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Effect of fuzzy logic controller on voltage stability of parallel boost converter configuration

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ABSTRACT

An increase in electricity load causes a change in grid voltage and current, causing losses to customers. In addition, the source of electricity from fossil energy has also decreased. Therefore this study aims to provide a stable DC voltage source from solar panels, with a Fuzzy Logic Controller (FLC). The proposed method is to design a boost converter in parallel with its output. The boost converter is used to increase the DC voltage from 24 V to 48 V. In this study, FLC is used to adjust the output voltage of each boost converter. If one of the boost converters fluctuates, the other boost converters will supply a voltage according to the load voltage. The results showed that the FLC can adjust the boost converter output voltage changes. Whereas when using the PI (Integral Proportional) controller, a voltage spike occurs in the range of 0 seconds to 0.6 seconds and the voltage stabilizes within 0.6 seconds to 1 second.

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1. INTRODUCTION

The need for a power source at this time is by technological developments, especially electronic technology. In addition, a stable voltage is needed for the operation of electronic equipment and other electrical loads. The use of renewable energy as a source of electricity is increasing, especially solar energy using solar panels. To increase the stability of the output voltage of solar panels, a DC-DC converter is used.

Some converter studies used fuzzy logic as follows. Fuzzy logic seeks to integrate human thinking that does not require numerical information [1]. The process converts system input that has firm values into linguistic variables using membership functions stored in the fuzzy knowledge base [2]. Author [3] designed a controller based on a type-2 fuzzy converter for a DC microgrid that operates independently. Fuzzy controllers are used to quickly increase voltage stability and adjust the current distribution for each load. The PID controller is used to compare the performance of type-2 fuzzy controllers. Author [4][5] designed a shunt converter using type-2 fuzzy logic to charge electric vehicle batteries. The design uses a bidirectional converter and is connected to the grid. When the battery is empty, battery charging occurs and when the grid source is disconnected, the battery will supply energy to the grid. The battery used is lithium-ion. Converter performance with type-2 fuzzy compared to type-1 fuzzy. The system is optimized with a genetic algorithm. The shunt converter design is modeled by Simulink Matlab.

In [6][7] proposes a DC-DC converter with fuzzy logic to improve MPPT performance, so that the output voltage of the solar panel will be maximum. This fuzzy calculation begins with converting linguistic variables into functions that describe variables in fuzzy form [8]. Fuzzy logic will generate PWM for the switching converter. The design is done using Simulink Matlab with a change in the shape of the membership function. The results of the study show that MPPT with the membership function GBell can improve the performance of the DC-DC converter compared to other member functions. Author [9] proposes an adaptive fuzzy controller for the buck converter. The proposed controller can increase the stability of the voltage against disturbances and changes in system parameters. Stability analysis is carried out with Lyapunov's theory and the system is implemented in the laboratory. Author [10][11] proposed a new design of grid-connected solar panel power quality. The design is carried out using fuzzy logic for DC-DC converters on solar panels, while for improving power quality it is carried out with static compensators. The system is modeled using Simulink Matlab and a solar panel capacity of 100 KWp. The model system is tested with changes in radiation and temperature. Authors [12][13] proposed a DC microgrid design on a ship with renewable energy sources and batteries. To overcome fluctuations in renewable energy, type-2 fuzzy logic is used in the DC-DC converter connected to the load. Designs are tested in real-real time dSPACE. The use of Fuzzy logic can overcome the dynamics of the converter. The system design used is effective for managing the power on the ship. Author [14] proposed a new reducer for type-2 fuzzy logic used for DC-DC converters. A converter with type-2 fuzzy logic is used to increase the output of solar panels with the MPPT algorithm. The proposed new reducer is the Nie-Tan type reducer. The proposed new reducer can limit the low power consumption of the switching converter. The converter is designed and simulated with Cadence Virtuoso software. The Nie-Tan reducer is capable of limiting the converter switching power. Author [15] designed a battery-charging DC-DC converter with fuzzy logic with SMC backstepping adaptive mode. The method used to overcome changes in converter parameters. The proposed method was compared with the PI controller. The modeled system is tested using LabView. The results of the study show that the proposed new method produces a more stable battery charging voltage and current.

