A NOVEL APPROACH USING PID CONTROLLED PERTURB & OBSERVE MPPT ALGORITHM FOR PHOTOVOLTAIC SYSTEMS

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Abstract: *Nowadays, renewable energy resources play a significant role in electric power generation. There are various resources such as solar, wind, geothermal and so on. Solar energy is a good choice for power generation because it is an everlasting energy resource and environmental friendly too. Since the efficiency of solar PV panel depends upon the irradiance level, several maximum power point tracking (MPPT) techniques have been introduced for the extraction of maximum power from the PV panel. This paper has been introduced a novel approach based MPPT technique for improving the performance of the standalone PV system. In order to extract accurate power point in the PV panel an intelligent Perturb & Observe algorithm is implemented along with closed loop PID controller. To simulate the panel power and justify the efficiency of the proposed algorithm by various simulations results are carried out using MATLAB software. The result reveals that the proposed method can effectively increase the system efficiency with fast, better dynamic response and enhanced regulated output power compared to the conventional P&O algorithm at different solar luminance levels. In order to validate the performance of the proposed algorithm a 50W prototype system with F28035 based Microcontroller has been used.*

Key words: *Accuracy, Digital Controller, Efficiency, Power generation, Solar energy.*

1. Introduction.

With the increased use of alternative sources of energy, the usage of fossil fuels can be diminished. In recent years a PV based power generation has been identified for electricity. The produced power by the PV system depends on climate changes like irradiation and temperature falls on the PV module. The Photovoltaic cells are able to convert sunlight into electricity accordingly. The voltage at which PV module can produce maximum power is called 'Maximum Power Point' (MPP) or peak power voltage. Maximum power varies with solar radiation, ambient temperature and solar cell temperature. For extracting the highest possible power and to maintain the MPP in the PV panel, different types of algorithms are required to operate the MPPT controller under enormous weather changes. A perturbation and observation (P&O) method with direct-prediction MPP has reduced the perturbation time and control scheme for PV inverters for the reduction of carbon dioxide (CO2) emissions and energy saving on roof top closed plant factory [1]. The battery-less PV system has been controlled by the fuzzy logic algorithm based MPPT for obtaining greater efficiency, fast transient response with minimum steady state error under quick variation of temperature, irradiance and load conditions. This control method has been compared with P&O and INC algorithms, which also keeps the load from over load protection for the period of light load [2]. The fractional short circuit current has taken the initial operating point and then it moves to conventional P&O method which can improve the tracking efficiency with low power oscillation [3]. An adaptive perturbation size has been generated by multiplying a two-dimensional Gaussian function with an Arctangent function and the time of the next duty cycle has been computed by variable perturbation frequency which improves the dynamic and steady state performance of the PV system [4]. A high voltage gain DC-DC converter with P&O algorithm has been implemented for low power applications with low cost [5]. The differential power algorithm has been calculated to find the difference of successive powers with corresponding voltages which generates the duty cycle of the boost converter to track the MPP effectively [6]. The fractional order with fuzzy logic method can reduce the oscillation with high speed and tracking accuracy compared with conventional fuzzy logic control method under varying climate conditions [7]. An auto-scaling variable step-size method has automatically adjusted the step size which can eliminate the troubles in conventional variable step size method and reach the stable output power with fast dynamic response [8]. The hybrid P&O and learning automata algorithm validate the performance of the PV system and compared with conventional and modified P&O algorithms, under different input conditions the tracking speed is high with less oscillation [9]. The Incremental Conductance (IncCond) with direct control algorithm based fuzzy logic duty cycle estimator is used to avoid the degraded performance of the PV system with accurate and faster in the era of stable state and dynamic conditions with oscillation free

