MAXIMUM POWER POINT TRACKING USING PERTURBATION AND OBSERVATION AS WELL AS INCREMENTAL CONDUCTANCE ALGORITHM

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ABSTRACT

This paper is comparative study of two type of maximum power point tracking (MPPT). The optimisation of energy generation in a photovoltaic (PV) system is necessary to let the PV cells operate at the maximum power point (MPP) corresponding to the maximum efficiency. Since the MPP varies, based on the irradiation and cell temperature, appropriate algorithms must be utilised to track the MPP. This is known as maximum power point tracking (MPPT). Different MPPT algorithms, each with its own specific performance, have been proposed in the literature. A so-called perturb and observe (P&O) as well as incremental conductance method is considered here and both are compared. This two method is widely diffused because of its low-cost and ease of implementation. When atmospheric conditions are constant or change slowly, the P&O method oscillates close to MPP. However, when these change rapidly, this method fails to track MPP and gives rise to a waste of part of the available energy. A comparative study has been done on both the methods by using MATLAB environment. The MPPT algorithm was set up and validated by means of MATLAB simulations and experimental tests, confirming the effectiveness of the method.

Keywords: *MPPT, MATLAB, Incremental Conductance, Perturb and Observe*

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INTRODUCTION

The comparisons between the PV water pumping system equipped with a Maximum power point tracker (MPPT) and the direct coupled system without MPPT has been done with the addition of a solar tracking using microcontroller. Microcontroller has been used to rotate the panel so that we can utilize maximum renewable energy in more efficient way.

Also, the design and simulations of MPPT has been done using MATLAB to perform comparative tests of the perturb and observe (P&O) and incremental Conductance (incCond) algorithm. Simulations also verify the functionality of MPPT with a resistive load and then with the DC pump motor load. The comparisons between the PV water pumping system equipped with MPPT and the direct coupled system without MPPT has been done also solar tracking using microcontroller has been used so that we can utilize maximum renewable energy in more efficient way.

The two MPPT algorithms, P&O and incCond, discussed and are implemented in MATLAB simulations and tested for their performance. Since the purpose is to make comparisons of two algorithms, each simulation contains only the PV model and the algorithm in order to isolate any influence from a converter or load. First, they are verified to locate the MPP correctly under the constant irradiance, as shown in Figure 1.

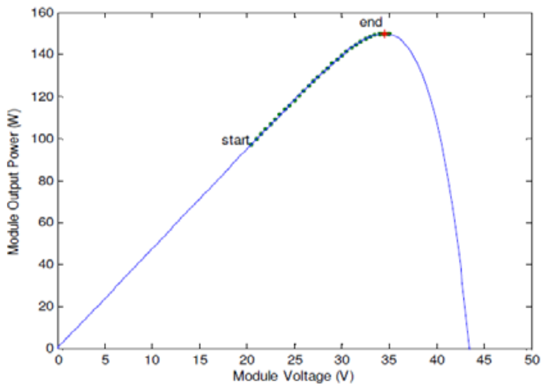

Figure 1: Searching the MPP (1KW/m2, 25^{o}C)The traces of PV operating point are shown in green, and the MPP is the red asterisk.

MAXIMUM POWER POINT TRACKER

When a PV module is directly coupled to a load, the PV module's operating point will be at the intersection of its *I–V* curve and the load line which is the *I-V* relationship of load. For example in Figure 2, a resistive load has a straight line with a slope of *1/Rload* as shown in Figure 3. In other words, the impedance of load dictates the operating condition of the PV module. In general, this operating point is seldom at the PV module's MPP, thus it is not producing the maximum power. A study shows that a direct-coupled system utilizes a mere 31% of the PV capacity [1]. A PV array is usually oversized to compensate for a low power yield during winter months. This mismatching between a PV module and a load requires further over-sizing of the PV array and thus increases the overall system cost. To mitigate this problem, a maximum power point tracker (MPPT) can be used to maintain the PV module's operating point at the MPP. MPPTs can extract more than 97% of the PV power when properly optimized [2]. This chapter discusses the *I-V* characteristics of PV modules and loads, matching between the two, and the use of DC-DC converters as a means of MPPT. It also discusses the details of some MPPT algorithms and control methods, and limitations of MPPT.

