the maximum power is only delivered to load. Hence, to draw maximum power from solar PV system, it is necessary to move the load trajectory correlated with MPP trajectory as a to a', b to b' ... and e to e' as shown in Fig 5.

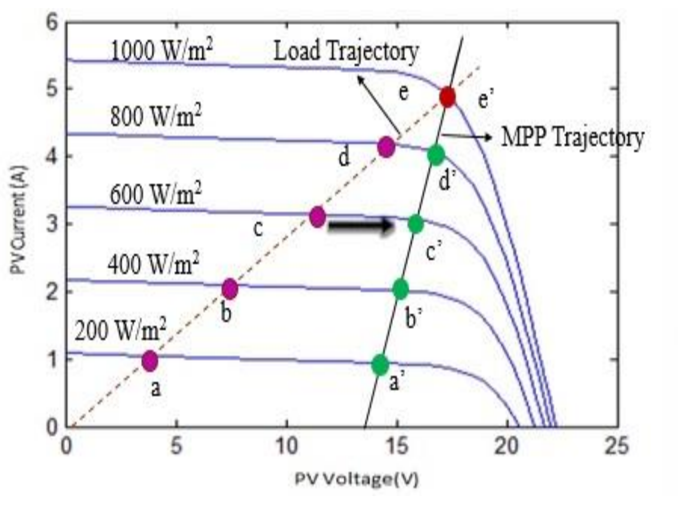


Fig.5. MPP Characteristics of a PV Cell

The MPPT controller design mainly involves the tuning of controller parameters efficiently and quickly for a PV system which has non-linear dynamic characteristics. In proposed method, the parameter tuning algorithm will recursively identify the MPP with adjustable parameters and modify its behaviour. It adapts to changes in the real time varying insolation condition to achieve high quality of feedback control. Recursive Identification of MPP mainly involves the principle of certainty equivalence [19], according to which control parameter duty cycle (k) is estimated for all instants of varying insolation conditions to produce the desired control output (k'=k(n-1)) for n^{th} iteration.

A. Design of Adaptive MPPT controller

In this method, adaptive perturbation of step size has been proposed to obtain the control signal at MPP using parameter estimation method to adjust the array terminal voltage with the optimal MPP voltage. The PV output voltage (Vpv) and output current (Ipv) are given as an input to the MPPT algorithm and it generates the V_{ref} voltage. This V_{ref} is the operating point of PV panel coincides with MPP of PV panel. The parameter estimation block apprehends the output of PV panel and varying insolation condition, accordingly updates the controller output (k'). It is mainly considered for analysing the performance of non-linear behaviour of the system [16]. The varying insolation condition and their corresponding operating points of current and voltage are taken as the regulating parameters to maintain the consistent operating MPP to improve the dynamic performance of the system.

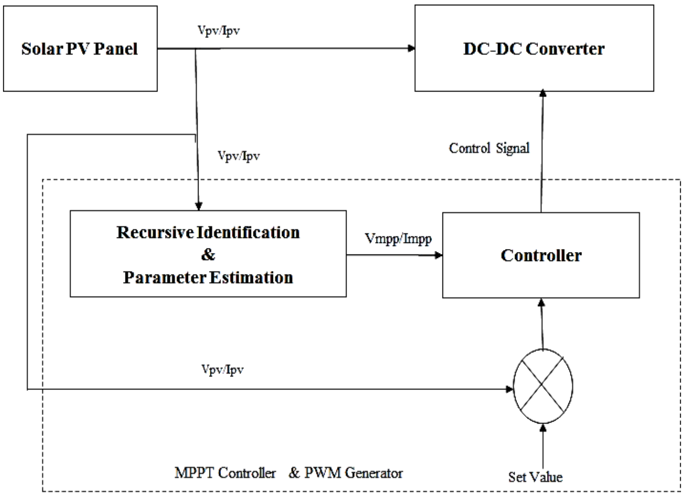


Fig.6. Functional Block Diagram of Adaptive MPPT controller

The objective function of the controller is to maintain the point at which maximum power is obtained from solar PV system as given by,

$$\frac{dPpv}{dVpv} = 0 \quad (14)$$

The simplified flowchart of this method is shown in Fig.7.

