

Photovoltaic system under uneven light condition and variable load with modified incremental resistance algorithm

Sreekanth.S^{1*}, Dr. X. Felix Joseph²

¹Research Scholar, School of Electrical & Electronics Engineering Noorul Islam Centre for Higher Education Noorul Islam University Kumaracoil 629180, India

²Associate Professor, School of Electrical & Electronics Engineering Noorul Islam Centre for Higher Education Noorul Islam University Kumaracoil 629180, India
E-mail: sreek.surabhi@gmail.com

Abstract

On scrutinizing Power vs. Voltage curves of P_V arrays which receives non-uniform insolation of light or simply during uneven lighting conditions (ULCs) multiple LMPPTs are exhibited. Conventional MPPT methods are efficient under normal conditions even though they failed to identify the GMPPTs from LMPPTs under ULCs. To improve the productivity of Maximum power point tracking method for P_V arrays under both ULCs and normal conditions some modifications are tried in this paper. The Incremental-resistance method added with some alterations enables to track the LMPPTs as well as GMPPTs very effectively and accurately with fewer numbers of steps. In proposed system losses during GMPP, tracking is minimized under ULCs. Simulation is performed in Mat lab.

Keywords: Global MPPTS; Local MPPTS; Uneven Lighting Conditions (ULCS); Incremental Resistance (INR); Photovoltaic.

1. Introduction

Surmount the paucity of energy; the sun is the most effective option. However, the incipient expenditure and the vast land requirement made the choice impediment. So an infinitesimal loses in power results unprofitable. If wisely used this energy could overcome energy demands and moreover it is cleanly & easily available. Global-MPPT of P_V array in all conditions, guarantees the extreme power possibly obtained from the sun. Popular MPPT methods like ripple correlation technique, short circuit current (SCC) technique and Incremental_Conductance (IC) methods are effective during normal light insolation condition, but these methods seem to be struggling to find GMPPTs under ULCs conditions i.e. when modules of solar array didn't receive uniform insolation of light. During normal solar insolation conditions P v's V curves of PV arrays exhibit only one peak, Multiple LMPPTs may be viewed in Power v's Volt curves of P_V arrays under ULCs. Hence several MPPT methods are proposed especially applicable for solar arrays under ULCs which can be listed in two groups: hardware_based and software_based methods.

In [7] INC-algorithm is modified to solve a simple first-degree polynomial equation to locate Global-MPP but hardware Complexity is being increased as it requires more measuring components and circuits also it couldn't assure to locate Global-MPP in P Vs V curves which are having more number of peaks. In [8] P&O algorithm is modified by adjusting the duty cycle between the maximum and minimum value of DC/Dc_converter and almost all the LMPPs are identified but consumption of time is more. In [9] Fuzzy logic based HC algorithm stores all the maximum values repeat in MCU and from saved data Global-

MPPT is obtained using fuzz. Although the system becomes precise one but the complexity of system and time consumption increased, consequently it gets less importance.

In [10] Particle swarm optimization GMPP are located precisely using a velocity equation, even though the error in setting governing equation parameters may cause the entire system disrupt. The Fig.01 shows the Pow-Volt and I (current) - Volt characteristics of a P_V module during normal light condition.

An extensive research on P_V curves under ULCs reported in [13] reveals the hike in the curve occurs approximately at the 0.8*Voc and curves exhibit the tendency to rise before GMPP and fall afterwards. Considering above characteristics PO algorithm is mostly utilized to identify the LMPPs and Global-MPP. Even though under ULCs the accuracy of PO algorithm is doubtful.

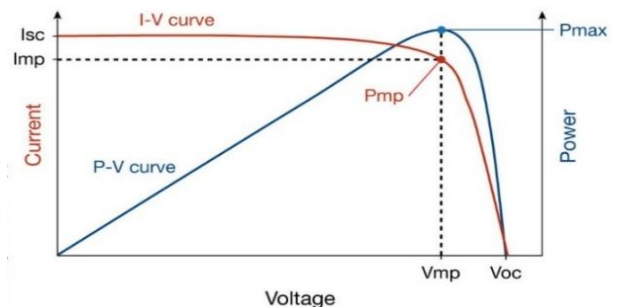


Fig. 1: Power-Volt and Current-Volt Characteristics of P_V Module under the Normal Light Condition.

