Zeta Converter Design for Solar Power Generation System with Controller Using Arduino Microcontroller

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ABSTRACT

Solar power plants (PLTS) are a promising solution to meet the need for clean and sustainable energy. One type of efficient power converter used in PLTS to regulate the output voltage of solar panels is the Zeta Converter. In this study, we propose a Zeta converter design integrated with an Arduino microcontroller to improve the performance and control of the PLTS system. The system control uses the pulse-width modulation (PWM) control method controlled by the Arduino microcontroller. This article details the design and implementation of a Zeta converter using an Arduino microcontroller, as well as analyzing system performance based on simulation and testing results. The use of solar energy as a renewable electricity source is growing as part of an effort to reduce dependence on fossil fuels. An efficient Zeta converter is one alternative that can be applied in a PLTS system. In this study, we present the design of a Zeta converter controlled by an Arduino microcontroller to maximize the utilization of solar energy and regulate the output voltage according to the required load. This article discusses the design and implementation of a Zeta converter using an Arduino microcontroller, as well as analyzing system performance based on simulation and testing results.

Keywords: Zeta Converter, Solar Energy System, Microcontroller

I.INTRODUCTION

With the development of increasingly advanced technology today, the demand for electricity supply is also increasing. Therefore, it is necessary to develop a larger electricity generation capacity. To overcome this challenge, the use of renewable energy resources is becoming increasingly important in everyday life. Electricity generation today no longer depends on fossil fuels as a source of electricity generation; instead, renewable energy sources such as solar power have become one of the options that will not run out. [1]

The use of solar power plants (PLTS) is increasingly popular as a solution to produce clean and environmentally friendly energy. To optimize the use of energy from solar panels, an efficient power converter is needed that is able to regulate the output voltage according to the load requirements. One effective option to overcome this challenge is to use a Zeta Converter. Zeta Converters offer several advantages, including the ability to increase or decrease the input voltage, a high level of efficiency, and a simple design. The purpose of this study is to design a Zeta Converter integrated with an Arduino microcontroller to improve the performance and control of the PLTS system. The Arduino microcontroller is used to control the Zeta Converter duty cycle using the Pulse-Width Modulation (PWM) method. This control approach allows for accurate and responsive output voltage regulation to load changes. This article will discuss the design details of the Zeta Converter, including component selection, circuit design, and Arduino microcontroller implementation. The

PWM control method used and the results of system testing will be explained in full. The performance evaluation of the Zeta Converter design based on the Arduino microcontroller in the PLTS system will be presented based on simulation and testing results. [3]Through the design of the Zeta Converter that integrates the Arduino microcontroller, it is expected to significantly increase the efficiency and control of the PLTS system. The use of the Arduino microcontroller allows for very flexible and accurate settings for the output voltage according to load demand. The hope of this research is a contribution to the development of more efficient and reliable PLTS technology, which is expected to have a positive impact on meeting the need for clean and sustainable energy. [4]

1.1 Solar Panels

Solar panels are devices that function to convert solar energy (energy from the sun) into electrical energy. Solar panels consist of a number of solar cells arranged in series to produce a typical operating voltage. The characteristics of the IV (current-voltage) and PV (power-voltage) curves of solar panels can be seen in Figure 1. [5]

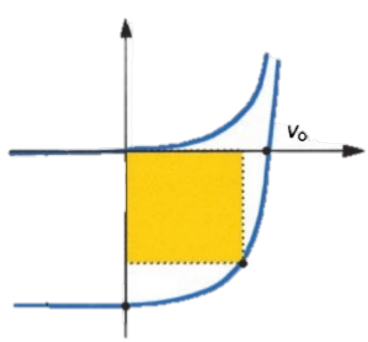


Figure 1. Characteristics of Solar Panels

1.2 Zeta Converter

The ZETA converter is a type of DC-DC converter used to increase or decrease the output voltage with minimal voltage levels in the waveform. Like the SEPIC converter, the ZETA converter also requires two inductors and two capacitors. The ZETA converter operates in continuous conduction mode (CCM) conditions, similar to the SEPIC converter topology. Just like in the SEPIC converter, the ZETA topology allows the generation of a positive output voltage from an input voltage that can vary above or below the desired output voltage. The components in the ZETA converter circuit include two capacitors, two inductors, one ultrafast diode, and one P-channel MOSFET, which are arranged according to Figure 6 (a). To better understand how the ZETA converter works in continuous conduction mode (CCM) conditions, analysis is carried out for on and off state conditions. [7], [8]

