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Maximum Power Point Tracking Technique for Photovoltaic Power System at Sudden Change in Irradiance using Fuzzy Self Tuning PID Controller

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ABSTRACT

This paper presented a new digital control scheme for photovoltaic (PV) system, using a new approach maximum power point tracking (MPPT) algorithm. Photovoltaic power generation system required an effective controller to overcome sudden irradiance change and to maximize their efficiency in order to be more efficient & more precise. This paper proposed a new approach of MPPT based on a voltage control approach of power converter with PI (proportional integral) controller combination for the boost converter to adapt the duty cycle. The input voltage reference is adaptively perturbed with variable steps until the maximum power is reached. A state-space model is derived through averaging method, with the control input being the duty ratio of the pulse width modulator for a dc–dc boost converter. The proposed control scheme achieved stable condition in the control region of the PV panel and eliminated the steady state oscillations when there is sudden change of irradiance in the maximum power operating point. Furthermore, the PV system became more efficient, as proven by sudden change in radiation conditions for 10 seconds, where energy can be saved approximately 76.66%.

Keywords *— Electrical engineering; Solar Energy; New MPPT; averaging model; combination IP; boost converter; photovoltaic; irradiance.*

1 INTRODUCTION

Solar power generation is becoming increasingly important as a renewable energy source due to advantages of clean energy, requiring less maintenance and so forth. The output power of photovoltaic (PV) arrays always changes according to the weather conditions, i.e., irradiance and atmospheric temperature. In many cases, the PV system has a disadvantage in the solar radiance conversion into electrical energy. University of Tokyo has tested more than 71 Japanese PV systems, and all showed losses of up to 25% (Fangrui Liu. 2008). Therefore, efforts to improve energy efficiency are conducted by using maximum power point tracking (MPPT) control [1], so that the maximum power extracted from the PV array in real time becomes indispensable in solar power systems. There are many techniques to get the MPP such as the P&O (Perturb &Observation), IC (Incremental Conductance) & FLC (Fuzzy Logic Control).[2] [3]

In recent years, a large number of techniques have been proposed for tracking the maximum power point (MPP). one of them is the PS (Particle Swarm) [4] .Fractional open-circuit voltage and short-circuit current strategies provide a simple and effective way to acquire the maximum power (Fangrui Liu. 2008). Hill climbing or perturb and observe (P&O) methods are widely applied in the MPPT controllers due to their simplicity and easy implementation.

Boost converter, also known as the step-up converter, is considered the most beneficial in the solar cell application because of its simplicity, low cost, and high efficiency. In theory, the steady state oscillations should be eliminated since the derivative of the power with respect to the voltage vanishes at MPP. However, the value of the slope of the PV array power versus voltage curve seldom is always null due to the resolution of digital implementation. The neural network and the Non iterative are also considered of the MPP techniques that helps in reaching the MPP [5] [6].

This research proposes the improvement of the tracking accuracy and dynamic performance under sudden change of irradiance conditions.

2 PHOTOVOLTAIC/ SOLAR CELLS SYSTEM MODEL

There are two types of solar cells model used for different purposes; firstly, a static model without using a transfer functions of low pass filter (LPF), and secondly, the state-space model of the PV-boost system is obtained based on the solar cells model integrated with LPF as a basis to make the solar power plant simulation such as a real condition, which is expected to design a new MPPT algorithm approach [7] [8]. The two modeling schemes are presented, respectively, in the following sections (Li, Xiao, Yaoyu Li, and John E, 2012).

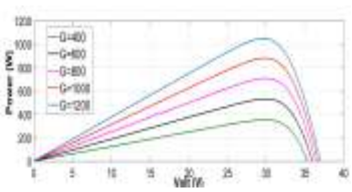
3 CHARACTERISTICS OF SOLAR CELLS

Exponential equation used to make a solar cell model is derived from the laws of physics for the p-n junction, which is generally accepted as presentation of cell characteristics. For modeling of PV statics, the equivalent circuit of PV system in Fig.1 is adopted. The characteristic of the I-V curve can be modeled.

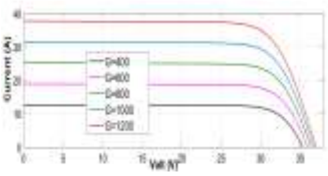
$$I = Iph - Is\left(exp\left(\frac{q(V+IRs)}{NKT}\right) - 1\right) - \frac{(V+IRs)}{Rsh} \qquad (1)$$

where, V and I are the voltage and current, respectively. Iph is the short-circuit current and Is is the reverse saturation (or leakage) current of the diode. N is the ideality factor of the diode, T is the thermal voltage of the solar cell arrays in Kelvin(K) . q is the electron charge with the value of 1.60217646 × 10exp−19 C, K = 1.3806503 × 10exp−23 , J/K is the Boltzmann constant. Rs and Rsh are the equivalent series and shunt resistance of the solar cell array, respectively. The output voltage and current of the solar cells are strongly influenced by environmental conditions, i.e. solar radiation and cell temperature. From Equation (1), Iph is connected with solar radiation, **K1 is the temperature coefficient of short circuit current**, Isc is the short-circuit current at a temperature of 25°C , T is the temperature of the solar cell, and λ is the solar radiation in kW/m².

