Design and Implementation of Zeta Converter based on PI-ABC Controller as a Battery Charging Control System with Solar Panel

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Abstract: The rapid development of innovation in the use of energy is one alternative that is used is to use sunlight. Solar panels have an important role in producing renewable electrical energy by converting light energy into electrical energy because of its abundant availability and low emissions which have relatively low output efficiency. However, based on its characteristics, solar panels produce electrical energy that fluctuates according to the amount of irradiance and temperature if operated under normal conditions, the power generated from solar panels will not be maximal and have low efficiency. In addition, the output power of the solar panel fluctuates because it is influenced by the level of light irradiation on the surface of the solar panel. In this study, to maximize solar panel power output and reduce output ripple is to use a constant voltage battery charging method using a zeta converter with a PI-ABC Controller as a solar panel output voltage controller from a zeta converter in order to produce a constant charging voltage according to the set point voltage of 14.4 volts. The output of the solar panel is the input from the zeta converter which is used to reduce the voltage with the PI-ABC Controller with the constant voltage method applied to the battery charging in order to increase efficiency in a fast response to battery charging. The output of the ABC controller which functions as a tuner for the KP value on the PI-ABC controller has a fixed Ki value. The efficiency generated during the close loop using the PI-ABC controller can reach 96.56%, while during the open loop system it reaches an efficiency of 83.36%.

1 INTRODUCTION

Significant progress has been made over the last few years with regard to research and development of renewable energy systems. Among the various renewable energy options available, solar energy is an inexhaustible source of energy and potential energy that is environmentally friendly so that it becomes an interesting issue related to environmental protection (Wolfe, 2018). Solar energy is one of the fastest growing renewable energies and is a very promising solution because it can reduce exhaust emissions of conventional vehicles by 92%. In fact, solar energy systems offer the advantages of low-cost fuel and lower maintenance. To make the most of the panel power, the voltage from the solar panel must be conditioned because solar cells have a characteristic graph between voltage, power and current. This relatively low output efficiency is due to differences in characteristics between solar panels and loads, and inconsistent output voltages due to weather changes that make the solar panel system non-linear (Indra, 2020). Therefore, a method is needed to maximize the output power of the solar panel.

One of the methods used to maximize the power output of the panel is to use a zeta converter as a DC-DC converter. The most suitable converter to overcome this weakness is the zeta converter which is used to control the solar panel output voltage and the duty cycle is very influential on the solar panel output voltage. , the output current can be continuous and free of ripples due to the presence of an inductor on the output side, and lower switching (Hilmi, 2017).

The zeta converter is a dc-dc converter that has the role of increasing and decreasing the voltage on the output side with low voltage ripple (Ahana Malhotra, 2016). The zeta converter method has better performance so that it can maximize the work of solar cells to be more efficient and effective than other methods (N. Sownya Smitha Raj, 2013). From the problem of irradiance changes, it causes changes in the output voltage of the solar panel and the duty cycle greatly affects the output voltage of the solar panel. So in this study, a constant output voltage

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controller was designed to output a zeta converter output voltage. The proposed method is to design a charging control system based on the PI-ABC Controller algorithm to track the set-point response and to reject interference due to external factors such as changes in solar radiation intensity (D. Pilakkat, 2018). The PI-ABC Controller is used to regulate the voltage, and the irradiation that will produce a duty cycle and the output voltage of the solar panel will be forwarded to the zeta converter for conversion to a lower dc voltage. effective for controlling PWM generation which functions to control the converter output voltage so that it is constant and the battery voltage can be controlled effectively (D. Pilakkat, 2018).

2 LITERATURE REVIEW

2.1 Zeta Converter

Zeta converter is a dc to dc converter in continuous conduction operating mode (CCM)(D.W.Hart, 2011). The zeta converter topology produces a positive output voltage from the input voltage up and down. Zeta converters also require two inductors and a series capacitor, commonly referred to as a flying capacitor. Zeta converter is configured from a buck controller that drives a high-side PMOSFET. This Zeta converter is run in CCM (Continuos Conduction Mode) conditions. There are two circuits in one switching period (T). When the switch is on and off. The zeta converter is shown in Figure 2.5. The zeta converter consists of an IGBT transistor as a switch, a diode and two capacitors C1 and C2 and two inductors L1 and L2 with the current load R. in the inductor increasing. When the switch is turned off, the diode will transfer energy to the capacitor. In this mode of operation, inductors L1 and L2 are in a state of releasing stored energy. The energy released from L1, is then charged to the capacitor C1 and the inductor L2 transfers the energy to the output circuit to the load.

