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Boost Buck Converter Based on Fuzzy Logic for Voltage Stabilizer

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Abstract

The wind turbine generator used for charging the battery produces an unstable electrical voltage, this is caused by the wind speed on the highway that varies. As a result of the instability of the electrical voltage, the energy storage charging process is not optimal. To deal with these problems, voltage stabilization is carried out using a boost buck converter to maximize the use of electrical energy generated from the wind turbine generator. This study discusses about a prototype voltage stabilizer for battery charging using a boost buck converter circuit. Implemented a comparison of two different techniques, including the application of fuzzy Mamdani logic control with PID using Ziegler-Nichols to minimize the value of settling time, percentage of overshoot, steady state error, and maximum voltage ripple. The results show that application of fuzzy Mamdani logic control is more effective than the application of PID using Ziegler-Nichols. In the study, it was found that the effectiveness of adding a charging circuit protection system and monitoring system did not exist in previous studies.

Keywords **:** *Boost buck converter**,** Fuzzy logic control**,** Voltage Stabilizer*

1. Introduction

The highway is one of the places where wind energy is produced, which is obtained from high-speed vehicles and transmits energy in the form of local wind energy [1]. The high potential of wind energy on highways can be used to generate electrical energy using wind turbines by converting the kinetic energy of the wind into mechanical energy to turn a generator that produces electrical energy that can be stored in batteries [2].

However, the electric voltage generated by the generator [3]–[7] unstable, this is caused by the wind speed on the highway that varies. Due to the instability of the electrical voltage, the battery charging process is not optimal. To overcome this, a voltage stabilizer circuit is made. From several studies that have been carried out to increase the voltage stability [8]–[16] only focuses on the output voltage, so it does not consider other factors such as settling time, overshoot, steady state error, and maximum voltage ripple. Even though these four factors greatly affect the duration of battery life.

The solution to stabilize the voltage by considering the duration of battery life is making a boost buck converter circuit with the application of fuzzy logic control aims to minimize the value of settling time, overshoot percentage, steady state error, and maximum voltage ripple. To overcome the occurrence of low charging voltage (under voltage) and excessive battery charging (over charged), this prototype is equipped with a protection system using a voltage cut off circuit [17]–[19] and added a real time monitoring system to make it easier to control the voltage stabilizer prototype and the battery charging process.

2. Proposed System Model

2.1. Research Design

This design research was carried out by a process of simulation, design, and analysis. This process is shown in Figure 1.

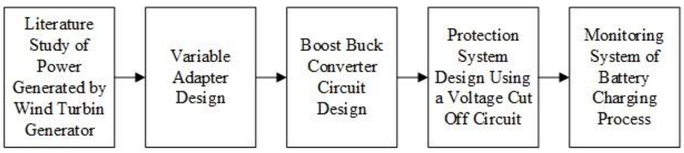


Figure 1. Research Proposed Design

Figure 1. shows that a literature study was conducted to obtain data on the power generated by the wind turbine generator from previous studies. Considering that the electrical voltage generated by the generator is unstable due to the influence of wind speed on changing road, in this case a boost buck converter circuit is designed to stabilize the voltage. Furthermore, the design of a battery charging circuit protection system uses a voltage cut off circuit to overcome the occurrence of under voltage and over charged. After that, a monitoring system is designed to make it easier to control the state of battery charging in real time. Each of the results of the design in this study carried out simulation, implementation, and then prototype testing. The research design is clarified in the block diagram of voltage stabilizer prototype for battery charging which is shown in Figure 2.