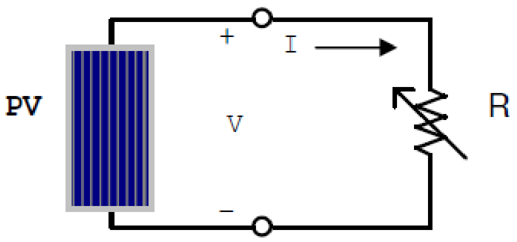

Figure 2: PV module is directly connected to a (variable) resistive load

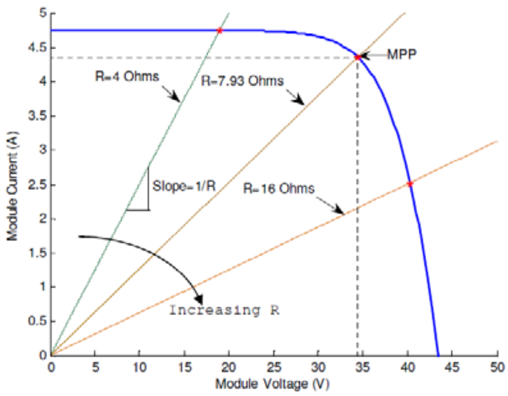

Figure 3: I-V curves of BP SX 150S PVmodule and various resistive loads Simulated with the MATLAB model (1KW/m^2, 25^{o}C

MAXIMUM POWER POINT TRACKING ALGORITHMS

The location of the MPP in the *I–V* plane is not known beforehand and always changes dynamically depending on irradiance and temperature. For example, Figure 4 shows a set of PV *I–V* curves under increasing irradiance at the constant temperature (25^oC), and Figure 5 shows the *I–V* curves at the same irradiance values but with a higher temperature (50^oC). There are observable voltage shifts where the MPP occurs. Therefore, the MPP needs to be located by tracking algorithm, which is the heart of MPPT controller. There are a number of methods that have been proposed. One method measures an open-circuit voltage (*Voc*) of PV module every 30 seconds by disconnecting it from rest of the circuit for a short moment.

Then, after re-connection, the module voltage is adjusted to 76% of measured *Voc* which corresponds to the voltage at the MPP [3]. The implementation of this open-loop control method is very simple and low-cost although the MPPT efficiencies are relatively low (between 73~91%) [3]. Model calculations can also predict the location of MPP; however in practice it does not work well because it does not take physical variations and aging of module and other effects such as shading into account. Furthermore, a pyranometer that measures irradiance is quite expensive. Search algorithm using a closed-loop control can achieve higher efficiencies, thus it is the customary choice for MPPT. Among different algorithms, the Perturb & Observe (P&O) and Incremental Conductance (incCond) methods are studied.

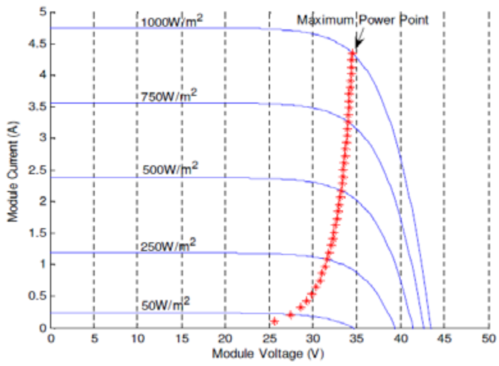

Figure 4: I-V curves for varying irradiance and a trace of MPPs (25oC)

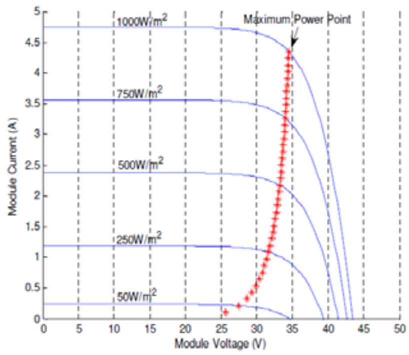

Figure 5: I-V curves for varying irradiance and a trace of MPPs (50^{o}C)

PERTURB & OBSERVE ALGORITHM

The perturb & observe (P&O) algorithm, also known as the “hill climbing” method, is very popular and the most commonly used in practice because of its simplicity in algorithm and the ease of implementation. The most basic form of the P&O algorithm operates as follows. Figure 6 shows a PV module’s output power curve as a function of voltage (*P-V* curve), at the constant irradiance and the constant module temperature, assuming the PV module is operating at a point which is away from the MPP. In this algorithm the operating voltage of the PV module is perturbed by a small increment, and the resulting change of power, ΔP, is observed. If the ΔP is positive, then it is supposed that it has moved the operating point closer to the MPP.