[10]. The modified IncCond method is used for avoiding the confusion in the first step change of duty cycle in the converter with zero power oscillation [11]. The IncCond algorithm controls the two different boost converter topologies which tested the speed and efficiency of the PV system [12]. The P&O algorithm is used to avoid the power losses in dynamic conditions due to the operating point fluctuations in the MPP region, the MPPT controller parameters has been modified based on the duty cycle of the boost converter [13]. The P&O based MPPT algorithm is used with buck and buck-boost converter topologies to improve the steady state and dynamic performance of the PV system. The fluctuations are suppressed effectively in buck converter than buck-boost converter [19]. The performances of the parameters are obtained by PID controller based artificial intelligence technique with free of over shoot, less settling time and high rise time [20]. The objective of this work is to reach the MPP of the PV system using digital feedback controller with Classical techniques of maximum power tracking. The issue of MPPT has been addressed in different ways in the literature. Recently, high performance microprocessor based platforms introduced in real time control applications which offer better flexibility for different control systems. In this work proposes a digital feedback controller with different MPPT algorithms to achieve maximum efficiency of the PV system. The remaining sections of this paper are prepared as follows. Section 2 describes the PV Panel Model under study. The boost type dc-dc converter architecture is explained in Section 3. In Section 4, the performance of the MPP tracker using proposed algorithm with closed loop PID controller is evaluated in detail in separate sections. Section 5 presents the experimental validation with simulation results and Section 6 ends with Conclusion

2. PV Panel Model

The Solar cell is a semiconductor device which converts the light energy in to electrical energy that exhibit the photovoltaic effect. The basic structural unit of a solar module is the PV cell. These cells are connected in series and/or parallel to increase the output power of the system. There are two types of PV models, such as single diode model, two diode model. The two diode model is more accurate and also complicated than single diode model because of more variables should be premeditated [12].

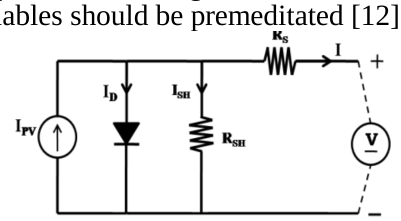

Fig. 1. Equivalent Circuit of Single Diode Model

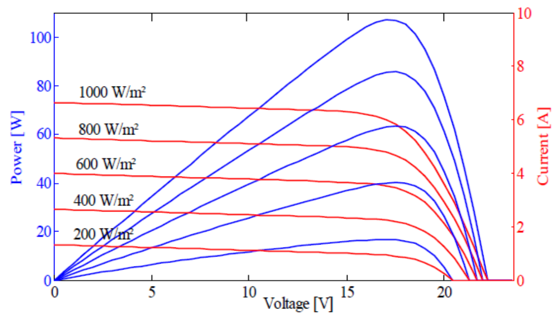

Fig. 2. Typical I-V and P-V Characteristic curve for PV module

The fig. 1 shows an equivalent circuit of a solar cell in single diode model. An ideal solar cell may be modeled by a current source in parallel with a diode. In practical, solar cell is not an ideal one, so the shunt and series resistances are connected with this model. To produce higher output voltage or current the solar cells are connected in series or in parallel correspondingly. The V-I characteristic based on the value of series, shunt resistances and temperature, irradiation levels [14]. The mathematical formula for calculating the current produced by the solar cell, current through the diode using Shockley diode equation and the relationship between the output current and.

$$I = I_{pv} - I_D - I_{SH} \tag{1}$$

$$I_D = I_0 \left\{ \exp\left[\frac{V + IR_S}{nV_T} \right] - 1 \right\} \tag{2}$$

Where

$$V_T = \frac{kT}{q}$$

$$I = I_{pv} - I_0 \left\{ \exp\left[\frac{V + IR_S}{nV_T} \right] - 1 \right\} - \frac{V + IR_S}{R_{SH}} \tag{3}$$

Table 1
Specifications of PV Panel Emulator.

Parameters	Values
Open Circuit Voltage (V_{oc})	**28V**
Short Circuit Current (I_{sc})	**3A**
Maximum Power Point Voltage (V_{mp})	**18A**
Maximum Power Point Current (I_{mp})	**2A**
Maximum Power Point (P_{mp})	**36W**

Here I and V are the output current and voltage of the PV cell. IPV and I0 represents the current generated by the solar cell and reverse saturation current, RS and RSH represents series and shunt resistance of solar cell of an equivalent circuit, ID is diode current, ISH is current through shunt resistance, n is diode ideality factor (one for ideal diode), q is the elementary charge, k is Boltzmann's constant, T is absolute temperature, VT is thermal voltage approximately equal to 0.0259V at 25oC. The fig. 2 shows the variation of the PV cell output power, output voltage and output current at different irradiance levels [15]. The curve shows clearly that the output characteristics of a solar cell are non-linear and are significantly influenced by solar radiation, temperature and load condition. The table -I shows the specifications of a PV panel emulator