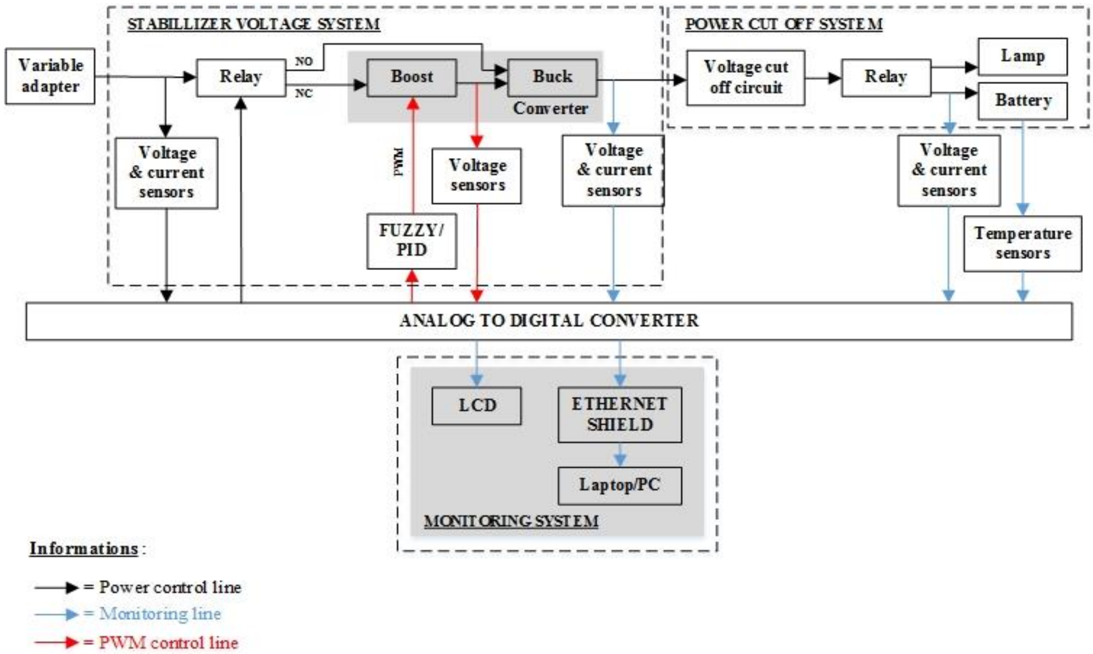


Figure 2. Block Diagram of Voltage Stabilizer Prototype for Battery Charging

Figure 2. explains that a variable adapter is used to replace the function of the wind turbine generator which will produce an unstable electrical voltage, according to the input power data in previous studies [6][7]. The input voltage generated by the variable adapter is detected by a voltage sensor and then processed by the ADC (Analog to Digital Converter) which activates the relay function. The input voltage to the relay is divided into two modes, namely boost buck mode or NC (Normally Close) voltage which goes to the boost converter and then to the buck converter, and buck mode or NO (Normally Open) voltage which goes directly to the buck converter. To get a stable charging voltage on the boost converter, a feedback is given in the form of a voltage sensor. The results of the sensor readings will be processed by the ADC (Analog to Digital Converter) and then implemented a comparison of two different techniques, namely fuzzy logic control with PID control for the PWM value setting, so that the boost converter output voltage can be stable and in accordance with the set point.

To overcome the situation of under charger / over charged when charging the battery, a voltage cut-off circuit is used as a protection system for the charging circuit by disconnecting the charging power automatically. The power from the cut off is then channeled to the grid when the battery is fully charged. The function of the grid in this study was replaced by led lights.

The implementation of a monitoring system is carried out to make it easier to control the battery charging process. Controlled parts include input power (variable adapter output), converter output power, voltage cut off circuit output power, battery capacity, and battery temperature. The results of the monitoring system will be displayed on the LCD and can be accessed on a PC/laptop/smartphone online with an internet connection on a microcontroller with a LAN module interface.

2.2. Boost Buck Converter Circuit

The voltage generated by the wind turbine generator is unstable due to changes in wind speed, it can be stabilized using a boost buck converter circuit and is shown in Figure 3. The boost buck converter circuit consists of a boost converter and a buck converter installed in parallel. The function of the converter is to increase/decrease and stabilize the input voltage to an output voltage (v_{out}) of 13.8 V for battery charging voltage. The boost converter functions to increase the output voltage of the adapter or the input voltage (v_s) to a capacitor voltage $C_2(v_{C2})$. The setting v_{C2} is always higher than v_{out} because the voltage will be lowered using a buck converter. While the function of the buck converter is to reduce v_{C2} to v_{out} which is used for battery charging voltage.