Here's a method which finds GMPP under ULCs very accurately along with good performance in above-mentioned factors is tried. This system performs by mapping solar insolation pattern using the P_V current measured at defined points and choose appropriate points for LMPPT, then it performs INR in these points and all the LMPs are obtained by LMPs comparison GMP is identified.

2. Proposed algorithm

In this, a few conclusions under ULCs reported in [13] is employed. The conclusion referred is the hike in the curve occurs approx. At the 0.8Voc and curves exhibit the tendency to rise before GMPP and fall afterwards. Here, Increment_Resistance is realized instead of P_O because of its consistency under ULCs. A new algorithm is introduced to track the MPPs instantly. From above conclusion, the GMPP may be located in the middle of three successive hikes or it may be situated at either end of the Power-Volt curve. Consequently, there exist 3 types of hike in Power-Voltcurve, Fig. 02. The first curve shows that Global MPP lies mid of the other LMPPs. The second and third curves shows probability of location of Global MPP at either side of P_V curve. From all these Local-MPPs, the proposed set of rules finds three successive hikes and identify the highest value. Following sections dealt with the set of rules used to record the Global-MPP in 3 distinct types of multiple hikes Power-Volt curve. The two variables taken are the Voc of the P_V module and the max number of the series-connected module (Mmax).

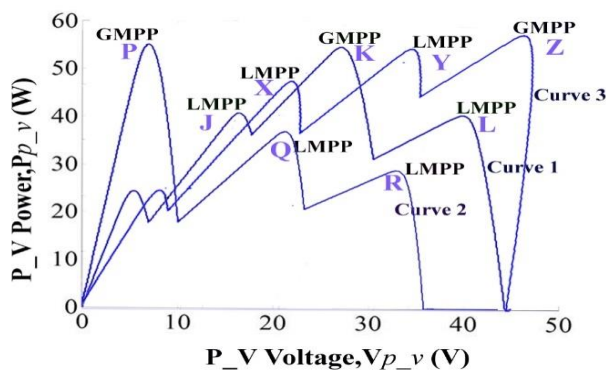


Fig. 2: Power-Volt Curves of the P_V Array under ULCs.

2.1. Case01: global-MPP lies in the middle of other two local-MPPS

Refer the flowchart, Fig 3 initially the values of power Pmpp_1 Pmpp_2 and Pmpp_3 and duty-cycles Duty_1, Duty_2, Duty_3, are adjusted to zero value (block-1). Then Mmax and the Voc are adjusted (block-2). Afterwards, the conventional INR method (block-3) is utilized to get maximum_power at pointJ (curve1) see Fig02, then converter's duty-cycle is saved into Duty_1 and the power is saved into Pmpp_1 (block-4). Afterwards check whether Vmax (Voc multiplied with Mmax) is attained or not (block-5), if not attained the algorithm will search the right side of pointJ to get new MPP (curve1). As in [13] at MPPs the value of voltages vary with 0.8*Voc from each other therefore Vref is

incremented by 0.8* Voc to Vmpp_1 (block-6). Then to ensure convergence of point of operation of the P_V array very close to pointK a subroutine MPP tracker (block-7) see Fig03 is used before the INR method (block-8) is utilized to identify the maximumpower at pointK. Consequently, at pointK converter's duty-cycle is stored as Duty_2 and power are stored as Pmpp_2 (block-9). If the Pmpp_2 value at pointK is higher than the value of Pmpp_1 (block-10) see Fig03 the algorithm moves to block-11 and Pmpp_1 and Duty_1 at point J is replaced with Pmpp_3 andDuty_3. Then Pmpp_2 and Duty_2 at point K are saved into Pmpp_1 and Duty_1. In brief, Pmpp_1 always contains the highest value of MPP. Then it goes back to block-5 and continues the search to identify Pmpp_2 at the right side of Pmpp_1 from block-6 to block- 9 until the Vmax is reached. Algorithm reaches block-12 when the value of Pmpp_2 at pointL is below Pmpp_1 at pointK. Since Pmpp_3 has data of point_ J, Duty_1 will be used as the Dc/Dconverter's on-off period (block-13) after that returns to block-21. To ensure P_V system is still at GMPP equation_1 is utilized.