Author [16] proposed a new DC-AC converter topology on a microgrid. The new topology is regulated by a centralized control method based on fuzzy logic. The proposed new topology is implemented with a prototype to improve voltage and power stability in a microgrid energy management system. In [17] developed a solar panel buck converter control connected to a shunt active filter. The goal is to increase the stability of the solar panel output so that the stability of the DC bus voltage is achieved and reduce the load reactive power harmonics. The converter design uses a fuzzy logic controller. The proposed method is compared with the P&O method. The design is modeled and simulated with Simulink Matlab. The proposed method can overcome radiation fluctuations and ambient temperature. Author [18] proposes a converter with an MPPT algorithm based on a radial basis function neural network for fuel cells in electric vehicles. The converter is designed for high voltage gain. The proposed method can reduce the load current and voltage ripple. Meanwhile, the authors [19] proposed a new control droop with type-2 fuzzy logic with constant load. This method aims to stabilize the voltage of several nano grids connected in parallel, while the author [20] proposes type-3 fuzzy logic to be applied to a DC-DC converter for battery charging. The converter source is obtained from the solar panel output. The method used shows better results than type-3 fuzzy logic. With changes in radiation and temperature, this method can produce a stable output voltage. In [21][22][23] designed a fuzzy logic controller to regulate the power flow of ultracapacitors in a hybrid storage system with a battery. Fuzzy logic is used to adjust the output voltage of the ultracapacitor converter so that it matches the DC bus voltage. The proposed method is modeled and simulated with Simulink Matlab. The study results show that the voltage is more stable when compared to the PI and PID controls.

The output of solar panels fluctuates and to increase the output of solar panels, the MPPT algorithm is used. It aims to supply power to the load uninterruptedly. Each MPPT method has strengths and weaknesses. To improve MPPT, fuzzy logic can be used which is optimized using genetic algorithms and particle swarm optimization. With the fuzzy logic optimization method, MPPT can be produced which is superior to the fuzzy logic method without optimization. The fuzzy logic optimization method is also better when compared to the incremental conductivity method [24][25][26]. In the development of microgrids, the problem faced is setting the converter voltage. One of the methods for increasing the DC-DC converter is by using the Adaptive Neuro-Fuzzy (ANFIS) controller. This strategy is used to improve the fuzzy logic method so that the occurrence of voltage instability, frequency changes, and harmonics can be avoided. The ANFIS method is compared with fuzzy logic and PI controllers with tolerance limits according to IEEE/IEC standards [27]. The ANFIS method was also developed for DC-DC converters with the MPPT algorithm connected to solar panels. This method is used to improve fuzzy logic weaknesses. ANFIS is more optimal in managing solar panel output to load and can be implemented using the TMS320F28335 DSP. The results of studies with simulations and prototypes show that ANFIS is superior to previous methods. Besides being used for solar panels, ANFIS can also be used for wind turbines in permanent magnet synchronous generator systems. To find out the performance of ANFIS, the study can be compared with the PI controller. In addition to Matlab's Simulink model, ANFIS can be modeled with DSpace (DS1104). The MPPT algorithm on the DC-DC converter can be improved by the ANFIS hybrid system and particle swarm optimization (PSO). This aims to improve the performance of ANFIS and PSO. The ANFIS-PSO method can be modeled using Dspace Matlab. The results of the study show that the ANFIS-PSO method improves the stability of the converter voltage more when compared to the ANFIS or PSO methods [28][29][30][31].

Based on previous research, a parallel configuration of two boost converters is proposed using a fuzzy logic controller (FLC), which functions to regulate the output voltage of each boost converter. After the introduction in our article, namely Chapter 2: Boost converter, chapter 3: Proposed method, chapter 4: Results and Discussion, and Chapter 5: Conclusion.

2. BOOST CONVERTER

There are three types of DC-DC converters for renewable energy development, namely buck converters, boost converters, and buck-boost converters. This study only discussed the boost converter and this converter has the same type of components as other DC-DC converters. The main components of the boost converter are diode (D), inductor (L), transistor (T), resistor (R), and capacitor (C). The boost converter functions to increase the voltage according to the load using the PWM controller. This PWM signal will set the boost converter transistor on and off with a certain frequency [32][33]. Figure 1 shows the basic boost converter circuit.

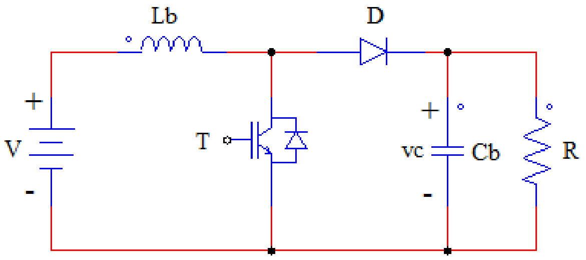

Figure 1. Basic boost converter circuit.