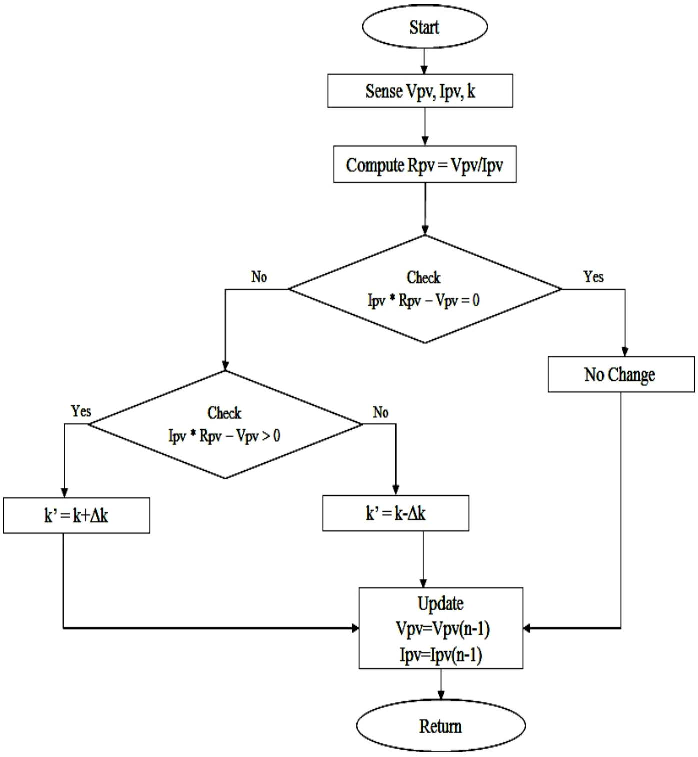


Fig.7. Flowchart for Adaptive MPPT Controller

The power obtained from solar PV system is,

$$Ppv = Vpv * Ipv \quad (15)$$

From equations (14) & (15),

$$Ipv + Vpv\frac{dIpv}{dVpv} = 0 \quad (16)$$

The dynamic resistance (Rpv) of solar PV system is given by,

$$Rpv = \frac{Vpv}{Ipv} \quad (17)$$

From equations (16) & (17),

$$Rpv = -\frac{dVpv}{dIpv} \quad (18)$$

From equations (16) & (18),

$$Ipv + Vpv\frac{dIpv}{dVpv} = Ipv - \frac{Vpv}{Rpv} \quad (19)$$

Due to varying insolation conditions, equation (16) is not possible for all atmospheric conditions and always results in tracking error (e).

From equation (19),

$$Ipv + Vpv\frac{dIpv}{dVpv} = Ipv - \frac{Vpv}{Rpv} = e \qquad (20)$$

Where e is the tracking error of solar PV system.

On simplifying equation (20),

$$Ipv * Rpv - Vpv = e * Rpv = e' \qquad (21)$$

At MPP, assume e’=0 and it satisfies,

$$Vpv = Vmpp \qquad (22)$$

And, again from Equation (15) to (22) are recursively repeated to identify MPP to operate the system at a consistent operating point.

V.SIMULATION RESULTS

The Simulation of solar PV system provides high reliability, continuous monitoring of Solar insolation variation and generates the control signal for Cuk Converter using MPPT algorithm based upon the Solar PV output for improved Voltage gain with reduced ripples. The Simulation for Cuk Converters in Solar PV System using adaptive MPPT Controller is shown in Fig.8.