$$Iph = [Isc + K1(T - 298)]\ \frac{\lambda}{100} \qquad (2)$$



(a)



(b)

Fig 1.(a) P-V , (b) I-V curves at 25 °C characteristics of solar cell under different irradiance

Based on Equation (2), it can be seen that at the time of constant temperature, the current generated by photon is directly proportional to the solar radiation. Effect of the solar radiation changes in the PV characteristic curve is shown in Figure 1. Isc is the short circuit current, which means the voltage is zero or the circuit voltage opens at the time, so no current flows [9]. At the time of the current value being zero, it means that the solar radiation of the sun is 1000 W/m² ; 0.75 sun with 750 W/m² ;0.5 sun with 500 W/m² , and so forth. If the solar radiation onto photovoltaic cells diminishes, Isc and Voc, change will not be significant as in Isc Fig. 1 shows the P–V & I-V curves characteristics at temperature of 25°C under different irradiance rates [10] [11]. The generated current is shown increasing with the irradiance level.

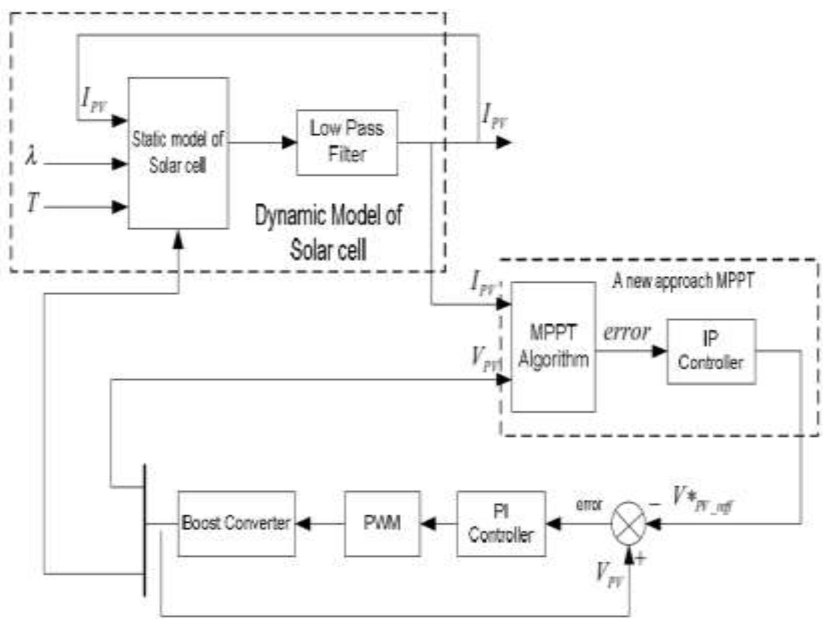


Fig 2 Block diagram of a new MPPT

4 PROPOSED DESIGN OF A NEW APPROACH

The word This paper proposes a new approach of MPPT, improved by using dual controller as compensation to output voltage. The controller uses integral proportional (IP) modified MPPT and PI controllers for boost converter, which consists of two parts:

$Proportional\ (P)\ part:\ up(t) = kp\ (ys(t) - y(t))$ (3)

$Integral\ (I)\ part:\ uI(t) = \frac{kp}{\tau i}\int_0^t (ys(\tau) - y(\tau))d\tau$ (4)

The output of PI controller equals to the sum of the two parts:

$u(t) = up(t) + uI(t)$ (5)

$u(t) = kp\ (ys(t) - y(t)) + \frac{kp}{\tau i}\int_0^t (ys(\tau) - y(\tau))d\tau$ (6)

$Gp(s) = \frac{u(s)}{ys(s) - y(s)}$ (7)

$Gp(s) = Kp + \frac{Kp}{\tau is}$ (8)

where, variables of controller ys(t) , y(t) and u(t) are setpoint , output process, and output of PIcontroller. Component variables kc ,τi are proportional gain and integrator. In experiment, their use as controller, setpoint and controller parameters kc and τi is set by user. Input and output of PIcontroller are ys(t)-y(t) and u(t) Thus, the transfer function of PI controller is as follows :

$Gc(s) = \frac{kp}{\tau is} - kp$ (9)

The proposed MPPT algorithm is aimed to achieve zero error value by providing a reference voltage, Vpv_ref, as a working point of solar cells. When the error rate is far from zero, then given large reference voltage in order to reach set point quickly and the error is close to zero, the change reference voltage is given little to prevent oscillation. The proposed MPPT algorithm is designed to provide reference voltage with two different purposes. First, a largereference voltage with constant changes is used as an PI controller of MPPT input to calculate the error. Second, reference voltage with large changes is varied from PI controller of MPPT to find the maximum power point working quickly and keep the system working at that point. The proposed MPPT requires feedback from the plant in the form of the gradient value of the P-V curve (Radjai, Tawfik, Jean Paul Gaubert, and LazharRahmani. 2014). Since the P-V curve of solar cell has nonlinear characteristics properties, the value ΔP/ΔV must be calculated by using a small value of ΔV. This is in contrast with the aim of varying a new actual value of ΔV, therefore, in this MPPT design, reference voltage is updated alternately by the PI controller and timer gradient. Fig 2. shows the block diagram of the new model of MPPT algorithm.

