Maximum Power Point Tracking in PV Arrays with High Gain DC-DC Boost Converter

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***Abstract*—Photovoltaic (PV) system is an electrical generator that has been widely used. Ease of implementation, supported by a large number of potentials and needs of Green Energy, has become a factor in the increasing number and quickly applied to PV arrays. However, PV arrays have constrained related to generator conversion efficiency and the amount of power produced due to inconstant irradiation and temperature. This problem can be solved by a Maximum Power Point Tracking (MPPT) approach. This article discusses the MPPT technique with High Gain DC-DC Boost Converter using the Perturb and Observe (P&O) algorithm. The same P&O algorithm is also tested in the conventional converter to show performance and superiority of each converter. The results obtained show the advantages and disadvantages of each converter used in MPPT by P&O algorithm.**

***Keywords*—DC-DC converter, Boost Converter, High Gain Ratio, MPPT, PV arrays, High Gain Boost, P&O.**

I. INTRODUCTION

PV systems offer a variety of advantages and new solution as electrical generators. A large number of potentials in various regions and the need to use new technologies as Green Energy make the PV systems fast to develop. Green Energy includes clean technology using non-fossil and non-polluting power supplies fuels [1]. The PV systems is considered to be a promising technology due clean, has abundant potentials, noise-free and environmental friendly as a generating system compared to conventional energy sources, such as fossil fuels [2], [3]. But in its developments, the PV systems as an electrical generator is still constrained by problems related to the efficiency of generator conversion and its output power.

PV-based electrical generation systems have problems related to generator conversion efficiency and the power that affected by environmental effects, such as irradiation and temperature that exposed to PV arrays. The effectiveness of the PV system decreases because maximum power is not achieved. Therefore, the control design is needed to track a maximum power point (MPP) [4] by considering the environmental changes [5]. To increase the efficiency of PV, the approach namely Maximum Power Point Tracking (MPPT) by extracting maximum output power from PV system [6], [7]. The MPPT control must be able to reach MPP quickly because the irradiation changes can occur quickly which allow it to reduce output power and power loss [8].

There are several MPPT control schemes from the conventional algorithms such P&O [9]–[11] and Incremental Conductance [12]–[14] or implement the Artificial Intelligence [15]–[21]. At present, Perturb and Observe (P&O) is the most widely used algorithm in MPPT due simple and easy to implement [22]. The advantage of the MPPT control algorithm, both conventional and intelligent algorithms is being able to provide maximum energy to be transferred to the load. Generally, MPPT can be operated by connecting a power converter between the PV system and load [23], [24]. To achieve maximum power, the MPPT technique adjusting the power converter's duty cycle. The duty cycle compares the internal resistance in PV and load resistance [7].

The converter device also affects the voltage quality produced by MPPT. The commonly used of the converter in PV is Boost Converter, Buck Converter or Buck-Boost Converter. Boost Converter has the main feature of continuous input current and the output voltage is higher than the input voltage. This is why Boost Converter is an important device in PV systems and battery charging. Conventional Boost Converter usually has a voltage ratio or gain of fewer than 5 times [25]. The voltage gain of the converter can be achieved but requires a high duty cycle ratio, so that the resulting efficiency drops [5]. Another effect that occurs is increasing the voltage on the switch and causing electromagnetic inference [26]–[28].

The high voltage ratio of Boost Converter can be achieved by a cascaded converter, but this method requires a twice processes so that its efficiency is decreased [25]. Another method is using a Quadratic Boost Converter (QBC) [5], [29]–[34]. This method connects two converters in series using one switch only. However, the voltage ratio produced is not different from a cascaded converter and its efficiency is lower than a conventional Boost Converter. High voltage gain can also be achieved by coupled the inductor [35]–[39]. But this method has a problem with leakage coupled inductor. Conduction losses in semiconductors and copper losses in inductor increase, thereby reducing efficiency at low power level.