Thus, further voltage perturbations in the same direction should move the operating point toward the MPP. If the ΔP is negative, the operating point has moved away from the MPP, and the direction of perturbation should be reversed to move back toward the MPP.

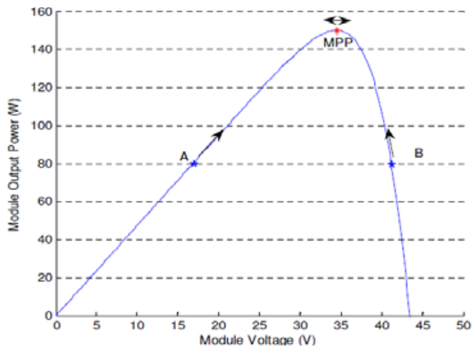

Figure 6: Plot of power vs. voltage for BP SX 150S PV module (1KW/m2, 25^{o}C)

INCREMENTAL CONDUCTANCE ALGORITHM

To solve the problem of the P&O algorithm under rapidly changing atmospheric conditions the incremental conductance (incCond) algorithm was proposed [1]. The basic idea is that the slope of *P-V* curve becomes zero at the MPP, as shown in Figure 6. It is also possible to find a relative location of the operating point to the MPP by looking at the slopes. The slope is the derivative of the PV module's power with respect to its voltage and has the following relationships with the MPP.

$$\frac{dP}{dV} = 0 \text{ at MPP} \quad (1)$$

$$\frac{dP}{dV} < 0 \text{ at the right of MPP} \quad (2)$$

$$\frac{dP}{dV} > 0 \; at\ the\ left\ tof\ MPP \quad (3)$$

The above equations are written in terms of voltage and current as follows.

$$\frac{dP}{dV} = \frac{d(V \cdot I)}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV} = I + V\frac{dI}{dV} \quad (4)$$

If the operating point is at the MPP, the equation (4) becomes:

$$I + V\frac{dI}{dV} = 0 \quad (5)$$

$$\frac{dI}{dV} = -\frac{I}{V} \quad (6)$$

If the operating point is at the left side of the MPP, the equation (4) becomes:

$$I + V\frac{dI}{dv} > 0 \qquad (7)$$

$$\frac{dI}{dV} > -\frac{I}{V} \qquad (8)$$

If the operating point is at the right side of the MPP, the equation (4) becomes:

$$I + V\frac{dI}{dv} < 0 \qquad (9)$$

$$\frac{dI}{dv} < -\frac{I}{V} \qquad (10)$$

Note that the left side of the equations (6), (8), and (10) represents incremental conductance of the PV module, and the right side of the equations represents its instantaneous conductance.

PI CONTROLLING OF MPPT

As shown in Figure 7, the MPPT takes measurement of PV voltage and current, and then tracking algorithm (P&O, incCond, or variations of two). The PI loop operates with a much faster rate and provides fast response and overall system stability [4] [5]. The PI controller itself can be implemented with analog components, but it is often done with DSP-based controller [4] because the DSP can handle other tasks such as MPP tracking thus reducing parts count.

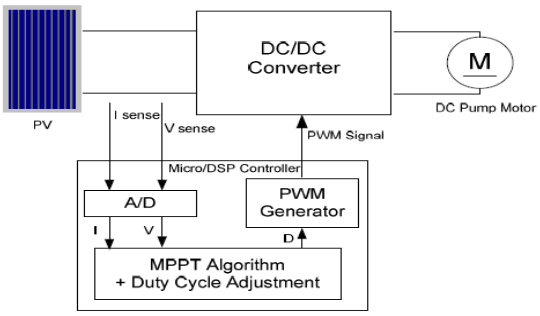

Figure 7: Block diagram of MPPT with the PI compensator

COMPARISONS OF P&O AND INCCOND ALGORITHM

The two MPPT algorithms, P&O and incCond, discussed are implemented in MATLAB simulations and tested for their performance. Since the purpose is to make comparisons of two algorithms, each simulation contains only the PV model and the algorithm in order to isolate any influence from a converter or load. First, they are verified to locate the MPP correctly under the constant irradiance, as shown in Figure 8.