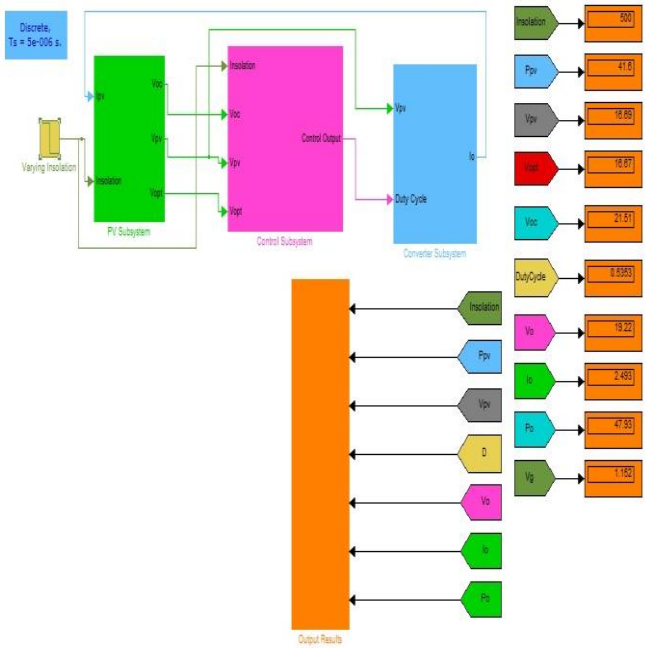


Fig.8. Simulation Diagram of SPV system with Cuk Converter using Adaptive MPPT Controller

The Solar PV system using cuk converter is simulated for the varying solar irradiations. Here the power is maintained at its maximum value using the MPPT controller. The maximum power obtained for varying insolation conditions are shown in Fig.9.

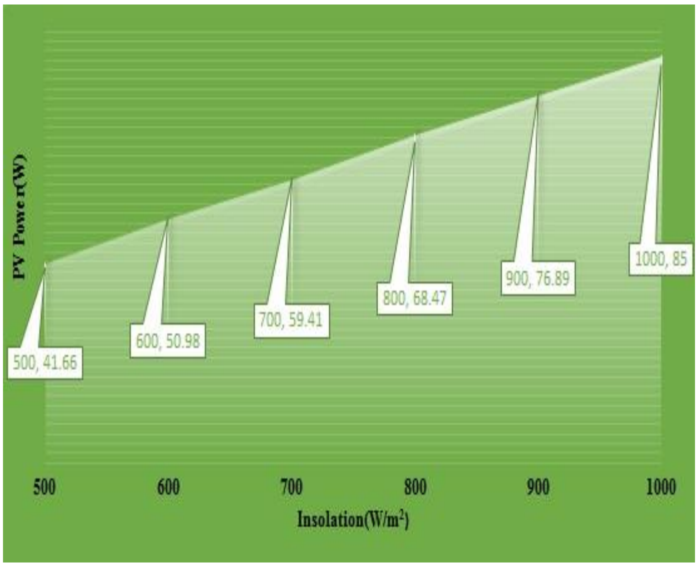


Fig.9. MPP for varying Insolation Condition

From Fig.10, it is clear that the MPP is reached faster in proposed MPPT method rather than IC method. Thus, in the proposed method by minimizing the MPP tracking error the convergence speed is increased. Under varying insolation conditions, the transition of system from 800 W/m^2 to 500 W/m^2 possess certain tracking error in obtaining the MPP, proposed MPPT system reaches its MPP in 10s ahead of IC method which is denoted as ‘e’. It is always necessary to operate a system with reduced ripple content for increased efficiency. Fig.11 to Fig. 15 show the PV system voltage Ripple (ΔVpv), Converter Output Voltage (Vo), Converter Input Current (Io) and their Ripple (ΔVo & ΔIo).From the results, it is observed that the PV system voltage ripple (ΔVpv) is reduced by 1.7021V in proposed MPPT method.