Not only is the ability to increase the voltage gain, but the converter used in MPPT PV system must also have high efficiency. The High Gain DC-DC Boost Converter proposed by Dahono [25] shows a better efficiency level compared to conventional converters. The high efficiency is achieved with the unique connection of two conventional DC-DC converters. In this article, the performance of the High Gain DC-DC Boost Converter will be evaluated as a converter in MPPT technique using the P&O algorithm. Simulation is done to verify the evaluation results obtained.

II. MAXIMUM POWER POINT TRACKING

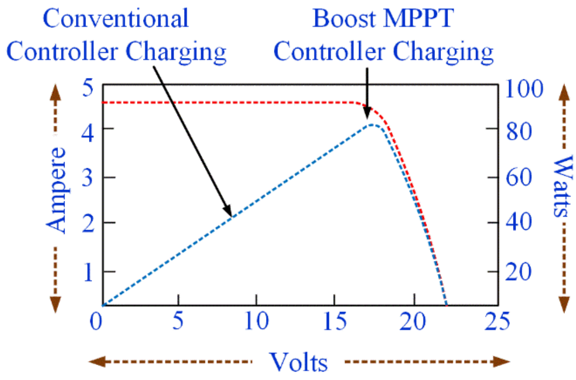


Fig 1. MPPT control and without MPPT control on characteristic curves.

Tracking of the MPP is a system that varies the PV electric operating point to achieve maximum power [40]. Tracking of the MPP to achieve maximum power is done by adjusting the load. Irradiation and temperature were due to changing atmospheric conditions around PV, making PV operation points also change. The maximum power produced by PV varies according to exposure irradiation and temperature of the sun [41], [42]. Irradiation changes affect the output current of the PV, while temperature changes affect the PV output voltage. Fig 1 shows the difference of PV performance with MPPT control and without MPPT control. PV without MPPT control that connected to the battery operates at battery voltage. But if use MPPT control, PV provides maximum power it achieves.

The third-order polynomial function can be used to achieve accurate PV fitting curves,

$$P = wV^3 + xV^2 + yV + z \tag{1}$$

the differentiation,

$$\frac{dP}{dV} = 3wV^2 + 2xV + y, \quad \text{on MPP, } \frac{dP}{dV} = 0 \tag{2}$$

so that the MPP voltage is,

$$V_{mpp} = \frac{-x \pm \sqrt{x^2 - 3wy}}{3w} \tag{3}$$

The coefficients $w, x, y,$ and z are determined by PV voltage and power sampling. The coefficient is sampled many times in the millisecond interval.

III. HIGH GAIN DC-DC BOOST CONVERTER

Boost Converter is a DC-DC power converter that converts a low input voltage into high output voltage according to the requirements of the electronic devices [43], [44]. The DC-DC boost converter is usually used for maximum utilization of PV with continuous input energy flow [45]. However, conventional converters commonly used on MPPT have a low maximum voltage ratio. So a DC-DC converter with high voltage gain is needed.

The need for DC-DC converter with high voltage gain is becoming increasingly important for power conversion [46]. The converter used in this article is shown in Fig 2 proposed by Dahono [25]. The advantage of this converter is that efficiency is better than conventional Boost Converter. This proposed converter has a parallel connected input and the output is connected in series to increase the voltage ratio. This method results in better efficiency than the cascaded connection which requires twice the processing power.

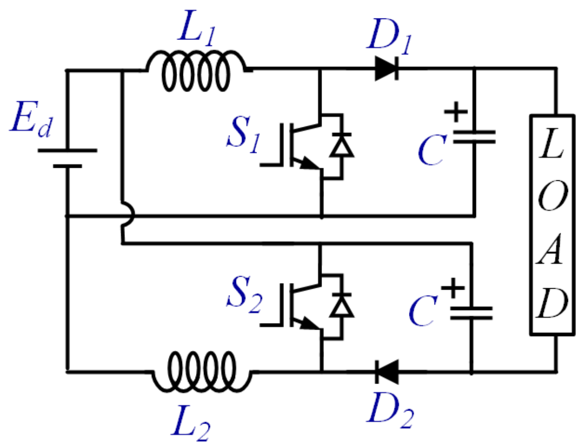


Fig 2. High Gain DC-DC Boost Converter.