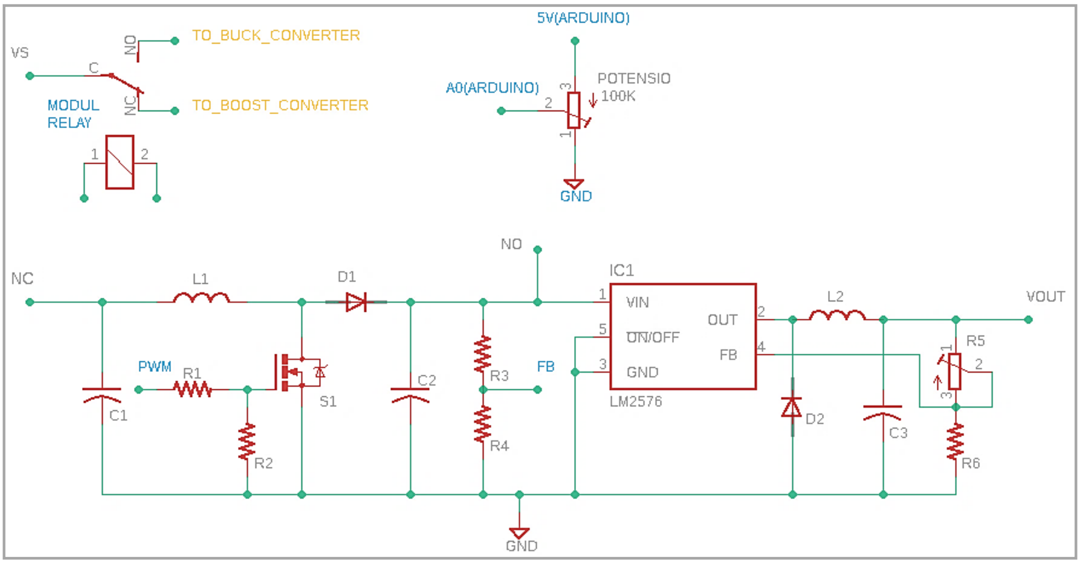


Figure 3. Boost-Buck Converter Circuit Schematic

The voltage detected by the DC voltage sensor is processed by a microcontroller in the form of an Arduino Mega 2560. Two modes that switch automatically are used, namely boost buck mode, and buck mode which functions to optimize the voltage generated by the wind turbine generator. The boost buck mode occurs when $v_s \leq$ set point, then the relay is in the NC position, which means the boost buck converter is working fully. While the buck mode occurs when $v_s >$ set point, then the relay is in the NO position, which means only the buck converter is working.

In the boost converter section, the frequency of the switching pulse is generated by the Arduino Mega 2560 at 30 KHz. A potentiometer is used to adjust v_{C2} which is connected to the Arduino Mega analog input. The working principle of this boost converter is that the analog value produced by the potentiometer is the same as the analog value in the feedback generated by the voltage divider (R_3 and R_4). Then from the two analog values, an IF statement is given which evaluates it to a change in duty cycle (k) to get the set point of v_{C2}. The setpoint value / boost converter output voltage used in this study is 14.2 V. To minimize the value of settling time, percentage of overshoot, steady state error, and the maximum voltage ripple is implemented by comparing two different techniques, namely fuzzy Mamdani logic control and PID using Ziegler-Nichols. It aims to extend duration of battery life.

The switching pattern is defined as the duty cycle (k) or the ratio between the power-on time interval (t_{on}) and the system period (T) as indicated by equation (1) [20]:

$$k = \frac{t_{on}}{t_{on}+t_{off}} = \frac{t_{on}}{T} \quad (1)$$

Where, $t_{on} = kT$ and $t_{off} = (1-k)T$

To find k in the boost converter is shown by equation (2):

$$v_{c2} = v_s\left(1\frac{t_{on}}{t_{off}}\right) \quad (2)$$

From the equation of $t_{on} = kT$ and $t_{off} = (1-k)T$, so the value (k) is obtained using equation as follows (3):

$$k = 1 - \frac{v_s}{v_{C2}} \quad (3)$$

The existence of inductance and capacitance greatly affects the current ripple (Δi) and voltage ripple (Δv). If Δi has been determined, the inductance value can be calculated from the switch on condition with equation (4) as follows [20]:

$$L_1 = 10 \times \frac{k(1-k)^2 R}{2f} \quad (4)$$

Capacitor value C_2 can be found by using equation (5):

$$\Delta v = \frac{v_{C2}.k}{R.C_2.f} \quad (5)$$

In the buck converter circuit, it uses IC LM2576 as a generator and controller of the PWM value. The function of this IC regulator is to reduce the v_{C2} and stabilize it to 13.8V $(13.8\text{ V} \leq \frac{v_S}{v_{C2}} \leq 40\text{ V}; 0.5\text{ A} \leq I_{load} \leq 5\text{A})$. The working principle of a buck converter circuit based on LM2576 is the same as a commercial buck converter, just that it has already produced a frequency of 52 kHz and the duty cycle value (k) is set automatically when pin 5 of the IC is grounded. The value of v_{out} can be adjusted by determining the resistance values of R_5 and R_6 using equation (6) [21].

$$v_{out} = v_{ref}\left(1 + \frac{R_5}{R_6}\right) \quad (6)$$

Where, v_{ref} = 1.23 V.