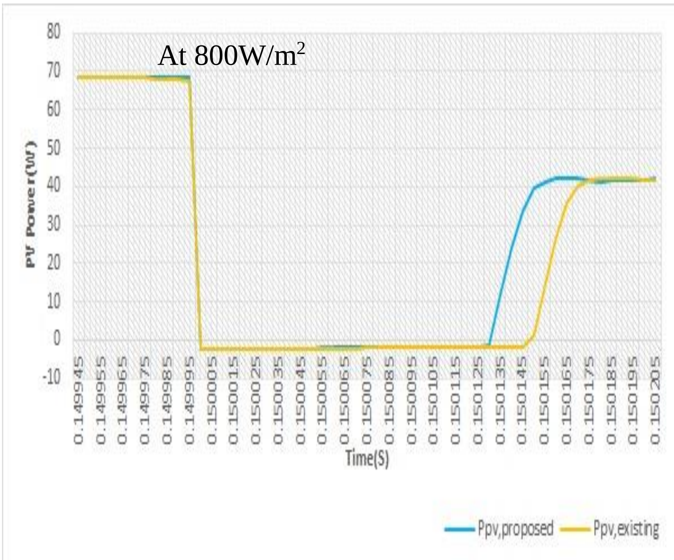
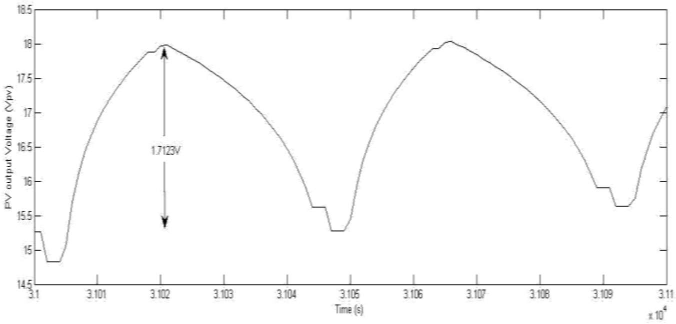
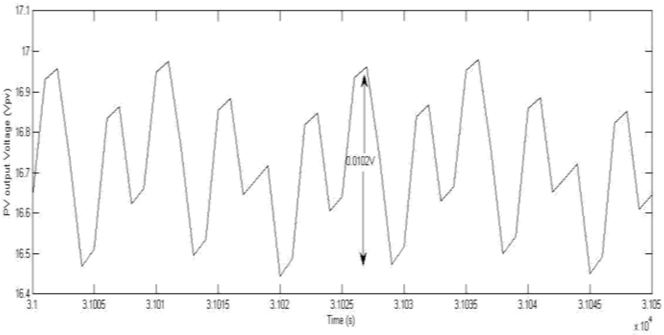


Fig.10. PV output Power (Ppv) of proposed and existing MPPT method



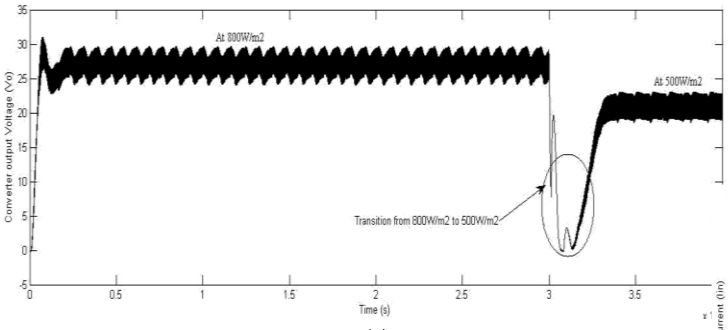
(a)



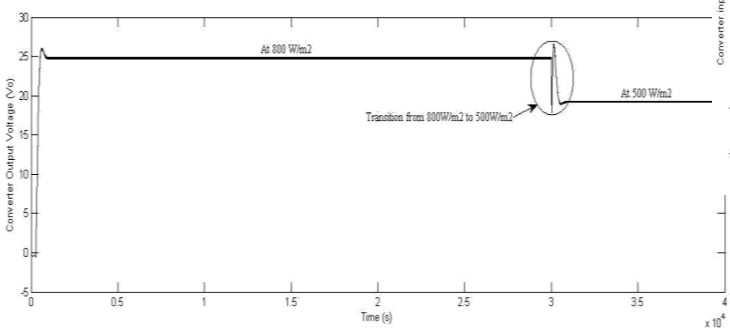
(b)

Fig.11. Projected view of PV voltage ripple (ΔVpv)
(a) Existing method (b) Proposed method

Fig.12. shows the converter output voltage (Vo) for existing and proposed MPPT method and also the transition occurring when insolation varies from 800 W/m^2 to 500 W/m^2 and Fig.13. shows projected view of converter output voltage ripple.



