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A novel approach to evaluate dynamic performance for photovoltaic system using software platform

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ABSTRACT

With the growing demand for renewable energy, solar photovoltaic (PV) systems have gained popularity as a reliable source of clean electricity. However, the performance of these systems can be limited by factors such as suboptimal maximum power point tracking (MPPT) algorithms. In order to improve the power generation efficiency of PV systems, it is important to evaluate the performance of dynamic MPPT algorithms that can adapt to varying operating conditions. Traditionally, such evaluations have been time consuming and expensive, often requiring extensive testing and measurement equipment. In this paper, we propose a novel approach to evaluate dynamic MPPT performance very quickly and simply using PSIM software. This approach enables accurate and efficient evaluation of MPPT performance under a wide range of operating conditions, while minimizing the cost and time involved in traditional testing methods. When applying the proposed method to a 3.7 kW inverter using the traditional perturbation and observation (P and O) method, we found that the highest average efficiency was 98.92% at an MPPT control period of 0.1s and a voltage perturbation of 1 V. This evaluation technique provides valuable insights into the design and optimization of more efficient MPPT control algorithms, leading to improved power generation efficiency and increased adoption of solar PV systems.

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1. INTRODUCTION

Solar photovoltaic (PV) systems have become an increasingly popular and cost effective means of generating renewable energy [1]–[3]. However, the efficiency of these systems can be limited by various factors, including suboptimal performance of the maximum power point tracking (MPPT) control algorithm [4]–[6]. MPPT is a critical function in photovoltaic systems that ensures that the output power of the PV array is maximized by continuously adjusting the operating point of the system [7]–[11]. Along with the development of various MPPT methods in an environmental condition where the irradiation and temperature continuously change, research on dynamic MPPT evaluation that can verify the efficiency is also important [12]–[15].

The evaluation of dynamic MPPT performance is crucial to ensuring optimal operation of PV systems [16], [17]. However, traditional evaluation techniques can be time consuming and expensive, requiring extensive testing and measurement equipment [18]. In this paper, a novel approach to evaluate the dynamic MPPT performance of PV inverters using the PSIM software platform is presented. This approach enables acceptable and efficient evaluation of MPPT performance under methods stipulated by international standards, while minimizing the cost and time involved in traditional hardware testing methods. To evaluate the performance of dynamic MPPT algorithms, the test profile for varying irradiance according to the IEC 62819 standard was used. This test profile includes six different irradiance levels, which can be simulated using PSIM to accurately model the behavior of PV systems. The results of a comprehensive performance evaluation of dynamic MPPT algorithms using PSIM software are presented, in accordance with IEC 62891. The impact of MPPT control period and perturbed voltage reference on the power generation efficiency of the system is also discussed. Our approach provides valuable insights into the design and optimization of more efficient MPPT control algorithms, leading to improved power generation efficiency and increased adoption of PV systems.

2. SYNOPSIS OF IEC 62891

IEC 62891 is an international standard that specifies test procedures for evaluating the performance of MPPT algorithms in PV inverters. The standard includes a range of test conditions for static and dynamic MPPT algorithms and provides guidelines for evaluating the efficiency and accuracy of these algorithms under varying operating conditions. The test profile is designed to simulate a range of operating conditions that PV systems may encounter in real world applications, allowing the performance of MPPT algorithms to be evaluated under realistic conditions. The use of this test profile is intended to ensure that the MPPT algorithms are able to accurately track the maximum power point of the PV array, leading to improved power generation efficiency and performance of the system.

The standard specifically provides the test conditions for dynamic MPPT efficiency testing, which include six different irradiances, 10/100/300/500/1,000 [W/m^2]. This standard provides test conditions specifically for dynamic MPPT efficiency testing, based on three cases of irradiances fluctuation conditions, and the rate of insolation fluctuation in each case is divided into several. Table 1 summarizes the magnitude and speed of irradiance fluctuations for the three cases. Figure 1 shows the test profile waveform based on the values specified in Table 1. The waiting time (T4) is set to 300 s whenever the magnitude and speed of each irradiance fluctuation occurs. In Case 1, when changing from 100 to 500 [W/m^2], the change rate is divided into a total of 11 groups, and the total required time is 15,936 s, that is, 4 hours 25 minutes 36 seconds. In Case 2, when changing from 300 to 1,000 [W/m^2], the change rate is divided into a total of 6 groups, and the total required time is 6,980 s, that is, 1 hour 56 minutes 20 seconds. Lastly, in Case 3, Finally, in Case 3, when changing from 10 to 100 [W/m^2], the rate of change is divided into only one group, and the total required time is 2,320 s, that is, 38 minutes and 40 seconds. If the experiment is performed for all cases, it takes about 6 hours, and this process requires excessive time, and expensive test equipment. In this paper, a technique to evaluate and verify MPPT performance required by IEC 62819 through simulation without using excessive time and equipment to develop and evaluate the optimal MPPT control technology is proposed.