Then, the search for the inductor L_2 Volt × *microsecond constant*, $E.T\ (V.\mu s)$ is carried out using equation (7) [21]:

$$E \times T = \left(v_{s(max)} - v_{out}\right)\frac{v_{out}}{v_{s(max)}} \times \frac{10^6}{f}\ [v \times \mu s] \quad (7)$$

The results of the substitution of the $E.T$ value equation are used and matched with the $E.T$ numbers on the vertical axis of the inductor value selection guide shown in Figure 4, and select the maximum load current to be used on the horizontal axis.

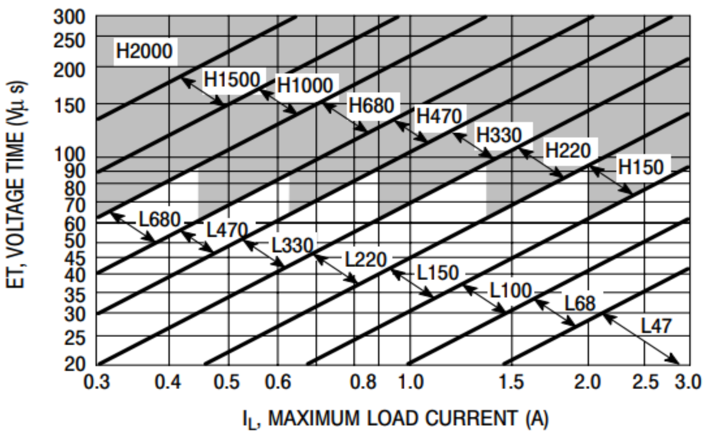


Figure 4. Equation with $[v \times \mu s] i_{Load(\max)}$[21]

To reduce the ripple voltage, a capacitor C_3 is used, which its value can be found using equation (8) [21]

$$C_3 \geq 13.300 \times \frac{v_S(\max)}{v_{OUT} \times L_2(\mu H)}(\mu F) \quad (8)$$

2.3. Application of Fuzzy Logic Control

In this research, fuzzy Mamdani logic control is used. This system is applied to MATLAB software in a simulation as a calculation and hypothesis, then hardware implementation is carried out by making a prototype. In this fuzzy Mamdani logic control, two inputs and one output are applied where the input variables are error (e) and delta error (de) which is taken by the boost converter output voltage (v_{C2}), while the output variable is PWM's corrected (Δk) which is correction value of duty cycle(k). The structure of the fuzzy logic control is shown in Figure 5.

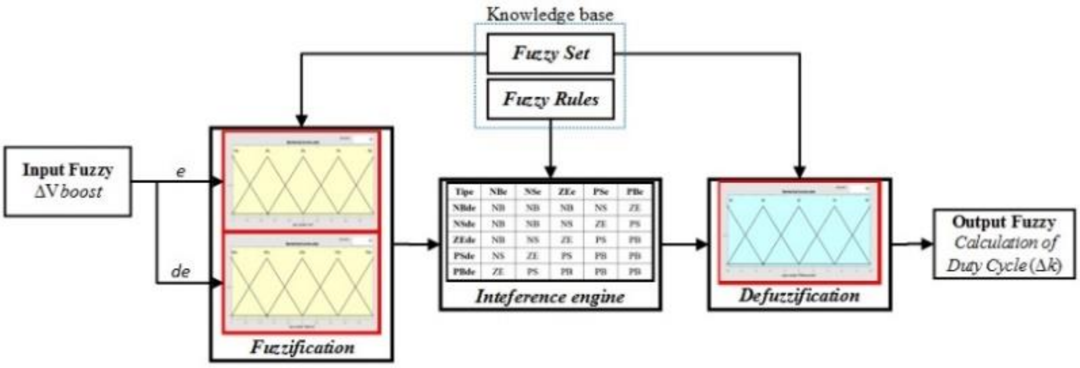
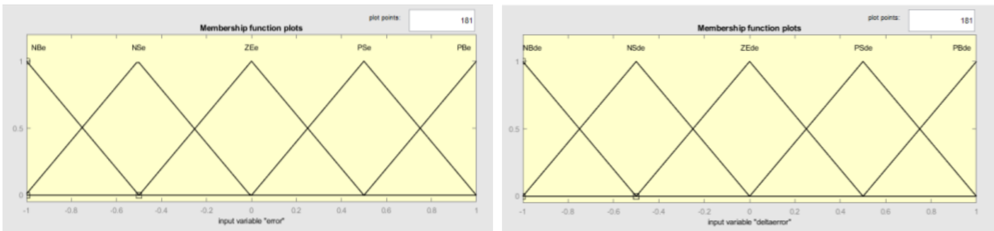