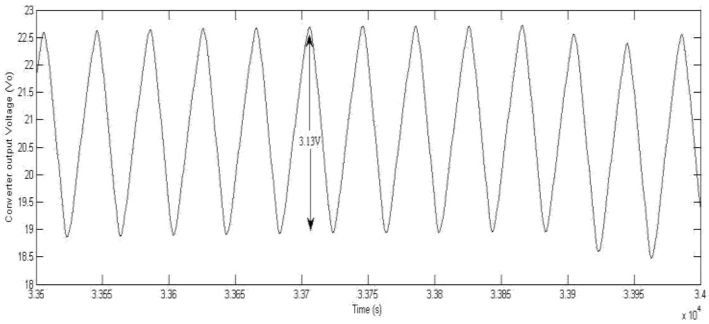
(a)



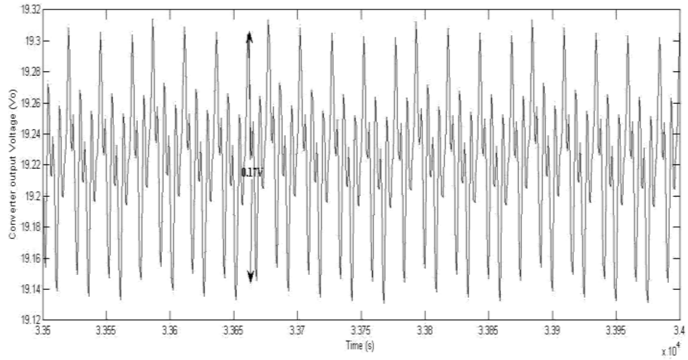
(b)

Fig.12. Converter Output Voltage (Vo)
(a) Existing method (b) Proposed method

From Fig.13, the ripple content (ΔVo) of proposed method is reduced to 0.17V where as it is 3.139V in case of existing method.



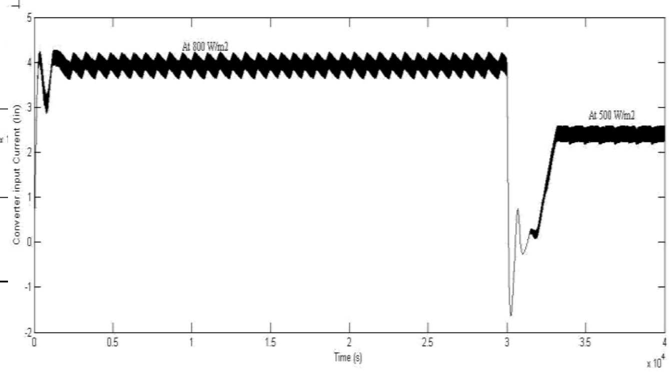
(a)



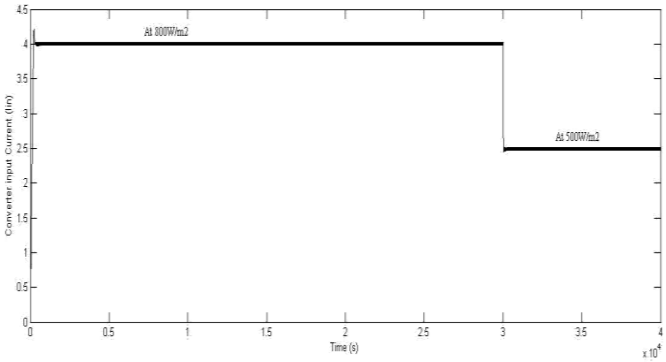
(b)

Fig.13. Projected view of Converter output voltage ripple (ΔVo)
(a) Existing method (b) Proposed method

Fig.14. and Fig.15. show the converter input current (Iin) for existing and proposed MPPT method and its projected view for ripple respectively.



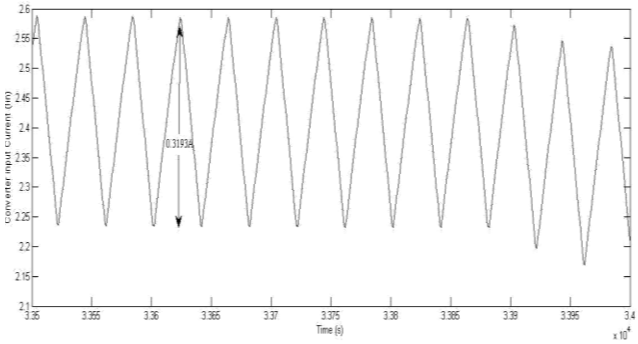
(a)