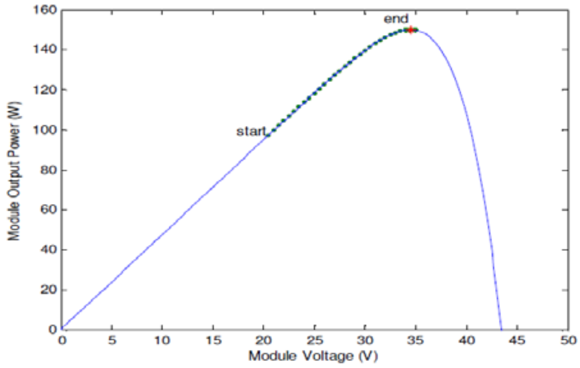

Figure 8: Searching the MPP (1KW/m2, 25oC)

The traces of PV operating point are shown in green, and the MPP is the red asterisk

Next, the algorithms are tested with actual irradiance data provided by [6]. Simulations use two sets of data, shown in Figure 9, the first set of data is the measurements of a sunny day in April in Barcelona, Spain, and the second set of data is for a cloudy day in the same month at the same location. The data contain the irradiance measurements taken every two minutes for 12 hours. Irradiance values between two data points are estimated by the cubic interpolation in MATLAB functions.

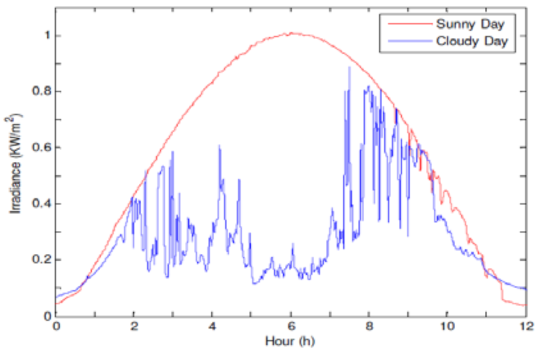

Figure 9: Irradiance data for a sunny and a cloudy day of April in Barcelona, Spain [6]

On a sunny day, the irradiance level changes gradually since there is no influence of cloud. MPP tracking is supposed to be easy. As shown in Figure 10 & 11, both algorithms locate and maintain the PV operating point very close to the MPPs (shown in red asterisks) without much difference in their performance.

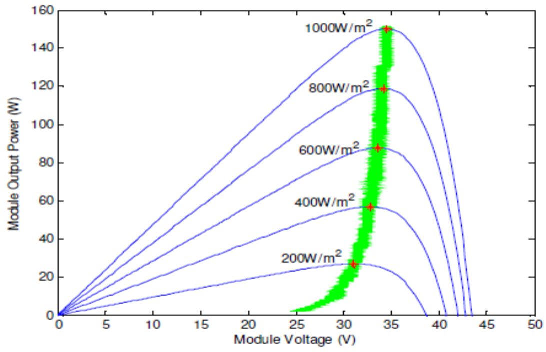

Figure 10: Traces of MPP tracking on a sunny day (25°C) by using P&O algorithm.

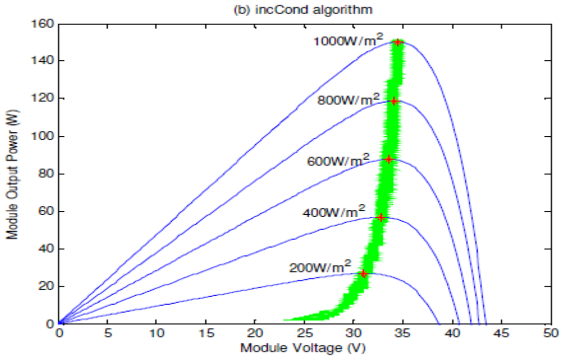

Figure 11: Traces of MPP tracking on a sunny day (25°C) by using inccond algorithm.

On a cloudy day, the irradiance level changes rapidly because of passing clouds. MPP tracking is supposed to be challenging. Figure 12 shows the trace of PV operating points of P&O algorithm and Figure 13 for incCond algorithm. For both algorithms, the deviations of operating points from the MPPs are obvious when compared to the results of a sunny day. Between two algorithms, the incCond algorithm is supposed to outperform the P&O algorithm under rapidly changing atmospheric conditions [1]. A close inspection of Figure 12 & 13 reveals that the P&O algorithm has slightly larger deviations overall and some erratic behaviours (such as the large deviation pointed by the red arrow). Some erratic traces are, however, also observable in the plot of the incCond algorithm.