Figure 5. Structure of the Fuzzy Logic Control

Membership function for error input (*e*) and delta error (*de*) can be seen in Figures 6 (a) and (b) which have five fuzzy subsets respectively, namely for input error (*e*) namely PS*e* (Positive Small error), PB*e* (Positive Big error), ZE*e* (Zero error), NS*e* (Negative Small error), and NB*e* (Negative Big error). As for the input delta error (*de*), namely PS*de* (Positive Small delta error), PB*de* (Positive Big delta error), ZE*de* (Zero delta error), NS*de* (Negative Small delta error), and NB*de* (Negative Big delta error).



(a) (b)

Figure 6. Membership Functions (a) Input Error (e) and (b) Delta Error (de)

Figure 6. shows the membership function of the input error and delta error with the universal set [-1.0 1.0] and the domain of the fuzzy set is NB*e*/NB*de* = [-1.0 -0.5], NS*e*/NS*de* = [-1.0 0], ZE*e*/ZE*de* = [-0.5 0.5], PS*e*/PS*de* = [0 1.0], and PB*e*/PB*de* = [0.5 1.0]. Then the membership function for PWM's corrected can be seen in Figure 7, which has five fuzzy subsets, which are PS (Positive Small), PB (Positive Big), ZE (Zero), NS (Negative Small), and NB (Negative Big) with sets the universe is [-10 10] and the domain of the fuzzy set, which are NB = [-10 -5], NS = [-10 0], ZE = [-5 5], PS = [0 10], and PB = [5 20].

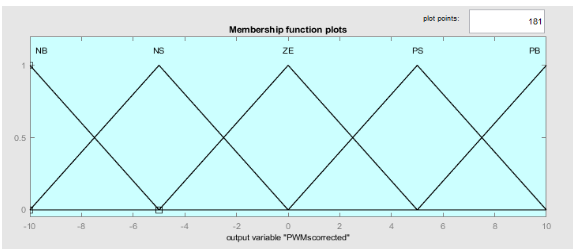


Figure 7. Membership function of PWM's corrected (Δk)

From the membership function that has been created, a fuzzy logic rule can be formed as shown in Table 1 by using the AND function rule or taking the minimum value of the two fuzzy set inputs. This value is taken from each set of error and delta error variables that are used to determine the fuzzy output in the form of PWM's corrected value (Δk).

Table 1. Fuzzy Logic Rule

Type	**NB*e***	**NS*e***	**ZE*e***	**PS*e***	**PB*e***
NB*de*	NB	NB	NB	NS	ZE
NS*de*	NB	NB	NS	ZE	PS
ZE*de*	NB	NS	ZE	PS	PB
PS*de*	NS	ZE	PS	PB	PB
PB*de*	ZE	PS	PB	PB	PB

2.4. Application of PID Control

The application of PID control in this study uses the Ziegler-Nichols method with an empirical approach based on the intended frequency response to minimize the maximum voltage ripple at v_{C2}. The maximum voltage ripple value is used as input from the PID control, which is the difference in the error value of $\Delta v_{C2}$with set point. The application of PID control is shown by the block diagram in Figure 8. The form of the transfer function of PID using Ziegler-Nichols in the form of equation 10.

