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# ADAPTIVE HYBRID MAXIMUM POWER POINT TRACKING METHOD FOR A PHOTOVOLTAIC SYSTEM

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## ABSTRACT

Recently, the importance of exploring the plausibility of renewable energy has been progressively increased, not only be-cause of concerns over the shortage of current fossil fuels but also the consideration of sustainable development and the negative en-vironmental impact caused by large scale use of fossil fuels. Among renewable sources, solar energy seems to be one of the promising energy sources for widespread application. Due to its inherent in-termittency and fluctuation, one of the important research interests is to harness the maximum power possible from the solar energy falling on a panel. To this end, an efficient maximum power point tracker to harvest as much energy as possible is a key to improving the system's efficiency and performance. This paper presents a novel hybrid maximum power point tracking mechanism with adaptive perturbation size. The proposed method is implemented, analyzed, and evaluated in MATLAB/Simulink. Both numerical and experimental evaluation results prove that by using the pro-posed method, better tracking performance can be achieved and the power delivered at steady state can be increased by a factor of 7.31% compared with conventional methods.

***Keywords:*** *Adaptive, hybrid, maximum power point track-ing, perturbation and observation, photovoltaic.*

## I. INTRODUCTION

THE growing demand for energy and the increasing concern about the environmental impact from excessive use of fos-sil fuels have progressively increased the interest in renewable energy research.

Among renewable energy sources such as wind, tidal, and geothermal heat, solar energy is becoming a promising energy source for widespread utilization due to its abundance and ac-cessibility. Solar systems have been deployed widely. According to [1], in 2011, the photovoltaic (PV) industry had added esti-mated 17 GW capacity worldwide (compared with just under 7.3 GW in 2009), bringing the global capacity to about 40 GW. The annual growth rate for capacity of solar PV has been around 50% since 2005, which is the fastest growth of all renewable energy sources, c.f. wind power (27%), geothermal power (4%), hydropower (3%), and ethanol production (16%).

PV arrays, which convert solar energy to electrical energy, possess strong nonlinear characteristics and there is a single operating point called the maximum power point (MPP) that provides the maximum power under certain light density and cell temperature conditions, as shown in Fig. 1. When connecting solar panels to the load, there is a probable mismatch between the load current and voltage characteristics and the MPP. Thus, tracking of this point is very important not only to improve the system's efficiency but also to reduce the cost of installation by reducing the number of solar panels required for desired output power [2].

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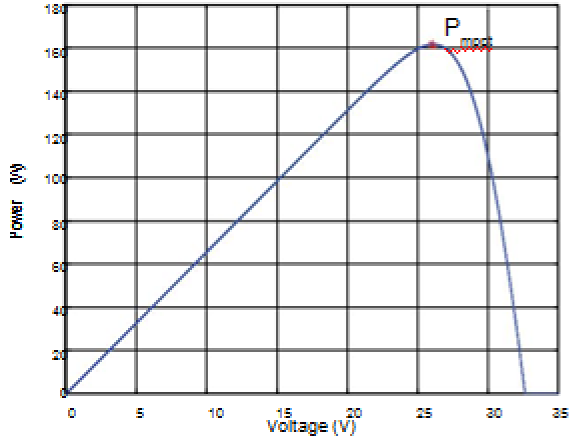


***Fig. 1. Typical V–P curve of PV module at 800 W/m$^2$ and 25 °C.***

Maximum power point tracking (MPPT) technology has be-come a very popular research topic in the past two decades [3]. In [3], more than a dozen of different MPPT methods are introduced.

*A. Fractional Method*

One of the simplest ways to estimate the MPP is the frac-tional method which has two variations called the fractional open circuit voltage method [4]–[6] and the fractional short circuit current method [5], [7]–[9].

For the fractional open circuit voltage method, it is found that the relationship between the voltage at MPP $V_{MPP}$ and open circuit voltage $V_{OC}$ is almost linear; therefore,

$$V_{MPP} = K_{OC} V_{OC} \quad (1)$$

where $K_{OC}$ is a constant proportional gain dependent on the PV array and its value needs to be identified beforehand for each specific PV array utilized.