In order for the solar cells to work at the maximum power point, the value of gradient P-V curve has to be close to zero. Therefore, the set point for the PI controller of MPPT constant is zero, while its feedback is the gradient of the P-V curve itself. Based on the P-V curve in Fig. 1, a positive gradient means the working point is on the left of MPP (Selvamuthukumaran, et al., 2016). In this case, reference voltage must be added, while the negative gradient be reduced. Therefore, error of PI controller or the MPPT is reversed, making the set point as a negative input, whereas the feedback controller is as positive input.

The new formula can be written as:

$$error = (\frac{dP}{dV}) - A \qquad (10)$$

where,

A = reference voltage updated automatically

dP = differential of power

dV = differential of voltage

Equation (10) gives the equation and error input of the new MPPT based on the transfer function of the IP controller. Therefore, the differential of IP controller is as follows:

Vertical lines are optional in tables. Statements that serve as captions for the entire table do not need footnote letters. Kp=Proportional Factor ,Ti= Integral Factor

$$V^{*}pv = k1i \int_{O}^{t} \left(Ipv + \frac{dIpvVpv}{dVpv} \right) dt - \; k\mathring{1}p \, Vpv) \qquad (11)$$

By assuming,

$$\frac{d}{dt} X1 = Ipv + \frac{dIpv\,Vpv}{dVpv} \qquad (12)$$

hence,

$$V^{*}pv = k1i \, X1 - k\mathring{1}p \, Vpv \qquad (13)$$

As for the second PI controller, the input error controller can be seen in the design of the system as in Fig. 2. The second differential equation of PI controller can be derived as :

$$D = k2p \, (Vpv - V^{*}pv) + \; k2i \int_{0}^{t} Vpv - V^{*}pv \, dt \qquad (14)$$

by assuming :

$$\frac{d}{dt} X2 = Vpv - V^{*}pv \qquad (15)$$

Then, by substituting equation (13) into equation (15) produces :

$$\frac{d}{dt} X2 = Vpv - (k1i \, X1 - k\mathring{1}p \, Vpv) \qquad (16)$$

hence,

$$D = k2pVpv - k2p\left[k\mathring{1}p \, Vpv - k1i \, X1\right] + k2iX2 \qquad (17)$$

5 SIMULATION RESULTS

The main component parameters of boost converter circuit and PI controller implemented in the Matlab Simulink are given in Table 1

TABLE 1. COMPONENT OF BOOST CONVERTER CIRCUIT

Symbol	Description	Value
L	Inductance	0.5 mH
fs	Frequency	5 KHz
Rl	Load Resistance	10 Ω
C	Load Capacitor	0.5 mF
Ncell	No. of cells per Module	60

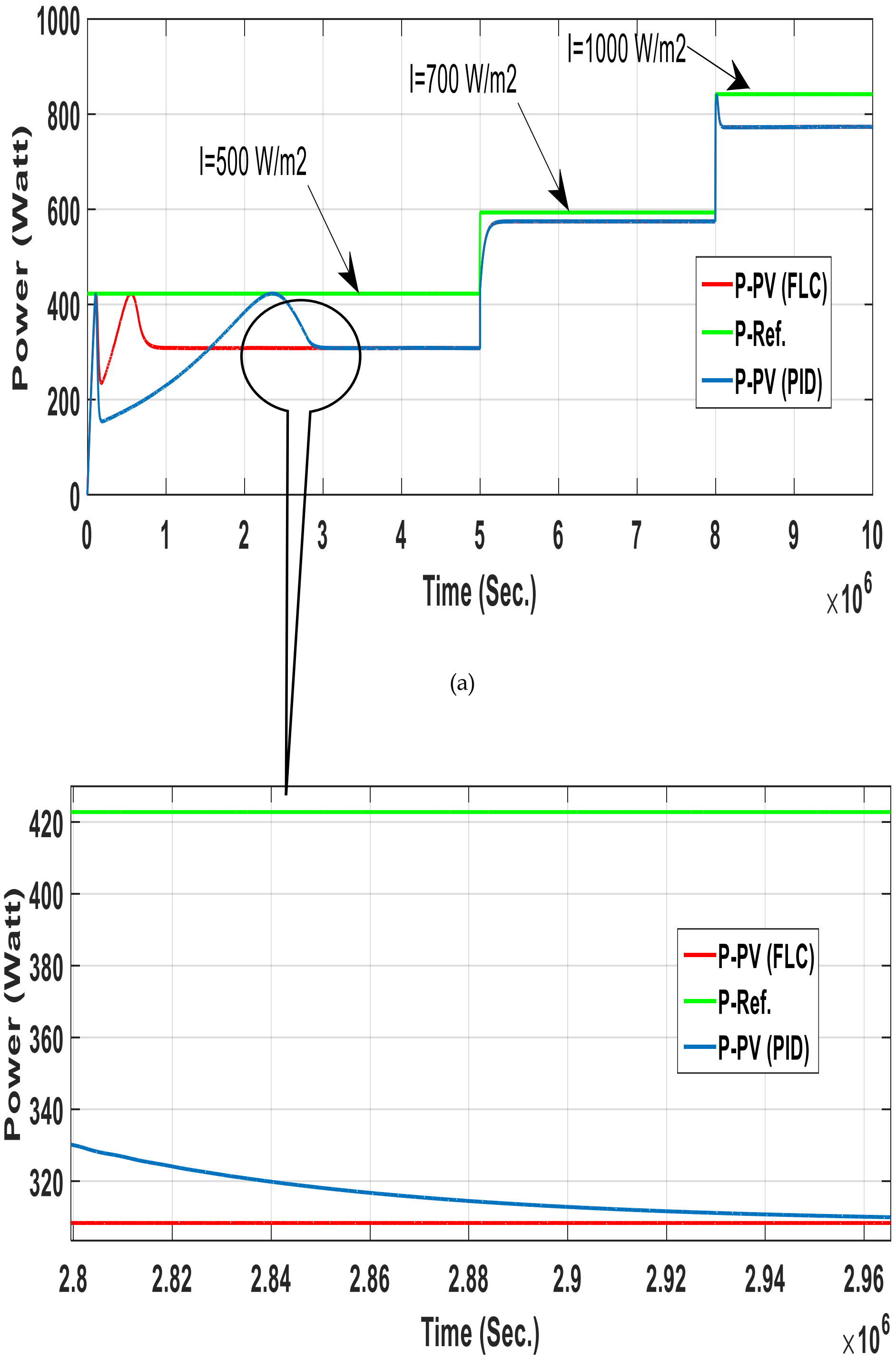
Vertical lines are optional in tables. Statements that serve as captions for the entire table do not need footnote letters. H = henry, Hz=hertz , Ω=ohms , F=Farad

