ENHANCING VOLTAGE STABILITY OF PHOTOVOLTAIC ENERGY CONVERTER USING POWER FACTOR CORRECTION TECHNIQUE

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Abstract: *Currently, the high penetration of photovoltaic energy (PV) in the power system raises many challenges due to the instability of this type of energy. To overcome this problem, this study analyzes the Power Factor Correction (PFC) control technique through the existing power grid to support converters integrated with the MPPT algorithm. Then, an experimental circuit model integrating two control methods will be fabricated and evaluated under the actual operating conditions. The experimental process shows that in the case of PFC support, output voltage response is more stable than the case that only uses the simple MPPT algorithm.*

Keywords: Boost converter; DC/DC; MPPT; PFC; PV.

1. INTRODUCTION

Nowadays, the high penetration of PV has a great influence on the stability during the operation of power systems due to non-inertial characteristics and the sudden change in power when the weather is disturbed [1-3]. In order to overcome this disadvantage, the power electronic converters integrating advanced algorithms to increase the stability of this energy source are being widely researched and implemented.

With the current penetration of PV into the power system, especially the increase of the PV rooftop form, research needs to simultaneously ensure two factors, including high power output and voltage flicker within the allowable range. To improve the power obtained from PV, converters with integrated maximum power point tracking (MPPT) algorithms have been studied [4-5]. However, the converter's output voltage will be changed continuously when the MPPT algorithm detects the maximum point on the P-V curve of the panels. Therefore, battery systems can be considered connected to the converter's output so that the voltage can be stabilized. Moreover, the use of the battery system for stabilizing the output voltage of the MPPT converters is costly due to investment costs and depreciation. The approach uses the converter model integrating Power Factor Correction (PFC) control technology based on model predictive control rules including discontinuous conduction mode (DCM), continuous conduction mode (CCM) [6-8] and aims to improve the stability of the output response by taking advantage of the existing AC power supply.

This paper proposes a model combining two control methods PFC and MPPT. In which, the control stage of MPPT is responsible for increasing the power obtained from PV sources while the PFC stage will take advantage of the available AC power source to support the voltage stabilization process. Finally, the actual model will be fabricated and experimented in many different operating conditions to demonstrate the effectiveness of the proposed model.

The paper is organized as follows: The PFC Boost converter is introduced in section 2. In section 3, the design process of the PFC Boost and MPPT combined model is shown. Experimental results are given in section 4. Conclusions are summarized in section 5.

2. PFC BOOST CONVERTER

2.1. Averaged model of the PFC Boost Converter

The PFC Boost converter shown in figure 1 [9], the relationship between voltage and current at both input and output terminals is determined by:

$$L\frac{d}{dt}\left(I_L+\hat{i}_L\right)=V_{in}+\hat{v}_{in}-\left(V_o+\hat{v}_o\right)D^{'}+V_o\hat{d} \tag{1}$$

$$\frac{C}{D^{'}}\frac{d}{dt}\left(V_o+\hat{v}_o\right)=-\frac{I_L}{D^{'}}\hat{d}-\frac{I_o+\hat{i}_o}{D^{'}}+I_L+\hat{i}_L \tag{2}$$

Where: L is the inductance value of the inductor in the converter; C is the capacitance value of the capacitor; V_{in} and $\hat{v}_{in}$ are constant and variable components of the converter input voltage, respectively; V_o and $\hat{v}_o$ are constant and variable components of the converter output voltage, respectively; I_o and $\hat{i}_o$ are constant and variable components of the converter output current, respectively; I_L and $\hat{i}_L$ are constant and variable components of the inductor current, respectively; D is the duty cycle of the converter and $D^{'}$ = 1-D; $\hat{d}$ represents the change in duty cycle during operation.