The advantages of this method include easy implementation and only requiring one voltage sensor. It also gives a good estimation. But the disadvantages are obvious. First of all, as an estimation, the system will never work on the real MPP. Second, typical implementation of such a method requires the PV array to be shut down PV array periodically to calculate the system's open voltage under certain solar irradiation and cell temperature. This shutting down, even just momentarily, will end up with a substantial amount of energy loss. One solution is to use another pilot panel instead of shutting down the entire array in order to reduce the energy loss [6]. By doing so, it will not only increase the complexity of the installation but also increase the capital cost of the entire system.

Similarly, the fractional short circuit current method argues that the current at MPP $I_{MPP}$ is approximately linearly related to the short circuit current $I_{SC}$ ; thus,

$$I_{MPP} = K_{SC} I_{SC} \quad (2)$$

where $K_{SC}$ is a constant proportional gain dependent on the PV array and its value needs to be identified beforehand for each specific PV array utilized.

Short circuit current is more difficult to measure. An addi-tional switch is normally used to short circuit the PV array to measure the $I_{SC}$ , or as in [9], a boost converter is used where the switch in the converter is utilized to short circuit the PV panel. Both methods will increase the number of required components and installation cost.

*B. Perturbation and Observation (P&O) Method*

Because of its simplicity and reasonable accuracy, the P&O method is widely used [10]–[17]. Fig. 2 shows the flowchart of a conventional P&O method. By using this method, when operating on the left hand side of MPP, as shown in Fig. 1, the increased voltage will lead to increased power, while on the right hand side of MPP, the decreased voltage leads to increased power.

The process is repeated until the MPP is reached. After that, the system will be oscillated around the MPP.

It is obvious that one of the most important parameters for P&O is the length of perturbation; small values will lead to a slow tracking performance while large values will increase the tracking speed but on the other hand will cause large oscillation at steady state. The oscillation around the MPP in steady state operation will cause energy loss and hence reduce the efficiency of the system. It has also been found that the P&O method can track in the wrong direction, away from the MPP, under rapidly increasing or decreasing irradiance levels [2].

*C. Incremental Conductance (INC) Method*

Another popular method is the INC method, as shown in the flowchart in Fig. 3.

The INC method is based on the necessity of establishing whether the array voltage is greater than or less than the value at the MPP [10], [18]–[21]. This is equivalent to the fact that when the array voltage is greater (less) than the peak power point voltage, *dP/dV* is less (greater) than zero, which can be expressed as follows:

$$\frac{dI}{dV} > -\frac{I}{V} \text{ when } V < V_{MPP}$$

$$\frac{dI}{dV} < -\frac{I}{V} \text{ when } V > V_{MPP}$$

$$\frac{dI}{dV} = -\frac{I}{V} \text{ when } V = V_{MPP} \qquad (3)$$

Unlike P&O that oscillates around the MPP, the INC algo-rithm can determine when the MPP has been reached. Also, INC can track rapidly increasing and decreasing irradiance con-ditions with higher accuracy than P&O. One disadvantage is the increased complexity of implementation compared with P&O. This method increases computational time and slows down the sampling frequency of the array voltage and current [2].

In this paper, a novel hybrid MPPT methodology is developed. By taking into consideration of the sunlight density and cell temperature as well as adaptive perturbation length, this simple method, compared with conventional P&O and INC method, can achieve much faster tracking speed with minimum steady state oscillation which increases the overall system's performance and efficiency.

## II. PV ARRAY MODEL

A PV array is a device which converts solar energy to electri-cal energy. Modern PV cells use a semiconductor p-n junction to absorb light energy. Single cells are wired in series or parallel combination to form a module to achieve certain voltage/current levels. Numerous modules are interconnected to form an array if necessary. The PV model possesses a strong nonlinearity. In this section, a common and accurate PV model is adopted [22]. The advantage of this model is that it will give an accurate

