Enhancement of the Maximum Power Point Tracking for the Solar Power Generation using ZETA Converter Circuit

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ABSTRACT

Nowadays, electric power production with solar cells increases in both households and solar power plants. The Maximum PowerPoint Tracking (MPPT) of the solar system is essential. This paper proposes to increase the efficiency of the maximum power drawn from a solar panel with the Zeta converter circuit. The solar panel, power of 80 W, was applied to study the MPPT. Bangkok Thonburi University in the central region of Thailand was used as the experiment area. The solar panel was turned to the south so that the panels are continually exposed to sunlight. This paper was divided into both the simulation and the experimental sectors. In the simulation sectors, the Psim program was used to simulate the power input and output from the Zeta converter circuit at the solar intensity of 1000 W/m2, the temperature of 25 oC. The power output from the Zeta converter circuit is 55.04 W, the power output 52.90 W, so the efficiency is 96.11%. In the experimental sectors, when the Zeta converter circuit is not installed, the maximum power produced is 43.21 W, but when the circuit was installed, the maximum power increase to 72 W and the maximum efficiency of 90%. It is shown that installing the Zeta converter circuit can help increase the efficiency of the maximum power draw on the solar generation system.

1. INTRODUCTION

Wasted energy is a source of energy from natural resources used up, cannot be renewed, or almost irreplaceable in a short period. These are fossils formed from plant and animal remains for millions of years, such as oil, coal, natural gas, shale, etc. Human beings find another source of energy to replace, known as Renewable Energy (RE), an energy source that can be obtained from renewable natural resources such as Hydro, Wind power, Biomass, Geothermal energy, and Solar energy. Solar energy is non-exhaustive energy, and it is suitable energy to generate electricity because Thailand is a sunny country all year round. In a zone with a high potential to utilize solar energy, it is suitable to apply photovoltaic technology to various applications [1]. A solar cell is an electronic device made of silicon or another substance that converts solar energy into electrical energy. The production of electricity from solar cells can be varied, from large-scale with photovoltaic power plants (Solar Farm) to small scale mounted on the roof of houses (Solar Roof) and solar floating that generates electrical energy reduces evaporation water in the pond.

The application of photovoltaic systems does not emit any greenhouse gas emissions and has minimal impact on the environment [2]. Generating electricity using solar energy requires a photovoltaic panel that converts solar radiation into electricity. Other variables are included, such as the light intensity, type of the panel's cells, and the solar panel area that may cause the efficiency of electricity production to vary. The efficiency of electric power generation does not address intractable natural problems such as the sun's rise and fall, the weather conditions caused by the cloud blocking the sun's light intensity. Cooler air, and degradation or dust, all of which reduce the efficiency of electricity production.

For this reason, the energy produced by photovoltaic systems is different daily and in different seasons, and the main factor depends on the light intensity and panel temperature [3]. Therefore, to use the energy for maximum power, solar panels must be monitored all the time for the solar panels to function at their peak efficiency. Currently,

