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Design and Simulation of Single Input Double Output Coupled Inductor Boost Converter with Bisection Method for Independent Home Application

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Abstract—**This paper proposed a converter design that functions as a voltage booster, increasing the input voltage while supplying two load outputs from a single voltage input using only one switch. Known as a single input double output (SIDO) converter, it aims to enhance power efficieny. The bisection method is employed as an output voltage controller through pulse width modulation (PWM) to achieve an optimal voltage value, adjusted to meet the load requirements. The loads used for inde-pendent home applications include a 72 V/12 Ah battery and a 24 V/22 W water circulation pump. The output of the high voltage level acts as a battery charger while the output of the low voltage level serves as an energy supply for the water cir-culation pump. The two loads were chosen because they are widely used, aligning with the goal of realizing independent home applications. The simulation test results showed that the voltage output for battery charging in constant voltage mode was 80.6 V, with an error of 0.0515%, and the voltage output for the water circulation pump was 24 V, with an error of 0.33%.**

Keywords: ***bisection method, boost converter, coupled inductor, single input double output***

I. Introduction

In today's world, energy conversion plays a crucial role in meeting various needs. One of the most important processes is converting energy into electricity, especially through the use of solar energy (solar cells) or light energy. Solar energy is an excellent choice because it is a renewable natural resource that can be harnessed continuously. This is particularly advantageous for Indonesia, which is located along the equator and receives sunlight throughout the year. Using solar energy as a renewable resource is an important step in reducing reliance on non-renewable resources like coal, natural gas, and petroleum, which are becoming increasingly scarce. Non-renewable energy sources are not only expensive but also contribute to global warming due to the harmful byproducts they release into the environment. By converting sunlight into electricity, Indonesians can access affordable and sustainable energy while contributing to efforts to protect the environment for future generations. Solar panels are essential in this process, as they convert sunlight into electrical energy in the form of direct current (DC).[1], [2], [3], [4].

To maximize the use of solar energy, a DC-DC converter is developed to support the use of electrical energy for household needs. For greater efficiency, a DC-DC converter, specifically a coupled inductor boost converter, is designed to generate an output voltage that is higher than the input voltage [5]. Furthermore, this coupled inductor boost converter uses a single voltage source to power two loads simultaneously, requiring only one switching operation, a technique known as a single-input double-output system. This design also simplifies the switching control system and reduces overall costs [6], [7]. To ensure both output voltages remain at optimal levels, the bisection method is applied. This method effectively controls the pulse width modulation (PWM) used in the switching process of the coupled inductor boost converter circuit [8], [9]. The bisection method offers several advantages over artificial intelligence, artificial neural networks, or fuzzy logic methods. These include computational simplicity, faster tracking of the desired set point, and lower implementation costs [10]. The loads used are a 72 V/12 Ah battery, which will be charged in constant voltage mode, and a 24 V/22 W water circulation pump. These loads are commonly utilized to meet the expectations for independent home applications.

The distinguishing characteristic of this work compared to previous studies is the use of a coupled inductor boost converter with a battery load and a water circulation pump, which are commonly used by many people. Additionally, this study attempts to utilize the bisection method as a voltage control for the battery load to maintain the charging voltage in constant voltage mode.

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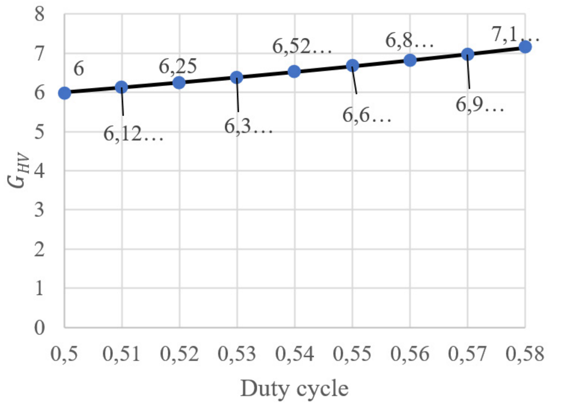