3. Boost Type DC-DC Converter.

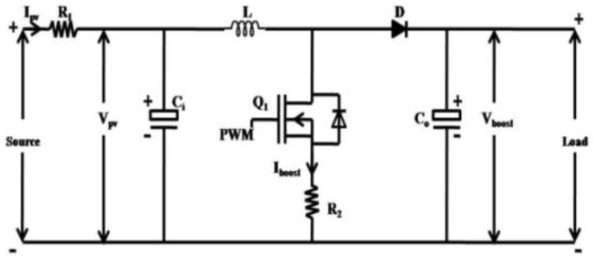

Fig. 3. Equivalent Circuit of Single Diode Model

In order to reduce the continuous losses occurring in the system, it is essential that the converter input current has very little ripple and conversion efficiency is very high. So the installation of a boost type converter will be recommended. A Boost converter is a power converter, which is an interface between module and the load. It has more benefits because of its simplicity, fast response with low noise. The output voltage is adjustable based on the duty cycle of the power switch which delivers maximum power to the load. Fig. 3 shows the schematic of boost converter. It consists of a MOSFET switch (Q_1) and a diode (D) with inductor (L) and capacitor (C_o) based filter circuit. When the switch Q_1 is closed, inductor stores energy during T_{ON} period. If the switch Q_1 is opened, the current is forced to flow through the diode and load for the period of $T_{OFF.}$ The boost converter is controlled by the panel voltage similar to the reference voltage [16]. If the converter losses are considered as negligible, then the input Power (P_{pv}) is equal to output Power (P_{Load}). In boost converter the output voltage (V_{LOAD}) is always greater than the input voltage (V_{pv}) and input current (I_{pv}) is less than output current (I_{Load}) .

$$V_{pv} * T_{ON} = (V_{LOAD} - V_{pv}) * T_{OFF}$$

Hence

$$V_{LOAD} = \frac{T_{ON} + T_{OFF}}{T_{OFF}} = \frac{T}{T_{OFF}}$$

The duty cycle $\boldsymbol{\alpha}$ can be calculated as

$$\alpha = \frac{T_{ON}}{T}$$

$$V_{LOAD} = \frac{1}{1-\alpha} * V_{pv}$$

Where T_{ON} is the time period of the switch is closed, T_{OFF} is the time period of the switch is opened, V_{pv} is the input voltage (Photovoltaic Voltage), V_{Load} is the output voltage. The boost converter is used to convert the magnitude of an input voltage to some higher level based on the load. This unique ability is achieved by storing energy in an inductor and releasing it to the load at a higher voltage. The power balance equation is used to calculate the input current of a boost converter and the input and output powers are the product of their particular currents and voltages while adding the triangular ripple current, the following equations has been arrived where ΔI is the peak to peak ripple current.

$$P_{pv} = \frac{P_{LOAD}}{\eta} \tag{4}$$

$$I_{pv} = I_{LOAD} * \frac{V_{LOAD}}{V_{ph}} * \frac{1}{\eta} + \frac{\Delta I}{2} \tag{5}$$

4. Proposed algorithms for PV system

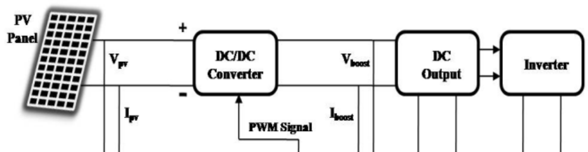

Fig 4. Block diagram of the proposed PV system

In recent years to improve the global efficiency of PV systems, many MPPT techniques have been introduced, which are an essential component of a Photovoltaic system. However, the maximum power point is not fixed due to the non-linear nature of the PV cell and changes with temperature, light intensity and so forth. To get the most energy out of the solar panel, the suitable converter with an automatic variation of the duty cycle α is allocated to an optimal value. The fig. 4 shows the block diagram of the proposed PV system. It consists of PV panel

Emulator, dc-dc boost converter with feedback PID controller with MPPT and the dc load. The PV panel emulator generates the current and voltage is I_{ph} & V_{ph} respectively. These sensed parameters are the input of MPPT controller. The output voltage from the MPPT is considered as reference voltage V_{ph_ref} it depends on the types of algorithm that has been applied. The feedback PID controller generates the suitable duty cycle for obtaining the maximum power consistently.