IV. P&O BASED MPPT

The main function of the MPPT is to adjust the PV output voltage to remain at maximum power output (P_{max}). This process aims for the energy transferred to the load to be maximum energy. The control unit contains a conventional or intelligent controller tracking MPP. At present, the P&O algorithm has become the most widely used choice in the MPP technique. The advantages of this algorithm compared to other conventional algorithms is simpler and result in higher accuracy [47].

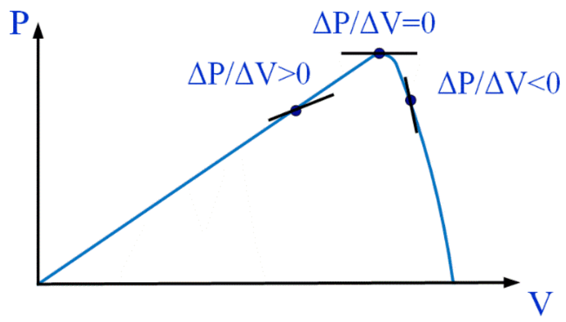


Fig 3. The ΔP/ΔV position on the characteristic curve V-P.

P&O is based on perturbation by increasing or decreasing V_{ref} to control the DC-DC converter duty ratio and observing PV output power [48]. If the current power value *P(k)* PV is longer than before *P(k-1)*, then the direction of the disturbance remains the same, but if *P(k)* shorter than *P(k-1)*, then the direction of the disturbance is reversed. So, based on changes in *P*, then perturbation *(ΔV)* in *V* according to the following rule [11]:

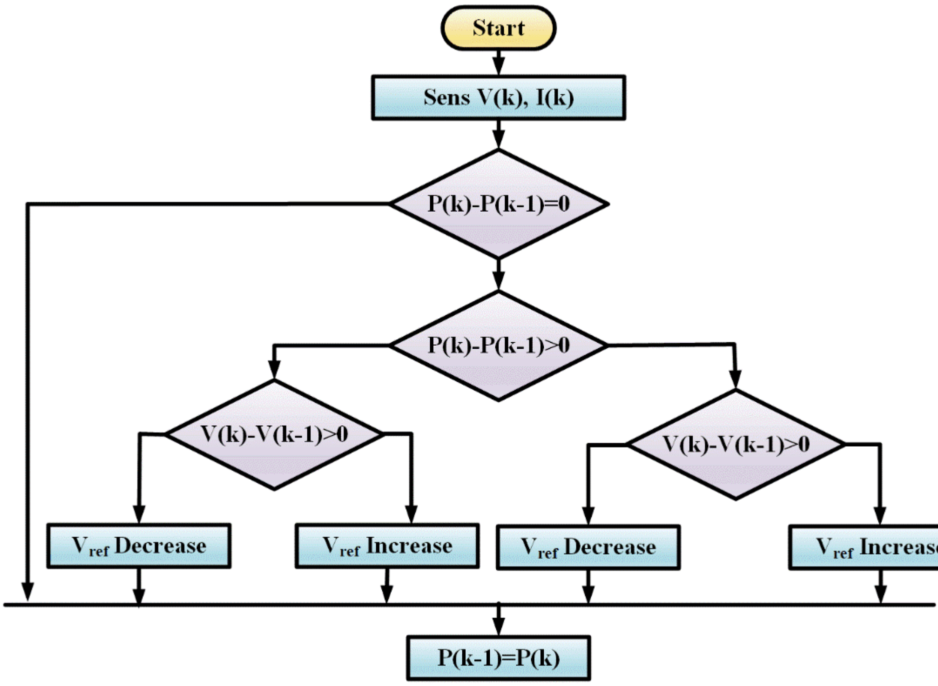


Fig 4. P&O algorithm flowchart.

$$V_k = V_{(k-1)} + \Delta V \ \times slope \quad (if\ P > P_{(k-1)})$$

$$V_k = V_{(k-1)} - \Delta V \ \times slope \quad (if\ P < P_{(k-1)})$$

The slope shows the direction of the disturbance, which is to the right (climbing) or to the left (descending). This algorithm refers to the slope (ΔP/ΔV) in the characteristics of V-P, as shown in Fig 3. At the peak is MPP with ΔP/ΔV=0, at the left is ΔP/ΔV>0 and at the right is ΔP/ΔV<0.