Figure 1. Relationship of G_{HV} voltage gain with duty cycle under turn ratio ($N = 2$)

II. Theoretical Background

A. Coupled Inductor Boost Converter Modeling

A converter topology is designed to produce two DC voltage levels on the output side with one DC voltage supply source. The creation of this converter is based on the concept of zero current switching (ZCS), coupled inductor, passive clamped network/clamped circuit, and medium energy storage capacitors that can be calculated using the following equations:

$$N = \frac{N_S}{N_P} \tag{1}$$

$$G_{HV} = \frac{V_{out2}}{V_{in}} = \frac{N+1}{1-D} \tag{2}$$

where N is the turning ratio, N_S and N_P respectively are the secondary and primary turns, G_{HV} is the gain of high voltage, V_{out2} is output voltage at battery side, V_{in} is input voltage, and D is duty cycle.

Based on (2), the value of for battery charging is 80.6 V with the value of as the input voltage of the converter of 12 V, thus the value of the G_{HV} is 6.71. With the value of the turning ratio (N) is 2, the appropriate duty cycle value is 0.56. Figure 1 shows the relationship between the G_{HV} and duty cycle with the winding ratio value is obtained. Furthermore, the coupled inductor can be modeled like an ideal transformer by including the turning ratio, air gap, and magnetizing inductor:

$$\Re_g = \ell_g / \mu A_c \tag{3}$$

$$L_m \approx \frac{N_P^2}{\Re_g} \tag{4}$$

$$L_m = L_P \tag{5}$$

$$L_S = N^2 \times L_P \tag{6}$$

where $\Re_g$ is the reluctance, ℓ_g is air gap, μ is reluctance, A_c is core section area, L_m is inductor magnetization, L_p is primary inductance, and L_s is secondary inductance.

For component such as auxiliary inductor that function as suppliers and supporters for DC pump loads, resistors, diodes, and capacitors are set with parameters to support the optimal performance of the system to be made listed in equations as below:

$$R_{o1} = \frac{V_{\text{out 1}}}{I_{\text{out 1}}} \tag{7}$$

$$R_{o2} = \frac{V_{\text{out 2}}}{I_{\text{out 2}}} \tag{8}$$

$$G_{LV} = \frac{V_{\text{out 1}}}{V_{\text{in}}} = \frac{2}{(1-D)+\sqrt{(1-D)^2+\left[\dfrac{8L_{\text{aux}}}{R_{o1}T_S}\right]}} \tag{9}$$

$$C_{o1} = \frac{(D-D_x)}{(R_{o1}\cdot f)\cdot\left(\dfrac{\Delta V_{\text{out 1}}}{V_{\text{out 1}}}\right)} \tag{10}$$

$$C_{o2} = \frac{D}{(R_{od}\cdot f)\cdot\left(\dfrac{\Delta V_{\text{out 2}}}{V_{\text{out 2}}}\right)} \tag{11}$$

where R_{o1} and R_{o2} respectively are the resistance at DC pump and battery side, I_{out1} and V_{out1} respectively are the current and voltage at DC pump side, I_{out2} is the current at battery side, G_{LV} is the gain of low voltage, L_{aux} is the auxiliary inductance, T_S is period, C_{o1} and C_{o2} respectively are the capacitance at DC pump and battery side, D_x is duty cycle in DC pump side especially not main duty cycle, ΔV_{out1} is ripple design of voltage at DC pump side, ΔV_{out2} is ripple design of voltage at battery side and f frequency.