When the transistor is in On mode, the diode is Off, resulting in a charging current in the inductor. In this first mode, the output voltage of the boost converter comes from the capacitor. When the transistor is in Off mode, the diode is On. So that the inductor current will flow through the diode, resistor, capacitor, and back to the inductor. In this way a higher output voltage will be generated at the source, this is because the inductor stores energy when the transistor is in On mode and is supplied to the load when the transistor is in Off mode. Therefore the boost converter parameters include the output voltage (Vo), inductor current (iL), capacitor voltage (Vc), and duty cycle (D) [34][35][36]. The relationship between the input and output voltages on the boost converter can be expressed by the following equation,

$$\frac{V_o}{V_i} = \frac{1}{1 - D} \quad (1)$$

In the equation to be described, it is assumed that transistors and diodes are in ideal condition, with negligible delay. Inductor and capacitor losses can be neglected. Figure 2 shows the boost converter circuit when the transistor is On and Figure 3 shows the boost converter circuit when the transistor is Off. While Figure 4 shows the boost converter circuit with an ideal switch when the transistor is On it is expressed by u = 1 and when the transistor is Off it is expressed by u = 0 [37][38][39].

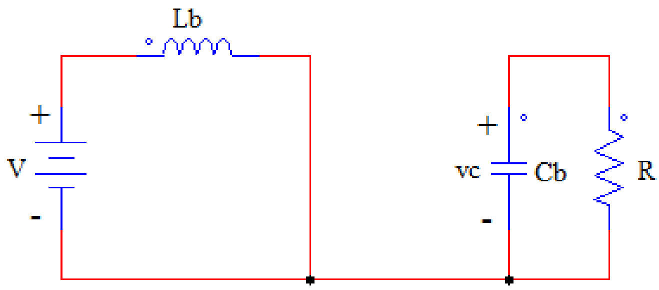

Figure 2. The boost converter circuit when the transistor is On.

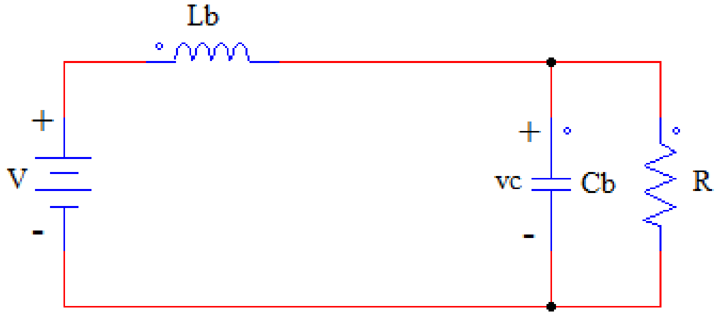

Figure 3. The boost converter circuit when the transistor is Off.

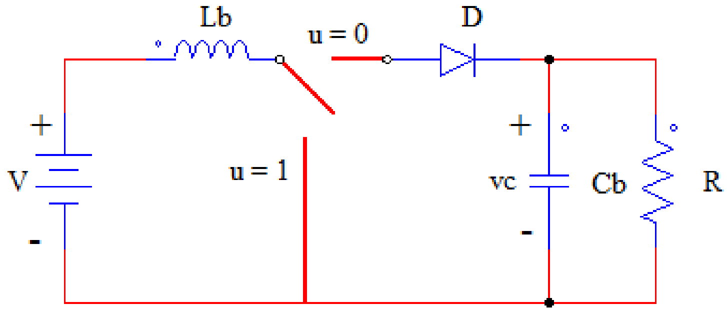

Figure 4. The boost converter circuit with an ideal switch.

To obtain the boost converter equation, Kirchoff's law is used when the mode is On and the mode is Off. The transistor is analogous to a switch which is in two conditions, namely when u = 1 and when u = 0. When the switch is in position u = 1 then by using KVL (Kirchoff Voltage Law) and KCL (Kirchoff Current Law) we obtain the equation as follows

$$L_b \frac{di}{dt} = V \quad (2)$$

$$C_b \frac{dvc}{dt} = -\frac{vc}{R} \quad (3)$$

When the switch is open or u = 0, the boost converter equation is as follows

$$L_b \frac{di}{dt} = -vc + V \quad (4)$$

$$C_b \frac{dvc}{dt} = i - \frac{vc}{R} \quad (5)$$

By using the bilinear system in the two equations above, the following equations can be derived