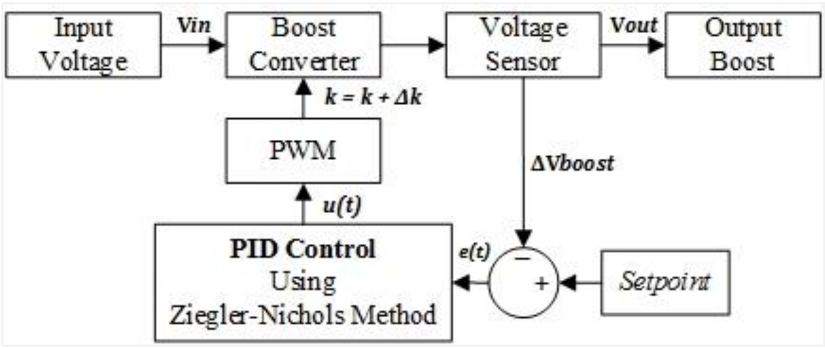


Figure 8. *Block Diagram of PID Control Implementation on Boost Converter*

Table 2. Ziegler-Nichols Formula for Controller Design

Controller Type	**Based on Frequency Response**		
	Kp	Ti	Td
Proportional (P)	$0.5\ K_C$	−	−
Integral Proportional (PI)	$0.45\ K_C$	$T_C/1.2$	−
Proportional Differential (PD)	$0.8\ K_C$	−	$T_C/8$
Proportional Integral Differential (PID)	$0.6\ K_C$	$T_C/2$	$T_C/8$

3. Results And Discussion

The simulation results of boost buck converter will be discussed. The component values used in the boost buck converter have been obtained from the substitution of equations (4)-(8), namely inductor L_1 = 110.37 µH, C_2 = 5603.95 µF, MOSFET = IRFZ44N, L_2 = 150 µH, C_3 = 154.2 µF (according to the datasheet command, the capacitor value is changed to 2200 µF[21], potentiometer R_5 = 50 KΩ, and IC LM2576. The load value used in this study is 4.7 Ω. The results of making a prototype of a voltage stabilizer physically are shown in Figure 9.

Figure 9. Physical of Voltage Stabilizer Prototype for Battery Charging

3.1. Simulation Results of Boost Converter Software Using Fuzzy Logic Control

The results of the boost converter simulation using fuzzy logic control are shown in Figure 10.

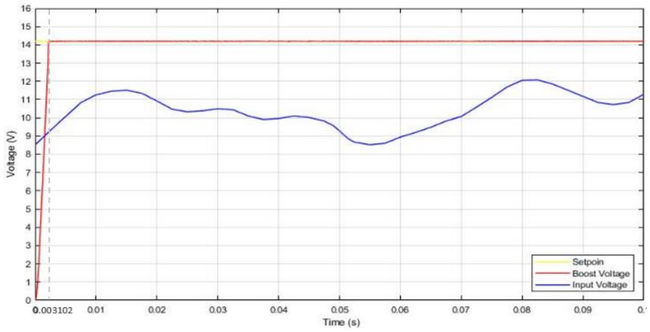


Figure 10. Simulation Results of Boost Converter Using Fuzzy Logic

Figure 10. concludes that the implementation of fuzzy logic control in a simulation has not been able to stabilize the boost converter output voltage because it still has a maximum ripple voltage of 0.24%. The percentage of overshoot at start up is 0.01%, the setting time is 3.102 ms, and does not have a steady state error.

3.2. Results of Hardware Boost Converter Implementation Using Fuzzy Logic Control

The results of implementing a hardware boost converter using fuzzy logic control are shown in Figure 11.

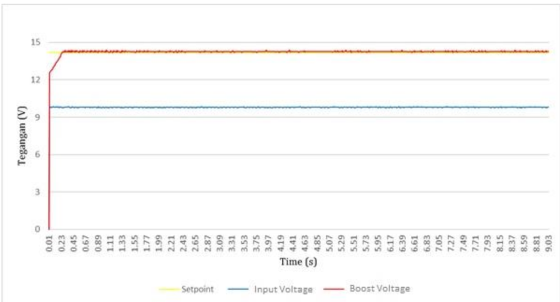


Figure 11. Results of Hardware Implementation of Boost Converter Using Fuzzy Logic Control

Figure 11. concludes that the implementation of fuzzy logic control in hardware implementation has also not been able to stabilize the boost converter output voltage because it still has a maximum voltage ripple of 1.2%. It was found that the percentage of overshoot and settling time was not as good as the simulation, namely 0.56% and 0.27 s, and no steady state error was obtained.