$$\frac{dV}{dI} + \frac{V}{I} \leq 0.06 \tag{1}$$

Generally, the equation-1 is equated to zero, but in the real situation, it is not possible to get zero because of truncation_error hence 0.06 errors are permitted to terminate the fluctuations while operating under steady-state and thereby increasing the P_V system efficiency. Then it goes from block-21 to block- 22 and then back to block-21as long as there is no ULCs.

Table 1: Voltage and Current Variation under Ulcs.

		Variation in Current (dI)	Variation in Voltage (dV)
Solar Insolation	Increases	Increases	Increases
	Decreases	Decreases	Decreases
Load Resistance	Increases	Decreases	Increases
	Decrease	Increases	Decreases

Afterwards, the algorithm moves to block-23 and changes in voltage as well as current are identified. The transition from the current, as well as the voltage of the P_V array during ULCs, is referred in Table-1. When load resistance changes the voltage variation will be different from current variation. Hence subroutine load variation is called to ensure tracking of GMPP very quickly. Voltage and current variation are proportional to solar insolation rate. Then the proposed algorithm restarts from block-3 to track maximum current and voltage of P_V array.

2.2. Case02: GMPP located left side or right side of all the MPPS

As same as first case variables such as Voc, Mmax is set (blocks-1 & block-2). Then the INR (block-3) is utilized to obtain the maximum power at pointQ in curve2 similarly it finds Point X in curve3 and the P_V array's power and on-off period of the Dc/Dconverter are stored into Pmpp_1 and Duty_1 (block-4). Afterwards it checks whether Vmax (Voc multiplied with Mmax) is attained or not (block-5), if not attained the proposedalgorithm will search right side of pointQ to get new MPP (block-6 to block-9) in case of the curve2, similarly the