TABLE 2. COMPONENT OF PI CONTROLLER

Symbol	Description	Value
Kp	Proportional Factor	0.001
Ti	Integral Factor	0.015

TABLE 3. COMPONENT OF FLC CONTROLLER

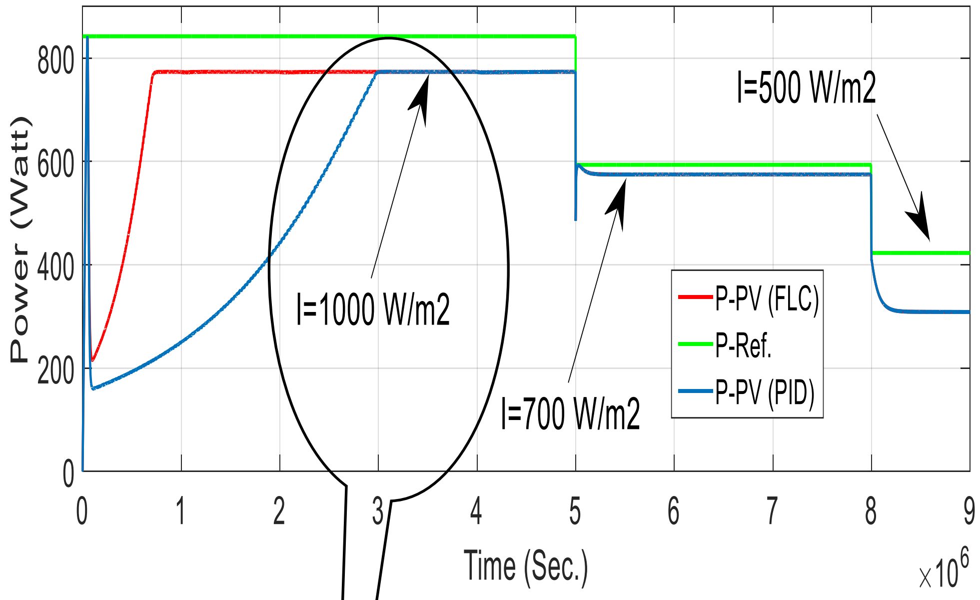
Symbol	Description	Value
GP	Proportional Gain	10
GI	Integral Gain	0.2
Kp	Proportional Factor	0.01
Ti	Integral Factor	0.1