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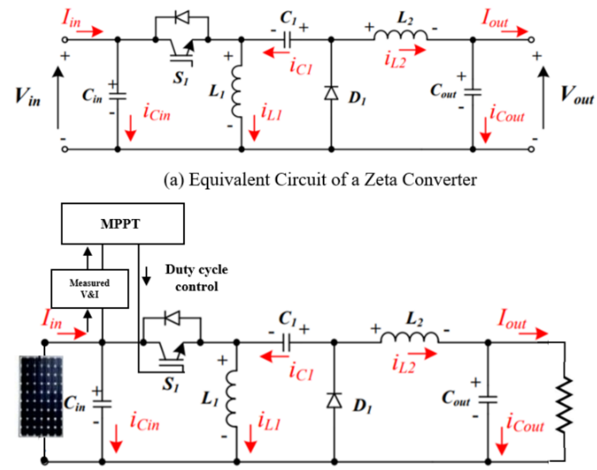
many circuits can track maximum power, including Buck circuits, Boost circuits, Buck-Boost circuits, Cuk circuits, Sepic converters, and Zeta converters [4]. The performance of photovoltaic power generation systems can increase by analyzing the soiling level identification of solar PV panels for cleaning planning. By applying the combination of image processing and neural network techniques to identify the soiling level of the PV panel [5]. Study DC-DC converter-based solar fed PV array system which can increase the efficiency of operated with Maximum Power Point Tracking (MPPT) control algorithm. Applying The Zero Voltage Switching (ZVS) technique can reduce the ripple voltage owing to junction capacity discharge [6]. The current status of MPPT methods for PV systems which are classified into eight categories. The characteristics and eleven selection parameters were applied to comprehensive analysis, and the selection of the MPPT technique should be based on the specific application and requirement of the utility [7]. The MPPT algorithm and the water-cooling system can remove heat and track the maximum power of a PV panel [8]. The MPPT is also applied to the on-off Control method, the rotor side converter of the wind turbine [9]. These converters are used in many circuits to draw the maximum power because they can lower the voltage and increase the voltage in a single circuit.

So, in this article, the Zeta converter circuit has been applied because of its distinctive feature: it can increase or decrease the voltage level, has a low ripple voltage, and supported high energy. Also, a Fixed Percentage of the Open-circuit Voltage method (FPOV) has been added to the Zeta converter circuit, making the circuit more efficient [10]. The Zeta converter circuit is developed from a Cuk converter and a Sepic converter, in which an LC inside the circuit at the output side acts as a good low pass filter. The MPPT was performed by the FPOV, as it can track maximum power quickly and conveniently [11-14]. Therefore, this article studies the enhancement of the MPPT for solar power generation using the ZETA Converter Circuit with the FPOV method. This paper was divided into both the simulation and the experimental sectors. The Psim program was used for simulation.

2. ZETA CONVERTER CIRCUIT

The Zeta converter circuit works as an increase or decrease of the voltage level. The output voltage is in the same direction as the input voltage, and there is an LC low pass filter on the output. The connection between the input and output of the Zeta converter circuit uses a capacitor, unlike a buck converter circuit and a buck-boost converter circuit that uses inductors to connect the input and output. The advantage of the Zeta converter circuit is that the current and the harmonic voltage on the output are low [15, 16]. A Zeta converter circuit consists of three capacitors, two inductors, one MOSFET, and one diode, as shown in Figure 1.



(a) Equivalent Circuit of a Zeta Converter

(b) Model of PV module with Zeta Converter

Fig. 1. MPPT implementation circuit using Zeta Converter.

Zeta converter circuit operation

In order to analyze the operation of the zeta converter circuit, it is necessary to set the circuit to operate in a stable state and define the operating conditions of the Zeta converter circuit as follows [17].

1) The large inductance results in the current flowing through the inductance constant.

2) The large capacitor results in a constant voltage across the capacitors.

3) The current and voltage at each period are equal.

4) The input power is equal to the output power. In this case, the losses caused by circuit operation are not taken into account. Since every device is ideal, the total efficiency of the circuit is one hundred percent.

5) The current conduction period is DT and the stopping moment is (1-D)T.

Start by finding the mean voltage across the capacitor C_{fly}, starting with the outermost voltage equation. The mean voltage across the inductors in each period is zero $V_{L1} = V_{L2} = 0$, and the mean voltage across the capacitor C_{fly} is in (1) and (2).

$$-V_s + V_{L1} - V_{C1} + V_{L2} + V_o = 0 \tag{1}$$

$$-V_s - V_{C1} + V_o = 0$$

$$V_{C1} = V_o - V_s \tag{2}$$

The equation for the current flowing through the capacitor C_{fly} can be found in equation (3).