The design of the coupled inductor boost converter includes the duty cycle value obtained from the substitution of the value of the winding ratio on the coupled inductor to achieve the output voltage value for charging the battery in (2). The capacitor filter on the second side of the load serves to reduce the voltage ripple in (10) and (11). The output current value on the battery side is obtained from 30% of the designed battery capacity and the output current on the DC pump side is obtained to meet the power

Table 1. Specifications of coupled inductor boost converter

Parameters	Values
Input voltage (V_{in})	12 V
Voltage at battery side ($V_{out\,2}$)	80.6 V
Voltage at DC pump side ($V_{out\,1}$)	24 V
Current at battery side ($I_{out\,2}$)	3.6 A
Current at DC pump side ($I_{out\,1}$)	0.91 A
Resistance at battery side (R_{o2})	22.38 Ω
Resistance at DC pump side (R_{o1})	26.37 Ω
Capacitance at battery side (C_{o2})	136 µF
Capacitance at DC pump side (C_{o1})	111 µF
Auxiliary inductor (L_{aux})	19.6 µH
Primary inductor (L_P)	24 µH
Secondary inductor (L_S)	96 µH
Frequency (f)	20 kHz

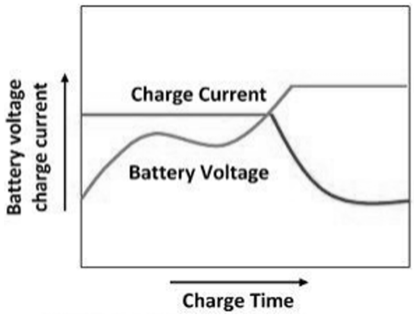

Figure 2. Constant voltage (CV) mode for charge battery [8]

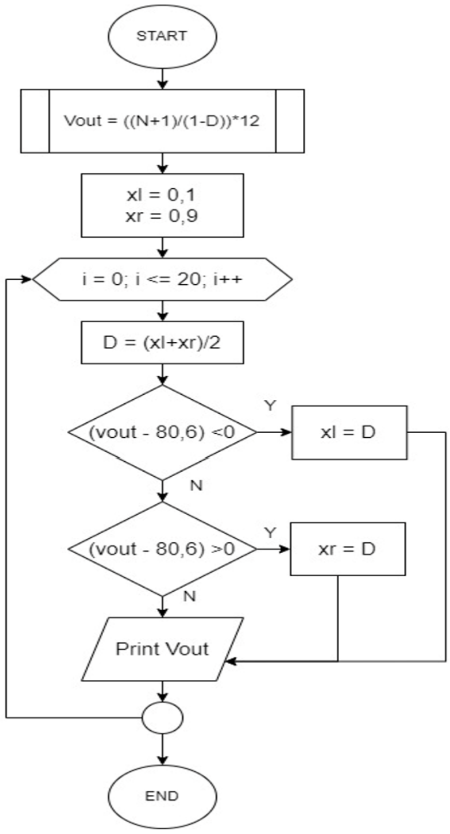

Figure 3. Flowchart of bisection method

stated in the DC pump specifications with a set voltage ripple (ΔV_{out1}) of 1%. A summary of the parameters of the coupled inductor boost converter is shown in Table 1.

B. *Constant Voltage (CV) for Battery Charging*

The battery charging mode will use the constant voltage (CV) technique where the output voltage of the converter that will charge the battery load is kept in a fixed or constant state [8]. Figure 2 shows the graph of the constant voltage charging mode.

In the initial charging process, the current value will be high and get closer to zero when the battery is fully charged. The change in duty cycle value has a role in keeping the battery charging voltage in a constant state. The advantages of constant voltage charging mode are easy to set up and relatively safer while the disadvantage of this mode is that charging the battery will take longer.

Table 2. Bisection iteration process

Iteration	*xl*	*xr*	*D*	V_{out} (V)
1	0.1	0.9	0.5	72
2	0.5	0.9	0.7	120
3	0.5	0.7	0.6	90
4	0.5	0.6	0.55	80
5	0.55	0.6	0.575	84.705
6	0.55	0.575	0.5625	82.285
7	0.55	0.5625	0.55625	81.126
8	0.55	0.55625	0.553125	80.559
9	0.55313	554688	0.5546875	80.842
10	0.55313	0.553907	0.5539065	80.7
11	0.55313	0.553907	.0.553516	80.62
12	0.55313	0.553516	0.5533205	80.594
13	0.55332	0.553516	0.5534185	80.612
14	0.55332	0.553419	0.55337	80.6

