LETTER
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# An improved dynamic maximum power point tracking method for PV application

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**Abstract:** Photovoltaic (PV) system has been regarded as one of the most popular renewable energy sources due to its easy installation and safe operation. As one of the key control algorithms, maximum power point tracking (MPPT) function of PV inverter has been researched widely. Usually, its performance has been evaluated under a fixed environmental condition including irradiance and temperature. However, recently the dynamic MPPT performance under varying irradiance conditions has been paid attention to the PV society. As the European standard EN 50530, which defines the recommended varying irradiance profiles, was released lately, the corresponding researches have been required to improve the dynamic MPPT performance. This paper presents the design and evaluation of the improved dynamic MPPT performance using the modified P&O MPPT method under EN 50530. By using 250 kW PV inverter, the performance of the modified P&O method is evaluated and compared with the conventional P&O MPPT methods. The experimental results show that modified P&O method shows higher dynamic MPPT efficiency under EN 50530than the conventional P&O one.
**Keywords:** PV power generation, maximum power point tracking, PV inverter, dynamic performance
**Classification:** Electron devices, circuits, and systems

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## 1 Introduction

As one of the prominent renewable energy resources, photovoltaic (PV) generation has been increasingly gaining considerable attention among industry players all around the world [1, 2]. In most of the PV applications, the key function of PV system is to extract maximum power from PV array during the daytime. The power-voltage characteristics have nonlinear characteristics that depend on environmental conditions like irradiance [1].

At each irradiance level, there exists a unique maximum power point of power-voltage curve of PV array. Maximum Power Point Tracking (MPPT) control algorithm of PV power converter is the function to maximize the power generation efficiency by regulating the PV array voltage, i.e. the input voltage of the converter. There have been many algorithms developed for MPPT [3], e.g. perturbation and observation (P&O) method [4], the fractional open circuit voltage or short circuit current [5, 6], the fuzzy logic control [7]. Basically, these methods is considered and evaluated under a fixed environmental condition including irradiance and temperature by the name of static MPPT performance. Recently, the dynamic MPPT performance which is evaluated under continuously varying irradiance intensities, has been regarded a good performance indicator for MPPT. As a result, European standard EN 50530 [8], which is now under review for IEC standard, was recently released and it presents the irradiance profile for evaluating dynamic MPPT efficiency.

In order to improve the dynamic MPPT performance, this paper presents the design and evaluation of the modified P&O MPPT method for PV inverter. In this paper, the synopsis of EN 50530 is introduced first. Then, the design process of the modified P&O method is presented with its main concept. Finally, through experimental results of 250 kW PV inverter, the dynamic MPPT efficiencies under EN 50530 are compared between the modified P&O method and the conventional P&O MPPT methods.

## 2 Synopsis of EN 50530

In the standard, a procedure for the measurement of overall efficiency of grid-connected photovoltaic inverters is provided. Especially, the dynamic MPPT efficiency is indicated as (1).

$$\eta_{dyn} = \frac{1}{\sum P_{mpp,PVS} \cdot \Delta T} \sum V_{dc} \cdot I_{dc} \cdot \Delta T \tag{1}$$

where $V_{dc}$ and $I_{dc}$ are sampled values of the inverter's input voltage and current, respectively, and $P_{mpp,PVS}$ is a maximum point power (MPP) provided by PV simulator, $\Delta T$ is period between two subsequent sample values.

Based on the definition of dynamic efficiency $\eta_{dyn}$ in (1), it has to be


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measured by the various irradiance profiles. The profile is consisted of ramp up time ($T_1$), dwell time ($T_2$), ramp down time ($T_3$), and waiting time ($T_4$). Totally the test is conducted for around 7 hours. There are basic two irradiance variations, as shown in Fig. 1. One is from 30% to 100% and the other is from 10% to 50%. Its maximum speed of irradiance variation is 100 W/m$^2$/s and its minimum one is 0.5 W/m$^2$/s. PV simulator, which is an input power source to PV inverter, should be emulated by the specified voltage-current characteristics under various irradiance profiles. An irradiance intensity of 100% in Fig. 1 is corresponding to the rated power capacity of PV inverter under test. For the calculation of the real dynamic MPPT efficiency by irradiance changes, it is not measured during the waiting time in Fig. 1 in order to wait for PV inverter to be stabilized before the next irradiance profile starts.