$$i_{C1,on} = I_{L2} \tag{3}$$

Consider when a switch is not conducting current. The current flowing through both inductors will flow in the direction that the diode conducts. Therefore, the current in the capacitor C_{fly} will be as equation (4).

$$i_{C1,off} = I_{L1} \tag{4}$$

The input power is equal to the output power as in (5). In this case, the losses caused by circuit operation are not taken into account. Since every device is ideal, the total efficiency of the circuit is one hundred percent.

$$V_s I_{L1} = V_o I_{L2} \tag{5}$$

The current and the voltage at any point in each period are equal to the same value because it is the active state and the average current in the capacitor is equal to zero. Equation (6) while the switch conducts current and equation (7) while the switch does not conduct current.

$$i_{C1,on}(DT) + i_{C1,off}(1-D)T = 0 \tag{6}$$

$$(-I_{L2})(DT) + (I_{L1})(1-D)T = 0 \tag{7}$$

$$\frac{I_{L1}}{I_{L2}} = \frac{D}{1-D} \tag{8}$$

The input power is equal to the output power in equations (9) and (10).

$$P_s = P_o$$

$$V_s I_{L1} = V_0 I_{L2} \tag{9}$$

$$\frac{I_{L1}}{I_{L2}} = \frac{V_o}{V_s} \tag{10}$$

Thus, the voltage gain is obtained in equation (11).

$$\frac{V_o}{V_s} = \frac{D}{1-D} \tag{11}$$

The ripple value of the output voltage can be obtained just like a Buck converter circuit in equation (12). The explanation is that the Zeta converter circuit's output is similar to that of a Buck converter; it has an LC low-pass filter and a current flowing through an inductor, just like a Buck converter.

$$\frac{\Delta V_o}{V_o} = \frac{1-D}{8L_2C_o f^2} \tag{12}$$

When calculating the ripple voltage in the C_{fly} while the switch does not conduct current, the current flowing through the inductor and the capacitor C_{fly} are equal. In terms of operating conditions, the inductance is large, the current flowing through the inductor is constant as equation (13), which can be rewritten as equation (14).

$$\Delta V_{Cfly} \approx \frac{1}{C_{fly}} \int_{DT}^{T} I_{L1} d(t) \tag{13}$$

$$\Delta V_{Cfly} \approx \frac{1}{C_{fly}} I_{L1}(1-D)T \tag{14}$$

From Equations (10) and (11), reformat to find I_{L1} and V_o get Equations (15) and (16).

$$I_{L1} = \frac{V_o}{V_s} \times I_{L2} \tag{15}$$

$$V_o = V_s\left(\frac{D}{1-D}\right) \tag{16}$$

So, the ripple of C_{fly} voltage is shown in equations (17) and (18).

$$\Delta V_{Cfly} \approx \frac{V_s}{C_{fly}Rf}\left(\frac{D^2}{1-D}\right) \tag{17}$$

$$\Delta V_{Cfly} \approx \frac{V_o D}{C_{fly}Rf} \tag{18}$$

Likewise, when looking for the current ripple value, it can be found from the equation of the voltage across the inductor L_1, which can be written as Equations (19) and (20).

$$V_{L1} = V_s = L_1 \frac{di_{L1}}{dt} \tag{19}$$

$$\frac{\Delta i_{L1}}{DT} = \frac{V_s}{L_1}$$

$$\Delta i_{L1} = \frac{V_s}{L_1} DT = \frac{V_s D}{L_1 f} \tag{20}$$

Hence, the ripple current in L_2 can determine from the voltage across L_2, and it can be written as equations (21) and (22).

$$V_{L2} = V_o + (V_s - V_o) = L_2 \frac{di_{L2}}{dt} \tag{21}$$

$$\Delta i_{L2} = \frac{Vs}{L_2} DT = \frac{V_s D}{L_2 f} \tag{22}$$

Hence the operating parameters in the mode of current flowing through a continuous inductor are shown as equation (23) - (27), which is a condition in which the most negligible designed inductance is obtained and operated at continuous current mode [18].