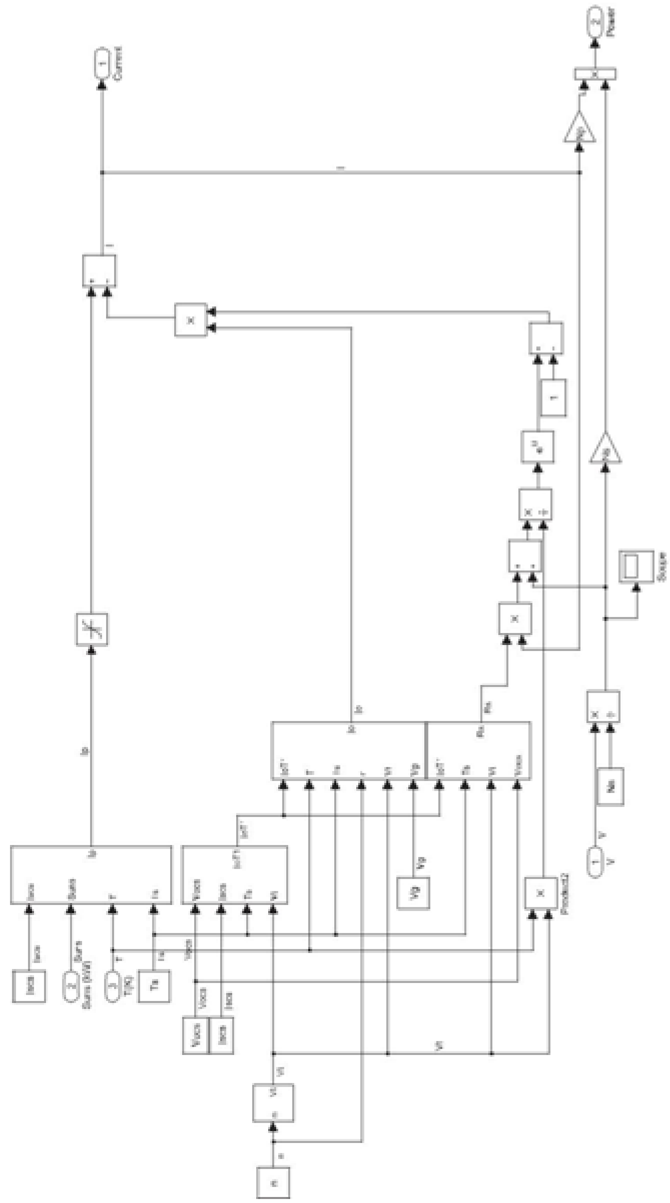

*Fig. 5. Model of the PV array.*

jump out of its current search status and reset the searching point to new initial start point according to the changes of the environment. This design is to increase the response speed of the searching and will guarantee that the searching will always start from the near MPP position in presence of rapidly changed solar irradiation and temperature.

It should be noted that the initial searching mechanism pre sented here is based on the information of the PV array to be controlled, a better match of the PV model and the actual system

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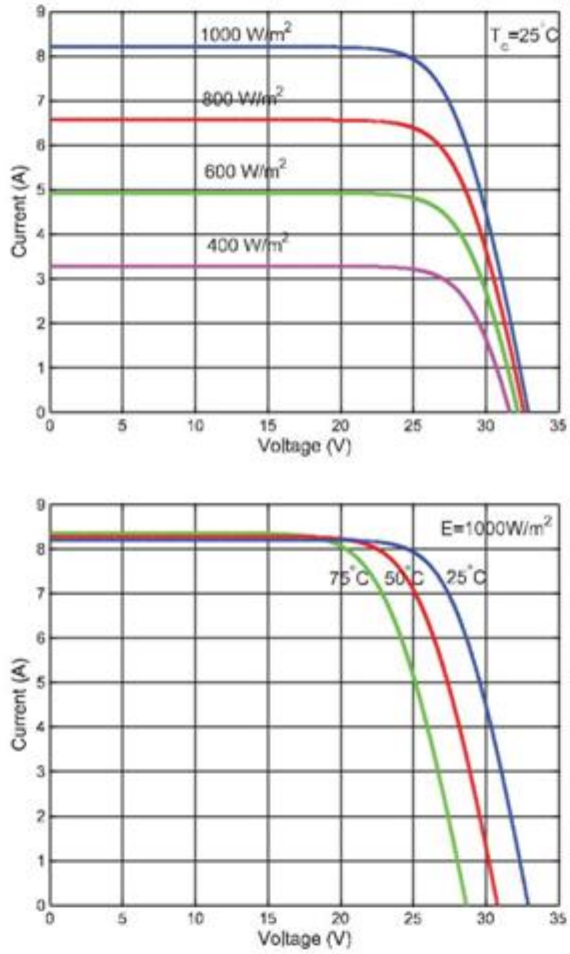