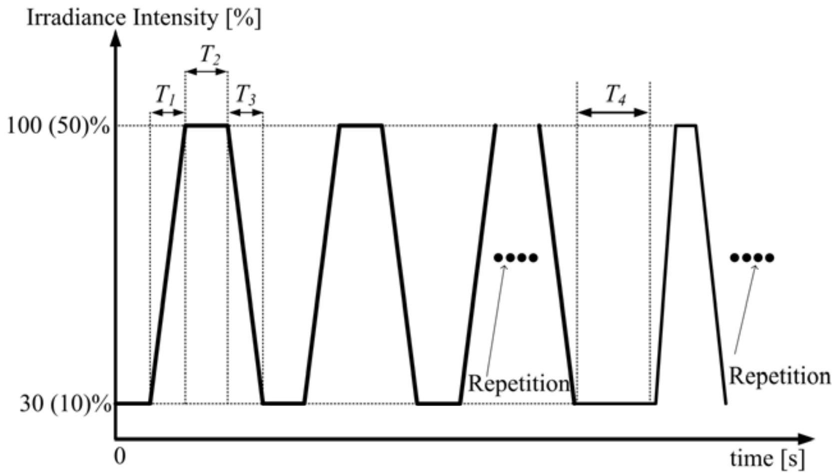


**Fig. 1.** Irradiance profile for dynamic MPPT performance by EN 50530 ($T_1$: Ramp up time, $T_2$: Dwell time, $T_3$: Ramp down time, $T_4$, Waiting time)

**Table I.** Irradiance variation profile by EN50530

| | Slope [W/m$^2$/s] | Ramp up ($T_1$)[s] | Dwell time ($T_2$)[s] | Ramp down ($T_3$)[s] | # of Case |
|---|---|---|---|---|---|
| Irradiance variation from 30% to 100% of PV nominal power | 10 | 70 | 10 | 70 | Case11 |
| | 14 | 50 | 10 | 50 | Case12 |
| | 20 | 35 | 10 | 35 | Case13 |
| | 30 | 23 | 10 | 23 | Case14 |
| | 50 | 14 | 10 | 14 | Case15 |
| | 100 | 7 | 10 | 7 | Case16 |
| Irradiance variation from 10% to 50% of PV nominal power | 0.5 | 800 | 10 | 800 | Case21 |
| | 1 | 400 | 10 | 400 | Case22 |
| | 2 | 200 | 10 | 200 | Case23 |
| | 3 | 133 | 10 | 133 | Case24 |
| | 5 | 80 | 10 | 80 | Case25 |
| | 7 | 57 | 10 | 57 | Case26 |
| | 10 | 40 | 10 | 40 | Case27 |
| | 14 | 29 | 10 | 29 | Case28 |
| | 20 | 20 | 10 | 20 | Case29 |
| | 30 | 13 | 10 | 13 | Case30 |
| | 50 | 8 | 10 | 8 | Case31 |


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## 3 Implementation of the modified P&O method

The modified P&O method is implemented based on the conventional P&O MPPT method by removing the wrong control phenomenon during rapidly irradiance changing period. As shown in Fig. 2 (a), the concept of P&O method is simple to observe the power variation and PV voltage reference after the PV voltage is observed. Basically, it is based on the assumption that the power variation is occurred by only PV voltage perturbation. Practically, power variation of PV array output could be caused by both the control of PV inverter and the environmental condition like irradiance variation. If the conventional P&O method is used for this rapidly changing irradiance condition from irradiance1 at $t_1$ to irradiance2 at $(t+\Delta t)$ in Fig. 2 (b), the PV inverter may fail to track its maximum power due to the irradiance changing. Specifically, PV inverter by the conventional P&O method commands the PV voltage to be increased from $V_1$ to $V_2$ under irradiance1 at $t_1$, assuming that the previous MPPT command is to