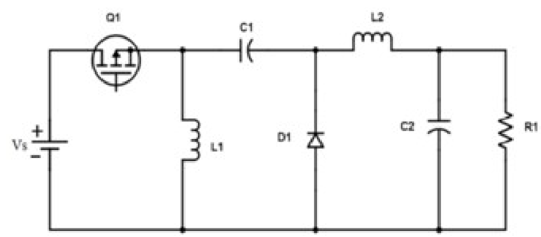


Figure 2. Zeta Converter Circuit

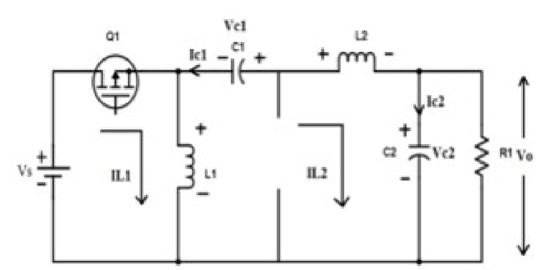


Figure 2b. State Off Condition on Zeta Converter

When in the on state, which indicates that transistor Q1 is active as seen in Figure 6 (b), this causes diode D1 to be in a reverse bias state or not conducting. At this time, inductor L1 is charged with voltage from the power source, while inductor L2 is charged from capacitor C1. As a result, in this condition, the current in both inductors increases linearly. When in the off state, which indicates that transistor Q1 is not active as seen in Figure 2.10, this causes diode D1 to be in a forward bias state or conducting. In this situation, inductors L1 and L2 will release energy through capacitor C1 and load R. Therefore, the current in both inductors will decrease because the inductor is in a state of releasing energy. The waveform of each component in the ZETA converter can be seen in Figure 7. When transistor Q1 is active, energy from the power source will be stored in capacitor C1, inductor L1, and inductor L2, and then inductor L2 will flow energy to the load. However, when transistor Q2 is in the off state, current from inductor L1 will continue to flow through capacitor C1, while inductor L2 will provide current to the load.[9][10]

The input voltage, output voltage and duty cycle (D) of the ZETA converter under CCM conditions can be calculated using the following equations:

1. Duty Cycle

$$Dmax = \frac{Vout}{VinMin+Vout}$$

$$Dmin = \frac{Vout}{VinMax+Vout}$$

Information:

D : Duty cycle

$Vout$:Output voltage (Volt)

$Iout$:Output current (Ampere)

Iin :Input current (Ampere)

2. Maximum Input Current $(IinMax)$
$$IinMax = IOut\ x\ (Dmax)/(1-DMax)$$
3. Current Ripple Estimation On Inductor When $VInMin\ (\Delta I\ L(ppD))$
$$\Delta IL(ppD) = \Delta IL\ x\ IinMax$$
4. Inductor Calculation
$$L1=L2=x\frac{1}{2}\frac{VInMin\ x\ DMax}{\Delta I\ L(ppD)\ x\ f}$$
5. Output Capacitor Calculation $(COut)$
$$COut=\frac{D\ Min}{8\ x\ \Delta\ Vout\ x Vout\ x\ f}$$
6. Clutch Capacitor Calculation
$$Cc = \frac{D\ Max\ x\ Iout}{\Delta\ Vin\ x\ Vout\ x\ f}$$
7. Load Resistor Value used
$$R=\frac{Vout}{Iout}[7]$$

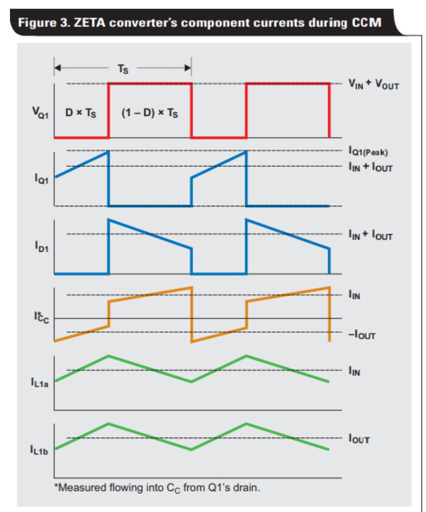


Figure 3. Waveforms of Each Component in Zeta [8]