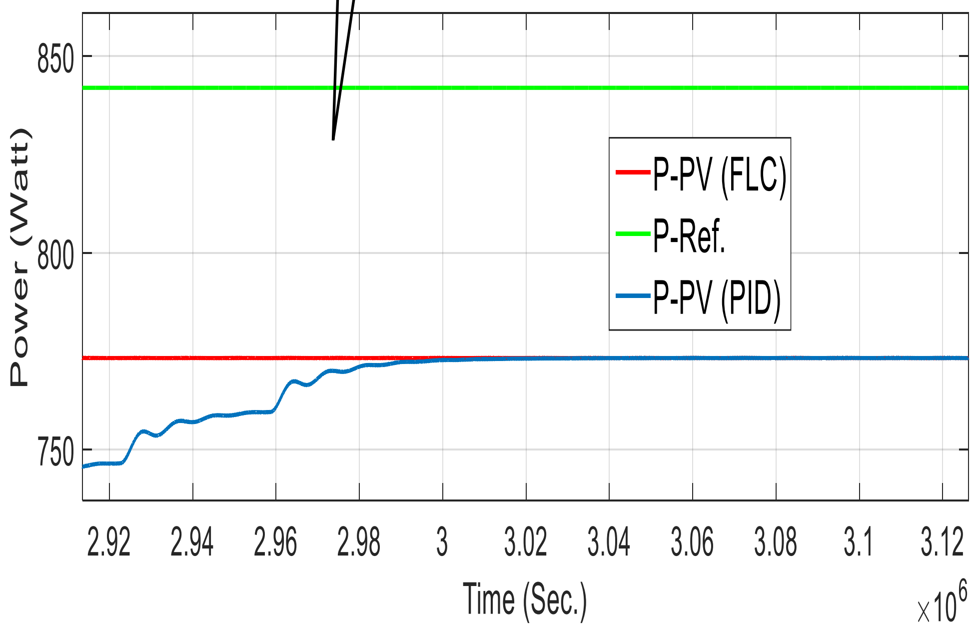
1000
800
600
400
200
0
Power (Watt)
I=500 W/m2
I=700 W/m2
I=1000 W/m2
P-PV (FLC)
P-Ref.
P-PV (PID)
0 1 2 3 4 5 6 7 8 9 10
Time (Sec.)
x10^6
420
400
380
360
340
320
Power (Watt)
P-PV (FLC)
P-Ref.
P-PV (PID)
2.8 2.82 2.84 2.86 2.88 2.9 2.92 2.94 2.96
Time (Sec.)
x10^6

(a)

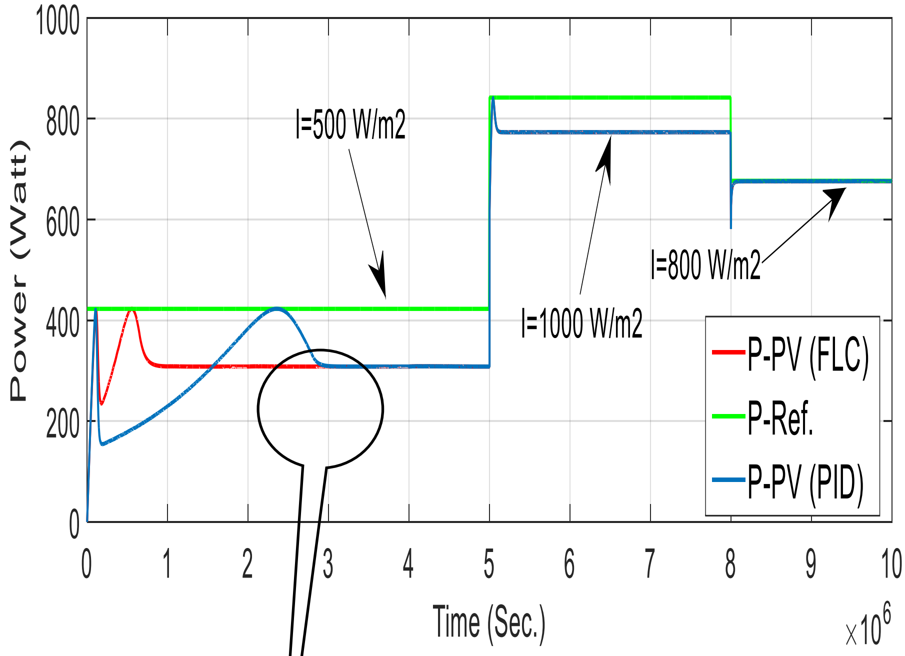
(b)


Power (Watt)
Time (Sec.)
x10^6
I=1000 W/m2
I=700 W/m2
I=500 W/m2
P-PV (FLC)
P-Ref.
P-PV (PID)
0
200
400
600
800
0 1 2 3 4 5 6 7 8 9

(c)