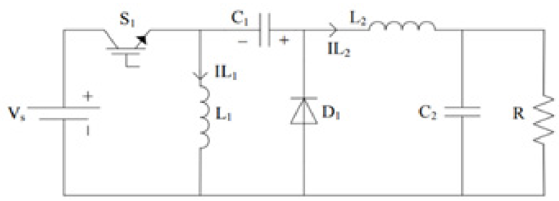

Figure 1: Zeta Converter Circuit.

The working principle of the zeta converter is that when the mosfet is off, the voltage that passes through L1b must be the output voltage as long as it is parallel to the output capacitor (Antonio, 2015). As long as the output capacitor is charged by the output voltage, the voltage across the mosfet when the MOSFET is off is Vin + Vout even though the voltage across L1a is -Vout relative to the drain of the MOSFET. When the mosfet is on, the coupling capacitor is charged by Vout which is connected in series with L1b, so the voltage across L1b is +Vin, and diode D1 is Vin+Vout. Figure 1, is a zeta converter topology, from this picture you can find out the working principle of the zeta converter.

2.2 Battery

A battery is a device consisting of two or more electrochemical cells that convert stored chemical energy into electrical energy. Batteries have two types of direct current (DC) source elements from chemical processes, namely primary elements and secondary elements. A chemical reaction in the primary elements that causes electrons to flow from the negative electrode (cathode) to the positive electrode (anode). Poles marked positive have a higher potential energy while negative to the external equipment. Electrolytes are ions producing chemical reactions at both poles. The working principle of the battery is if there is movement of the ions in the battery that drains an electric current out of the battery.

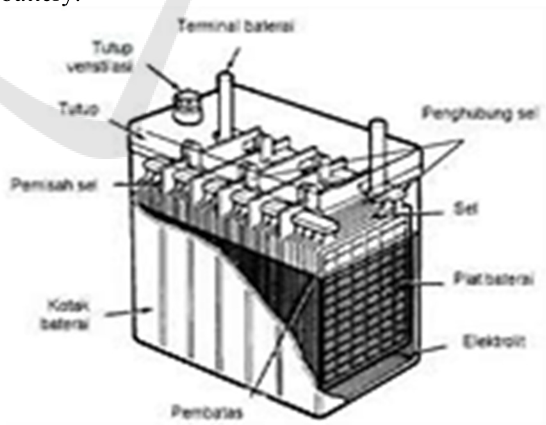

Figure 2: Battery.

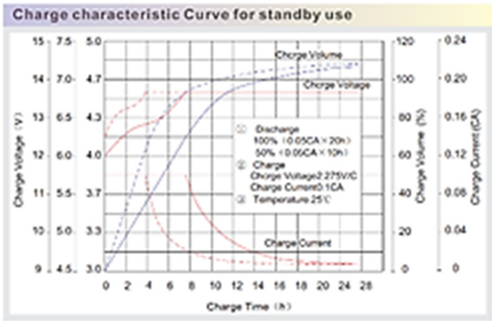

Figure 3: Charge characteristic Curve for standby use.

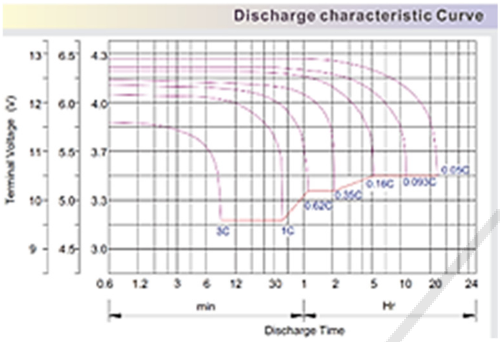

Figure 4: Discharge characteristic Curve.

2.3 Constant Voltage (CV)

There are various charging methods that can be used for the charging circuit. The methods differ in the way the electrical energy is delivered from the power supply to the battery. This method is a charging process that is carried out with a constant voltage from the beginning to the end of the charging process with the charging current continuing to decrease (David, 2001). Constant Voltage (CV) in this study the method used is a constant voltage during the charging process through a current source into the battery as an effort to force the battery voltage to reach the set point. At the beginning of the charging process with a large current, after a while the current will decrease according to the process. charging the battery until the current cannot flow so that the battery will be full and the battery charging process is complete. Figure 5, is a graph of the battery charging method used when charging the battery.