Table 1. Summarized test conditions for dynamic MPPT efficiency in IEC 62819

Case	Irradiance change [W/m^2]	Repetition	Slope [W/m^2/s]	Ramp Up, T1 [s]	Dwell time, T2 [s]	Ramp Down, T3 [s]	Dwell time, T2 [s]	Duration [s]
Case 1	100→500	2	0.5	800	10	800	10	3540
		2	1	400	10	400	10	1940
		3	2	200	10	200	10	1560
		4	3	133	10	133	10	1440
		6	5	80	10	80	10	1380
		8	7	57	10	57	10	1372
		10	10	40	10	40	10	1300
		10	14	29	10	29	10	1080
		10	20	20	10	20	10	900
		10	30	13	10	13	10	760
		10	50	8	10	8	10	660
Case 2	300→1000	10	10	70	10	70	10	1900
		10	14	50	10	50	10	1500
		10	20	35	10	35	10	1200
		10	30	23	10	23	10	960
		10	50	14	10	14	10	780
		10	100	7	10	7	10	640
Case 3	10→100	1	0.1	980	30	980	30	2320

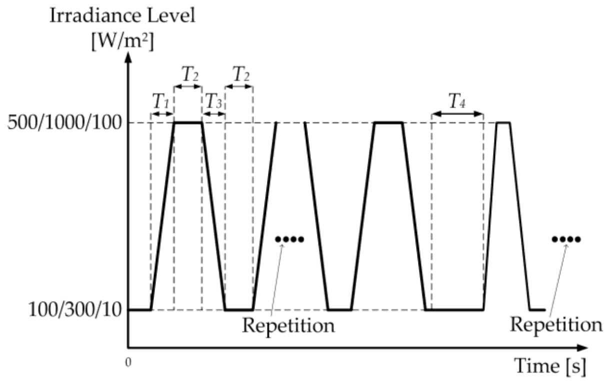


Figure 1. Test sequence profiles for irradiance fluctuations according to IEC 62819

3. THE PROPOSED SIMUATION PLATFORM

A typical PV inverter system for residential applications consists of boost DC/DC converter for MPPT control and full bridge DC/AC inverter for grid connection, as shown in Figure 2. As shown in Figure 2, the voltage and current of PV array are sensed, and the following PV array voltage command is derived through the MPPT algorithm. Accordingly, the switching duty in the boost converter that follows this command is determined, and it is usually followed within 2 cycles of the boost converter switching cycle. In other words, since the switching frequency of a normal boost converter is around 20 kHz, MPPT command is completed within about 100 us. On the other hand, the control output of the MPPT controller is changed relatively slowly over 1,000 times compared to the switching command at around 1 second. Since the switching cycle command of the boost converter is negligibly shorter than the MPPT controller command generation cycle, it is assumed that the MPPT performance according to the boost converter switching command can be ignored, and the performance can be evaluated only with the MPPT controller command. Therefore, in this paper, a platform that evaluates MPPT power generation performance in software based on the MPPT control algorithm is proposed. Through this platform, it is possible to easily evaluate the design of MPPT algorithms developed in various forms, and to optimize the MPPT controller design from the evaluation results.

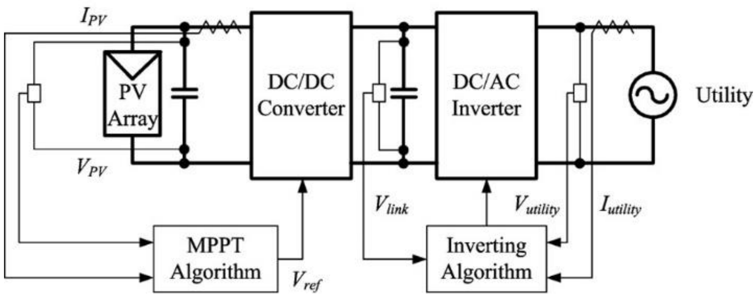


Figure 2. A Typical grid-connected PV inverter system configuration for residential applications