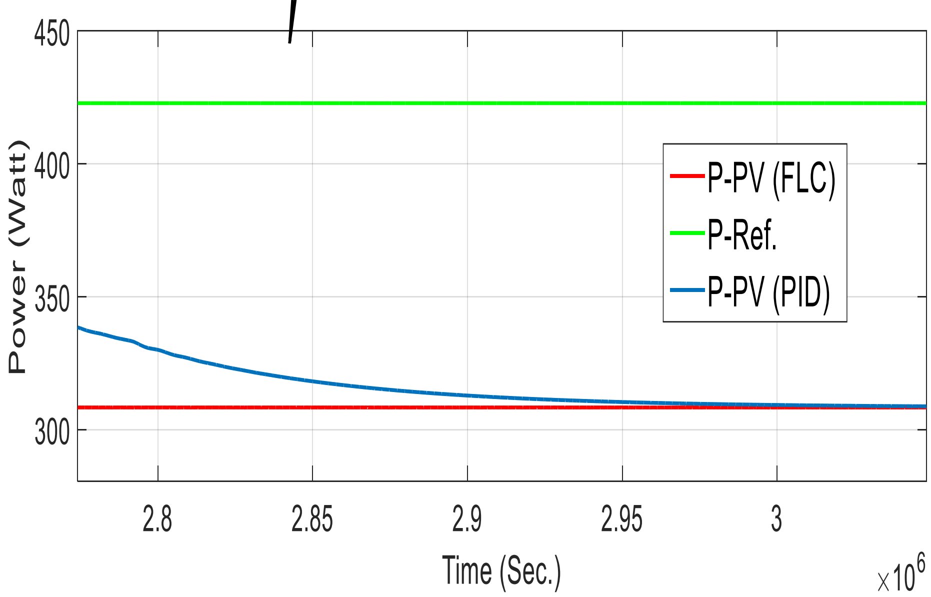

Power (Watt)
Time (Sec.)
x10^6
P-PV (FLC)
P-Ref.
P-PV (PID)
750
800
850
2.92 2.94 2.96 2.98 3 3.02 3.04 3.06 3.08 3.1 3.12

(d)



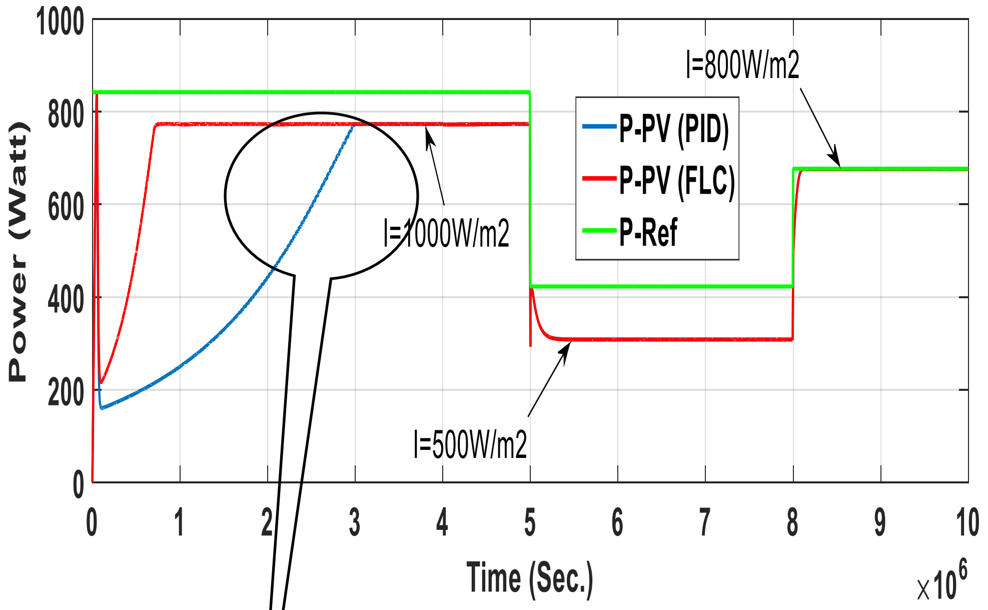
Power (Watt)
Time (Sec.)
x10^6
I=500 W/m2
I=1000 W/m2
I=800 W/m2
P-PV (FLC)
P-Ref.
P-PV (PID)

(e)

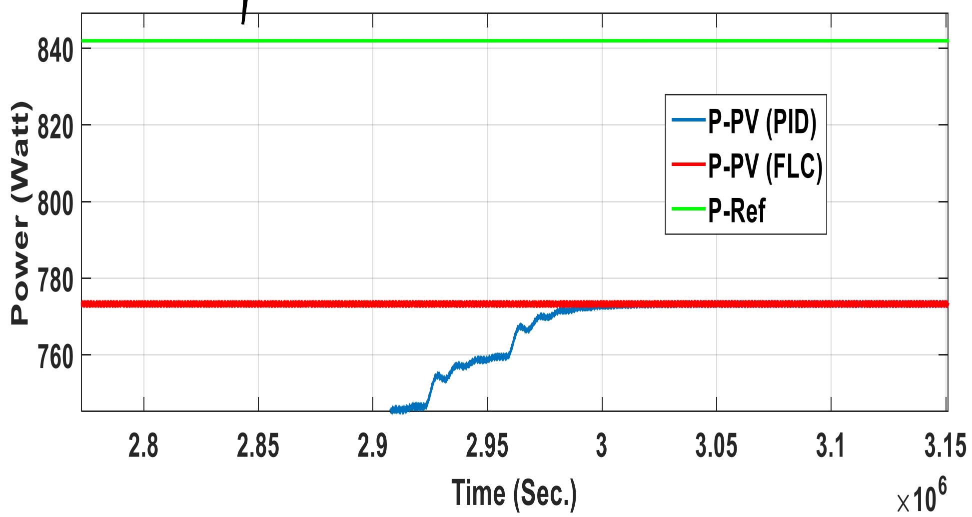


Power (Watt)
Time (Sec.)
x10^6
P-PV (FLC)
P-Ref.
P-PV (PID)

(f)



(g)



(h)