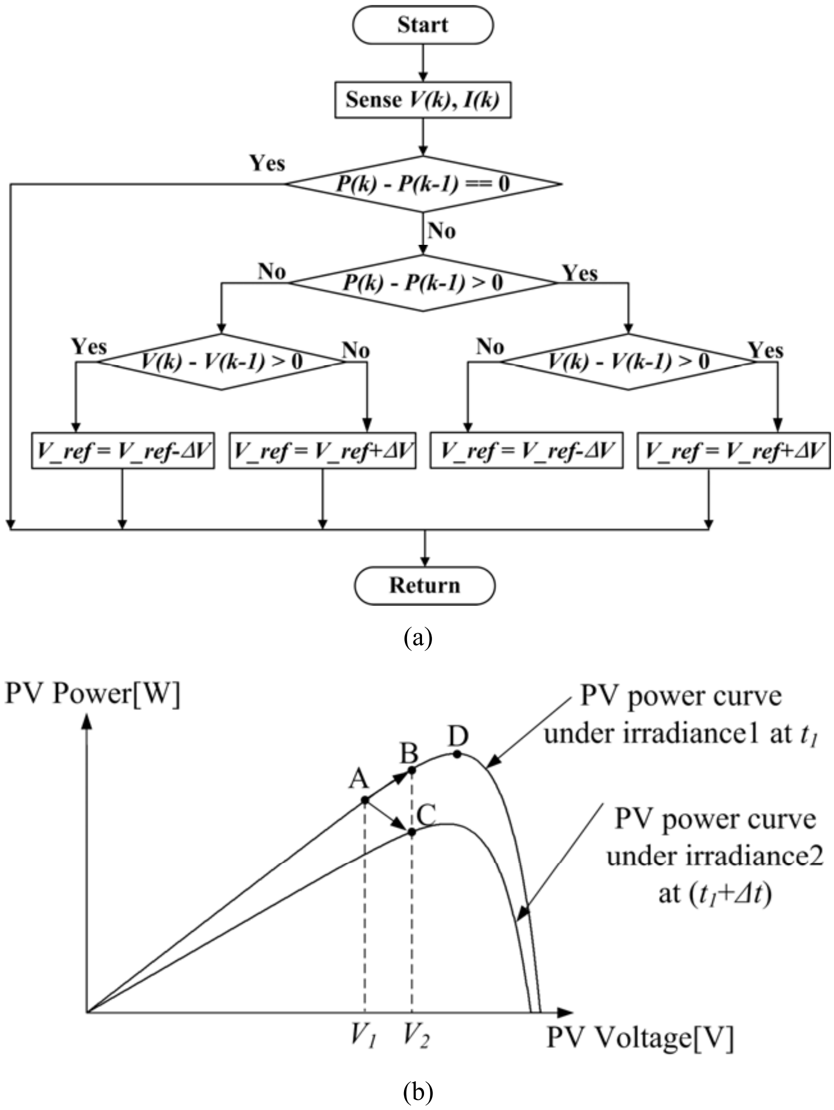


**Fig. 2.** (a) Flow charts of the conventional P&O method, (b) Malfunction phenomenon of the conventional MPPT control when the irradiation is changing from irradiance1 to irradiation2


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increase the PV voltage. However, after a short time $\Delta t$, the next operating point stays at point C not point B in Fig. 2 (b) because the irradiance changes rapidly. This phenomenon can be summarized that PV power is decreased after the PV voltage command is increased. Thus, the next PV voltage command by the conventional P&O algorithm would be decreased. This is the reverse way to track the real maximum power point (MPP), which is point D in Fig. 2 (b). This is why the conventional P&O method fails to track MPP under rapidly changing irradiance.

In response to this irradiance disturbance, the modified P&O method is presented to differentiate the power variation caused by between irradiance change and MPPT control. As shown in Fig. 3, the modified P&O method adds an additional measurement of PV array power at the mid-point of MPPT control period. PV power for MPPT control is calculated on average in order to reduce the noise influence. The power difference $dP_{0.5}$ in (2) between the mid-point power $P(k-0.5)$ and the starting power $P(k-1)$ of MPPT control contains both power change by MPPT control and irradiance change. However, the value $dP_1$ in (3) contains only the power caused by irradiance change. As a result from (2) to (4), a power difference $dP$ caused by the only MPPT control command can be calculated.