Based on the characteristics of V-P in Fig 3, the duty cycle must be perturbed to be in MPP [10]. Fig 4 shows the P&O algorithm flowchart to control the duty cycle.

V. Result and Discussion

The P&O algorithm created and connected to other circuits to support the MPPT technique on PV arrays using MATLAB/Simulink toolbox. PV used is connected in 2 parallel and 4 series. The Boost Converter that is built is a new circuit that has high voltage gains and efficiency. The overall circuit is shown in Fig 5.

Input on the high gain DC-DC Boost Converter is connected in parallel, while the output is connected in series. PWM generator is given to conventional and High Gain DC-DC Boost Converter of 100 kHz. Constant irradiation given to PV is 1000 W/m^2, then given irradiation changes to 800 W/m^2 then 600 W/m^2 as a representation of changing atmospheric conditions.

The simulation results show that the High Gain DC-DC Boost Converter produces a large voltage ratio of 2.957, while the conventional converter is 1.982 at a working frequency of 100 kHz. The graph of the output voltage, current, and power of each converter is shown in Fig 6.

Fig 6 shows a graph of PV that experiences rapid changes conditions. This causes drift, especially in the High Gain DC-DC Boost Converter topology. The P&O method often causes drift in weather changes. The P&O drift occurs

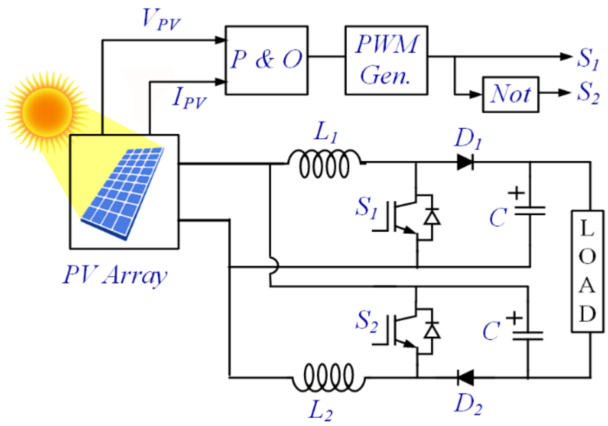
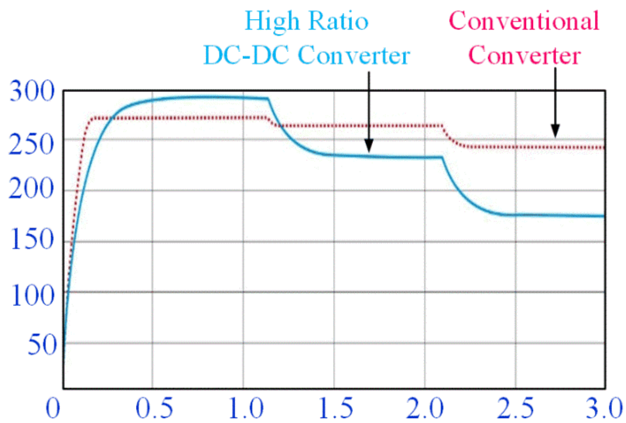
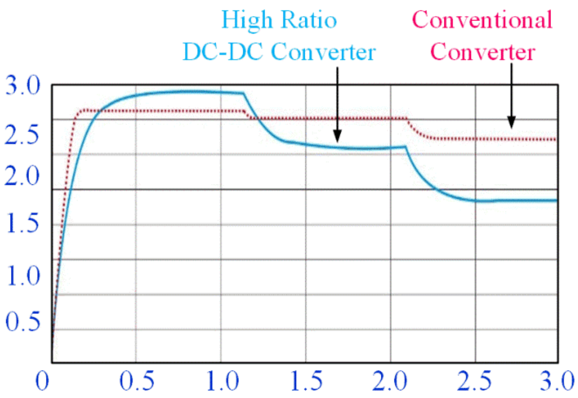