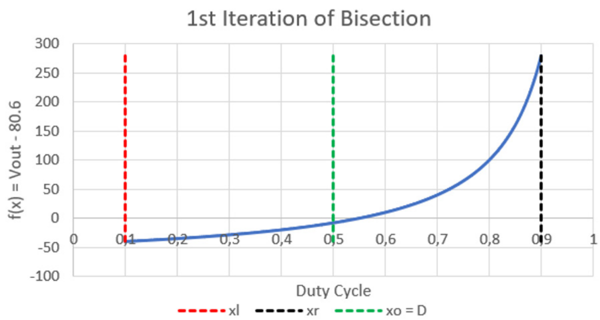

Figure 4. First iteration data of bisection method

C. *Bisection Method*

The bisection method is based on the intermediate value theorem of continuous functions, namely that the interval (x_l, x_r) must contain a zero point [10]. The bisection method requires two initial values as guesses which refer to the range of values in the duty cycle (i.e. 0 to 1). Where x_l is the value at the lower limit and x_r is the value at the upper limit. From these two values, a bisection calculation will be performed with the result being the center value of bisection.

Figure 3 shows the center value that acts as a duty cycle that will substitute the *D* parameter as in (2) to obtain the on the battery load side. Then the V_{out} value will be compared with the V_{out} set in the planning which is 80.6 V and the conditioning applies as shown in Figure 3. The repetition process will stop if the V_{out} value has met the converter parameter set or has reached the epsilon value. Table 2 presents the iteration data of the bisection. From the data, it is known that the iteration process stops at the 14th iteration and the is achieved in accordance with the converter planning value which is 80.6 V with a duty cycle of 0.55337.

Figure 4 illustrate a data visualization from Table 2 which presents data changes from *xl*, *xr*, and *xo* (or *D*) for each iteration. For the first iteration, data of the bisection

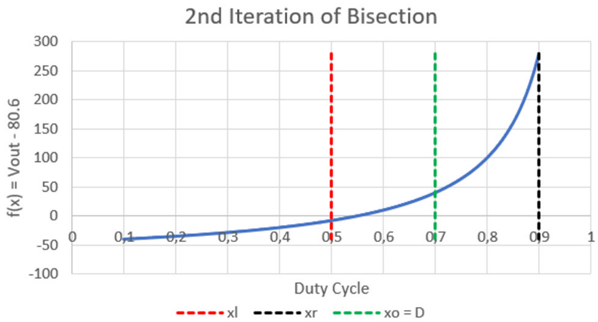

Figure 5. Second iteration data of bisection method

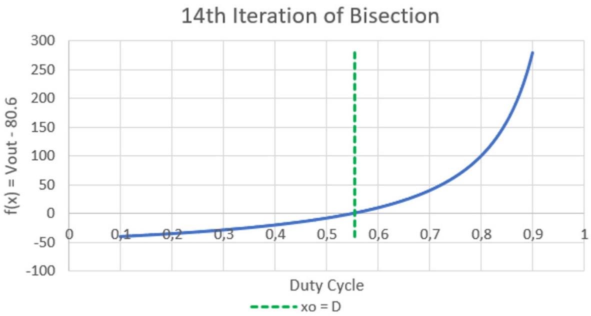

Figure 6. The last iteration data of bisection method

method with an initial value of xl=0.1 and xl=0.9 results in so or D= 0.5. The V_{out} value obtained is 72 V, which is does not meet the desired set point. Therefore, the iteration is continued.

Figure 5 shows the second iteration data from the bisection method where it can be seen that xl, xr, and xo (or D) are getting closer together with an initial value of xl=0.5 and xr=0.9 result in xo or D = 0.7. The V_{out} value obtained is 120 V, which is exceeds the desired set point. Therefore, the iteration is continued. Finally, Figure 6 shows the values of xl, xr, and xo (or D) are already close, indicating that the bisection calculation process has stopped. This is because it has reached the predetermined V_{out} set value of 80.6 V or met the epsilon tolerance.