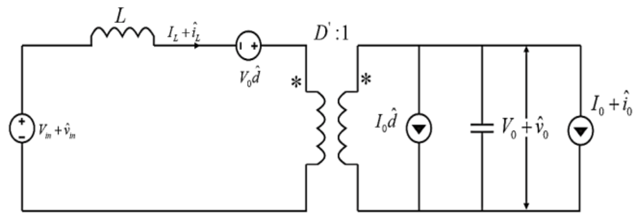


Figure 1. *Averaged switching model of PFC Boost.*

The PFC control technique is depicted in figure 2. The control system consists of the voltage control stage which has a slow effect and makes a response in each half of the voltage cycle (100Hz) and the current control stage which has a fast effect according to the switching cycle of the converter [10-12]. The current control loop is based on two control rules, one for operation in DCM and one for operation in CCM, which will be changed based on the corresponding converter mode.

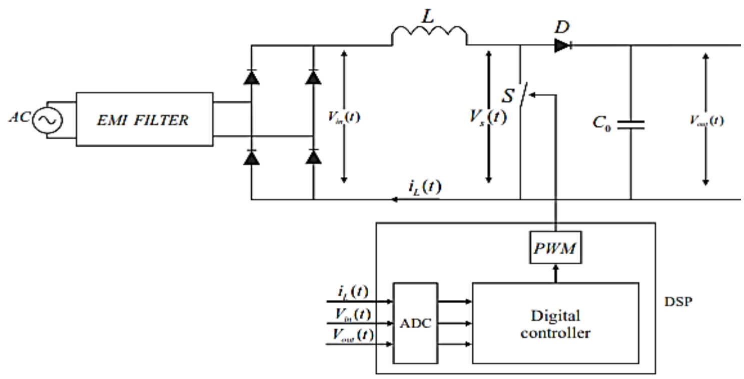


Figure 2. *General control model of PFC Boost converter.*

2.2. Discontinuous conduction mode (DCM)

The difference between the two current control modes is the DC conversion ratio expressed by the ratio between the input voltage and the output voltage of the converter. In DCM, this ratio is determined by:

$$\frac{V_o}{V_{in}}=\frac{1+\sqrt{1+\frac{4D^2}{k}}}{2} \tag{3}$$

Where: K is a constant calculated by the following formula.

$$K = \frac{2L}{RT_s} \tag{4}$$

Where: R is the load resistance at the output; T_s is the switching frequency of the semiconductor valve.

Then, the output power P_o of the converter is calculated by:

$$P_o = \frac{V_o^2}{R} \text{ or } R = \frac{V_o^2}{P_o} \tag{5}$$

From (3), (4), (5), the duty cycle in DCM is expressed through:

$$D^2 = \frac{2L}{RT_s} \times \frac{P_o}{V_o V_{in}} \times \frac{V_o - V_{in}}{V_{in}} \tag{6}$$

With the reference current of the inductor i_{ref} is given by:

$$i_{ref} = \frac{P_o}{V_{in}} \tag{7}$$

The duty cycle of PFC Boost in DCM is rewritten as the following equation:

$$D = \sqrt{\frac{2L}{T_s} \times i_{ref} \times \frac{V_o - V_{in}}{V_o V_{in}}} \tag{8}$$

This is the value applied to the semiconductor valve at the actual switching cycle based on converter input and output parameters.

2.3. Continuous conduction mode (CCM)

In CCM, the mean value of the inductor voltage V_L is calculated by:

$$V_L = \frac{L\Delta I}{\Delta T} \tag{9}$$

Where: ΔI is the inductor ripple current; ΔT is the switching time.