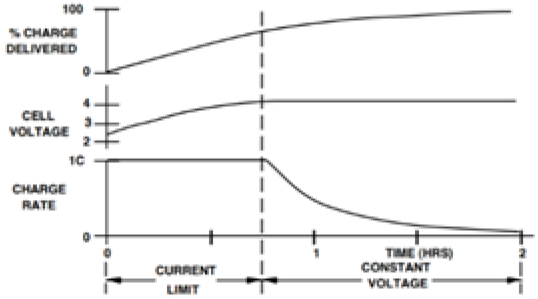

Figure 5: Battery Charging Method.

2.4 State Of Charge (SOC) Battery

Calculation of State Of Charge (SOC) is charging and balancing power on the battery. Estimation of the SOC can avoid damage to the internal battery that can result in overdischarged and overcharged. SOC can display the available energy in percentage of battery capacity that is utilized in the battery charging process (Omnia S.S, 2019).

SOC measurement of the battery can be done in several ways:

1. Voltage measurement can be carried out with a voltmeter or voltage sensor at battery power at a constant value

2. Measurement of Specific Graphity (SG) in this way is carried out depending on changes in the weight measurement of the active chemical.

3. Estimating SOC based on voltage by measuring battery cell voltage as the basis for calculating SOC or remaining battery capacity.

2.5 PI Control

PI Controller (Proportional Integral Controller) is a controller that can determine the precision of an instrumentation system with the characteristics of the presence of feedback on the system. The PI controller is a PID controller derivative where the derivative (D) is an error. So the following equation is obtained:

$$K_P + K_I \int edt \quad (1)$$

Where K_P and K_I are proportional and the integral gain is the error or derivative of the read value (MV) of the set point (SP).

$$e = SP - MV \quad (2)$$

The transfer function of the PI controller is given below:

$$G = K_P + \frac{K_I}{S} \quad (3)$$

General approach to PI tuning:
1. Initially set the gain integral to zero
2. Increase K_P until the response matches the setpoint
3. Adjusting the K_I gain until it is stable, there are no errors that affect the setpoint

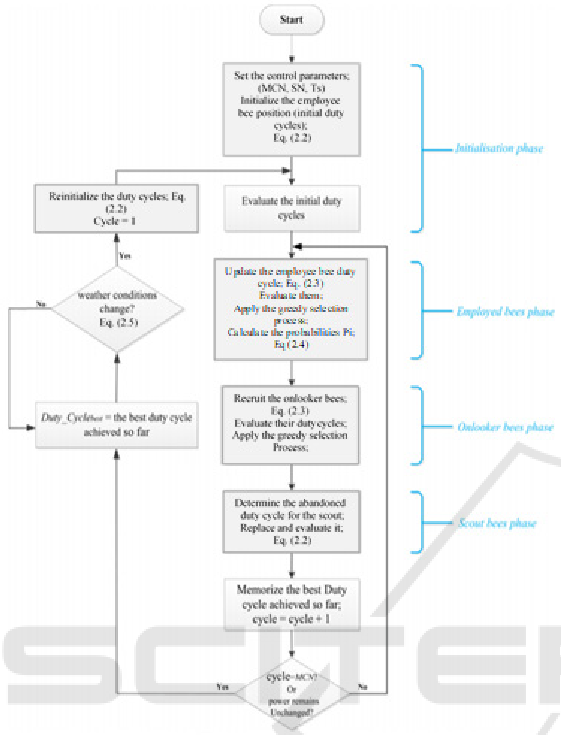

Figure 6: ABC Algorithm Flowchart.

2.6 Artificial Bee Colony (ABC)

In 2005, Dervis Karaboga introduced an optimum algorithm called Artificial Bee Colony Algorithm, which is based on the process of honey bees foraging. ABC has three groups that are distinguished based on their work. They are (A) employed bees, (B) onlooker bees and (C) scout bees. Fifty percent of all bee colonies consist of employed bees and another fifty percent are onlooker bees (D. Pilakkat, 2018). The ABC algorithm is stated as follows:
1. The first step, employed bees go to the location where previously identified there is nectar.
2. Employed bees will communicate with each other to notify the amount of nectar that has been found through waggle dance, the location with the less nectar amount will be forgotten and replaced with the more nectar location.
3. Employed bees will pass the memorized location on to the onlooker bees so that they go from hive to location to collect nectar
4. Meanwhile Employed bees become scout bees who go in search of new nectar locations.