$$L_b \frac{di}{dt} = -(1-u)\, vc + V \quad (6)$$

$$C_b \frac{dvc}{dt} = (1-u)\, i - \frac{vc}{R} \quad (7)$$

The boost converter equation can be converted into the state equation as follows

$$\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = \begin{pmatrix} \frac{1}{V}a & 0 \\ 0 & \frac{1}{V} \end{pmatrix} \begin{pmatrix} i \\ vc \end{pmatrix}, \qquad \tau = \frac{t}{\sqrt{L_b C_b}}, \quad a = \sqrt{\frac{L_b}{C_b}} \tag{8}$$

$$\frac{dx_1}{d\tau} = -(1-u_r)\, x_2 + 1 \tag{9}$$

$$\frac{dx_2}{d\tau} = (1-u_r)\, x_1 - \frac{x_2}{Q} \tag{10}$$

Where Q represents the quality factor of the boost converter circuit, x1 represents the variable inductor current, and x2 represents the output voltage. The variables x1 and x2 are normalized variables with no change in the switch position. The equations are derived from the transistor switching cycle, the transistor On equation (d), and the equation during the transistor Off (1-d). Therefore there are two differential equations, namely when the transistor is in On mode and the transistor is in Off mode, so that the model can be obtained during the PWM cycle [40][41][42]. Figure 5 shows two parallel boost converters connected to a PV array in a DC microgrid. In this figure the output voltage, output current and cable resistance of converter-1 and converter-2 are expressed as V_{DCA}, V_{DCB}, I_A, I_B, and R_A, R_B. If V_{DCA} is greater than V_{DCB}, circulating current (I_C) flows from converter-A to converter-B. Therefore, case studies for the distribution of current and circulating current and cable resistance are stated in Table 1 [43][44].

Table 1. Case studies for load sharing and circulating currents.

Case	V_{DCA}, V_{DCB}	R_A, R_B	I_A, I_B	I_C
1	Same	Same	Same	Zero
2	Same	Different	Different	Zero
3	Same	Same	Different	non Zero
4	Same	Different	Different	non Zero

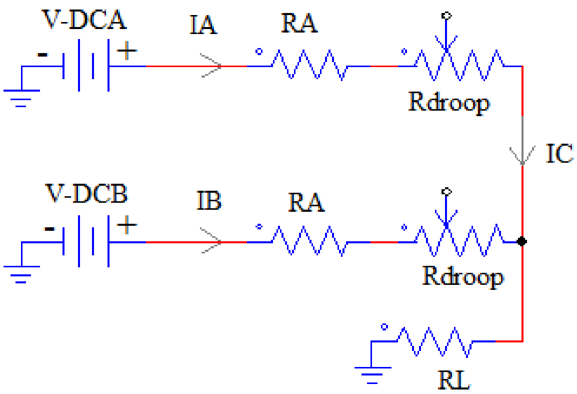

Figure 5. Boost converter connected in parallel with different output voltages.

By using Kirchoff's voltage law (KVL) in Figure 5, the following equation can be derived

$$V_{DCA} - I_A - R_A = 0 \tag{11}$$

$$V_{DCB} - I_B - R_B = 0 \tag{12}$$

While the output current of the boost converter is expressed by the equation below

$$I_A = \frac{(R_B + R_L)V_{DCA} - R_L V_{DCB}}{R_A R_B + R_A R_L + R_B R_L} \tag{13}$$

$$I_B = \frac{(R_A + R_L)V_{DCB} - R_L V_{DCA}}{R_A R_B + R_A R_L + R_B R_L} \tag{14}$$

3. PROPOSED METHOD

The goal in designing a fuzzy logic controller (FLC) for parallel connected boost converters is to regulate the DC output voltage flow from each boost converter to a DC load. When one of the boost converters is disturbed, the other boost converters will supply voltage and current to the load. With the boost converter model connected in parallel, the load voltage will be stable. In this study, a boost converter is designed to increase the solar panel voltage from 24 V to 48 V DC. Figures 7, 8, and 9 show the membership functions of the FLC. Figure 10 shows a schematic of a boost converter connected in parallel with a fuzzy logic controller.