For the desired model, the value V_L should be asymptotic to 0. In this way, the ripple current of the inductor also progressively approaches 0. Therefore, during each switching cycle, the error of the inductor current also needs to be 0. Thus:

$$\Delta I = e = i_{ref} - \hat{i}_L \tag{10}$$

$$V_L = DV_{in} - (V_o - V_{in})(1 - D) \tag{11}$$

From (9), (10), and (11), the duty cycle D in this mode is determined by:

$$D = 1 - \frac{V_{in}}{V_o} + \frac{L\Delta I}{V_o T_s} \tag{12}$$

3. DESIGN OF PFC BOOST AND MPPT COMBINED MODEL

3.1. MPPT and PFC Boost combined model

The operation of PV depends on solar radiation and temperature on the surface of the PV panel, leading to unstable power flow and output voltage on the load. With MPPT only, the power can be enhanced, but the output voltage is always fluctuated due to continuously detecting the maximum power point. Combining PFC Boost circuit and MPPT circuit will be able to ensure stable output voltage while ensuring high power flow for PV.

With this combined model, the power supplied to the consumption load consists of two sources, from the AC grid and the PV system. When the PV power is smaller than the load demand, the grid is involved in the compensation process to ensure power stability. The block diagram of the model is shown in figure 3.

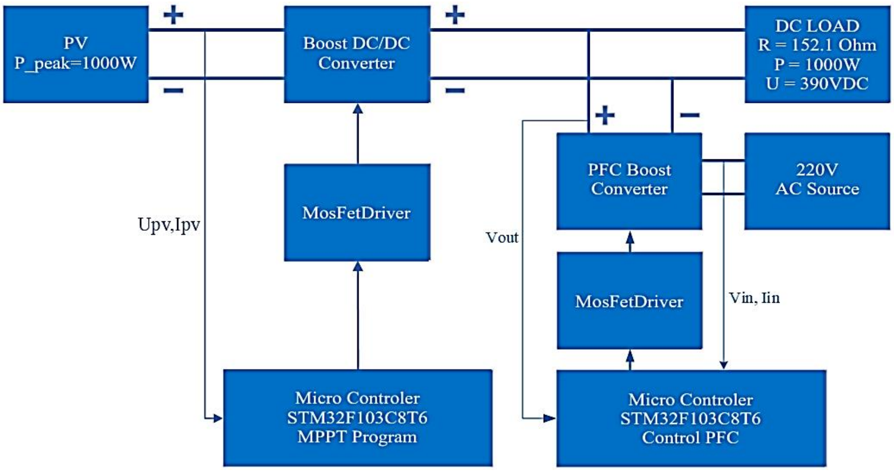


Figure 3. *Block diagram of the combined model.*

3.2. Experimental circuit model

The experimental circuit shown in figure 4 is designed and installed based on the diagram described in figure 3. Two circuits of PFC Boost Converter and MPPT Converter will be connected at the output of each converter and through a protection device before supplying to the load. Input power of PFC Boost converter will be connected in series with AC grid 220V - 50Hz, while input source of MPPT converter is supplied by PV system with a capacity of 1000Wp. From this circuit model, experiments under real operating conditions will be conducted in order to show the benefits of the combined model.

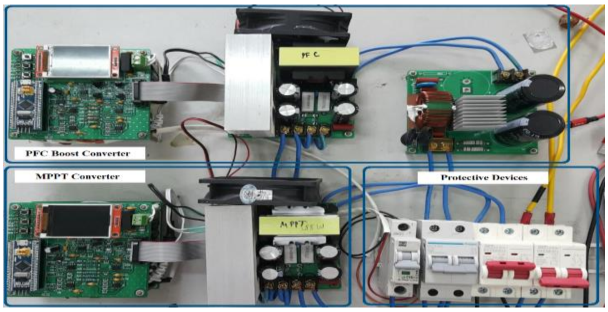


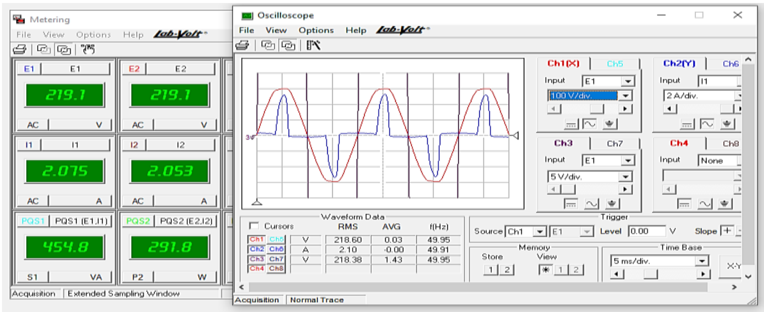
Figure 4. *Combined PFC Boost and MPPT experimental circuit.*