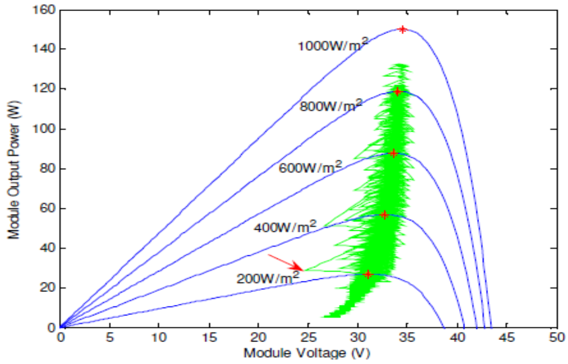

Figure 12: Traces of MPP tracking on a cloudy (25°C) by using P&O algorithm

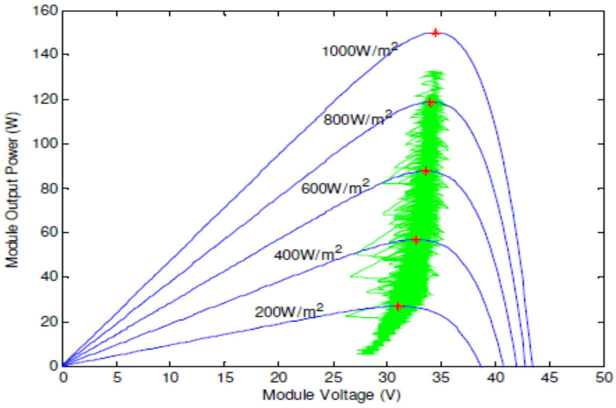

Figure 13: Traces of MPP tracking on a cloudy day (25°C) by using inccond algorithm.

Table 1: Comparison of the P&O and incCond algorithms on a cloudy day.

	P&O Algorithm	incCond Algorithm
Total energy(simulation)	479.63Wh	479.69Wh
Total energy (theoretical max)	480.38Wh	480.38Wh
Efficiency	99.85%	99.86%

Total electric energy produced with the incCond algorithm is narrowly larger than that of the P&O algorithm. The MPP tracking efficiency measured by {Total Energy (simulation)} ÷ {Total Energy (theoretical max)} ×100% is still good in the cloudy condition for both algorithms, and again it is narrowly higher with the incCond algorithm. The irradiance data are only available at two-minute intervals, thus they do not record a much higher rate of changes during these intervals. The data may not be providing a truly rapid changing condition, and that could be a reason why the two results are so close. Also, further optimization of algorithm and varying a testing method may provide different results. The performance difference between the two algorithms, however, would not be large. There is a study showing similar results [3]. The simulation results showed the efficiency of 99.3% for the P&O algorithm and 99.4% for the incCond algorithm. The experimental results showed 96.5% and 97.0%, respectively, for a partly cloudy day.

MPPT SIMULATIONS WITH RESISTIVE LOAD

First, MPPT with a resistive load is implemented in MATLAB simulation and verified. The selection of the P&O algorithm permits the use of the output sensing direct control method which eliminates the input voltage and current sensors. The MPPT design, therefore, chooses the P&O algorithm and the output sensing direct control method because of the advantage that allows of a simple and low cost system. The simulated system consists of the BP SX 150S PV model, the ideal Cúk converter, the MPPT control, and the resistive load (6Ω). The MATLAB function that models the PV module is the following:

$$I_a = bp\_sx150s(V_a, G, T) \qquad (11)$$

The function, *bp_sx150s*, calculates the module current (*Ia*) for the given module voltage *Va*), Irradiance (*G* in *KW/m*^{2}), and module temperature (*T* in ^oC). The operating point of PV module is located by its relationship to the load resistance (*R*) as explained in Section.

$$R = \frac{V_a}{I_a} \qquad (12)$$

The irradiance (*G*) and the module temperature (*T*) for the function (11) are known variables, thus it is possible to say that *Ia* is the function of *Va* hence *Ia = f(Va)*. Substituting this into the equation (12) gives:

$$V_a - R \cdot f(V_a) = 0 \qquad (13)$$

Knowing the value of R enables to solve this equation for the operating voltage (Va). MATLAB uses fzero function to do so. Appendix for details. Placing Va, back to the equation (11) gives the operating current (Ia).

For the direct control method, each sampling of voltage and current is done at a periodic steady state condition of the converter. The following equations describe the input/output relationship of voltage and current, and they are used in the MATLAB simulation.

$$V_0 = \frac{D}{1-D} . V_S \qquad (14)$$

$$I_0 = \frac{1-D}{D} . I_S \qquad (15)$$

Where: *D* is the duty cycle of the Cúk converter.