In implementing the Artificial Bee Colony algorithm on GMPP the output power of the PV system is considered as the amount of nectar, and the duty cycle ratio of the converter is referred to as the position of the food source in the ABC algorithm. In order to better explain the steps in the Artificial Bee Colony algorithm, see the flowchart in Figure 6.

3 METHOD

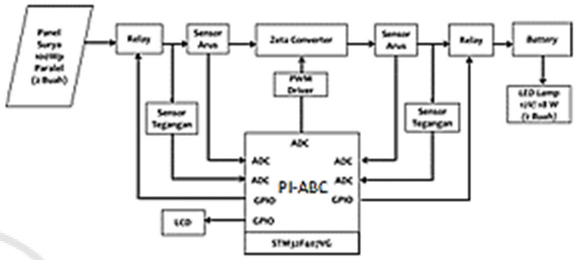

Figure 7: System Block Diagram.

From Figure 7, the system diagram above, the working principle is as follows:

In the block diagram there is a solar panel which is a supply source that is connected to the system. When the button is pressed, the system will control the voltage to match the set point. The system is equipped with a voltage sensor and a current sensor located on the input side of the converter and from the converter output it is used for sensing the ARM STM32F4 microcontroller as a duty cycle control reference for monitoring the amount of current and voltage on the output side of the converter. In the microcontroller the received data is processed and the results are continued to the ADC (Analog to Digital Converter).

The method used in the solar panel output voltage system uses a converter circuit. The selection of power efficiency on solar panels in this study can be done using a zeta converter which can increase and decrease the voltage according to the output output from the solar panel. will be on as cut off to disconnect charging. The system block diagram in Figure 7 describes the order in which the system will be created. Starting from the source of supply by using solar panels to dc loads.

4 PI-ABC CONTROLLER SYSTEM INTEGRATION SIMULATION

Testing the PI-ABC Controller system with a battery load is carried out with the aim of knowing the SOC of the battery charging system with the constant voltage method. In this battery charging simulation using a 12V/45 Ah battery according to the design by using SOC charging starting from 20% - 95%. battery on PSIM software. The battery load used in the following circuit uses a value of 12V/45Ah where the parameters of the battery circuit are obtained from the corresponding battery characteristic circuit in Matlab. Figure 8 is a series of system testing simulations with a Close-loop Battery Load.

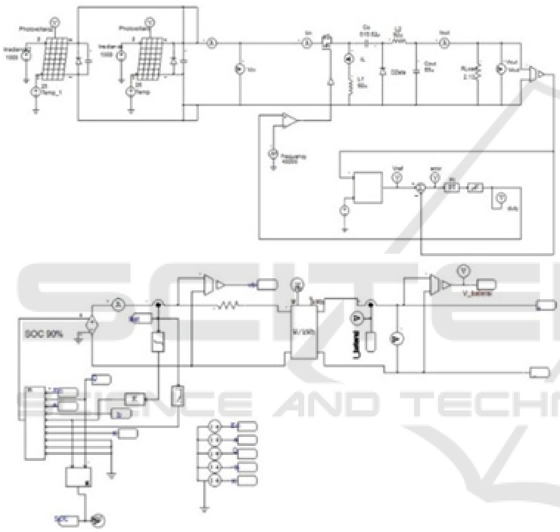

Figure 8: System Testing Simulation Circuit With Battery Load In Close Loop.

Table 1: Close Loop Simulation Test Data With SOC Battery.