When analyzing current and voltage in the open and closed switch conditions, it is necessary to look at the waveform depicted in Figure 3. In Figure 3, when the switch is on, capacitor C charges Vout and is connected in series with Lib, so the current passing through Lib is +Vin. On the other hand, in the condition when the switch is off, the voltage across Lib is the same as Vout because it is in parallel with Cout. Since Cout charges Vout, the voltage flowing through the switch when the switch is off is Vin + Vout, which results in the current flowing through Lia being –Vout. [11][12]

1.3 Arduino Uno R3

Arduino Uno R3 is included in the Arduino family which is a type of microcontroller. The specialty of Arduino is that it is open source, making it easy to use and develop. Arduino is powered by an Atmel AVR processor and uses a unique programming language, and has a variety of libraries available. Arduino Uno R3, in particular, is powered by the ATmega328p chip and has many pins on its circuit board. Please see Figure 1.6 to see the hardware components of the Arduino Uno R3. [13], [14]

Figure 4. Physical Form of Arduino Uno R3 (www.Arduino.cc)

Following are the specifications of the Arduino Uno R3, which are outlined in Table 2.2 below:

Microcontroller chip	**Atmega328P**
Operating voltage	5V
Input voltage (which recommended, via DC jack)	7V - 12V
Input voltage (limit, via DC jack)	6V - 20V
Digital I/O pin	14 pieces, 6 of which provide PWM output
Analog Input pin	6 pieces
DC current per I/O pin	20 Ma
DC current pin 3.3V	50 mA
Flash Memory	32 KB (Atmega328P), 0.5 KB has been used for bootloader
SRAM	2KB (Atmega328P)
EEPROM	1 KB (Atmega328P)
Clock speed	16 Mhz
Dimensions	68.6 mm x 53.4 mm

1.4 PWM (Pulse Width Modulation)

Pulse Width Modulation (PWM) is a form of modulation in which the ratio of positive and negative pulse widths is changed in a signal with a fixed frequency. This means that the total duration of one period (T) of the PWM signal remains constant. On the Arduino platform, PWM signals operate at a frequency of 500Hz. On the Arduino Uno board, pins that support PWM are marked with a tilde (~), such as pins 3, 5, 6, 9, 10, and 11[15][16]. PWM on Arduino operates at a frequency of 500Hz, with values that can vary from 0 to 255 in each cycle.[17]

Duty Cycle is the ratio of the duration of time in which a signal is in a conducting condition divided by the total time that includes both conducting and non-conducting conditions, then the result is multiplied by one hundred percent.[18]

PWM or Pulse Width Modulation is a signal modulation technique in which the duty cycle (the ratio between the time the signal is active and inactive) can be changed. The PWM technique is generally used in analog applications that are digitally controlled or using a microcontroller, especially when the microcontroller is not capable of generating analog voltage signals directly [19]. There are several methods for generating PWM signals, but they are basically divided into two types: analog methods and digital methods or using a microcontroller [20]. In the analog method, one of the simplest ways to generate a PWM signal is to compare a triangle or sawtooth signal with a reference voltage, as shown in Figure 2.15. The triangle or sawtooth wave is used as the carrier frequency which is also the frequency of the PWM output signal. The reference voltage determines the duty cycle of the PWM output signal.[9],[14]

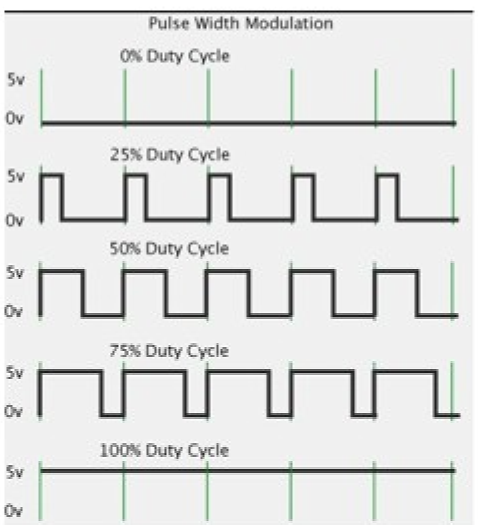


Figure 5. PWM width

II. RESEARCH METHOD

2.1 Hardware Design

The design of this research involves the creation of a rectifier circuit and a Zeta type direct current converter circuit.