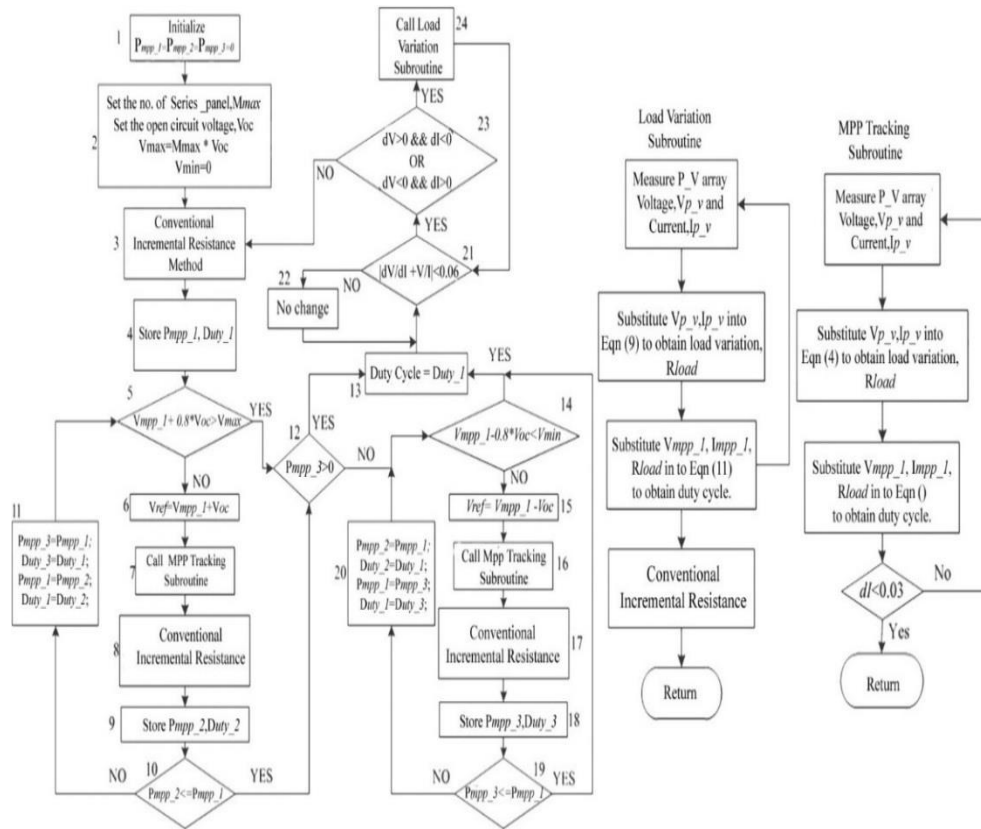


Fig. 3: Flowchart of Proposed System.

proposed-algorithm will search right side of point X to get new MPP (block- 6 to block-9) in case of curve 3. Then in curve2 the proposed-algorithm compares Pmpp_2 at point R and Pmpp_1 point Q (block_10) and in case of curve3 it compares Pmpp_2 at point X to Pmpp_1 at point Y (block_10). Since Pmpp_2 lower than Pmpp_1 the algorithm jump to block-12 in case of curve 2 and jumps to block-11 in case of curve 3. If Pmpp_3 value is not registered yet (block-13) and the Vmin is not equal to zero (block-14) the algorithm continues to identify Pmpp_3 at point P the left-hand side of Pmpp_1 in case of curve 2 and the algorithm continues to identify Pmpp_3 at point Z the right-hand side of the Pmpp_1 in case of curve 3. The Vref is decreased by 0.8*Voc (block-15) in case of curve 2 and increased by 0.8*Voc in case of curve3. A subroutine MPP tracker (block-16) is called upon to obtain the point of operation of the P_V array nearer to the Pmax at pointP before the INR (block-17) is utilized to identify the Pmax at pointP. The value of pointP are saved into Pmpp_3 and Duty_3 (block-18). Since Pmpp_3 at point P is more comparable to Pmpp_1 at point Q, the data of point Q are now saved to Pmpp_2 and Duty_2 & the values of point P are now saved into Pmpp_1 and Duty_1 (block-20). Then the algorithm return to (block-14) and Duty_1 is used as the converter's duty-cycle since Vmin is achieved. Then the P_V system operates on the leftmost side of the P_V curve (point P), which is its Global-MPP. Similarly, a subroutine MPP tracker (block-16) is called upon to obtain the point of operation of the P_V array nearer to the Pmax at point Z before the INR (block-17) is utilized to identify the Pmax at point Z. The value of point Z is saved into Pmpp_3 and Duty_3 (block-18). Since Pmpp_3 at point Z is more as compared to Pmpp_1 at point Y, the data of point Y are now saved to Pmpp_2 and Duty_2 & the values of point Z are now saved into Pmpp_1 and Duty_1 (block-20). Then the algorithm return to (block-14) and Duty_1 is used as the converter's duty_cycle since Vmin is achieved. Then the P_V system operates on the rightmost side of the P_V curve (point Z), which is its Global-MPP. Finally, the algorithm starts looping between block-21 to block-22, till it observes any variation in ULCs.