*Fig. 6. Characteristics of solar cell with different radiation and cell temperature*

*Table II truth table of the conventional p&o mppt method*

| sign of $P$ | sign of $V$ | Direction of next step |
|---|---|---|
| + | + | $+C$ |
| − | − | $+C$ |
| − | + | $-C$ |
| + | − | $-C$ |

*B. Modified P&O Searching*

If there is no obvious change in solar density or cell temper-ature, then the system will go to the modified P&O mechanism.

To simplify the programming, in this method, a truth table as shown in Table II is adopted to determine the direction of searching (which is indicated as "Slope" in the flowchart) by comparing the difference of the output power and the voltage.

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*C. Determination of Perturbation*

The determination of the size of perturbation is a compromise between dynamic response and steady state performance. In practice, it is best to make the step size large during the transient stage, which will lead to fast response and small step size in steady state which will reduce the oscillation, thus increasing the efficiency of the overall system.

In this paper, an adaptive method is proposed as

$$C(k) = N \log_{10} \frac{P}{V} \qquad (10)$$

where $P = P(k) - P(k-1)$, $V = V(k) - V(k-1)$, $N$ is the constant parameter, and finally, $k$ represents the sample point. This setting is to make sure that the step will be large enough to cope with the rapid change of either irradiation or cell temperature, and gradually reduced down to zero when the system reaches steady state.

## III. RESULTS AND DISCUSSION

*A. Performance Indicator*

Efficiency is a common factor used to assess the performance of an MPPT method at steady state, and it is calculated from the following equation [2]:

$$\eta_{MPPT} = \frac{P_{actual}(t)dt}{P_{max}(t)dt} \qquad (11)$$

where $P_{actual}$ is the actual power produced under the control of specific MPPT method, and $P_{max}$ is the theoretical maximum power the PV array can produce under given illumination and cell temperature.

*B. Numerical Analysis*

The proposed MPPT controller was implemented in MAT-LAB/Simulink. The detailed block diagram for the proposed method is demonstrated in Fig. 8.

In this section, the performance of the proposed MPPT method is compared with the conventional P&O with two differ-ent fixed perturbation sizes $V = 0.3$ V and $V = 0.6$ V.

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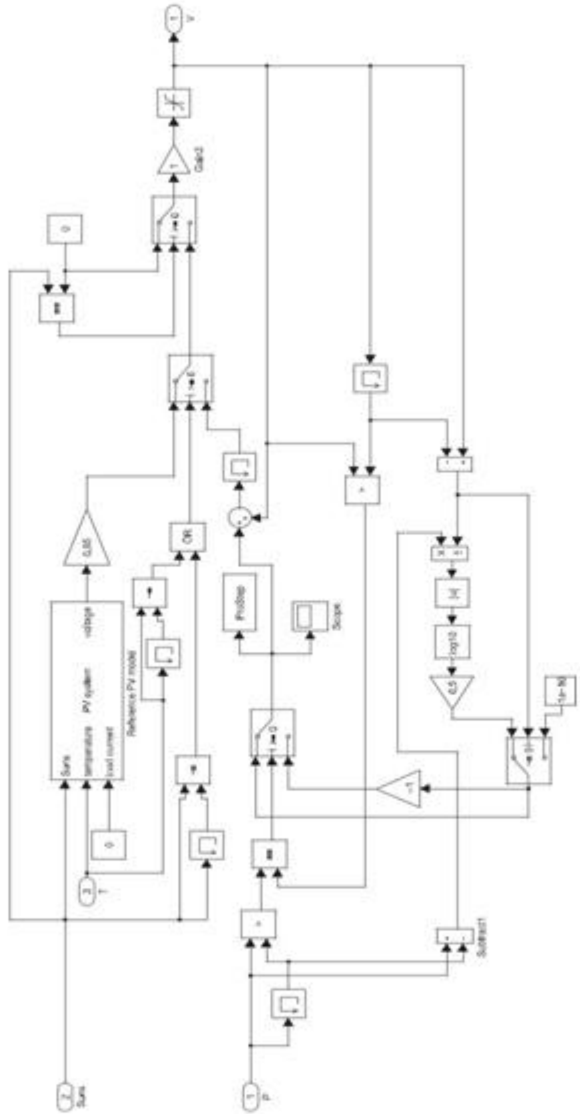