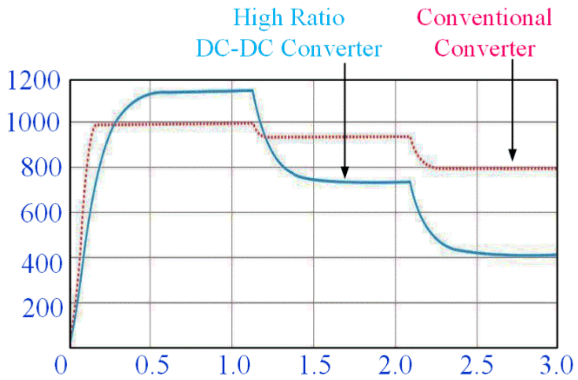
Fig 5. P&O on High Gain DC-DC Boost Converter.



(a)



(b)



(c)

Fig 6. Scope of the output (a) voltage, (b) current and (c) power on conventional and High Gain DC-DC boost Converter.

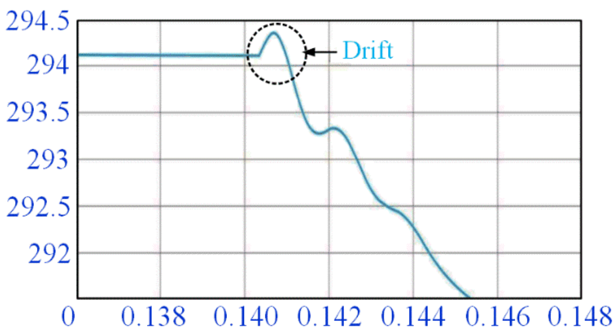


Fig 7. Drift in High Gain DC-DC boost Converter.

in the plant, since the logic of increasing power ($\Delta P > 0$) caused by perturbation.

The oscillations that occur in both topologies have different values. High Gain DC-DC Boost Converter has very small oscillations compared to the conventional converter. But the tracing speed in the conventional converter is better. The results obtained from several parameters are shown in TABLE I.

TABLE 1. RESULT OF TESTING THE P&O ALGORITHM ON CONVENTIONAL AND HIGH RATIO DC-DC BOOST CONVERTER.

Parameters	**Conventional Converter**	**High Ratio DC-DC Boost Converter**
Output Voltage	1.982 V	2.957 V
Output Current	0.333 A	0.229 A
Power Ratio	0.656 Watt	0.677 Watt
Voltage Oscillation	0.0054 V	0.00001 V
Current Oscillation	0.0001 mA	0.0000 A
Power Oscillation	0.04 Watt	0.0000 Watt
Tracking Speed	0.1 s	0.45 s

VI. CONCLUSION

Solar energy has great potentials that can be used to be developed and implemented, because of the abundant resources it becomes the right step if this energy source gets more attention. The PV power used as an electric generator utilizing that solar energy. MPPT techniques with various algorithms and converter topologies have also been widely applied to improve output efficiency. In some applications, a converter that produces high gain is required, while conventional converters are unable to cope with these needs. High Ratio DC-DC Boost Converter has been developed evaluated its performance in the MPPT technique in this article. The simulation results show that the High Ratio DC-DC Boost Converter tested on MPPT techniques with the P&O algorithm has a performance that is not inferior to conventional converters. Even with a large voltage ratio, the oscillations produced by the High Ratio DC-DC Boost Converter are smaller than the conventional converter. But the tracking speed of the High Ratio DC-DC Boost Converter to go to MPP in weather conditions changes more slowly than conventional converter. The result obtained in this study can be used as material for evaluation and development to obtain a suitable system, so that High Gain DC-DC Boost Converter approaches the optimum result in the MPPT technique. Then the final goal of the research is to implement in the real device.

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