$$dP_{0.5} = P(k-0.5) - P(k-1) \tag{2}$$

$$dP_1 = P(k) - P(k-0.5) \tag{3}$$

$$dP = dP_{0.5} - dP_1 \tag{4}$$

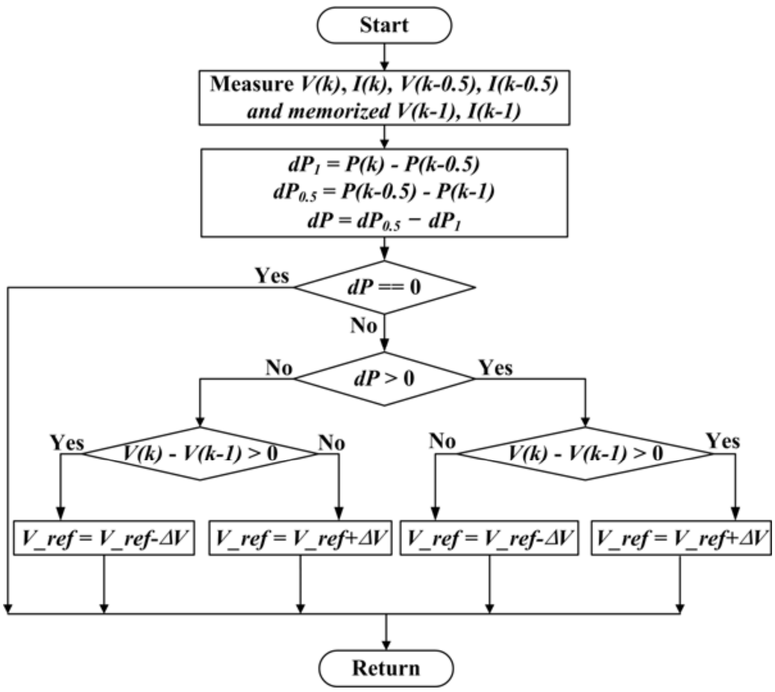


**Fig. 3.** Flow charts of the modified P&O method

Based on the power variation by only MPPT command in (4), the MPPT controller for PV inverter can track the right direction to find the maximum power point of PV array.


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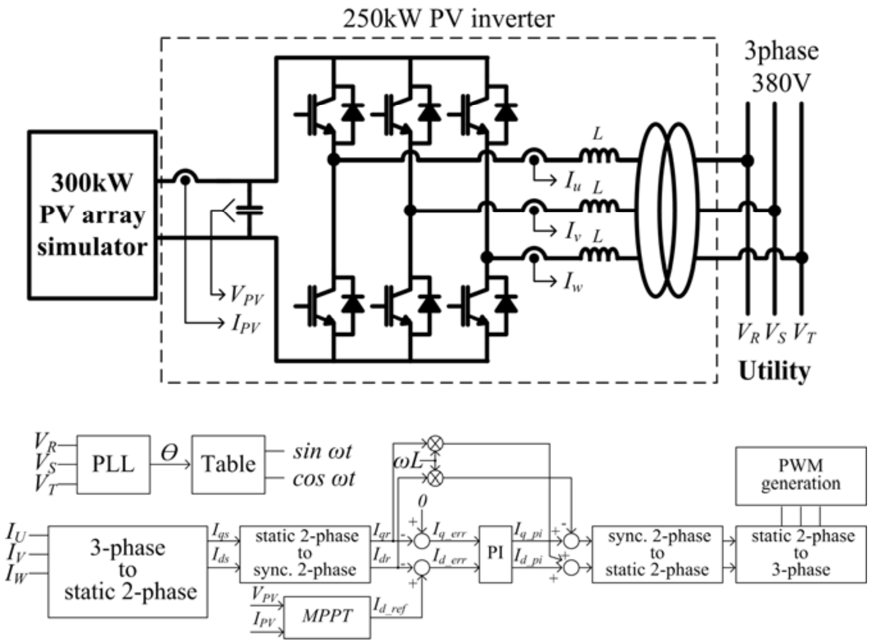
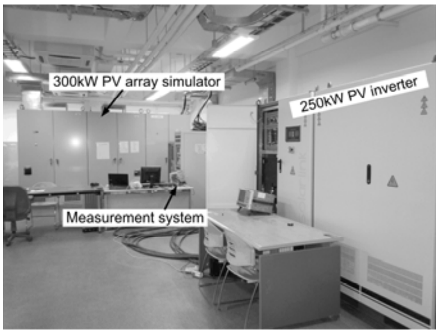
## 4 Experimental results