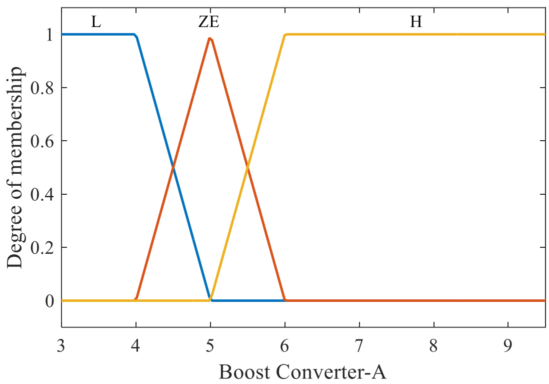

Figure 7. Membership function of boost converter-A.

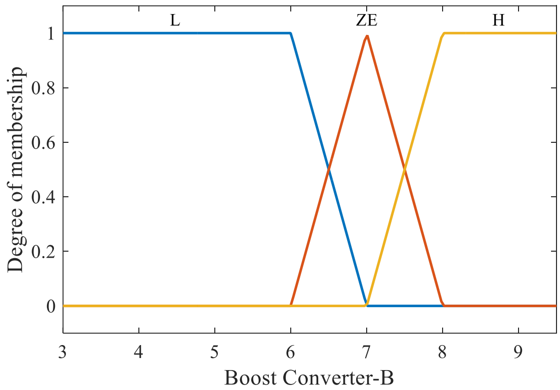

Figure 8. Membership function of boost converter-B.

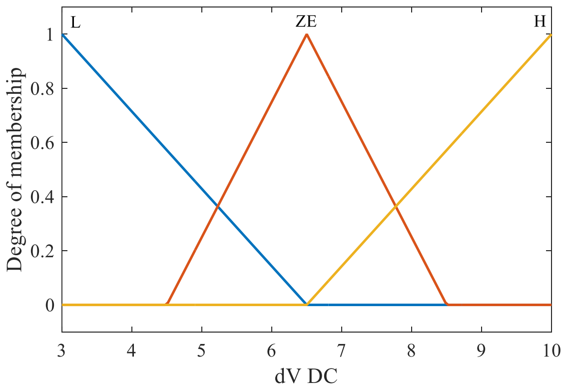

Figure 9. Output membership function.

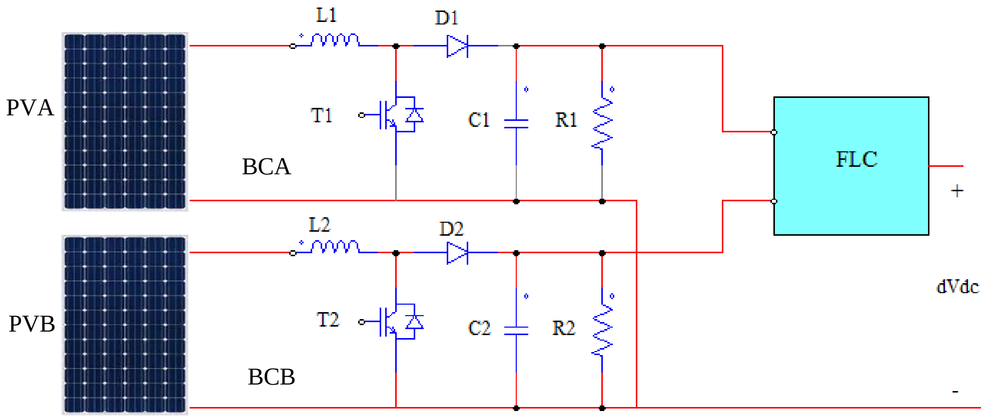

Figure 10. Block diagram of the proposed system.

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The FLC parameters used for the boost converter control design are the voltage change in the boost converter A (BCA) voltage and the boost converter B (BCB) voltage change. The FLC controller used has two inputs and one output. The rules in FLC are all rules as a combination of two inputs and one output. FLC has two inputs, each with three membership functions, namely L (Low), Zero (ZE), High (H), while the FLC output which is a change in DC voltage also has three membership functions, namely L (Low), Zero (ZE), and High (H). The purpose of using FLC is to adjust the DC voltage value to reach the load voltage value. FLC generates a PWM wave to trigger the base of the transistor. The final step of FLC is defuzzification using the centroid area (COA) method. Table 2 shows the FLC rules with each of the three membership functions.

Table 2. Rule Base for FLC.