Battery Load Close Loop Test		
SOC (%)	Vout(V)	Iout (A)
20	14,4	5,32
30	14,4	4,347
40	14,4	3,59
45	14,4	3,282
50	14,4	3,01
55	14,4	2,75
60	14,4	2,48
65	14,4	2,227
70	14,4	1,983
75	14,4	1,694
80	14,4	1,389
85	14,4	1,07
88	14,4	0,849
90	14,4	0,713
92	14,4	0,592
94	14,4	0,408
95	14,4	0,323

From the data in Table I. Testing the system simulation with a battery load in a close loop when the SOC of the 12 V/45 Ah battery is close to full, namely when the SOC is 95%, the condition of the battery charging process to a constant voltage with a charging voltage value of 14.4 V. This proves whether the control of the PI control combined with ABC works well when the charging voltage reaches the set point constant voltage, the duty cycle will continue to track so that the charging current decreases. In accordance with the characteristics of charging the battery, when the SOC of the battery approaches 100%, the output current of the charging process will approach 0 which means the battery is fully charged. In Figure 8 is the output voltage response when constant voltage

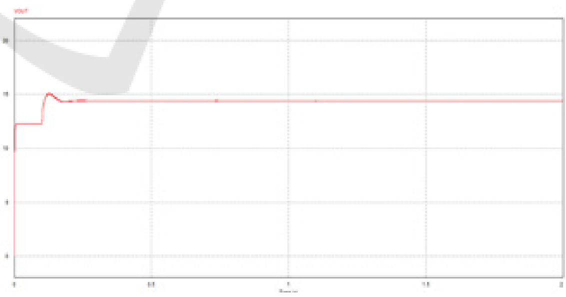

Figure 9: Output Voltage Response When Constant Voltage.

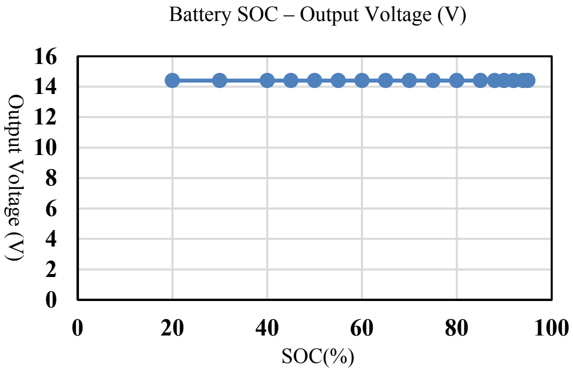

Figure 10: Output Voltage Response Graph With Close Loop Battery SOC.

In Figure 10, there are outputs, namely constant voltage testing and battery load testing in a loop, whether the control is working as expected. While in Figure 9. there is an output voltage response using a battery load. At the same time, the control value is set in the PI-control ABC by setting the Kp value so that the output is constant at 14.4 Volts. This is in accordance with the working principle of the charging system where the output voltage is constant because it uses a constant voltage method while the current decreases. Figure 11 is a graph of the output current response with the battery SOC.

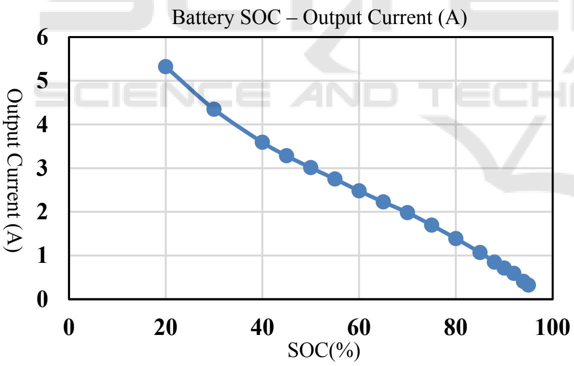

Figure 11: Output Current Response Graph With Close Loop Battery SOC.

In Figure 11. there is an output of the working principle of the charging system where the output current is against the SOC. In the graph it can be analyzed that when the SOC of the battery is close to 100% (in full condition) with the control set in the ABC control-PI it can be analyzed that the current value of charging the battery (battery) will approach 0, according to the results of the battery close loop simulation test data. using PSIM in table I, when the initial SOC of charging the battery was recorded at 5.32 A, the parameter after the battery was full with 100% SOC recorded a current of 0.323 A. From the graph of the output current response to the SOC of the battery, it can be said that it is in accordance with the characteristics of battery charging in general.

5 CONCLUSIONS

After carrying out the testing planning process and analysis as well as comparing with supporting theories, it can be concluded that: Controlling the ABC-PI as a zeta converter output voltage controller is able to have a value of set points (14.4 volts). The average efficiency of taking Close loop data in simulation with PSIM software can reach 94.6%. When the system is given the influence of non-linear photovoltaic characteristics, the system can control it according to the set point, so it can be said that the ABC-PI control can work well.

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