In order to compare the dynamic MPPT efficiencies between the conventional P&O method and the modified P&O one, 250 kW PV inverter is implemented and conducted for experiment. Fig. 4 (a) shows the block diagram of system configuration including its control block. Phase angle is detected from the utility voltage and transferred to PLL control block. The MPPT control command is used for an effective power command control. As the key testing equipment for dynamic MPPT, the 300 kW class PV array simulator is used shown as in Fig. 4 (b) and it is programed to implement the irradiance variation profiles suggested by EN 50530. Additionally, the YOKOGAWA scopecorder DL750 is used to measure the long time waveforms such as PV voltage and current waveforms, as shown in Fig. 5 and Fig. 6. For high power PV inverter application, the switching frequency of IGBT device is limited than lower one. Therefore, in this paper, the MPPT control period for 250 kW PV inverter is set as 1 sec with 3.5 kHz PWM control frequency. Table II shows the total system specification, including PV array specification and PV




(a)




(b)

**Fig. 4.** (a) Circuit diagram and its control block for 250 kW PV inverter (b) Front view of the laboratory for MPPT experiment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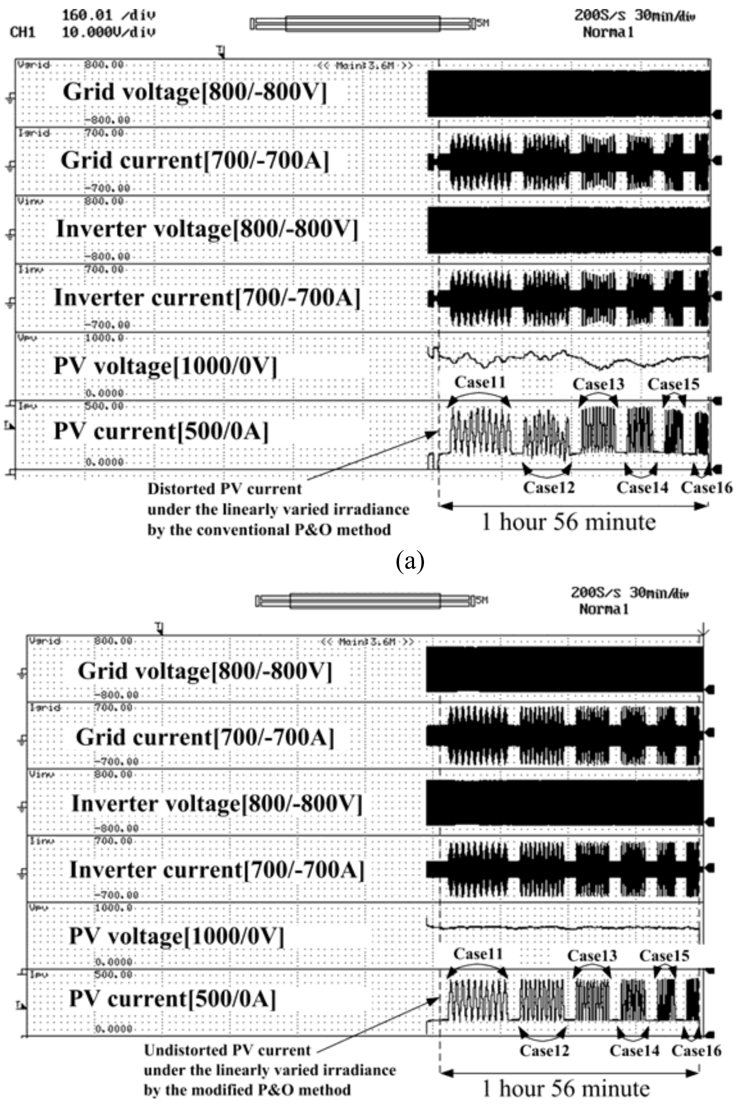


**Fig. 5.** The experimental result of PV current under the irradiance variations when the irradiance is varied from 30% to 100%. (a) By using the conventional P&O method, (b) By using the modified P&O method

inverter specification. For static MPPT performance evaluation, under the fixed irradiation, both the conventional P&O method and the modified P&O method show over 99% MPPT static efficiency. This is because the modified P&O method implements the same MPPT command with the conventional P&O method under the fixed irradiation.