3.3. Simulation Results of Software Boost Converter Using PID Control

The simulation was carried out by comparing 4 types of controllers, namely P, PI, PD, and PID using the values of K_C = 5 and T_C = 3.064x10-3. The simulation results of the comparison of the 4 types of controllers are shown in Figure 12.

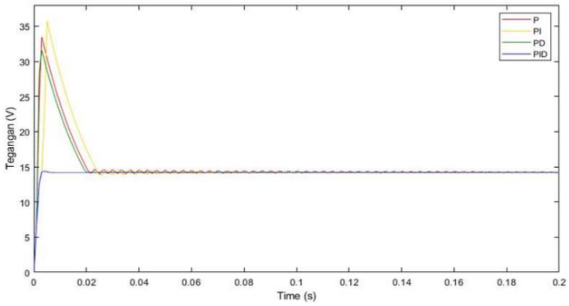


Figure 12. Simulation Results of PID Using Ziegler-Nichols

Figure 12. concludes that the type of controller that is better applied in this study is using PID. By using the tuning value P = 3, I = 1958.2, D = 0.0011 able to stabilize the voltage without producing a voltage ripple with a time to stabilize of 10 ms. The overshoot percentage is 1.6%, the setting time is 9.9 ms but produces a steady state error of 0.02%.

3.4. Results of Hardware Boost Converter Implementation using PID Control

The results of implementing a hardware boost converter using PID control are shown in Figure 13.

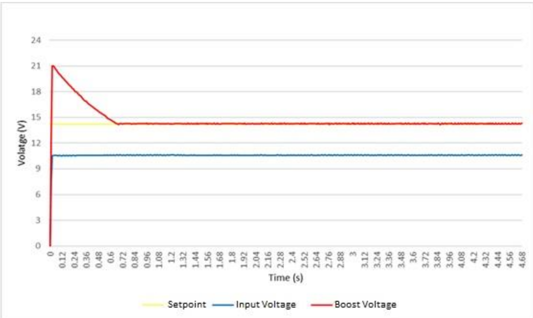


Figure 13. Implementation Results of the Output Boost Converter Using PID Control

Figure 13. explains that the implementation has not been able to stabilize the boost converter output voltage because it still has a maximum voltage ripple of 0.78%. The percentage of overshoot that is worse than the simulation is 47.9% and the settling time is 0.69 s, but it does not produce a steady state error.

3.5. Results of Comparison of Output Boost Converter Tests Using Fuzzy Logic Control with PID Control

The results of the comparison of the two techniques have been summarized and shown in Table 3.

Table 3. Application Comparison Results Fuzzy Logic Control with PID Control

No	Specification	Simulation		Hardware Implementation	
		FLC	PID	FLC	PID
1	Settling time	3,102 ms	9.9 ms	0.27 s	0.69 s
2	Maximum overshoot	0.01%	1.6%	0.56%	47.9%
3	Steady state error	0%	0.02%	0%	0%
4	Max. voltage ripple	0.24%	0%	1.2%	0.78%

Table 3. concludes that the application of fuzzy logic control gets the value of settling time, percentage of overshoot, steady state error, and the maximum voltage ripple at the boost converter output is smaller, but for voltage stability, the application of PID control is better. From the output boost converter on the hardware implementation, it produces a value that is less good than the simulation, this is due to the use of components that are of poor quality so the tolerance value of the components used is too large and different.

4. Conclusion

In the research and discussion of making a prototype voltage stabilizer for battery charging that has been carried out, the conclusion is that a prototype voltage stabilization on battery charging has been obtained using a boost buck converter circuit equipped with a charging circuit protection system to overcome under voltage / overcharge as a solution to extend duration of battery life and equipped with a monitoring system to facilitate prototype control.

Comparison of the implementation of two different techniques is carried out on the boost buck converter circuit, namely the application of fuzzy Mamdani logic control with PID using Ziegler-Nichols. From the results of the comparison, it is concluded that the application of fuzzy mamdani logic control is able to minimize the settling time of 0.27 seconds, with an overshoot of 0.56%, and there is no steady state error. However, the application of PID using Ziegler-Nichols is able to minimize the maximum voltage ripple which is 0.42% smaller than the application of fuzzy logic control.

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