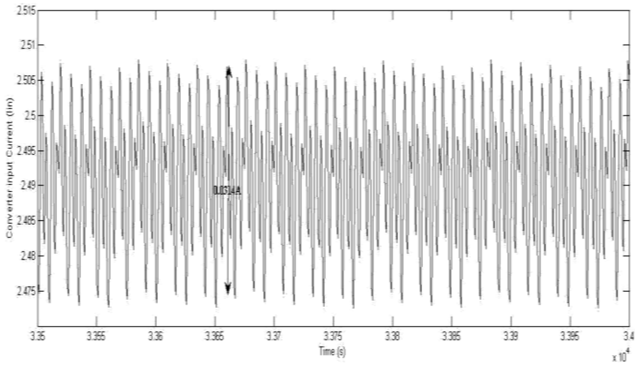
(b)

Fig.14. Converter Input Current (Iin)

(b) Existing method (b) Proposed method



(a)



(b)

Fig.15.Converter Input Current Ripple (ΔIin)

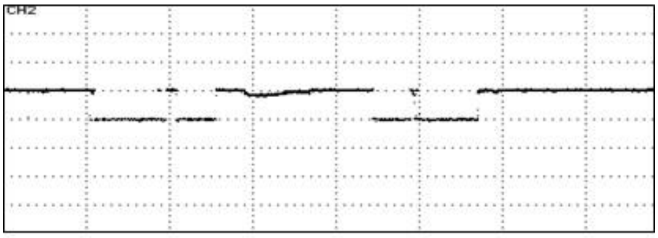
(a) Existing method (b) Proposed method

From Fig.15, the ripple content (ΔIin) of proposed method is reduced to 0.0314A compared to 0.3193A in existing method.

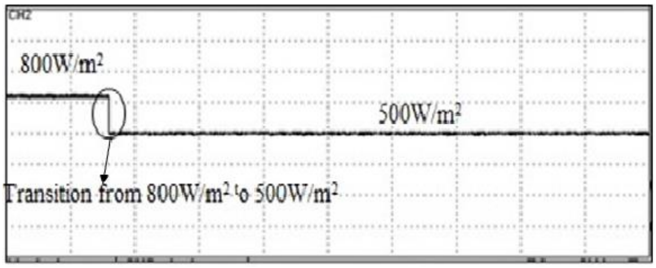
VI. EXPERIMENTAL RESULTS

The experimental setup is constructed according to the simulation specification. The PIC controller PIC 16F877A from microchip is used to implement the control algorithm to generate the duty cycle for Cuk converter. The experimental setup for the proposed PV system is shown in Fig. 16. MOSFET IRF 840 is chosen as the switching device with switching frequency of 10 kHz.

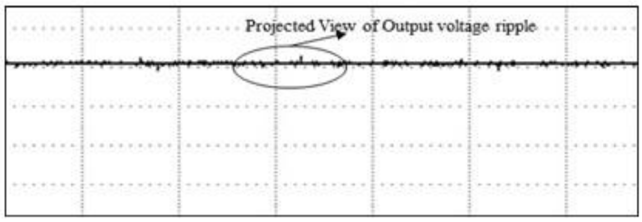
Fig. 16. Experimental Setup for the proposed Solar PV system



(a)



(b)



(c)

Fig. 17. Experimental results for the proposed Solar PV system

(a)PWM signal generated for Cuk converter

(b) Output Voltage of Cuk converter

(c)Projected View of output voltage ripple

Fig.17. shows the Experimental results for insolation variation, where the results are found to be similar to results obtained from simulation. Fig 17(a) shows the PWM generated for Cuk converter using the proposed method. Fig.17 (b) shows the converter output voltage with quick transition when insolation varies from 800 W/m^2 to 500 W/m^2 with reduced oscillations. Fig. 17 (c) shows the projected view of converter output voltage ripples, it is found to be around 0.181V compared to 0.17 V in simulated results.

VII.CONCLUSION

In this paper, Adaptive MPPT Controller is proposed to track the optimal MPP of PV array based on controlling the duty cycle of the Cuk converter connected to the PV array output terminals. The proposed system is simulated and their functionality is proven using Math Work Simulation environment and also verified experimentally**.** From the results obtained, it proves that the proposed controller is skilled of tracking the PV array maximum power under varying insolation conditions improving the efficiency of solar PV system offering improved dynamic performance with reduced ripple content and high tracking efficiency.

REFERENCES

[1] Azadeh Safari and Saad Mekhilef," Simulation and Hardware Implementation of Incremental Conductance MPPT with Direct Control Method Using Cuk Converter", IEEE Transactions on Industrial Electronics, Volume 58, Issue 4, April 2011.