ΔE / E	L	ZE	H
L	L	L	ZE
ZE	L	ZE	H
H	ZE	H	L

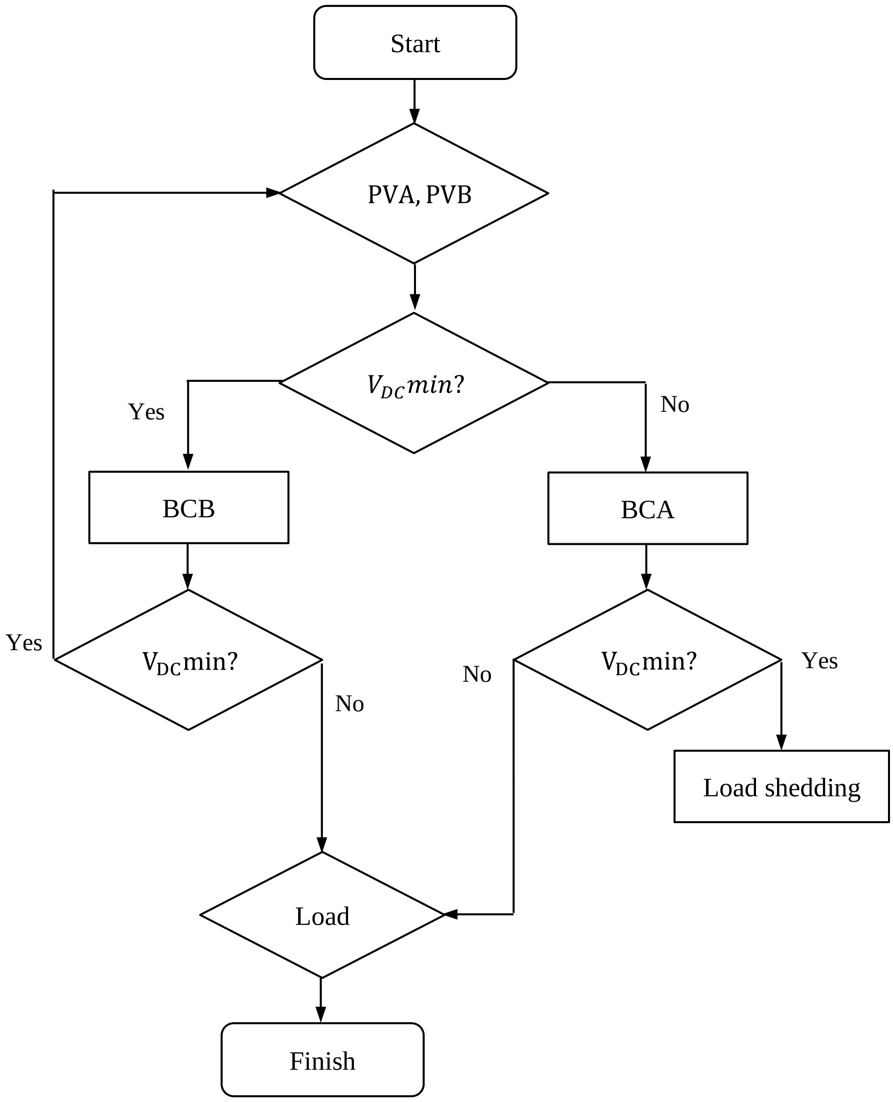

Figure 11. Flowchart boost converter connected in parallel.

Figure 11 shows the flowchart for setting the voltage for each boost converter to load. In this flowchart solar panel A (PVA) supplies DC voltage to boost converter A, while solar panel B (PVB) supplies voltage to boost converter B. At the start of the boost converter A supplies the load and when the boost converter A voltage drops it will release the load. Then boost converter B will supply the load voltage. When converter B's boost voltage drops due to changes in PVB, the system will return to its initial state, depending on the availability of solar panel output.

4. RESULTS AND DISCUSSIONS

In this study, a simulation was carried out by Simulink Matlab to design the boost converter configuration. For solar panels A and B used solar panel modules with a capacity of 50 Wp each. While the solar panel voltage is 24 V DC. Figure 12 shows the Simulink Matlab design with FLC. In the picture, two boost converters are connected parallel to the output voltage. The boost converter function in the simulation design is used to increase the output voltage of solar panel A and solar panel B. Table 3 shows the value of the components used in the boost converter design.