D. *Close Loop Simulation Modeling*

Close loop integration simulation is a closed loop simulation using feedback or control in order to achieve the planned results. The voltage source using a DC Power Supply of 12 V using a coupled inductor boost converter will supply two loads at once. Simulation using MATLAB version 2020a.

III. Proposed Method

In this work, design and simulation will be carried out related to the coupled inductor boost converter as a voltage supplier to battery loads and DC pumps using the bisection method with a source voltage from a 12 V power supply. Figure 7 shows the proposed system design consists of three stages: (1) The voltage sensor reads the output voltage, which has been boosted by the converter and sent to the battery load, which will later be used as the reference

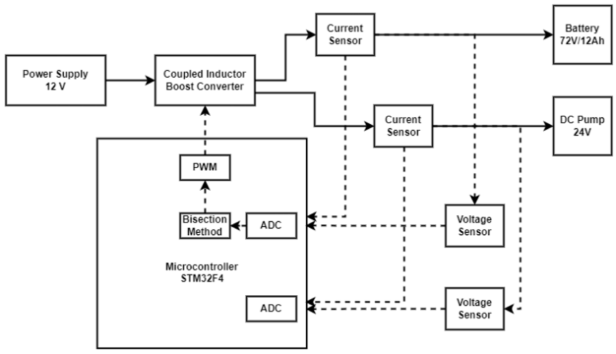

Figure 7. Block diagram of proposed system design

voltage by the bisection method. (2) The bisection method compares the reference voltage obtained from the voltage sensor on the battery load with the predetermined set point voltage for battery charging, which is set at 80.6 volts. It then tracks and determines the duty cycle value for the converter to maintain the output voltage on both loads at an optimal level. (3) Charging the battery load uses the constant voltage mode, with the charging voltage maintained at 80.6 volts by the bisection method.

IV. Simulation Results and Analysis

Simulation is carried out in two modes, namely open loop and close loop using MATLAB 2020a software. The power supply acts as a source with the converter will supply two loads, namely the battery and DC pump. Battery charging uses CV mode with bisection method as a control to maintain the converter output voltage to be optimal.

A. *Open-loop Testing Simulation*

Open-loop simulation is a system simulation without control or feedback. The voltage source uses a dc power supply with a fixed voltage set at 12 V. The duty cycle value is changed from 60%-80% and the state of charge (SOC) value of the battery is observed from 40%-90%. The coupled inductor boost converter will supply energy to two loads, namely a 72 V/12 Ah battery and a 24 V DC pump. Table 3 present an open-loop simulation of proposed converter design that is performed with a battery load and the DC pump load using a resistor. From the data obtained, the output voltage is not constant because the duty cycle value changes and there is no control used for feedback. While the change in SOC to the output voltage has no significant effect.

In Figure 8 it can be seen that when the duty cycle increases, the output voltage value on the battery will also increase.

B. *Close-loop Testing Simulation*

Close-loop simulation with the bisection method as control aims to get the output voltage on both sides of the load optimally. The battery will be charged with constant

Table 3. Open-loop simulation data of the proposed converter design

Duty Cycle (%)	SOC (%)	$V_{out\,2}$ (V)	$I_{out\,2}$ (A)	$V_{out\,1}$ (V)	$I_{out\,1}$ (A)
60	40	79.65	0.8	23.85	0.88
	50	79.66	0.82	23.86	0.88
	60	79.66	0.82	23.87	0.88
	70	79.68	0.84	23.87	0.88
	80	79.68	0.84	23.9	0.88
	90	79.7	0.88	23.92	0.88
70	40	80.28	2.6	24.19	0.89
	50	80.29	2.6	24.2	0.89
	60	80.29	2.6	24.21	0.89
	70	80.3	2.7	24.21	0.89
	80	80.32	2.7	24.22	0.89
	90	80.35	2.7	24.25	0.89
80	40	80.64	3.7	23.43	0.86
	50	80.62	3.71	23.47	0.86
	60	80.63	3.75	23.48	0.86
	70	80.67	3.78	23.49	0.86
	80	80.67	3.78	23.49	0.86
	90	80.69	3.78	23.51	0.86