4. THE SIMULATION RESULTS

In this paper, a performance evaluation and design of a dynamic MPPT for a total of 3.7 kW PV array system composed of 10 series-connected 370 W PV modules is conducted, as shown in Figure 3. The electrical specifications of the unit PV module and array used in this case are presented in Table 2. In Figure 3, PV voltage V_{pv} and PV current I_{pv} are sensed from the PV array and injected into the input of the MPPT controller of the PV converter. The MPPT algorithm developed is used to derive the control command V_{ref} of the converter [19]–[21]. Each PV module is input with a constant temperature of 25 °C, and the solar irradiance is provided under the test conditions of IEC 62819, as shown in Table 1.

The Perturbation and Observation method (P and O method) shown in Figure 4 was used as the MPPT algorithm in this paper. The P and O method is a popular MPPT algorithm used in PV inverters [22]–[25]. The P and O method works by perturbing the operating point of the PV system and observing the corresponding change in the power output. Based on this observation, the algorithm adjusts the operating point in the direction of the maximum power point (MPP). As shown in Figure 4, the perturbation is usually carried out by increasing or decreasing the system voltage V_{pv}, and the observation is done by measuring the power output P_{pv}, of the system. The P and O method is simple and efficient and can be implemented with relatively low computational resources. However, it has some limitations, such as oscillations around the MPP in certain operating conditions. The main design parameters of the P and O method are the generation cycle of the MPPT control command and the magnitude of the voltage perturbation. For the evaluation in this paper, the MPPT control cycle ΔT was set to 1 s and 0.1 s, and the magnitude of the voltage perturbation ΔV was 1 V and 0.1 V. Therefore, in this paper, the proposed simulation platform based on these cycle and perturbation sizes is used to compare, analyze, and evaluate the performance of dynamic MPPT.

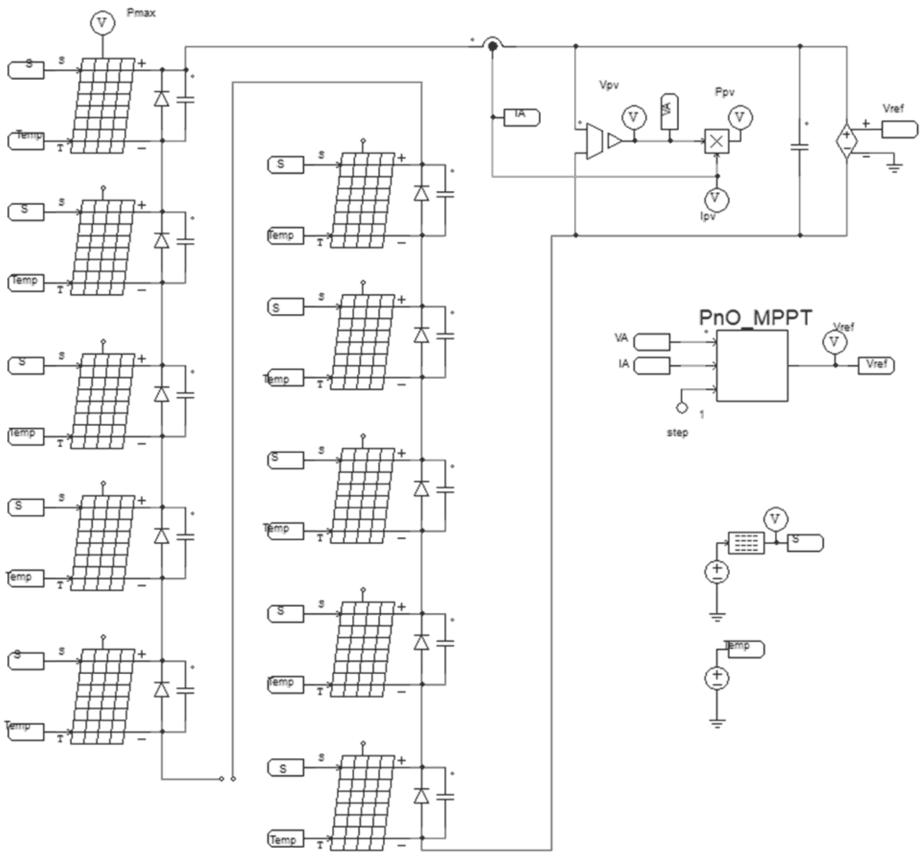


Figure 3. A simulation circuit for evaluating the dynamic MPPT performance

Table 2. An electrical specification for the residential PV string configuration

Parameter	Value	
	PV module	PV array
Open circuit voltage, V_{oc} [V]	42	420
Short circuit current, I_{sc}, [A]	12.16	12.16
Voltage at maximum power at STC, V_{mp}, [V]	33.2	332
Current at maximum power at STC, I_{mp}, [A]	11.14	11.14
Maximum power at STC, P_{max}, [W]	370	3700
Number of series connected PV modules	1	10
Temperature, T, [°C]	25	25