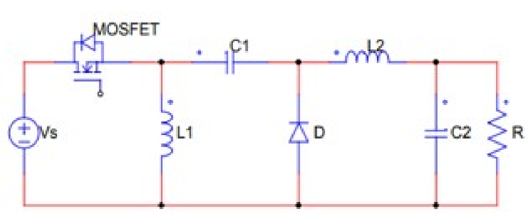


Figure 6. Zeta Converter Circuit

1. DC Voltage Source (Vin) The DC voltage required to power the converter comes from two renewable energy sources. The diode that functions as a resistor at the input aims to prevent reverse current from the higher voltage source to the lower voltage source.
2. The MOSFET switch used is the IRFZ 44N MOSFET with a Drain-Source voltage of 55V and a maximum drain current capacity of 49A, so the use of this IRFZ 44N type MOSFET is safe to use, considering that the average current flowing in the power circuit is 0.25A.
3. The diode used is the SR5100, which is a Schottky diode with the ability to conduct currents up to 5A and a voltage of 70V.
4. The inductor used in this DC converter is designed by considering its values to suit other related parameters. The inductor used is a solenoid type made of copper wire preserved on a ferrite core.[13]
5. Capacitor Cc acts as a connected capacitor, while capacitor Cout functions as a voltage filter to reduce voltage fluctuations that may arise due to changes in load value.

2.2Control Circuit

In this study, Arduino Nano is used as a microcontroller. To measure the current in the battery, the ACS712 current sensor will be used, while to measure the voltage, a voltage divider circuit is used.[11]

1. The Current Sensor used is the ACS712 sensor which operates based on the Hall Effect principle.

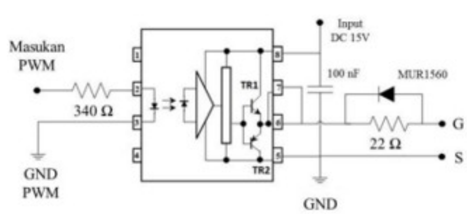
This principle explains that the flowing current will produce a magnetic field. This magnetic field is detected by the integrated hall IC and then converted into the appropriate voltage.

2. The Voltage Sensor works by using a voltage divider circuit to read the desired voltage. This circuit reduces the input voltage value and divides it with the help of two resistors.
3. In this study, the Arduino Nano microcontroller was used as a PWM value generator.[11]

2.3TLP250 MOSFET Driver Circuit

The TLP250 MOSFET driver circuit is used to amplify the PWM output signal from the microcontroller before going to the Zeta DC converter circuit with two inputs. Figure 3 shows the TLP250 MOSFET Driver circuit as follows:

Duty Cycle	Burden	Measurement Voltage (V)	Sensor Voltage(V)	Devariation (V)
10%	22	0.06	0.07	0.01
20%	22	0.16	0.15	0.01
25%	22	0.22	0.23	0.01
30%	22	0.29	0.29	0
35%	22	0.37	0.37	0
40%	22	0.46	0.44	0.02
45%	22	0.55	0.51	0.04
50%	22	0.67	0.66	0.01
55%	22	0.81	0.81	0



In Figure 7, the TLP250 gets a 15 V Vcc supply from the Flyback DC converter circuit. In the TLP250 circuit there is also a 100 nF bypass capacitor between the power supply IC and the output ground. The 22 Ω resistor connected to pins 6 and 7 goes toThe MOSFET gate functions as a current limiter for the TLP250 output signal.

2.4 Test Load

In testing the Zeta converter circuit with two inputs, two types of loads are used, namely resistor loads and accumulators. The accumulator used is a Panasonic accumulator with a nominal voltage of 12 volts and a capacity of 7.2Ah/10Hr.

Figure 8. Battery or Accumulator

III. RESULTS AND DISCUSSION

3.1 Control Circuit Testing

3.1.1 Arduino Nano PWM Testing

Figure 9 illustrates the PWM pin output with a duty cycle of 50% with a time scale and a voltage scale. The voltage produced by the Arduino Nano is 5 volts. [11] $t/¿=10\,\mu s\,V/¿=5V$.