2.3. Conventional incremental resistance method

Power (P) when differentiated w.r.t Current I and equate to zero variables of INR algorithm is obtained. Consequently, the slope of the P_V array will be zero at maximum_power Point, also negative or positive on either side of the MPP, given by

$$\frac{dP_{p,v}}{dI_{p,v}} = 0, MPP$$

$$\frac{dP_{p,v}}{dI_{p,v}} > 0, MPP \text{ left} \tag{2}$$

$$\frac{dP_{p,v}}{dI_{p,v}} < 0, MPP \text{ right}$$

Since

$$\frac{dP_{p,v}}{dI_{p,v}} = \frac{d(I_{p,v}V_{p,v})}{dI_{p,v}} = V_{p,v} + I_{p,v} \frac{dV_{p,v}}{dI_{p,v}}$$

$$\cong V_{p,v} + I_{p,v} \frac{\Delta V_{p,v}}{\Delta I_{p,v}} \tag{3}$$

Equation (3) becomes

$$\frac{\Delta V_{p,v}}{\Delta I_{p,v}} = -\frac{V_{p,v}}{I_{p,v}}, MPP$$

$$\frac{\Delta V_{p,v}}{\Delta I_{p,v}} > -\frac{V_{p,v}}{I_{p,v}}, MPP \text{ left} \tag{4}$$

$$\frac{\Delta V_{p,v}}{\Delta I_{p,v}} < -\frac{V_{p,v}}{I_{p,v}}, MPP \text{ right}$$

The maximum power point can thus be identified by matching the values of $\frac{V_{p,v}}{I_{p,v}}$ with the $\frac{\Delta V_{p,v}}{\Delta I_{p,v}}$. Iref is the reference current at which the P_V array is pushed to operate. At the Maximum-power point, Iref becomes IMPP. Once the MPP is achieved, the point of operation of P_V array is maintained at that level until a variation in Voltage is noted, indicating ULCs. The value of Iref is decreased or increased to identify the new MPP. The P_V array Pout is applied to directly control the Dc/Dc_converter output Iref which is also the output Iref of the P_V array, contributing to a noncomplex control-system.

3. Calculate duty cycle for CUK converter

A Dc/Dc-converter is connected to P_V and the load. Equations (5) and (6) show the relationships between the output-voltages and input-current of the dc/dc_converter (CUK). Fig04 shows CUK converter circuit.

$$V_{in} = \frac{1-D}{D} V_{out} \tag{5}$$

$$I_{in} = \frac{D}{1-D} I_{out} \tag{6}$$

Divide (5) by (6) to get (7)

$$Z_{in} = \frac{(1-D)^2}{D^2} Z_{out} \tag{7}$$

Where,

Dconverter's Duty_cycle;

Vinconverter has input voltage

Iin converter has input Current

Zinconverter has input Impedance

Zoutconverter has output Impedance

ZloadLoadimpedance.

In the PV system, (7) can be rewritten too btain (8) and (9)

$$\frac{V_{p,v}}{I_{p,v}} = \frac{(1-D)^2}{D^2} Z_{load} \tag{8}$$

$$Z_{load} = \frac{D^2}{(1-D)^2} \frac{V_{p,v}}{I_{p,v}} \tag{9}$$

At any operating point (Vp_v, Ip_v) of the P_V array and the D is known, the Zload at the converter output can be obtained by using (9). After getting the value of load impedance, equation (9) becomes equation (10). With known voltage & current of the P_V array, using equation (11) the on-off period (Duty_cycle) can be calculated. This duty_cycle is utilized by the converter to required voltage and current.

$$\frac{D^2}{(1-D)^2} = \frac{I_{p,v}}{V_{p,v}} Z_{load} \tag{10}$$

$$D = \frac{\sqrt{\frac{I_{p,v}}{V_{p,v}} Z_{load}}}{1 + \sqrt{\frac{I_{p,v}}{V_{p,v}} Z_{load}}} \tag{11}$$

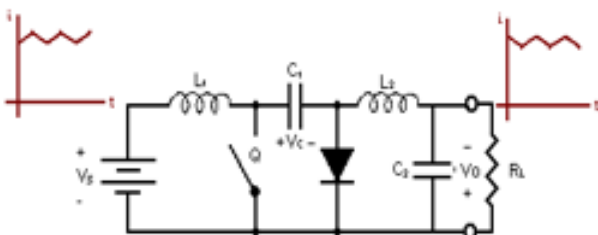


Fig. 4: Dc/Dccuk Converter Circuit

4. Simulation results

The model of P_V array under ULCs, the CUK_converter, and Maximum-PPT controlled is generated in a MAT_LAB Simulink model. The specification of the P_V module in the P_V array refers Table 2.