4. EXPERIMENTAL RESULTS

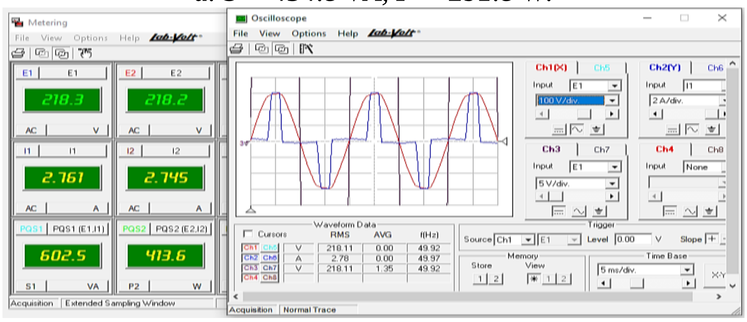
4.1. MPPT converter model

First, the experimental model without PFC Boost converter (only MPPT converter) has been measured in actual conditions. The collected data are retrieved through the Lab Volt measurement system.

Figure 5 shows the results in two different cases of input values and waveform of the voltage and current. Furthermore, detailed measured values of the apparent power S and the active power P of the converter are also observed. In both cases, the results in figure 5 show that there is a large difference in phase angle between the current and voltage waveform responses. The power factor in the two cases is 0.6416 and 0.6865, respectively.



a. S = 454.8 VA, P = 291.8 W.

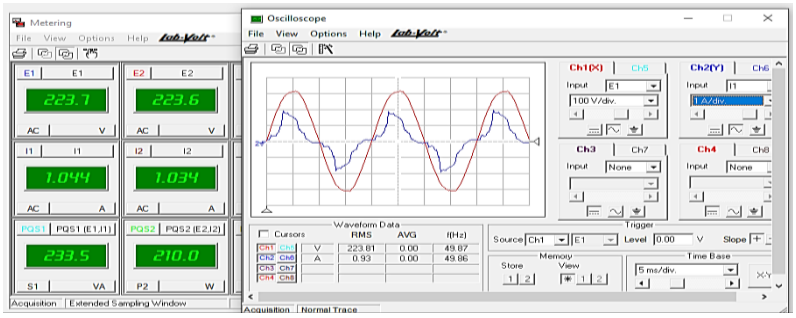


b. S = 602.5 VA, P = 413.6 W.

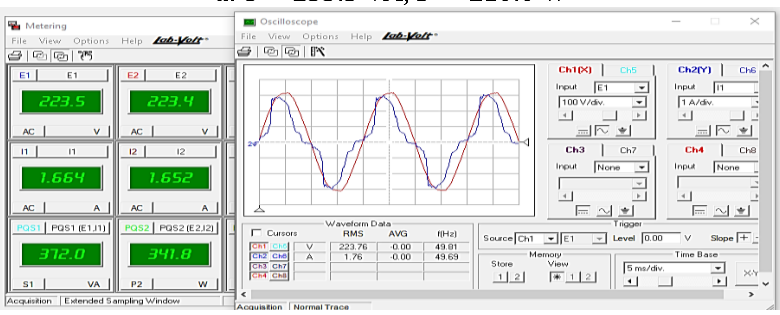
Figure 5. *Experimental results without PFC Boost Converter.*