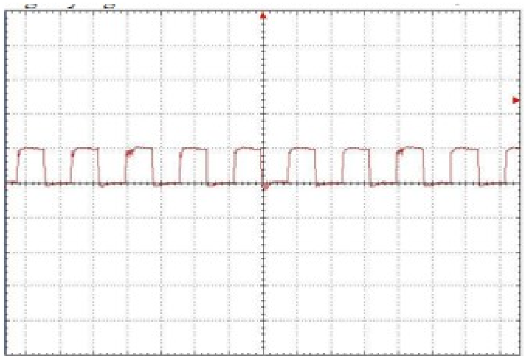


Figure 9. Arduino Uno R3 PWM wave

3.1.2 TLP250 MOSFET Driver Circuit Testing

In Figure 10, the output of the TLP250 is shown with a duty cycle value of 50%. On the time scale and voltage scale, the Arduino Nano produces a voltage of 15 volts, which is enough to activate the IRFZ44N MOSFET.$t/¿=10\,\mu s\,V/¿=5\,V$.

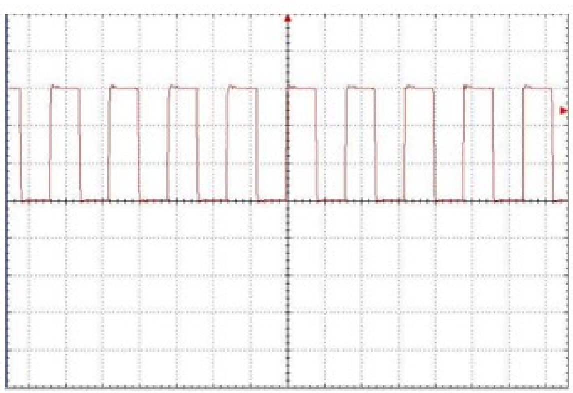


Figure 10. Arduino Uno R3 PWM Waveform with 50% Duty Cycle

3.1.3 Voltage Sensor Testing

Voltage sensor testing was carried out to compare the reading results obtained from the designed sensor with the voltage reading results measured using the Sanwa CD800a Multimeter.

Table 1. Comparison of measurement voltage with sensor voltage

Data to-	Measurement Voltage (V)	Sensor Voltage(V)	Devariation (V)
1.	9.43	9.78	0.35
2.	10.58	10.8	0.22
3.	11.31	11.53	0.22
4.	12.2	12.4	0.2
5.	13.27	13.4	0.13
6.	14.63	14.8	0.17
7.	15.65	15.8	0.15
8.	16.11	16.24	0.13
9.	17.63	17.8	0.17
10.	18.01	18.3	0.29

According to the data in Table 1, there is an average difference of 0.203 volts between the measured voltage reading and the reading given by the sensor.

3.1.3 Current Sensor Testing

The purpose of testing the current sensor is to compare the reading results of the designed current sensor with the current reading results using the Dekko DM133D Multimeter.

Table 2. Comparison of current measurement results with current sensors

Data to-	Measurement Voltage (V)	Sensor Voltage(V)	Devariation (V)
1.	9.43	9.78	0.35
2.	10.58	10.8	0.22
3.	11.31	11.53	0.22
4.	12.2	12.4	0.2
5.	13.27	13.4	0.13
6.	14.63	14.8	0.17
7.	15.65	15.8	0.15
8.	16.11	16.24	0.13
9.	17.63	17.8	0.17
10.	18.01	18.3	0.29

According to Table 2, there is an average difference of 0.011 volts between the measured current reading and the reading given by the sensor.

3.2 Testing the Zeta DC Converter Circuit

Testing the Zeta converter circuit includes two main aspects, namely testing the Zeta converter output voltage using voltage feedback, and testing the Zeta converter output current with feedback.

3.2.1 Testing the Zeta Converter Circuit with Voltage Feedback

Testing the Zeta converter circuit with voltage feedback is done by connecting the Zeta converter output to a voltage divider circuit, which functions as a voltage sensor. The output from this voltage divider circuit is then fed back to the Arduino Nano, so that the Zeta converter circuit operates in a closed loop condition. An illustration of the Zeta converter circuit with voltage feedback can be found in Figure 10, as described in references [13] and [15].