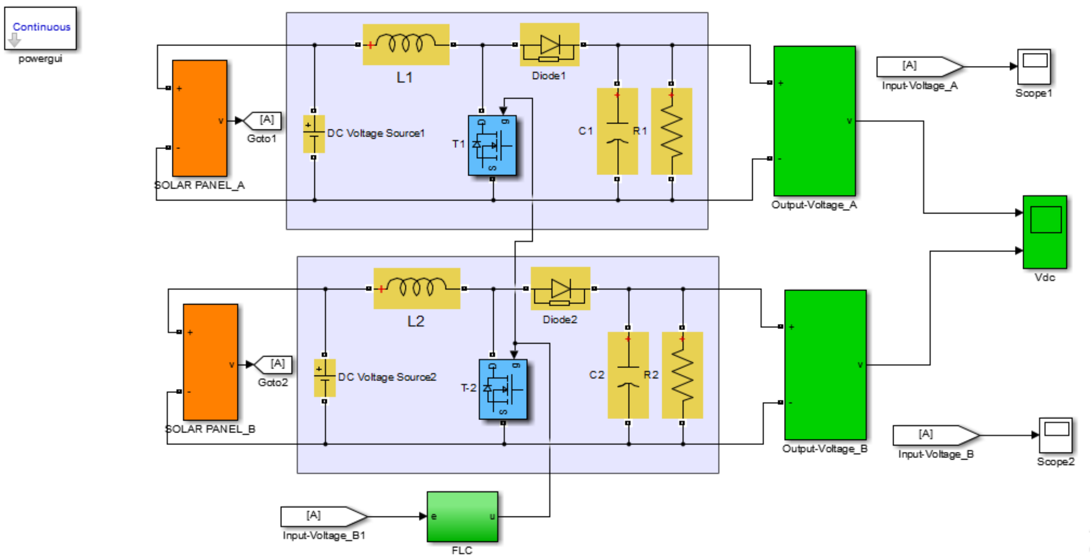

Figure 12. Matlab simulink design.

Tabel 3. Boost converter components.

Component	Value
R	30 Ω
L	47 µH
C	33,33 µF
D	0.5
f	50 KHz

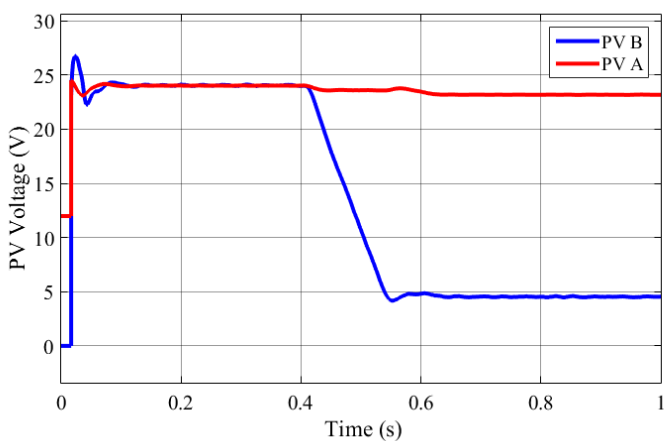

Figure 13. Solar panel output voltage.

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Figure 13 shows the output voltage of each solar panel. In the visible output voltage changes as a result of changes in the intensity of solar radiation. Solar panel A changes within 0.6 seconds, while solar panel B experiences a voltage change of 19 V in 0.5 seconds.

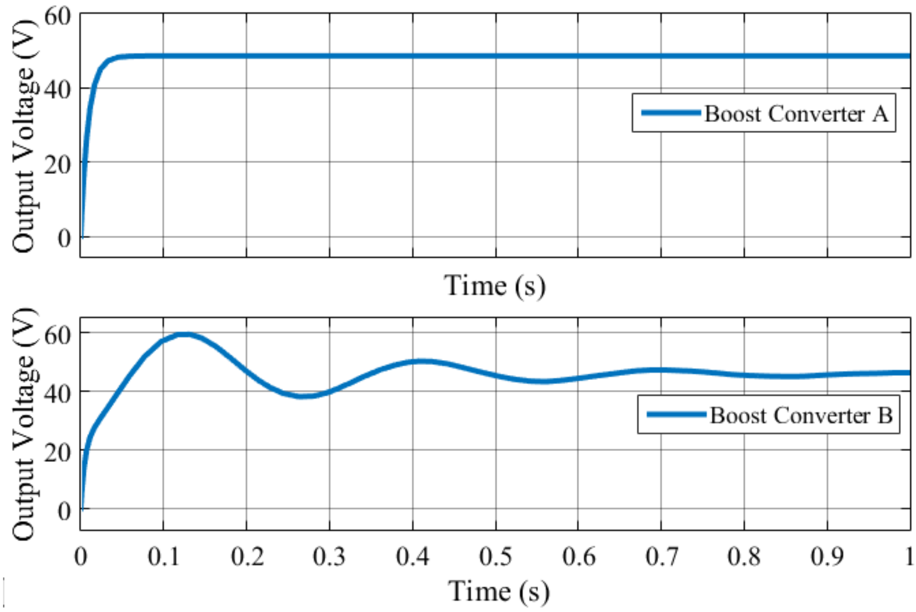

Figure 14. Boost converter output voltage.