For dynamic MPPT performance evaluation, PV array simulator is set to generate electric power by the time-varying irradiation profile according to EN 50530. Fig. 5 (a) and (b) show the key waveforms of 250 kW PV inverter including PV inverter voltage, PV inverter current, PV array voltage, and PV array current when the irradiance is changed from 30% to 100%. For irradiation from 30% to 100%, the ramp up time and the ramp down time are divided into 6 groups, respectively 70 s, 50 s, 35 s, 23 s, 14 s, and 7 s with the dwell time 10 s in Fig. 1. Totally, the waveform is measured for around 1 hour and 56 minute. Even though both the

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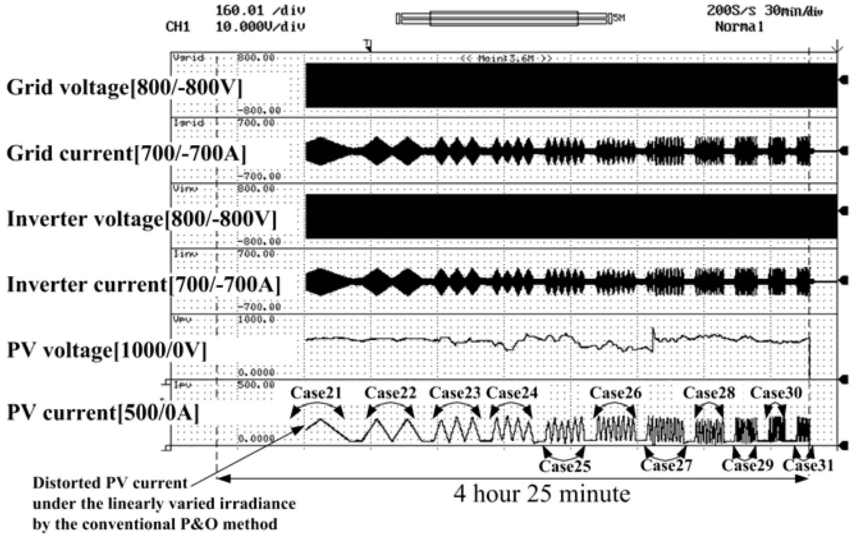
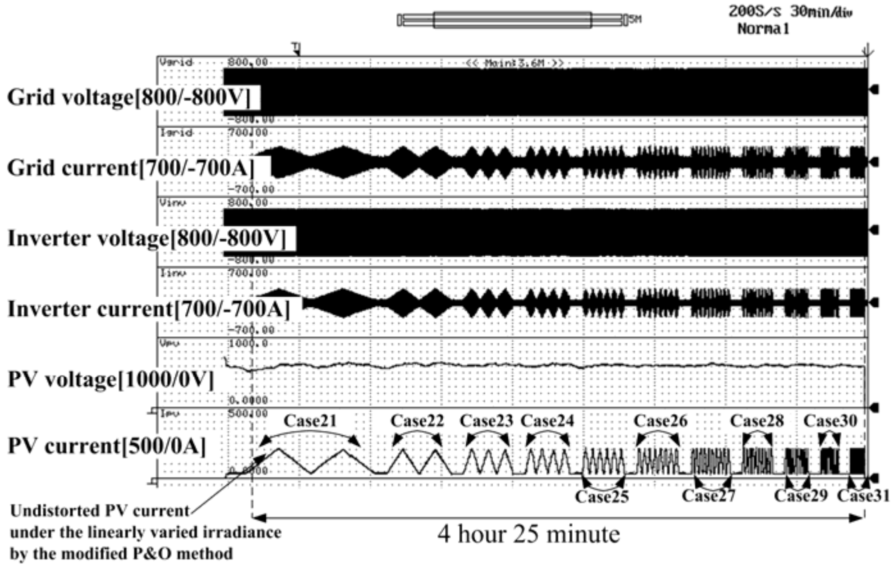



(a)




(b)

**Fig. 6.** The experimental result of PV current under the irradiance variations when the irradiance is varied from 10% to 50%. (a) By using the conventional P&O method, (b) By using the modified P&O method