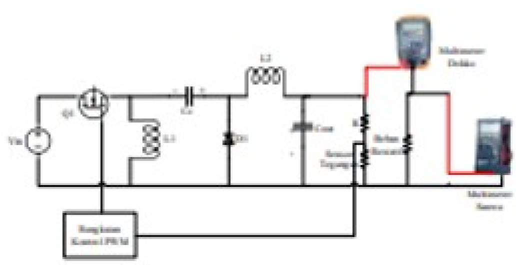


Figure 10. Zeta circuit with voltage feedback

Test data for the Zeta converter circuit with voltage feedback can be found in Table 3 below:

Table 3. Test Results of Zeta Converter Circuit with Voltage Feedback

Duty Cycle	Vin(V)	Lin(A)	Vout(V)	Iout	Load Ω
45.2%	17.58	0.28	13.48	0.32	39
45.2%	17.6	0.24	13.61	0.27	47
44%	17.68	0.19	13.53	0.21	57
43.8%	17.89	0.17	13.57	0.18	68
43.8%	17.75	0.17	13.5	0.16	78
43.8%	17.8	0.14	13.52	0.15	82
43.8%	17.78	0.11	13.51	0.13	95
43.8%	17.85	0.11	13.5	0.11	109
43.8%	17.85	0.10	13.56	0.10	120
43.8%	17.85	0.09	13.65	0.08	139

From Table 3, it can be seen that when the voltage setpoint is set at 13.5 volts, the output voltage of the Zeta converter is observed. The choice of 13.5 V voltage is because it is used for charging the accumulator at the float charge stage. Voltage feedback testing is carried out by varying the load using a 5 Watt stone resistor. The output voltage fluctuates in load variations, which is caused by oscillations in the output voltage. However, it should be emphasized that the output voltage value is still close to the desired setpoint.
Below is the accumulator charging test data presented in Table 5.

Table 5. Accumulator Charging Test Data

Duty Cycle	Burden	Measurement Voltage(V)	Sensor Voltage(V)
0	42.8	0.24	12.04
30	42.8	0.22	12.42
60	42.8	0.24	12.56
90	42.8	0.25	12.58
210	42.8	0.24	12.63
330	42.8	0.25	12.71
570	42.8	0.20.254	12.84
960	42.8	0.24	12.89
1020	42.8	0.24	12.91
1140	42.8	0.24	13.14
1290	42.8	0.24	13.25
1440	42.8	0.23	13.38

From Table 5 above, it can be seen that during the bulk charge phase, the current used ranges from 0.22 to 0.25 A. During the absorption charge phase, the voltage is maintained at 14.4 volts, and when entering the float charge phase, the voltage is changed to 13.5 volts. The accumulator charging process lasts for 1770. The accumulator charging process is stopped when entering the float charge phase

IV.METHODOLOGY (14 pt)

The test results show that the Zeta converter with voltage feedback successfully maintains the output voltage at 13.5 V with an average deviation of about 0.047 V. The average efficiency of the Zeta converter also reaches about 83.74%. In addition, the test with current feedback shows that the Zeta converter can maintain the output current at 0.1 A with an average deviation of about 0.015 A. In the accumulator charging test, the Zeta converter is able to charge the accumulator with a constant current in the bulk charge phase of 0.25 A. The voltage is also successfully maintained at around 14.4 V in the absorption charge phase, and when entering the float charge phase, the voltage remains at around 13.5 V.

V.RESULTS & DISCUSSION

The test results show that the Zeta converter with voltage feedback is able to maintain the output voltage at 13.5 V with an average deviation of about 0.047 V. In addition, the average efficiency of the Zeta converter reaches about 83.74%.

Testing with current feedback also shows that the Zeta converter is able to maintain a steady output current of 0.1 A with an average deviation of about 0.015 A.

In the battery charging test, the Zeta converter successfully charged the battery with a constant current in the bulk charge phase of 0.25 A. The voltage can also be kept constant in the absorption charge phase at around 14.4 V, and when entering the float charge phase, the voltage remains at around 13.5 V.

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1.Results

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2.Discussion

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VI.CLOSING

1.Awards

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