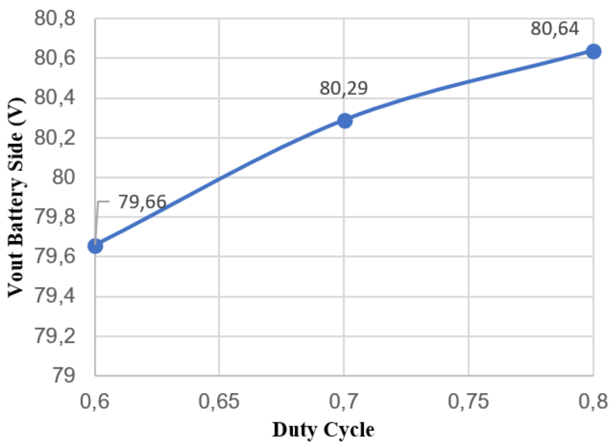

Figure 8. Relationship of duty cycle value change to battery output voltage value

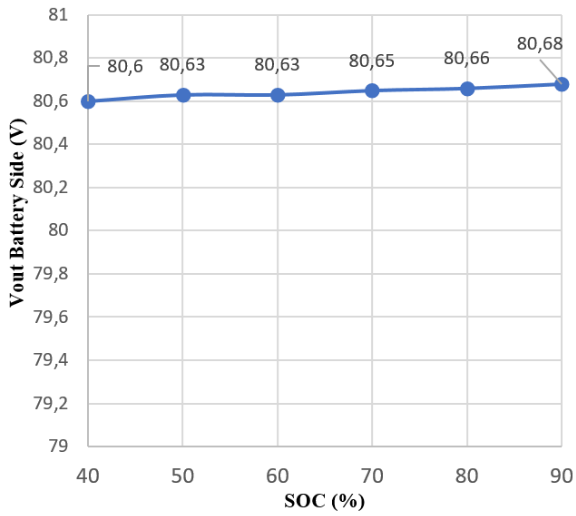

Figure 9. Relationship of duty cycle value change to battery output voltage value

Table 4. Close-loop simulation data of the proposed converter design

SOC (%)	$V_{out\,2}$ (V)	$I_{out\,2}$ (A)	$V_{out\,1}$ (V)	$I_{out\,1}$ (A)
40	80.6	3.71	24.01	0.82
50	80.63	3.74	24.2	0.82
60	80.63	3.74	24.2	0.82
70	80.65	3.7	24.02	0.82
80	80.66	3.73	24.02	0.82
90	80.68	3.74	24.03	0.82

Table 5. Comparison of simulated output voltage to set point

SOC (%)	$V_{out\,2}$ (V)	$I_{out\,2}$ (A)	Error (%)	$V_{out\,1}$ (V)	$I_{out\,1}$ (A)	Error (%)
40	80.6	80.6	0	24.01	24	0.041
50	80.63	80.6	0.037	24.2	24	0.826
60	80.63	80.6	0.037	24.2	24	0.826
70	80.65	80.6	0.0619	24.02	24	0.0832
80	80.66	80.6	0.0743	24.02	24	0.0832
90	80.67	80.6	0.0991	24.03	24	0.124
%error average			0.0515	%error average		0.33

voltage mode so that the output voltage for battery charging is maintained in a constant condition with %SOC observed from 40%-90%. The source voltage uses a DC power supply of 12 V during the energy delivery process.

Table 4 shows the simulation data of the proposed converter design with %SOC range of 40%-90%, which is the battery charging voltage is maintained in a constant condition in the range of 80.6 V. In addition, the output voltage on the load side of the DC pump is obtained in the range of 24 V, which is very close to the converter design and the needs of independent home applications.