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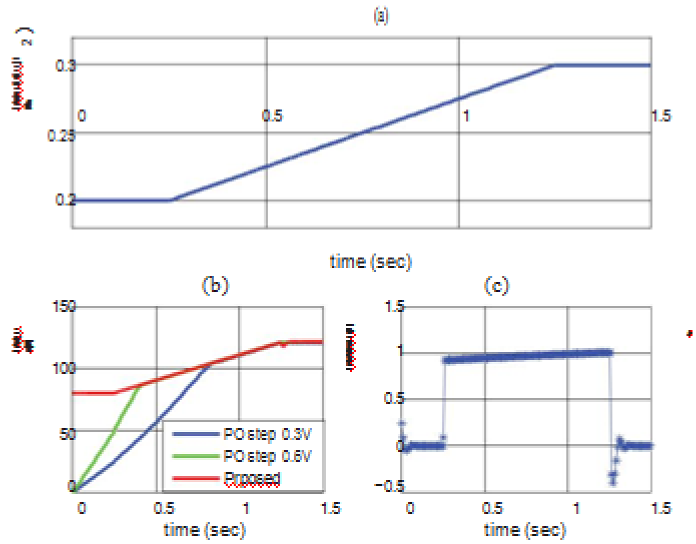


*Fig. 9. Performance comparison of the conventional P&O method and the proposed method under slow solar irradiation increase. (a) Slow raising so-lar irradiation. (b) Performance comparison. (c) Perturbation of the proposed method*

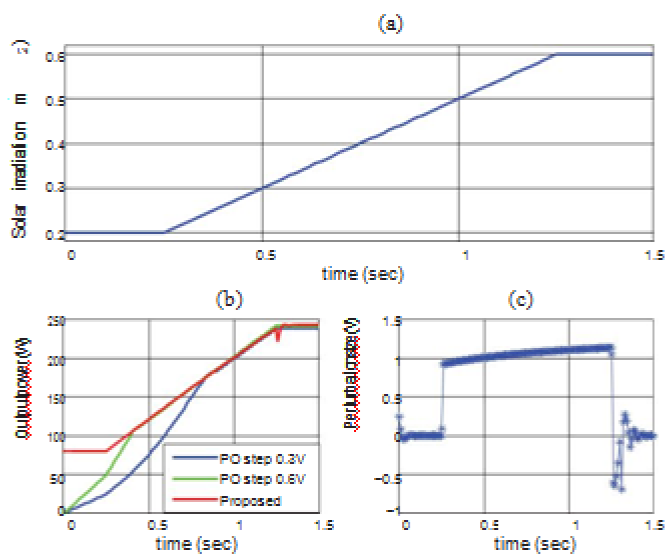


*Fig. 10. Performance comparison of the conventional P&O method and the proposed method under fast solar irradiation increase. (a) Fast raising solar irra-diation. (b) Performance comparison. (c) Perturbation of the proposed method*

for 0.25 s before changing to another level. The first two tests are especially designed to examine the changes of the perturbation according to the changes of the solar irradiation, while the last test is used to observe the response of the proposed method to a more realistic situation of solar density fluctuation.

From the numerical results shown in Figs. 9(b), 10(b), and 11(b), it is clear that under the control of the proposed MPPT method, a faster and smoother tracking performance can be achieved. The proposed method also eliminates the tracking deviation which happens to both P&O methods as shown in Fig. 11(b) when there is a sudden drop of irradiation from 0.8 to 0.5 kW at 0.25 s. This is due to consideration of the solar irradiation and cell temperature as well as adaptive perturbation size.