$$L_{1,\min} = \frac{(1-D)^2}{2Df} \times R \tag{23}$$

$$L_{2,\min} = \frac{(1-D)}{2Df} \times R \tag{24}$$

$$C_{fly} = \frac{I_o \times V_o}{(V_s + V_o) \times f \times V_{ripple}} \tag{25}$$

$$C_{in} = I_o \times \frac{1}{2 \times f \times I_{ripple} \times V_s} \tag{26}$$

$$C_o = \frac{1 - D}{8 \times L \times V_{ripple} \times f^2} \tag{27}$$

Fixed Percentage of the Open-circuit Voltage (FPOV)

The FPOV method is based on the voltage at the maximum power, linearly related to the closed-circuit voltage, with the voltage at the maximum power of approximately 76 percent of the open-circuit voltage. However, the open-circuit voltage is not constant over time, so this method works periodically by cutting off the load to measure the open-circuit voltage to find the Maximum power [19].

3. RESEARCH METHODOLOGY

A power sim program is a program commonly used to simulate power electronic circuits and electrical circuits. It is ideal for simulating motor drives with digital control and renewable energy conversion. In this paper, Power sim programs were used to simulate the operation of the Zeta converter circuit [20-22]. Figure 2 shows the parameter setting of solar modules in the Power sim program, the equivalent circuit of a photovoltaic power generation system with a Zeta converter, as shown in Fig. 3. When the circuit is designed with a Psim program, the Zeta converter circuit used for testing was obtained, as shown in Fig. 4.

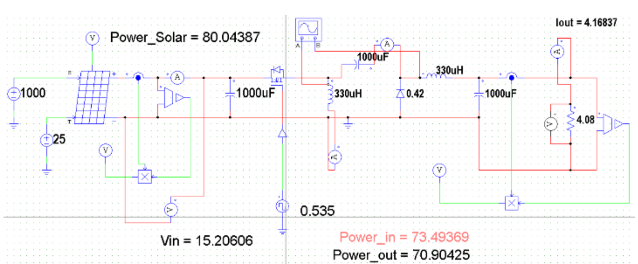


Fig. 2. Solar Module in the Psim program.

This article aims to design and simulate results with the Power sim program, and it is then built into a circuit for the actual testing. The Bangkok Thonburi University area, Central Thailand, is used as a case study area. The study results can be shown in the next section.

4. RESULTS AND DISCUSSION

This simulation collects both the voltage and current generated and traces the solar panel's maximum power to bring the results obtained to compare with the actual experiments. The simulation has conducted a comparison of the efficiency of voltage ripple and ripples current. The voltage and current signals generated at the inductor simulate the operation of the Zeta converter circuit. Figure 5 shows the simulation of the maximum power draw of a photovoltaic system with a Zeta converter circuit using the Psim program.

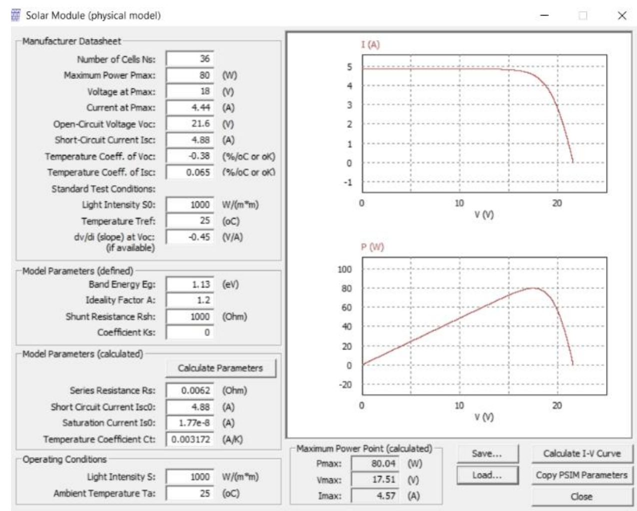


Fig. 3. Equivalent circuit of a photovoltaic power generation system with Zeta converter.