4.1. An Intelligent Perturb and Observe Algorithm

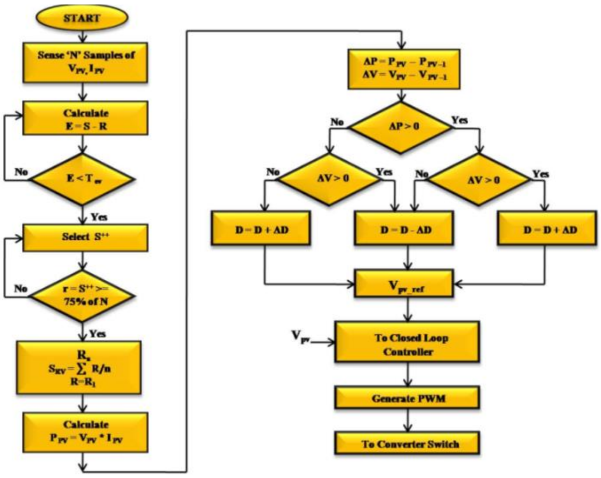

Fig 5. Flow chart of the proposed algorithm

The Perturb and Observe algorithm is the most commonly used in practice because of its simple structure, easy to implement and the number of parameters to be measured is also less and it is an iterative process to reach the maximum power point. In order to track the greatest power point, the operating point is perturbed and then to determine the direction of the next perturbation, the PV output power is increased by increasing the PV voltage. If the power increases the consequent perturbation will be continued in the same direction, and if the power decreases then the direction is reversed. The drawback of this algorithm is it fails under rapidly changing weather conditions [22]. This occurs when the change in power due to suddenly varying atmospheric conditions the perturbation is in the opposite direction which results the operating point shifting in the opposite direction [23]. To avoid this serious effect due to error inputs and also for improving the performance of the output power the proposed method is applied. This method begins with the evaluation of the optimal samples from the PV panel voltage Vpv and current Ipv with free of error. To find the optimal data samples for obtaining the maximum power at varying solar temperature and irradiation conditions. The optimal operating voltage and current can be determined from the sensed value of the PV panel at varying weather conditions. The optimal value can be calculated using the following steps from 1 to 9. The set of samples (Vpv and Ipv) obtained from the panel are S1, S2, S3, … Sn and the reference values are R1, R2, R3, …… Rn. To take care about the degradation problem in the output power by removing the noise from the sensed data, a data averaging technique [21] based special type of low pass filter is used it is referred in step 8 where X(n) is the computation of the exponential moving average at time instance (n), X(n-1) is the exponential moving average at time instance (n-1), S(n) is the input data of the instantaneous samples (n) and α is the smoothing constant. The table II shows the efficiency optimization of the PV panel using the proposed algorithm under various weather conditions.

Table 2
Efficiency optimization using proposed algorithm under various Luminance conditions

Luminance (Lux)	P_{pv} (W)	P&O		IP&O	
		P_0 (W)	η_0 (%)	P_1 (W)	η_1 (%)
0.20	7.17	6.59	91.91	7.01	97.35
0.28	10.05	9.42	93.73	9.98	90.75
0.37	12.15	11.48	94.49	13.01	96.16
0.42	15.12	14.19	93.85	15.04	97.82
0.45	16.17	15.04	93.01	16.1	98.89
0.54	19.41	18.12	93.35	19.32	97.37
0.59	21.24	20.06	94.44	21.02	97.22
0.67	24.12	23.04	95.52	24.09	98.05
0.72	24.88	23.74	95.42	25.75	96.21
0.77	26.85	25.52	95.05	27.62	97.04
		Efficiency	94.29		99.26

Step: 1 Obtain 'N' no. of samples (V_{pv} and I_{pv}) from the PV panel

Step: 2 Determine the difference (E) between the sampled data (S) and the reference (R) using the formula E = S - R

Step: 3 Calculate the optimal value from the set of samples using the formulae $E_{11} = S_1 - R_1$ ….. $E_{1n} = S_n - R_1$ …….. $E_{n1} = S_1 - R_n$ ….. $E_{nn} = S_n - R_n$

Step: 4 Find out the error values from the step 3 which is less than the tolerable error value (T_{ev} is 1% of the sample rate) from $E < T_{ev}$

Step: 5 Select the sample values from step 4 in each set S^{++}

Step: 6 If the selected samples from step 5 are more than 75% of the number of samples in each set then take that reference value ‘R’