Quantity	Value	Unit
Maximum power	86.95	W
MPP Voltage	17.44	V
MPP Current	5.02	A
Voc	21.7	V
Isc	5.34	A
No. of series Cells	36	
No. of series cells with Bypass diodes	18	

The converter's component values are Cin and Cout = 3900 μF, L1 and L2 = 125 μH, and 10-Ω resistance as the load. The switching frequency for the switch (Insulated-gate-bipolar-transistor) is adjusted to 25 kHz. In this, the maximum_power point tracker controller sampling time is adjusted to 0.05 s, and the converter's duty-cycle step size is set to 0.005. The model has one bypass diode across eighteen-series connected P_V cells in the module, which means [2] bypass diodes in one P_V module. Therefore, there are maximum chances of producing [2] maximum-power points by one P_V module during ULCs. Therefore, here Voc is taken as 10.8 V, which is half times the Voc of the P_V module. Then, parallel connected bypass diode P_V module creates the P_V array. Hence, two-series connected P_V modules have a maximum of 4 hikes during ULCs.

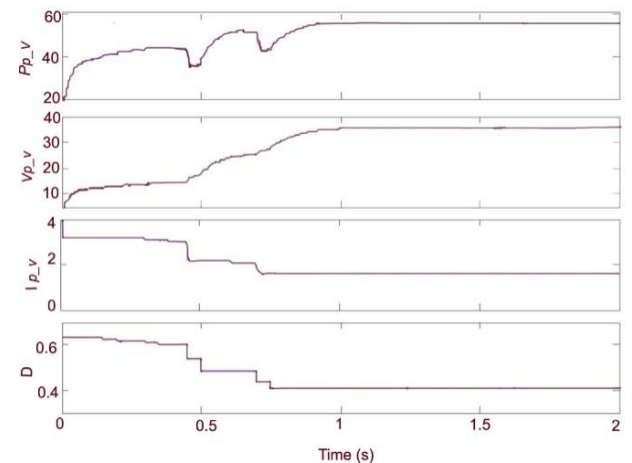


Fig. 5: Results of Simulation for the P_V System under Uneven Lighting Conditions Where the Solar Insolation Values for Each of the 18-Series_Connected P_V Cells are (A) 1.2kw/M2, 0.8kw/M2, 0.6kw/M2, and and0.5kw/M2

Fig.05_shows the simulation results for two different ULCs, where [4] distinct levels of solar insolation on each of the eighteen-series_connected P_V cells of the two-series_connected P_V modules. Initially, using conventional INR method first MPP, (P1) is identified (which is stored into Pmpp_1), and then the algorithm goes to the right of P1 (uses MPP tracking subroutine algorithms in block-7 for fast computation of duty_cycle) to find the next MPP (P2). Since P2 (51.4 W) is greater than P1 (44.1 W), the power at P1 is now stored into Pmpp_3 and the power at P2 is stored into Pmpp_1. Then, the algorithm goes to the right of P2 again and tracks the next MPP at P3. After that, the power at P2 is stored into Pmpp_3, and the power at P3 is stored into Pmpp_1 because P3 (56.4 W) is greater P2 (51.4 W). Then, the algorithm stops the searching process because Vmax (43.2 V) is reached and Duty_1 is used as the duty cycle of the converter since P3 has the largest

power among the others, and it is at the rightmost side of the P_V curve. Finally, the power of P_V array is observed in block-21.