Figure 5 shows the main waveform representing the dynamic MPPT efficiency under the conditions of MPPT control cycle of 1s and voltage disturbance of 1 V. As shown in Figure 5(a), under Case 1 conditions where the reference irradiance changes from 10% to 50%, it was confirmed that the tracking performance is the lowest at the irradiance change rate of 5 [W/m^2/s], and the average efficiency in Case 1 was 96.09%. As shown in Figure 5(b), under Case 2 conditions where the reference irradiance changes from 30% to 100%, it was shown that the lowest tracking performance is observed at a somewhat slow irradiance variation rate of 10 [W/m^2/s], and the average efficiency in Case 2 is 97.24%. As shown in Figure 5(c), In Case 3, under the conditions where the reference irradiance changes from 1% to 10%, the power generation performance shows 98.44%.

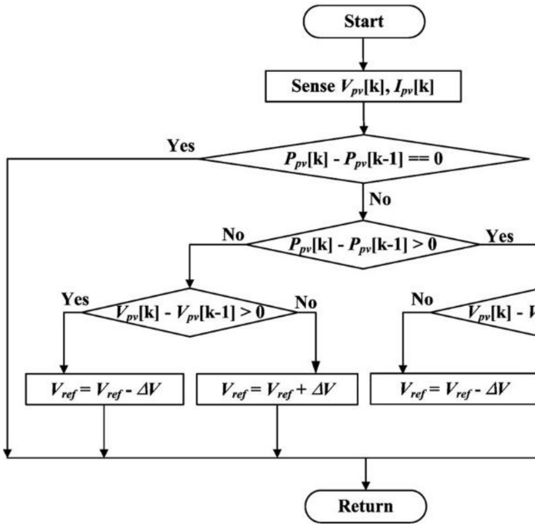


Figure 4. A flowchart for the conventional P and O MPPT method

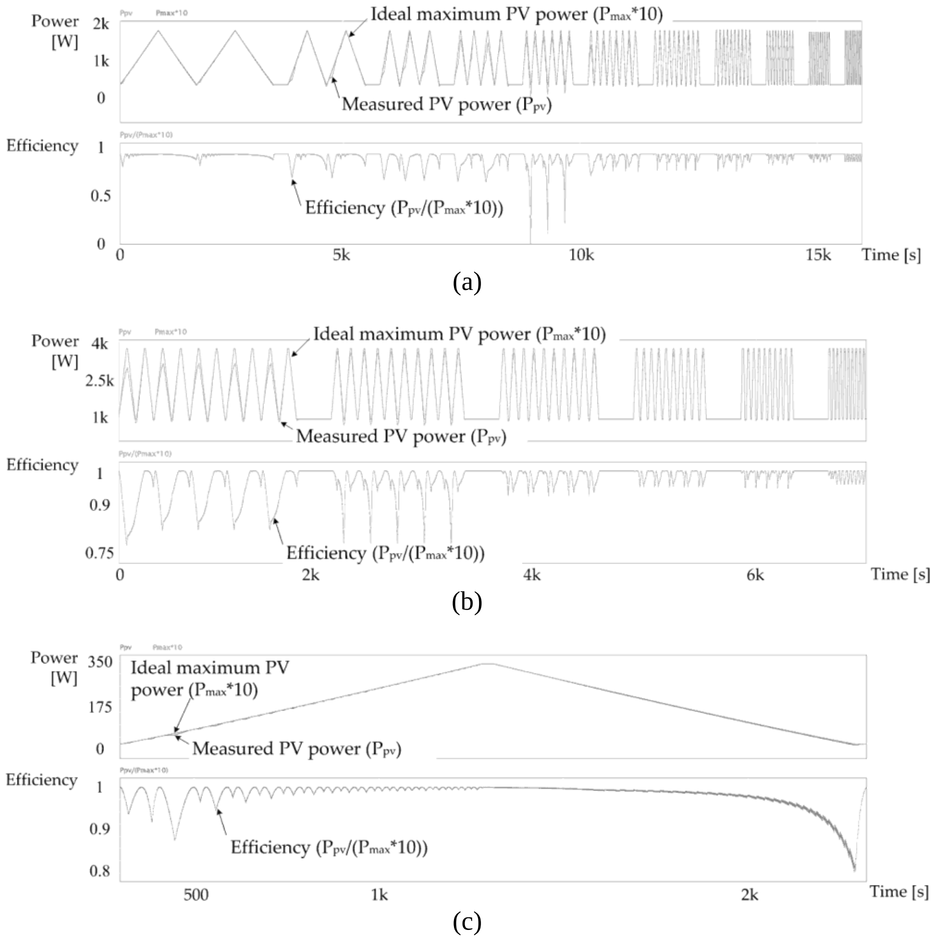


Figure 5. Key waveforms for dynamic MPPT performance under MPPT control cycle of 1 s and voltage perturbation of 1 V: (a) Case 1, (b) Case 2, and (c) Case 3

In the same way, Figures 6(a)-(c), Figures 7(a)-(c), and Figures 8(a)-(c) (see in Appendix) show the tracking performance in each irradiance profile as a waveform, depending on different MPPT control cycles and voltage disturbance magnitudes. Table 3 summarizes quantitative data of MPPT tracking efficiency for each case, depending on the design parameters of the P and O method mentioned above. Overall, the final average efficiency shows the highest performance at 98.92% under the