**Table II.** System parameters for experiment

| | | |
|---|---|---|
| PV array specification | Rated output power | 265kW |
| | Open circuit voltage | 810V |
| | Short circuit current | 453A |
| | MPP voltage | 650V |
| | MPP current | 409A |
| PV inverter specification | Rated output power | 250kW |
| | Output voltage | 380V |
| | Output frequency | 60Hz |
| | PWM frequency | 3.5kHz |
| | MPPT control period | 1s |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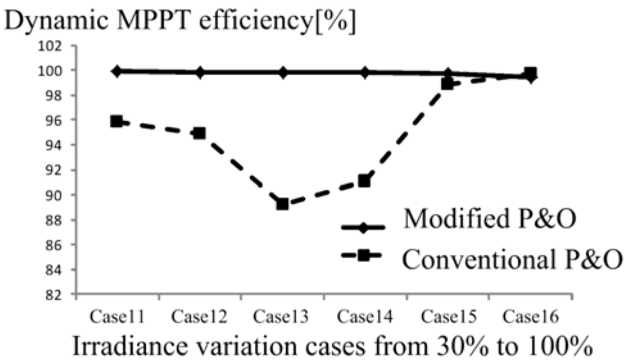
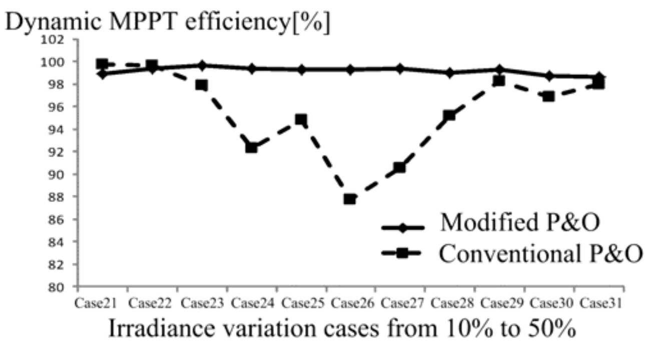
conventional P&O method and the modified P&O method show good MPPT performance under the fixed irradiation, the conventional P&O method fail to track the maximum power point by showing collapsed current variation in Fig. 5 (a). However, the modified P&O method tracks the maximum power point correctly by showing the linearized current waveform correctly corresponding to the irradiation profile shown in Fig. 5 (b). Fig. 6 (a) and (b) show the key waveforms of 250 kW PV inverter while the irradiance is varied from 10% to 50%. For irradiation from 10% to 50%, the ramp up time and the ramp down time are divided into 11 groups, from 800 s to 8 s with the dwell time 10 s in Fig. 2. Totally, the waveform is measured for around 4 hour and 25 minute. Obviously, as shown in Fig. 6 (b), the modified P&O method has a linear PV array current without distortion, which is corresponding to the irradiance variation profiles. However, the conventional P&O method let PV array current waveforms be distorted even the irradiation changing linearly in Fig. 6 (a). Quantitatively, as shown in Fig. 7, the dynamic MPPT efficiencies are measured and calculated by (1) for both the conventional P&O method and the modified P&O method under the various irradiance profile in Table I. As inferred from these waveforms, the modified P&O method has much higher dynamic efficiencies than the conventional P&O method. In Fig. 7, on an average, the modified P&O method shows around 99% dynamic MPPT efficiency for both from 30% to 100% irradiation and from 10% to 50% irradiation. On the other hand, averagely, the conventional P&O method shows around 94% for from 30% to 100%




(a)




(b)

**Fig. 7.** Comparison results between the conventional P&O method and the modified P&O method under the various irradiance profiles. (a) From 30% to 100%. (b) From 10% to 50%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irradiation and around 96% for from 10% to 50% irradiation. The modified P&O method shows much higher dynamic MPPT efficiency than the conventional P&O method throughout the whole irradiation profile.

## 5 Conclusion

This paper presents the design and implementation of improved dynamic MPPT performance using the modified P&O MPPT method, which is evaluated by EN 50530 standard. By using 250 kW PV inverter, the performance of modified P&O method is evaluated and compared with the conventional MPPT methods. The experimental results show that modified P&O method shows higher dynamic MPPT efficiency than the conventional P&O MPPT method under EN 50530 test condition.

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