5. Conclusion

In this paper, a modified Incremental_Resistance algorithm has been used to identify the Global-MPP for the P_V array under uneven light conditions and also load variation. To increase the response of maximum-power point identifying system a new algorithm is used, in which turn on and turn off period of the converter is adjusted. The simulation results show that the Increment_Resistance method added with some alterations enables to track the LMPPTs as well as Global MPPTs very effectively and accurately with fewer numbers of steps. In proposed system losses during Global, MPP tracking is minimized under ULCs.

References

- [1] Faicel El Aamri, Hattab Maker and Dezso Sera "A Direct Maximum Power Point Tracking Method for Single-Phase Grid-Connected PV Inverters" IEEE Trans on Power Electronics, Vol:1, no.99, August 2017.
- [2] Bader N. Alajmi, Khaled H. Ahmed, Stephen J. Finney, and Barry W. Williams "A Maximum Power Point Tracking Technique for Partially Shaded Photovoltaic Systems in Microgrids" IEEE Trans on Industrial Electronics, vol. 60, no. 4, pp. 1596-1606, April 2013.
- [3] Mohammed A. Elgendy, Bashar Zahawi and David J. Atkinson "Assessment of the Incremental_Conductance Maximum Power Point Tracking Algorithm," IEEE Trans on Sustainable Energy, Vol. 4, No. 1, PP 108-118 January 2013.
- [4] Azadeh Safari and Saad Mekhilef, "Simulation And Hardware Implementation of Incremental_Conductance MPPT with Direct Control Method Using Cuk_Converter," IEEE Trans on Industrial Electronics, VOL. 58, NO. Four, pp.1154-1161, April 2011
- [5] Christos Konstantopoulos and Eftichios Koutroulis, "Global Maximum_Power Point Tracking Of Flexible Photo_voltaic Modules," IEEE Trans On Power Electronics, Vol. 29, No. 6, pp 2817 June 2014
- [6] T. Eswam and P. L. Chapman, "Comparison of photovoltaic_array maximum_power_point tracking techniques," IEEE Trans. Energy Convers., vol. 22, no. 2, pp. 439-449, June 2007.
- [7] Guan-Chyun Hsieh, Hung-I Hsieh and Cheng-Yuan Tsai, "Photovoltaic Power-Increment-Aided Incremental-Conductance MPPT With Two-Phased Tracking" IEEE Transactions on Power Electronics", Vol.28, no.6, pp. 2895 – 2911, June 2013.
- [8] N. Femia, G. Petrone and G. Spagnuolo "Optimization of perturbing and observe maximum power point tracking method" IEEE Trans on Power Electronics Vol 20, no. 4, pp. 963 – 973, July 2005.
- [9] Sathish Kumar Kollimalla and Mahesh Kumar Mishra "A Novel Adaptive P&O MPPT Algorithm Considering Sudden Changes in the Irradiance" IEEE Transactions on Energy Conversion, vol: 29, no. 3, pp. 602 – 610, Sept. 2014.
- [10] Jinhua Liu, Junyin Li, Jianan Wu and Wenhui Zhou "Global MPPT algorithm with coordinated control of PSO and INC for rooftop PV array" The Journal of Engineering, Issue: 13, pp. 778 – 782 August 2017.
- [11] Hiren Patel and Vivek Agarwal "Maximum Power Point Tracking Scheme for PV Systems Operating under Partially Shaded Conditions" IEEE Transactions on Industrial Electronics vol: 55, Issue 4, pp. 1689 – 1698 April 2008.
- [12] Tat Luat Nguyen and Kay-Soon Low, "A Global Maximum Power Point Tracking Scheme Employing DIRECT Search Algorithm for Photovoltaic Systems" IEEE Trans On Industrial-Electronics, Vol. 57, No. 10, pp. 3456-3467, October 2010
- [13] Alireza Ramyar, Hossein Iman-Eini, and Shahrokh Farhangi "Global Maximum_Power_Point Tracking Method For Photovoltaic Arrays Under Partial Shading Conditions," IEEE Trans On Industrial Electronics, vol.61, no.6, pp. 239– 249, Nov 2016.