The simulation is performed under the linearly increasing irradiance varying from 100W/m^2 to 1000W/m^2 with a moderate rate of 0.3W/m^2 per sample. Figure 14 and 15 show that the trace of operating point is staying close to the MPPs during the simulation. Figure 16 shows the relationship between the output power of converter and its duty cycle. Figure 17 shows the current and voltage relationship of converter output. Since the load is resistive, the current and voltage increase linearly with the slope of $1/R_{load}$ on the *I-V* plane.

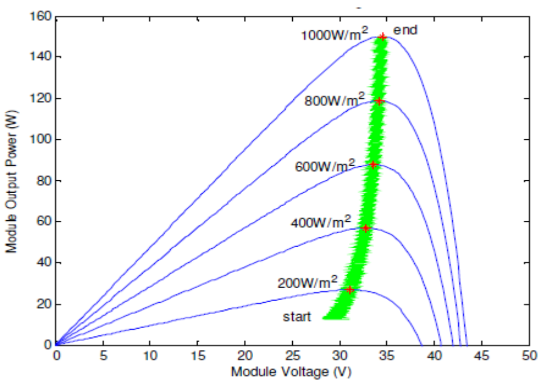

Figure 14: operating point between o/p power vs voltage

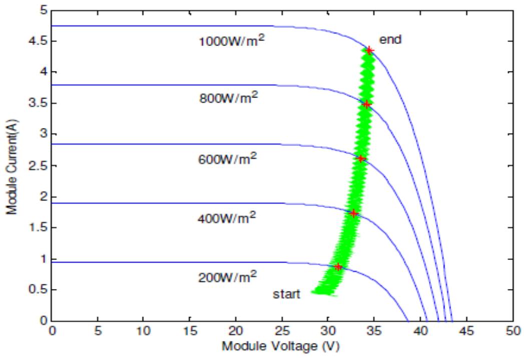

Figure 15: operating point between module current vs module voltage

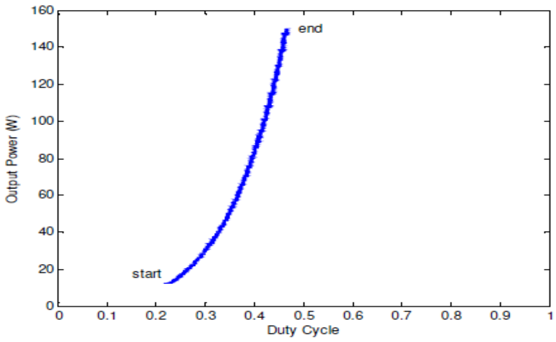

Figure 16: operating point between o/p power vs duty cycle.

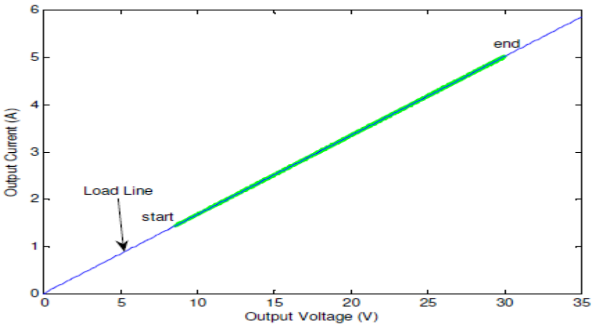

Figure 17: operating point between o/p current vs o/p voltage

RESULT ANALYSIS

The comparative study of P&O algorithm and incCond algorithm has been observed by MATLAB simulation. For both algorithms, the deviations of operating points from the MPPs are obvious when compared to the results of a sunny day. Between two algorithms, the incCond algorithm is supposed to outperform the P&O algorithm under rapidly changing atmospheric conditions.

The theoretical study of solar tracking system has been studied which can provide more benefits compare to simple photovoltaic system. We can utilize maximum renewable energy source by solar tracking system, although we can get more solar energy by connecting more number PV system either series or parallel but it will be more complex as well as costly.

A close inspection reveals that the P&O algorithm has slightly larger deviations overall and some erratic behaviours (such as the large deviation) pointed by the red Some erratic behaviour, however, also observable in the plot of the incCond algorithm. Total electric energy produced with the incCond algorithm is narrowly larger than that of the P&O algorithm. The MPP tracking efficiency measured by {Total Energy (simulation)} ÷ {Total Energy (theoretical max)} ×100% is still good in the cloudy condition The simulation results showed the efficiency of 99.3% for the P&O algorithm and 99.4% for the incCond algorithm. The experimental results showed 96.5% and 97.0%, respectively, for a partly cloudy day.

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