Step: 7 The obtained reference (S_{RV}) samples are applied in the following formula where R = R_1 + R_2 ….. R_x and ‘n’ is the number of obtained samples

$$S_{RV} = \sum_{R=R_1}^{R_n} R/n$$

Step: 8 To remove the noise in the estimated values from step 7 are applied in the special type of low pass filter

$$X_{(n)} = \alpha * [S_{(n)} - X_{(n-1)}] + X_{(n-1)}$$

Step: 9 The optimal samples from step 8 are the input of P&O algorithm, it calculates the reference voltage V_{pv_ref} and compare with panel voltage V_{pv} and generate the suitable PWM signals using closed loop PID controller

From the above steps the instantaneous power Ppv is calculated from the instantaneous voltage Vpv and current IPV of the PV panel emulator. The power Ppv is compared with the preceding power Ppv-1. If the power is increased, then the algorithm checks the last change in the panel voltage and continues to change it in the same direction, and if the power is decreased, it is changed to the opposite direction. Based on the instantaneous voltage and current, the MPPT controller can point out the related reference voltage Vph_ref. This voltage is the input of the closed loop PID controller which is explained in the following session 4.2 that will generate the suitable PWM signal for DC-DC boost converter switch. This process is repeated till the system reaches MPP. This proposed algorithm is summarized in a flowchart in Fig.5.

4.2. Closed Loop PID Controller.

The main advantages of the PID controller are oscillation free, higher stability and fast response. The united operation of proportional, integral and derivative control gives control strategy for process control. It continuously calculates an error value e(t) as the variation between a preferred position point and a calculated variable and applies a rectification based on Proportional (P_r), Integral (I_n) and Derivative (D_e) terms. This controller has much attention required for selecting finest values of proportional, integral and derivative gains. The basic equation of this controller is as follows. The equation (12) and (16) shows the time domain and Laplace domain form, where K_{pr}, K_{in}, K_{de} are the Coefficient of Proportional, Integral and Derivative terms respectively.

The gain of the PID controller can be obtained by trial and error method. Here 2-pole 2-zero, 50 KHz controllers are used to close the inner DC-DC boost current loop and the outer input voltage loop. The MPPT algorithm provides reference input voltage Vpv_ref is to enable the panel operation at maximum power point. Here the sensed input voltage of

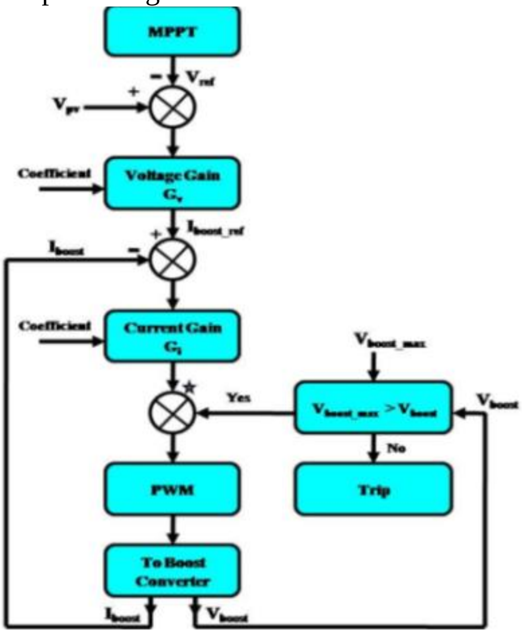

Fig 6. MPPT with closed loop PID Controller

the panel Vpv is compared with the reference voltage Vpv_ref generated by the MPPT controller. The deviated output of the comparator is fed in to the voltage control loop (Gv), an outer voltage loop that regulates input voltage and the current of the boost stage can be controlled by an inner current loop. The output of the voltage controller Iboost_ref is compared with the DC-DC converter output current Iboost feedback in the current control loop (Gi). The output of the controller decides the amount of duty cycle to be instructed to the PWM so as to regulate the input voltage.

$$u_{(t)} = K_{pr} e_{(t)} + K_{in} \int e_{(t)} * dt + K_{de} \frac{de_{(t)}}{dt} \tag{12}$$

where

$$P_r = K_{pr} e_{(t)} \tag{13}$$

$$I_n = K_{in} \int e_{(t)} * dt \tag{14}$$

$$D_e = K_{de} \frac{de_{(t)}}{dt} \tag{15}$$

Taking Laplace Transform,

$$u_{(s)} = \left[K_{pr} + \frac{K_{in}}{s} + sK_{de} \right] E(s) \tag{16}$$

The voltage feedback is mapped to the internal comparators, to avoid the output voltage from getting higher than the maximum voltage of the boost converter which trips the PWM. This process is repeated till the system reaches MPP. The steps involved in the feedback PID controller are illustrated in fig. 6.