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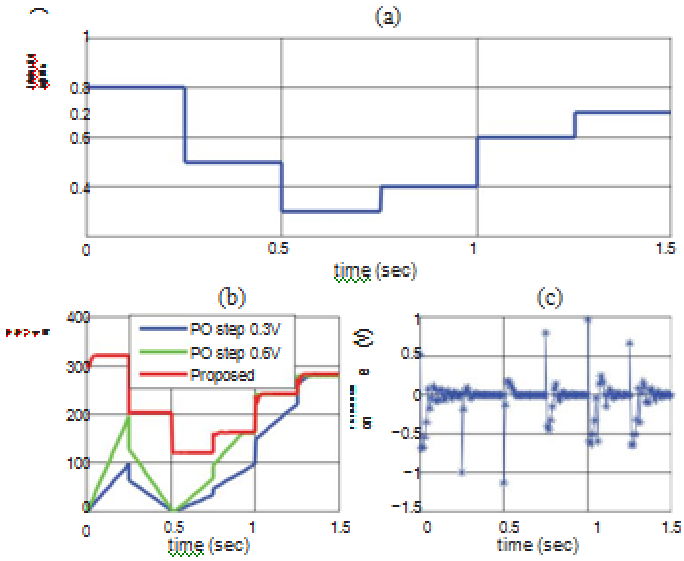


*Fig. 11. Performance comparison of the conventional P&O method and the proposed method under fast solar irradiation increase. (a) Solar irradiation. (b) Performance comparison. (c) Perturbation of the proposed method*

*Table III comparison of average output power and efficiency under different mppt methods*

| Solar irradiation ($kW/m^2$) | 0.4 | 0.6 | 0.8 |
|---|---|---|---|
| Theoretical Maximum Power ($W$) | 162.5509 | 243.0630 | 321.1476 |
| Output Power P&O (0.3$V$)<br>Efficiency (%) | 162.4360<br>99.93 | 242.8667<br>99.92 | 321.0317<br>99.96 |
| Output Power P&O (0.6$V$)<br>Efficiency (%) | 162.3460<br>99.87 | 242.7619<br>99.88 | 320.5406<br>99.81 |
| Output Power Proposed Method<br>Efficiency (%) | 162.4493<br>99.94 | 242.9897<br>99.97 | 321.0830<br>99.98 |

From Figs. 9(c), 10(c), and 11(c), it can be seen that during the transient state, the proposed MPP tracker will generate larger perturbation to increase the tracking speed, and when the system reaches the steady state, this perturbation will automatically be reduced down to zero in order to reduce the oscillation, hence increasing the system's efficiency.

Table III shows the average output power and corresponding efficiency under different MPPT methods at steady state, and it also indicates that the proposed MPPT method can deliver more energy compared with the conventional P&O method.

*C. Experimental Analysis*

In this section, the proposed MPPT method is evaluated us-ing the solar data extracted from the University of Glamorgan Hydrogen Centre over the year 2010. For comparison purposes, the proposed method is compared with the conventional P&O with fixed step size of 0.3 V and the conventional INC method with fixed step size of 0.5 V. The test is carried out using data associated with a single KC200 PV module.

The performance of the three different methods between 12.00 and 17.00 h on July 16, 2010 is demonstrated in Fig. 12. It is clear that the proposed method has faster response to the

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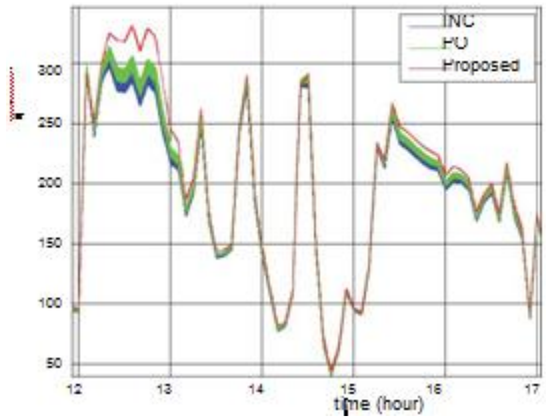