Figure 9 shows the relationship of the change in %SOC value to the battery charging voltage. Any change in the %SOC value, the battery charging voltage value will be maintained in a constant condition by the bisection method control in the range of 80.6 V. Then, the following is the result of close loop simulation of system integration with the bisection method control.

Table 5 shows the comparison of the output voltage data on the load side between the simulation results and the set points that have been determined when planning the converter. The difference between the two data will result in a %error. On the battery load side, there is an average % error of 0.0515% with a comparison of the value of V_{out2} or the charging voltage at the battery to the set point of 80.6 V. On the load side of the DC pump, there is an average % error of 0.33% with a comparison of the value of V_{out1} or the system output voltage for the DC pump to the set point of 24 V.

Figure 10 and Figure 11 respectively shows a snapshot of the results of a close-loop system on voltage and current

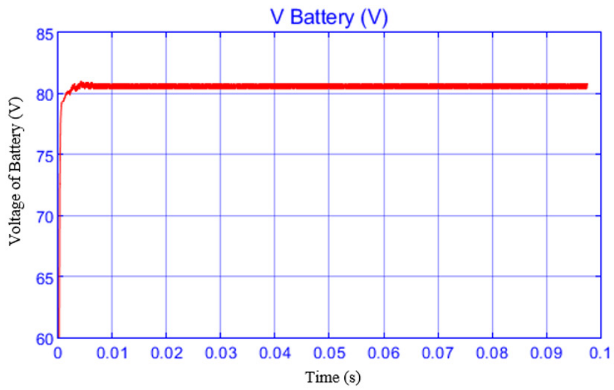

Figure 10. Simulation results of the integrated close-loop system on voltage charging battery

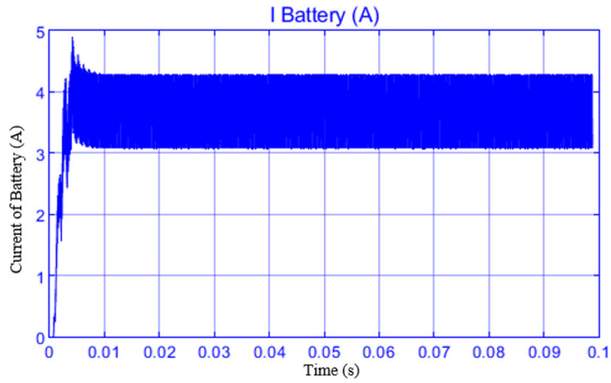

Figure 11. Simulation results of the integrated close-loop system on current charging battery

charging battery with bisection method on the battery load side at 50% of SOC. The value of the battery charging voltage is 80.6 V which is in accordance with the planned set point.

V. Conclusion

The simulation of proposed converter design consists of two model, i.e., open-loop and close-loop system. The open-loop simulation aims to get the output voltage as planned on both sides of the load by changing the duty cycle value in the SOC observation in the range of 40%-90%. In the open-loop simulation, it can be seen that the more the duty cycle value increases, the output voltage value will also increase. To reach the optimal output voltage on both sides of the load, a close loop simulation is performed with bisection method control that will formulate a constant duty cycle to produce optimal conditions. Battery charging uses constant voltage mode so that the battery charging voltage is maintained in a constant voltage condition, which is in the range of 80.6 V and the average % error is obtained from the data comparison of the simulation results to the set point of 0.515%. In addition, the use of constant voltage mode also aims to condition the output voltage on the load side of the DC pump to be in the range of 24 V and the average % error is obtained from the comparison of the simulated data to the set point of 0.33%.

This work has successfully developed and tested a voltage control method using the bisection method on a coupled inductor boost converter system with a battery load. However, several aspects still need attention for future research. First, the use of more adaptive control methods, such as fuzzy logic or predictive control, can be explored to enhance system stability under varying load conditions. Second, further optimization of the converter design can be conducted to improve overall power efficiency, especially in applications requiring high-power conversion. Therefore, this research opens opportunities for further development in more efficient and adaptive converter design and voltage control, as well as its application in various renewable energy sectors and energy storage technologies.

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