5. Experimental Validation and Simulation results

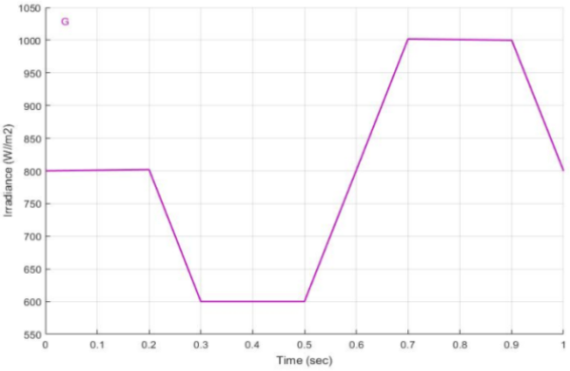

Fig .7 Irradiance Vs Time

To evaluate the performance of an Intelligent Perturb & Observe method, the solar explore kit TMDSSOLAR(P/C) EXPKIT is used. For immediate demonstration of the power processing from the solar panel, a PV emulator power stage is integrated on the board. The buck-boost converter in the PV panel emulator accepts the DC power typically 20V, which generates the DC output based on the light sensor, this sensed output voltage and current makes the V-I characteristics. The boost and stage is used to enhance the voltage from the panel track the MPP. The switching frequency of the boost converter is 100 KHz. The simulation results are carried out by MATLAB software. The irradiance is varied consequently with time is shown in fig.7 and the voltage, current and power of the conventional P&O is compared with proposed method is illustrated in fig.8. The selection of experimental output voltage range is 0-30V. The control code is developed using Code Composer Studio and downloaded on the kit for real time operation. In order to realize a precise analysis of the performance of the proposed MPPT technique has been tested and the experimental results of the entire system is implemented and validated by Code Composer Studio is shown in fig.9. and these are carried out at different irradiation levels. If the conventional P&O method is implemented it couldn't find its maximum power point location immediately because of oscillation. To validate the performance of the proposed algorithm a 50W prototype system has been implemented with F28035 based Microcontroller. The obtained result in table II clearly shows that the proposed P&O method gives a better performance compared to conventional algorithms resulting in higher efficiency.