Fig3. P-PV (Reference , Using PID & Using FLC Controller)

(a) & (b) I= 500 -700 - 1000 W/m2

(c) & (d) I= 1000 -700 - 500 W/m2

(e) & (f) I= 500 -1000 - 800 W/m2

(g) & (h) I= 1000 -500 - 800 W/m2

Fig 3. shows the Power measurement, Vpv of boost converter circuit having oscillation when Vref given by the MPPT algorithm getting no closer to the maximum power point (MPP), except away from it (Figures, 2008). Solar cell temperature was set at standard conditions, 25°C , solar radiation was changed from 1000W/m2 to 600W/m2 in the Fifth second, and from 600W/m2 to 200W/m2 in the eighth second. In the fifth & eighth seconds ,when the solar radiation decreased, the solar cell of Vpv working at MPP also decreased. However, before the working point of solar cells decreased, the output voltage dropped for 0.2seconds because the Vref given by the MPPT algorithm was lower than the output voltage Vpv of boost converter. This can be understood by looking at Ipv measurable of boost converter circuit. This shows the potential of MPPT to overcome the drawbacks of the PIMPPT.

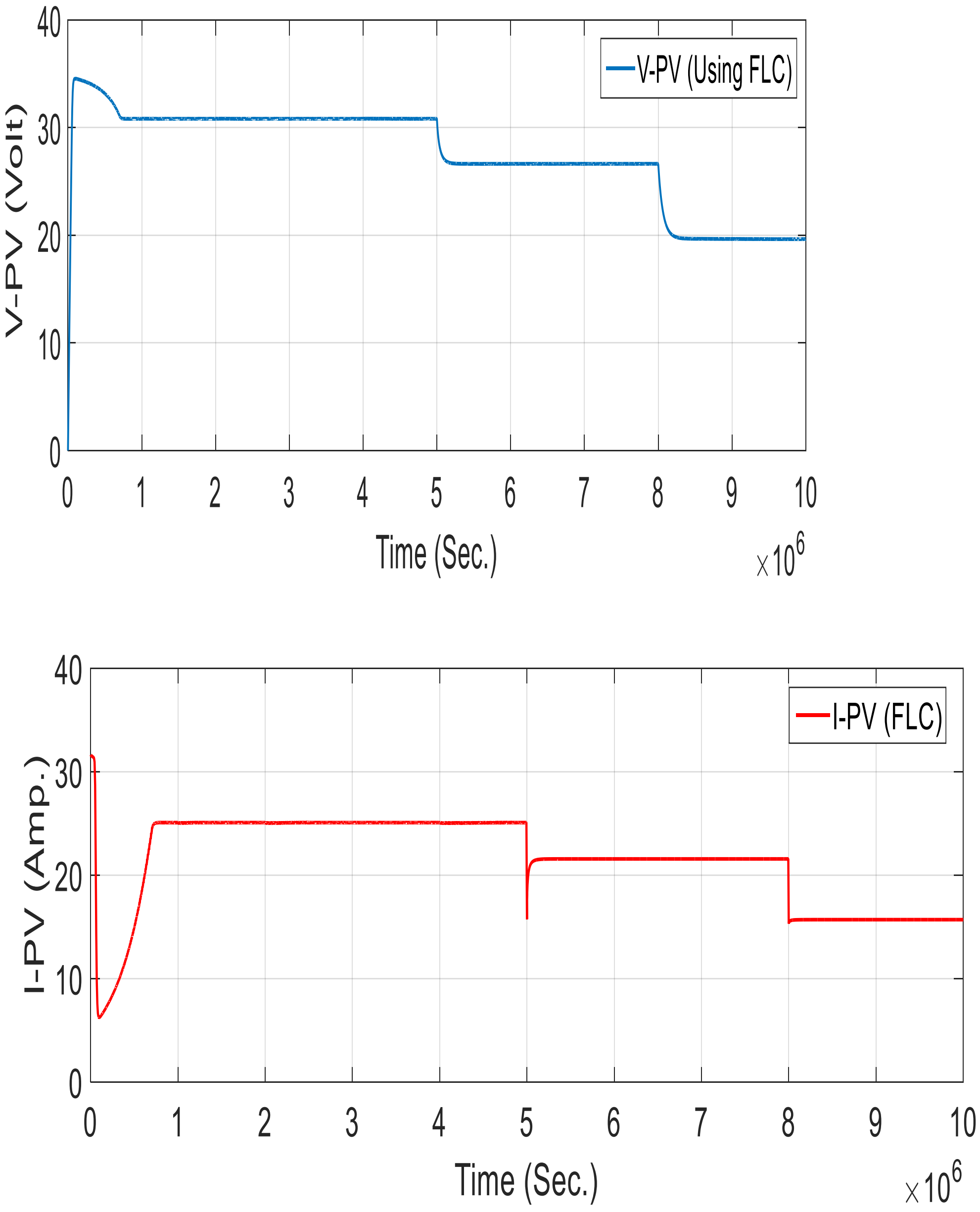
A vital component of the reference solar cell used in this research is the solar cells, manufactured by AREi (Advanced Renewable Energy) , model 220W-M6-G Datasheet), whose specification parameters values are given in Table 3