condition of a control cycle of 0.1 seconds and a voltage disturbance of 1 V. However, the power generation performance may decrease due to disturbances at the normal state as the control cycle becomes shorter, and the size of the disturbance becomes larger. For example, under irradiation conditions that reach up to 100% of the reference solar radiation, such as Case 2, a disturbance of 0.1 V shows better performance than a disturbance of 1 V. This is due to the phenomenon that more output fluctuations occur when the disturbance size that deviates from the MPP point is 1 V rather than 0.1 V. However, as shown in Table 3, in the design condition where the disturbance size is fixed at 0.1 V, the final average efficiency, including efficiency under different solar irradiance variations, is somewhat lower at 96.00%. From this, it can be inferred that increasing the MPPT control cycle speed and setting the initial disturbance to a large value like 1 V, and then decreasing the disturbance after reaching the maximum power point can improve the target dynamic performance. The next research topic is to propose a tracking MPPT algorithm optimized for static and dynamic MPPT using this platform of dynamic MPPT performance.

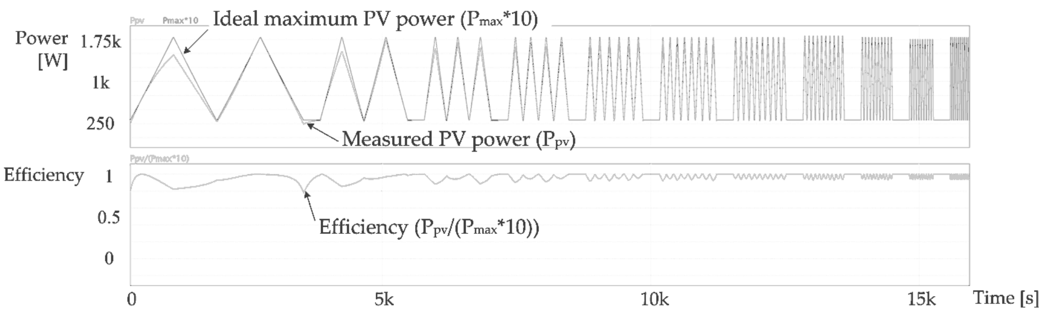
Table 3. Comparison of dynamic MPPT efficiency of the P and O method according to design parameters under IEC 62819 conditions

No.	MPPT Control Period [s]	Voltage perturbation [V]	Dynamic MPPT efficiency [%]			
			Case 1	Case 2	Case 3	Average
1	1	1	96.09	97.24	98.44	97.25
2	1	0.1	95.93	98.92	93.14	96.00
3	0.1	1	98.65	98.12	99.98	98.92
4	0.1	0.1	96.37	97.28	98.42	97.36