4.2. MPPT and PFC Boost combined model

In order to improve power factor as well as power quality, the model of combining PFC Boost converter with MPPT converter was experimentally designed to show the effectiveness of the proposed solution. Experimental results in this case and in Section 4.1 were carried out under the same input conditions to ensure accuracy. The results of the proposed solution are shown in figure 6.



a. S = 233.5 VA, P = 210.0 W



b. S = 372 VA, P = 341.8 W

Figure 6. *Experimental results of the combined model.*

It can be seen that, when using the combined model, there is a significant change compared to the results in section 4.1. The current waveform gradually has a shape that is asymptotic to the voltage waveform as well as the phase deviation decreases as the output power increases. This effectively improves output power, which stabilizes responses, with the participation of the PFC Boost converter. More specifically, the power factors in the three cases observed in figure 6 are 0.9 and 0.92, respectively.

The output voltage response of the combined model is presented in figure 7. Unlike the pure MPPT converter, the integration of the PFC stage helps to keep the voltage on the load stable and close to the set value. With actual results, when the power of the PV system fluctuates, the output voltage on the load Vout remains stable at ± 1.5% compared to the nominal voltage. Furthermore, losses in the system can be reduced by improving the power factor

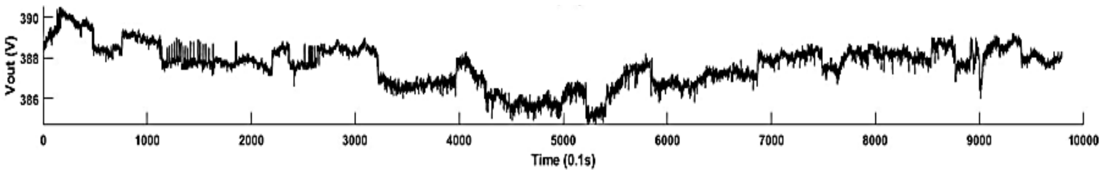


Figure 7. *The output voltage of the combined model.*

5. CONCLUSIONS

The PFC Boost converter combined with MPPT converter model shows remarkable performance in increasing power factor, ensuring power quality and stability. Moreover, this model can take advantage of existing AC power sources to replace the battery system in the task of keeping the output voltage stable, thereby reducing the investment cost of installing PV systems and electronic waste from the old battery.

However, despite the high investment costs of the battery system, it is more convenient to use as a power supply for consumption load. Using the battery system can store energy from the PV system when the power consumption of the load is low and provide power for the load when needed at times of the day. Therefore, it is necessary to have research to optimize the technical-economic criteria with the proposed model together with the energy storage system to come up with a comprehensive solution for PV systems.

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TÓM TẮT

CẢI THIỆN ỔN ĐỊNH ĐIỆN ÁP CỦA BỘ CHUYỂN ĐỔI NĂNG MẶT TRỜI BẰNG KỸ THUẬT ĐIỀU KHIỂN HỆ SỐ CÔNG SUẤT

Ngày nay, sự xâm nhập cao của nguồn năng lượng mặt trời hiện nay khiến cho hệ thống điện phải đối mặt với nhiều thách thức do sự mất ổn định của loại hình năng lượng này. Để có thể khắc phục được nhược điểm này, nghiên cứu này kết hợp kỹ thuật điều khiển Power Factor Correction (PFC) thông qua nguồn điện lưới có sẵn để hỗ trợ các bộ chuyển đổi có tích hợp thuật toán MPPT. Kết quả nghiên cứu được chứng minh bằng cách chế tạo mô hình mạch thực tế tích hợp hai phương pháp điều khiển và đánh giá trong điều kiện hoạt động cụ thể. Quá trình thực nghiệm cho thấy trong trường hợp có sự hỗ trợ của kỹ thuật PFC thì đáp ứng điện áp đầu ra có độ ổn định cao hơn so với trường hợp không có sự hỗ trợ của kỹ thuật PFC.

Từ khóa: Bộ chuyển đổi tăng áp; DC/DC; MPPT; PFC; PV.

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