Meanwhile, Figure 14 shows the output voltage of each boost converter. In the picture, boost converter A can stabilize the output voltage. This is because the output of solar panel A does not experience a large change in voltage. Meanwhile, boost converter B shows a change in the output voltage and stabilizes within 0.9 seconds. This is due to solar panel B experiencing a large output change so that the boost converter can stabilize the voltage within 0.9 seconds.

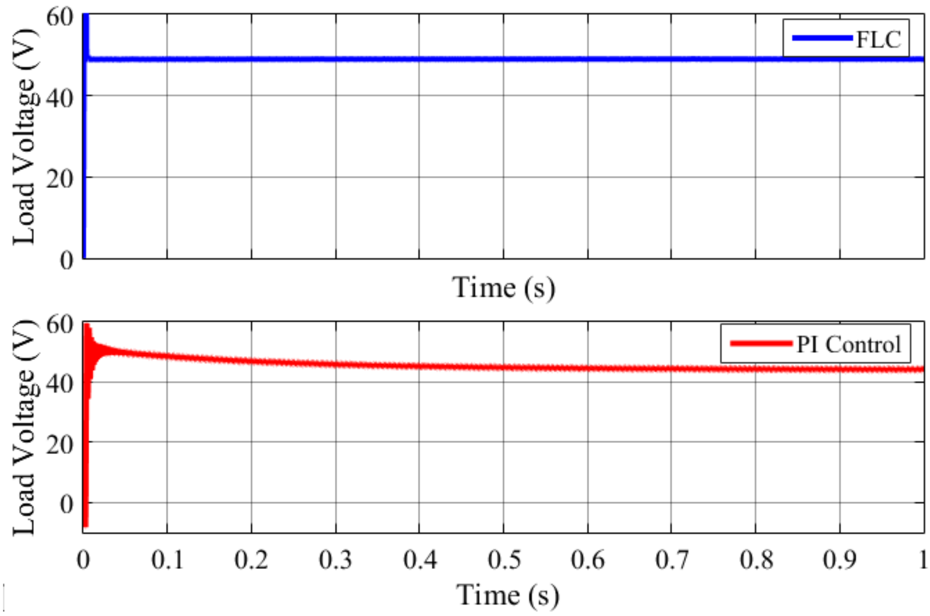

Figure 15. Load voltage.

Therefore, to provide a stable load voltage, a parallel configuration is used at the output of the boost converter. It is intended that if one of the boost converters fluctuates, the other boost converters will supply voltage according to the load voltage. With this method, the need for electrical load will be met. Figure 15 shows a comparison of boost converter performance settings using FLC and control PI. In the figure, it can be seen that the FLC can adjust the alternation of the output voltage of the boost converter, so that the load voltage is stable at 48 V. Meanwhile when PI control is used, a voltage spike occurs within 0 seconds to 0.6 seconds and the voltage stabilizes within 0.6 seconds to 1 second. The study results show that FLC shows better performance in controlling the load voltage. Based on the results of the study, the boost converter coordination strategy is more effective in dealing with changes in source and load voltages when compared to the control droop method in balancing the load voltage. Because droop control is affected by the linear characteristics of the voltage and current (V-I) at the source, a study has been carried out by the authors [3]. Likewise, other authors use the control droop method which is heavily influenced by the linear characteristics of the source and load. Many authors use Fuzzy Logic, but the control coordination method on the boost converter using Fuzzy Logic produces a faster response than using droop control.

5. CONCLUSION

The boost converter is a type of DC-DC converter that is used to increase the DC voltage to a certain voltage level as needed. If the load is supplied using solar panels, voltage fluctuations will occur when the weather changes. One of the methods used to stabilize the output voltage of a solar panel that has been increased with a boost converter is to use a boost converter connected in parallel. If one of the boost converters fluctuates, the other boost converters will supply a voltage according to the load voltage. With this method, the need for electrical load will be met. The results showed that the FLC was able to regulate the alternation of the boost converter output voltage, so that the load voltage was stable at 48 V. Therefore, the FLC showed better performance in controlling the load voltage when compared to the control PI. Studies can be continued using a bidirectional multi-boost converter.

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