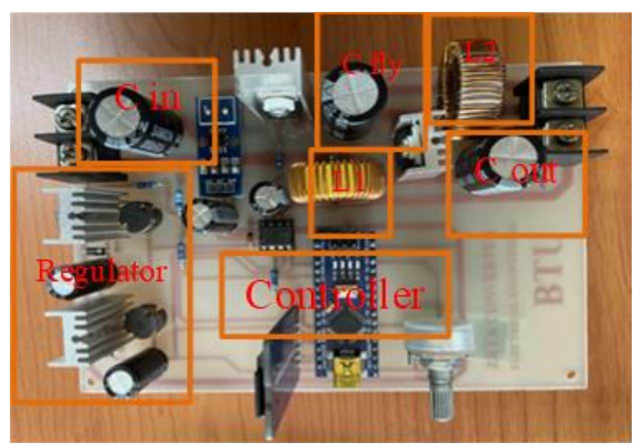


Fig. 4. The implementation of a photovoltaic power generation system with a Zeta converter.

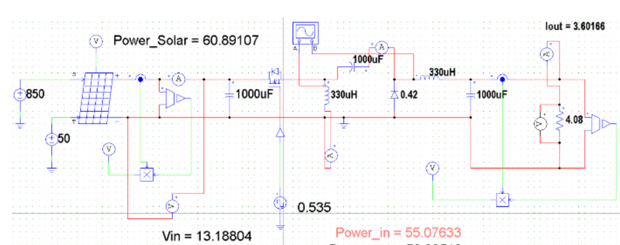


Fig. 5. The MPPT of a solar system with a Zeta converter circuit using the Psim program.

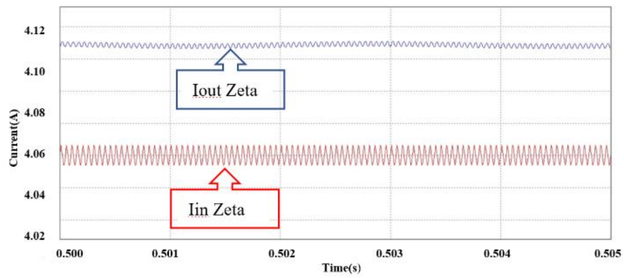


Fig. 6. The upper side's ripple current waveform is the output current, and the lower side is the input current.

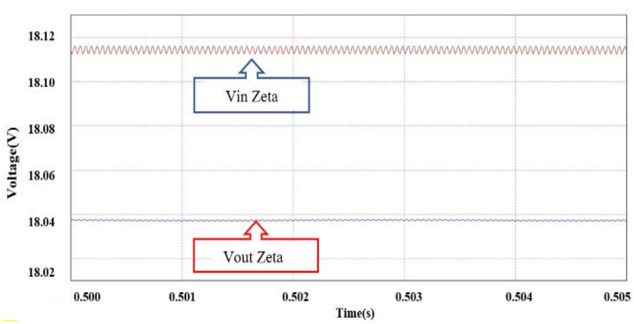


Fig. 7. The ripple voltage waveform, the upper side is the output current, and the lower side is the input current.

Figure 6 shows the ripple current of the zeta converter circuit, in which the simulation results show that the ripple current on the input side is more than the ripple current at the output side due to the output side. The circuit consists of the inductors and capacitors, characterized by a low pass filter, making the harmonic current on the output more minor than the input current. Concerning the current increase, the ripple current on the input side increased by 0.32%, as the input side has a MOSFET and a capacitor. On the other hand, the ripple current on the output side shows that the ripple current decreased at 0.04% when the current increase. Figure 7 shows the simulation result of the voltage occurring on both the input and output sides. It is found that the input ripple voltage is 0.75% higher than the output ripple voltage of 0.64%. The simulation results compare the input power and output power of the Zeta converter circuit and the maximum power of the photovoltaic panels, which will show the simulation results from the Psim program, as shown in Figure 8.