[2] Ahmed G. Abo-Khalil, Dong-Choon Lee , Jong-Woo Choi and Heung-Geun Kim, "Maximum Power Point Tracking Controller Connecting PV System to Grid", Journal of Power Electronics, Volume 6, Issue 3, July 2006.

[3] Milad Momayyezan and Hossein Iman-Eini, "Developed MPPT Algorithm for Photovoltaic Systems without a Voltage Sensor", Journal of Power Electronics, Volume 13, Issue 6, November 2013.

[4] Sathish Kumar Kollimalla and Mahesh Kumar Mishra, "Variable Perturbation size Adaptive P&O MPPT Algorithm for Sudden Changes in Irradiance" IEEE Transactions on Sustainable Energy, Volume 5,Issue 3, July 2014.

[5] Kashif Ishaque, Zainal Salam, Muhammad Amjad, and Saad Mekhilef, "An Improved Particle Swarm Optimization based MPPT for PV with Reduced-Steady Oscillation" IEEE Transactions on Power Electronics, Volume 27, Issue 8, August 2012.

[6] Moacyr Aureliano Gomes de Brito, Luigi Galotto, Jr., Leonardo Poltronieri Sampaio, Guilherme de Azevedo e Melo, and Carlos Alberto Canesin," Evaluation of Main MPPT Techniques for Photovoltaic Applications", IEEE Transactions on Industrial Electronics, Volume 60, Issue 3, March 2013.

[7] Tey Kok Soon and Saad Mekhilef," A Fast-Converging MPPT Technique for Photovoltaic System under Fast-Varying Solar Irradiation and Load Resistance", IEEE Transactions on Industrial Informatics, Volume 11, Issue 1, February 2015.

[8] Weidong Xiao, Fonkwe Fongang Edwin, Giovanni Spagnuolo, and Juri Jatskevich," Efficient Approaches for Modelling and Simulating Photovoltaic Power Systems", IEEE Transactions of Photovoltaics, Volume 3, Issue 1, January 2013.

[9] R. Durga Devi and S. Nageswari,"Analysis and Implementation of MPPT Technique and Battery Voltage Regulation System for a Standalone Solar PV System", Middle-East Journal of Scientific Research, Volume 25, Issue 2, March 2017.

[10] Fu-Sheng Pai, Ru-Min Chao, Shin Hong Ko, and Tai-Sheng Lee," Performance Evaluation of Parabolic Prediction to Maximum Power Point Tracking for PV Array", IEEE Transactions on Sustainable Energy, Volume 2, Issue 1, January 2011.

[11] Neha Adhikari, Bhim Singh and A.L.Vyas," Performance Evaluation of a Low Power Solar-PV Energy System with SEPIC Converter", IEEE PEDS, December 2011.

[12] Parastoo Khademi Astaneh, and Khalil Valipoor," Study of Developed Cuk Converter for Renewable Energy Sources", International Journal of Scientific & Engineering Research, Volume 4, Issue3, March 2013.

[13] K.J.Astrom, U.Borrison, L.Ljungs and B.WittenMark, "Theory and Applications of Self-Tuning Regulators", Automatica, Pergamon Press, Great Britain, Volume 13, 1977.

[14] Fang Lin Luo and Hong Ye, "Advanced DC-DC Converters", CRC Press, Boca Raton, London, New York, Washington, D.C.,2004.

[15] Muhammad H. Rashid, "Power Electronics-Circuits, Devices and Applications", Third Edition, Pearson Education Inc, 2004.

[16] I.J.Nagrath and M.Gopal,"Control Systems Engineering", Fifth Edition, New Age International (P) Limited, Publishers, 2012.

[17] Fang Lin Luo and Hong Ye,"Renewable Energy Systems-Advanced Conversion Technologies and Applications", CRC Press, Taylor & Francis Group, 2013.

[18] Fang Lin Luo, Hong Ye and Muhammad Rashid, "Digital Power Electronics and Applications", Elsevier Academic Press, 2005.

[19] V.Bobal,J. Bohm, J. Fessl andJ. Mach a cek, "Digital Self-tuning controllers-Algorithms, Implementations and Applications", Springer-Verlag London Limited, 2005.