5. CONCLUSION

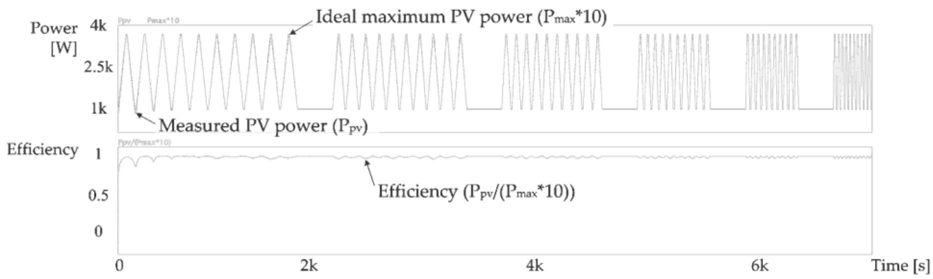
This paper proposes the simulation platform to evaluate dynamic MPPT performance according to IEC standard using simulation software. To reduce simulation executing times, switching part of converter that negligibly faster than MPPT control period would omitted. To verify the proposed method, the tracking performance of MPPT control cycles and voltage disturbance magnitudes under different irradiance profiles according to IEC standard through the proposed simulation platform summarizes the MPPT tracking efficiency quantitatively based on the P and O method design parameters. The simulation results showed that the highest average efficiency was 98.92% under a MPPT control cycle of 0.1 seconds and a voltage disturbance of 1 V. The proposed technique could be used to evaluate the standardized performance of various MPPT methods.

APPENDIX

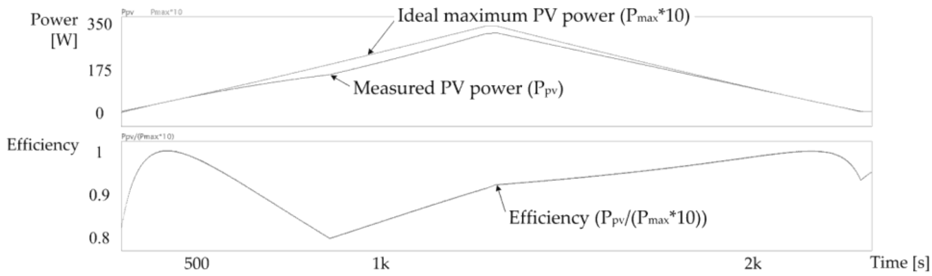


(a)

Figure 6. Key waveforms for dynamic MPPT performance under MPPT control cycle of 1 s and voltage perturbation of 0.1 V. (a) Case 1, (b) Case 2, (c) Case 3 (*Continues*)

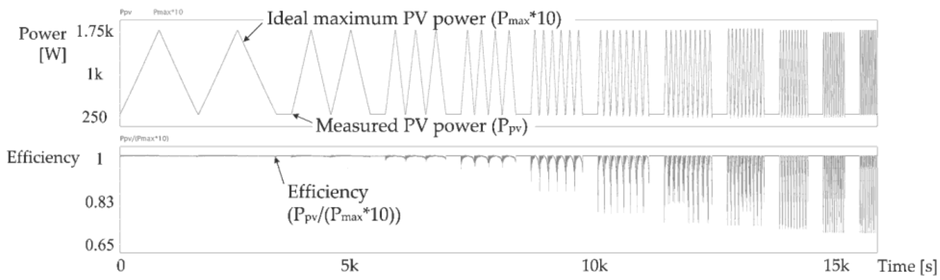


(b)

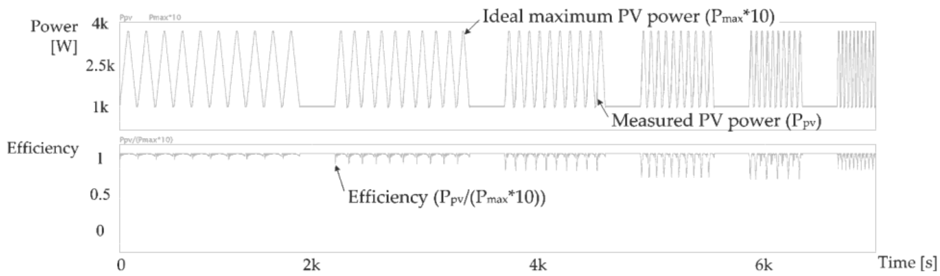


(c)

Figure 6. Key waveforms for dynamic MPPT performance under MPPT control cycle of 1 s and voltage perturbation of 0.1 V: (a) Case 1, (b) Case 2, (c) Case 3