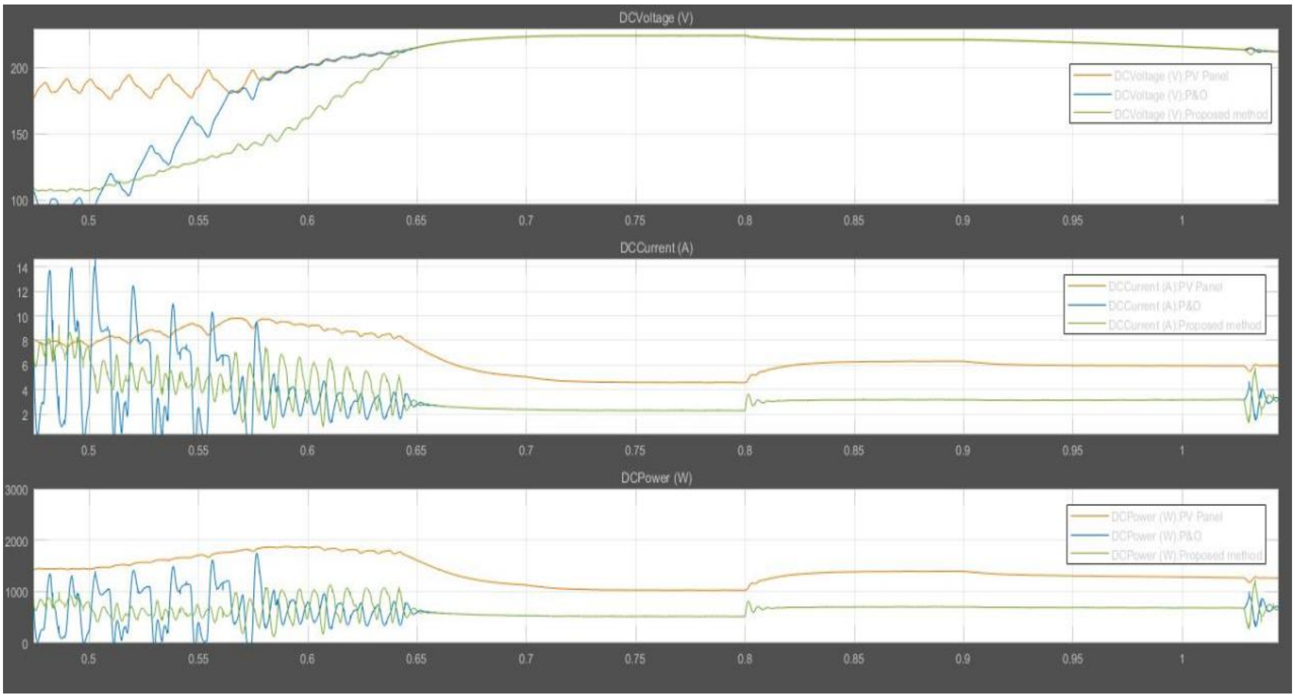

Fig. 8 Panel voltage, current and power is compared with proposed method

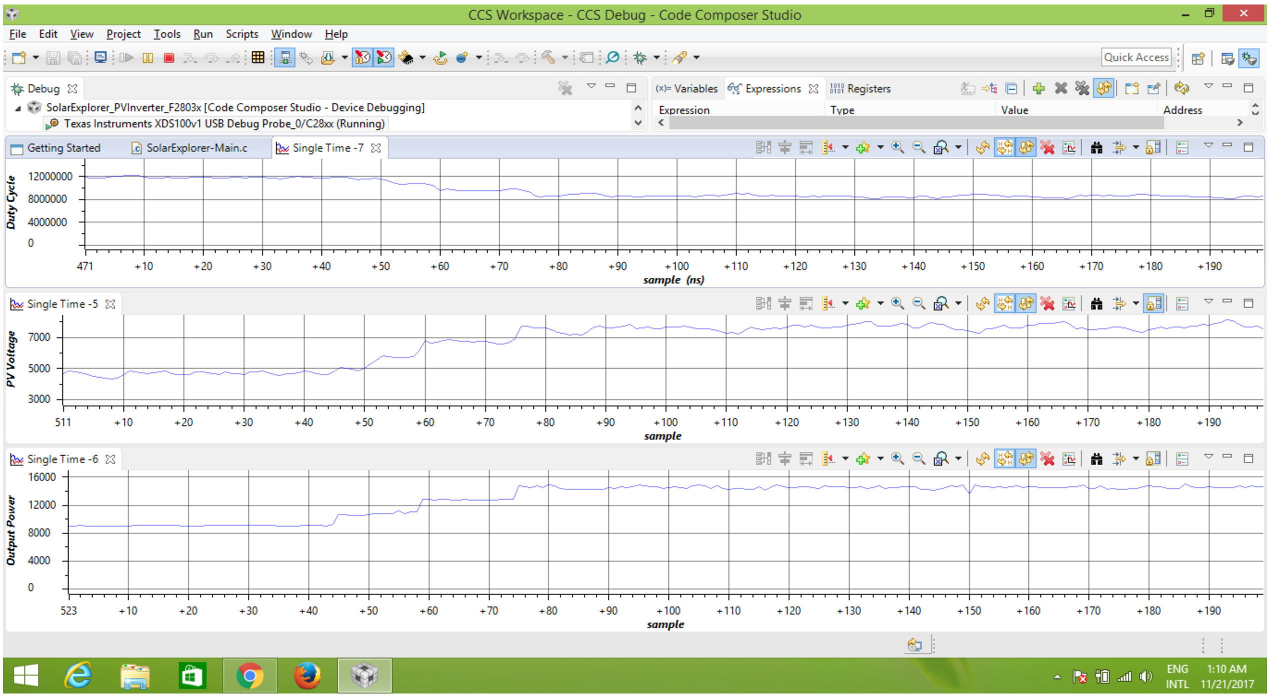

Fig. 9 Experimental validation of the proposed method using CCS

5. Conclusion.

The main idea behind this work is to make a PV system with good accuracy and high performance. In order to get maximum utilization of available PV power production, an intelligent P&O algorithm is integrated with closed loop PID controller has been implemented. To verify the system performance, the laboratory based experimental setup was developed and tested and also the results were observed at different luminance conditions. Under varying weather conditions the proposed algorithm can reduce the oscillation around the operating point efficiently. The experimental result proves that the efficiency of the system can be improved in the case of proposed algorithm with good accuracy.

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