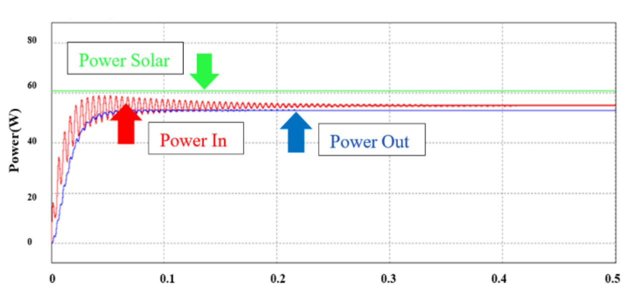


Fig. 8. Comparison of the input power and output power of the Zeta converter circuit.

From the experiment and recording the power, determining the maximum power point every 1 hour by adjusting the V_{ref} from 11-19 V, it can be seen that the V_{ref} at 16 V is the most efficient at drawing the maximum power and plot the graph of the relationship of time and power as shown in Figure 9. Figure 10 shows the inspected daily power from implementing a photovoltaic power generation system with a Zeta converter. The results show that the PV power generation system will produce a higher power when applying the Zeta converter circuit than without the Zeta circuit. The power generation without the Zeta converter circuit, the maximum power produced is 43.21 W, but when applying the Zeta converter circuit, the maximum power increases to 72 W.

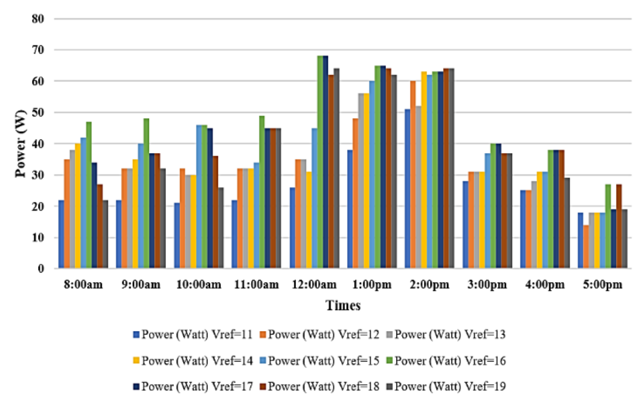


Fig. 9. Determination of the voltage magnitude that produces the maximum power.

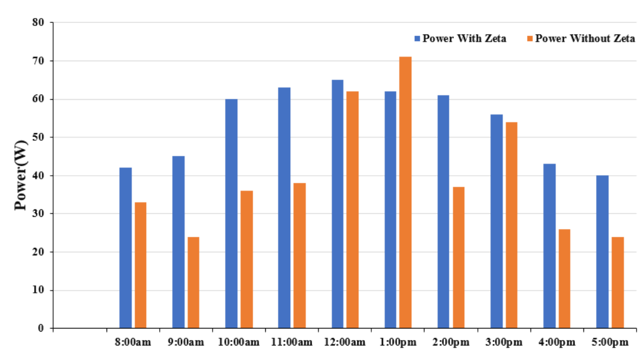


Fig. 10. The PV power with the Zeta converter circuit.

5. CONCLUSION

The production of electricity by solar power generation systems in Thailand is on the rise. Therefore, increasing the efficiency of the solar power generation system is an important issue. One way to optimize a solar power generation system is to track the solar system's power. In this article, tracking maximum power by the Zeta converter circuit with the FPOV method was proposed. The FPOV method can be used effectively for maximum power point tracking by fixed the voltage of 16 V. The MPPT with Zeta circuit can stabilize the voltage better than without Zeta circuit, the maximum power of 72 W at 01.00 pm. The use of solar power generation systems is on the rise, so devices that can help increase power generation efficiency are also necessary.

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