(a)



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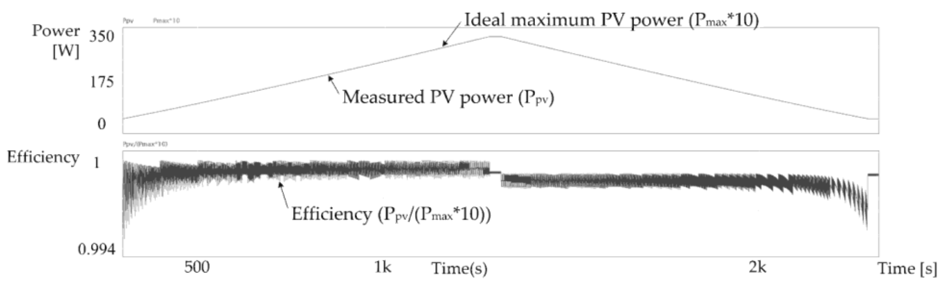

(c)

Figure 7. Key waveforms for dynamic MPPT performance under MPPT control cycle of 0.1 s and voltage perturbation of 1V: (a) Case 1, (b) Case 2, (c) Case 3

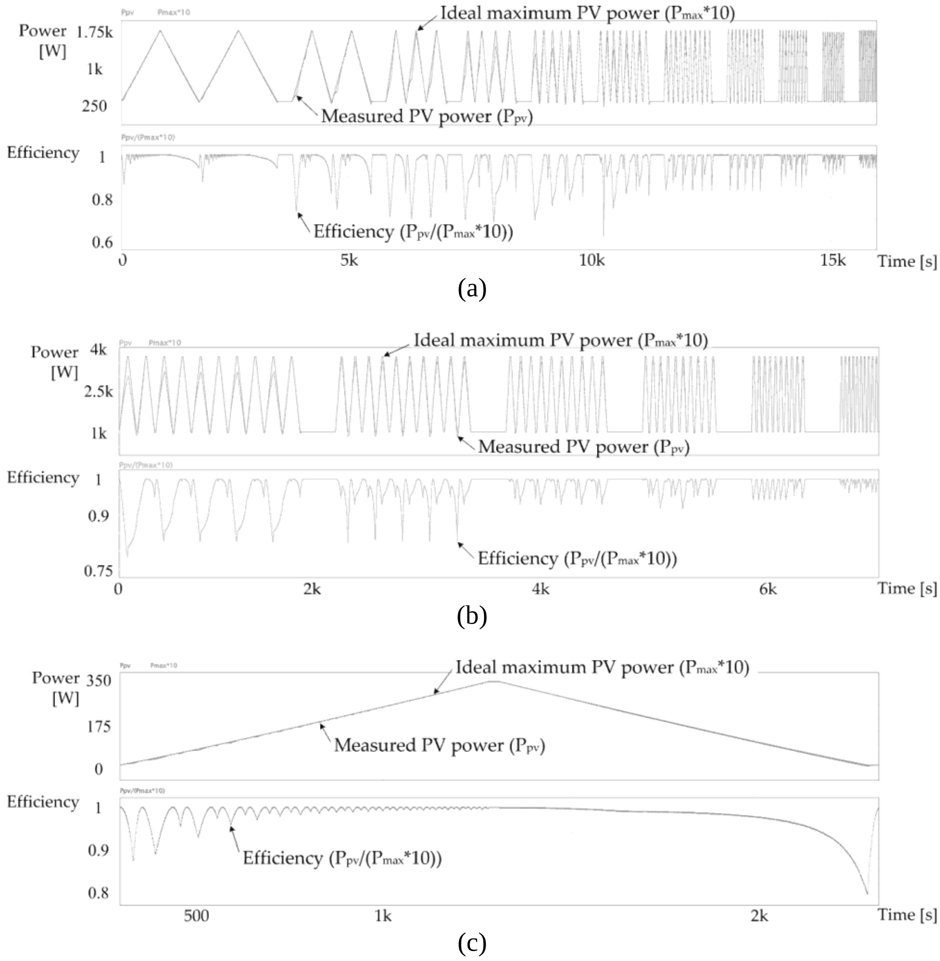

Figure 8. Key waveforms for dynamic MPPT performance under MPPT control cycle of 0.1 s and voltage perturbation of 0.1 V: (a) Case 1, (b) Case 2, (c) Case 3

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