*Fig. 12. Performance of all three different methods between 12.00 and 17.00 h on July 16, 2010*

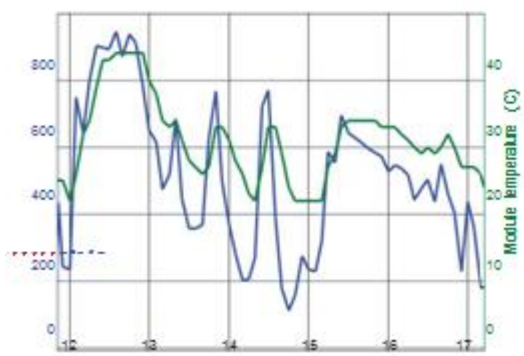


*Fig. 13. Solar irradiation and module temperature for the test period*

*Table IV comparison of solar power generated by three different mppt methods in kwh*

| Month | Conventional P&O | Conventional INC | Proposed Method |
|---|---|---|---|
| January | 13.2356 | 13.1633 | 13.5161 |
| February | 18.0691 | 18.0546 | 18.9277 |
| March | 30.3381 | 30.2017 | 32.1006 |
| April | 45.0048 | 44.9472 | 49.3555 |
| May | 50.2761 | 49.9641 | 54.9902 |
| Jun | 58.5839 | 58.4377 | 64.6474 |
| July | 42.2320 | 42.2522 | 44.4126 |
| August | 40.7312 | 40.4912 | 42.7927 |
| September | 32.4688 | 32.2676 | 34.4381 |
| October | 26.0255 | 25.9908 | 27.5901 |
| November | 14.3228 | 16.2693 | 14.8435 |
| December | 12.0926 | 12.0422 | 12.4077 |
| Total | 383.3803 | 382.0828 | 410.0221 |
| Increased Ratio | 0.34% | – | 7.31% |

## IV. CONCLUSION

A novel hybrid MPPT algorithm has been developed to im-prove the efficiency and performance of the conventional P&O method. The algorithm is focused on improving the transient tracking speed and increasing the steady state stability. The ba-sic philosophy behind this proposed algorithm is that it will de-tect the changes in solar radiation and module temperature and start searching at near MPP; then, by adaptively changing the perturbation, a fast convergence speed and no oscillation around the MPP can be achieved. The proposed method can also avoid tracking deviation during rapid changes in solar irradiation as well as cell temperature.

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The proposed algorithm has been first validated by means of numerical simulations. The results reveal that the dynamic response is quicker compared with the traditional P&O method, and the steady state stability is improved, together with im-provement of overall energy conversion efficiency. The pro-posed method also been evaluated using the experimental solar data. From the comparison between conventional P&O and INC methods, the results show that the proposed method can achieve much better system efficiency by generating more solar power by a factor of 7.31% when compared with the conventional INC method, while the conventional P&O and INC methods have a very similar performance. Due to the fact that the proposed method is based on the conventional P&O method, therefore, the cost for hardware upgrade is minimized and hence has potential for further commercial investigation.

Future work includes experimental implementation of pro-posed method, analysis of its robustness, and effects on the dc/ac side, etc

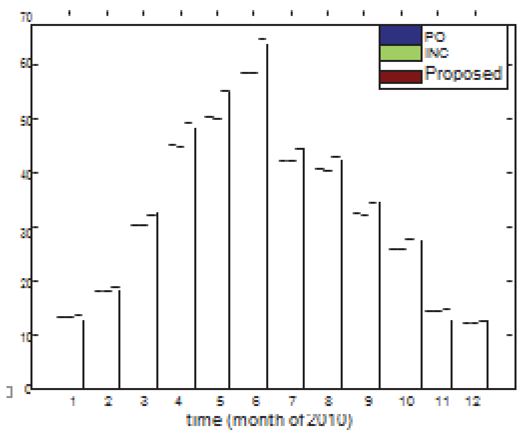


***Fig. 14. Bar plot of power generated by different methods***

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