TABLE 4. PARAMETERS OF AREI 220W-M6-G

Symbol	Description	Value
Pmax	Maximum Power	220.0716 Watt -5% +10%
Voc	Open Circuit Voltage	36.72 V
Isc	Short Circuit Current	7.85 A
	Temperature Coefficient of Voc	-0.3534 % / °C
	Temperature Coefficient of Isc	0.05535 % / °C
Vmp	Maximum Power Voltage	29.82 V
Imp	Maximum Power Current	7.38 V
Ns	Number of cells	4

Fig 4. shows the output voltage & current V-PV &I-PV consequence measured on the boost converter circuit. Vref was updated to calculate the error input at the FLC MPPT, or if the new MPPT had small value, a constant or positive. If the output voltage V-PV had decreased , likewise I-PV would have subsided automatically, as shown in Fig 1. This oscillation occurred because when the algorithm calculated the error for PI controller input, there was an decrease in solar radiation at the same time. The decrease in solar radiation decreased the I-PV .The error calculation involved the decrease of V-PV . Therefore, I-PV should be smaller, but since there was an decrease in solar radiation, the I-PV got even greater. This caused an error in calculation, thus the Vref given by the PIMPPT algorithm was also wrong. This shows that when there is gradient or PIMPPT controller input error in the

event of oscillation, the value of the gradient becomes very extreme. It can be used as a parameter for detecting oscillation. An Anti-windup was added in the proposed algorithm to reduce the effects of the extreme error.



(a)

(b)

Fig4. (a) V-PV & (b) I-PV (Simulated)

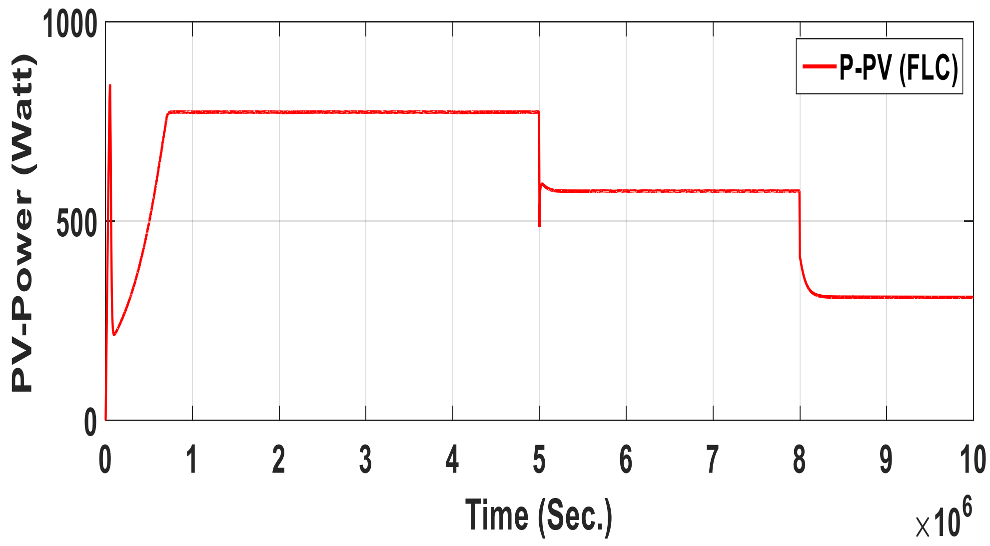


Fig5. P-PV (Simulated)

Fig. 5 shows the output power produced by the proposed MPPT system in standard environmental conditions. The power generated was around 820 Watt. Oscillation in the power derived from the system was smaller than the oscillation by PI MPPT. Power obtained from the voltage current weakened each other, so there were small oscillations at the output power. Overcoming oscillation for 0.2seconds was found able to save energy loss approximately 66.2%. Overall, the MPPT system was capable of finding the maximum power point and maintaining solar cells to work at that point. Basically, the model of the boost converter had a natural ripple that did not come from the MPPT algorithm, but caused by PI MPPT controller, making it difficult to achieve steady state conditions. By using the proposed MPPT, the oscillations could be reduced.

6 CONCLUSION

In this paper, a new approach MPPT has been proposed to extract the global maximum power point of solar cell system under sudden change conditions. The proposed MPPT has been implemented by combining reference voltage-based MPPT with Integral-Proportional algorithm. A new duty ratio is derived from Proportional-Integral controller for boost dc–dc converter to adjust the PV terminal voltage. A new mathematical model has been proposed to represent the behavior of the P–V characteristic under sudden change conditions. Matlab/Simulink simulations of a sudden change in PV system have been carried out to validate the proposed MPPT. The results show that the proposed MPPT is able to reach the global MPP and eliminate oscillation under sudden change conditions. Moreover, the controller indicates a fast converging speed, with small oscillation around the MPP during steady state. Furthermore, energy can be saved approximately76.66% (FLC. Started the saturation at t=0.7 Sec. while PI Controller started at t=3 Sec. (Energy can be saved by approximately = (3-0.7)/3 = 76.66 %)

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