

Design and Implementation of Buck Boost Converter for fuzzy Logic Controller Based DC Motor Speed Control

Abstract. DC motor is an electric machine that is widely used in the industrial and home fields. In its application, the speed of a DC motor often decreases the voltage caused by the load received by the motor, so that the speed is not constant. So to maximize the performance of a DC motor, a speed controller is needed that is used to adjust the speed of the DC motor to be constant and in accordance with the actual speed. The method of the Fuzzy Logic Controller is used to adjust the speed of the DC motor so that the actual speed obtained is more precise and has resistance to interference and has an accurate response. In this research, a buck boost converter will be designed using the Fuzzy Logic Controller method to control the speed of a DC motor. In its implementation, the buck boost converter has an average efficiency of 85.3% for buck mode and 86.79% for boost mode at 10-100% loading. While on a DC motor with a load, the buck boost converter has an average of 71.55% for buck mode and 74.89% for boost mode. Then in testing the DC motor which is kept at a constant speed, the buck boost converter can maintain its average output voltage of 23.98 Volts with an error value of 0.02% when in buck mode and the average output voltage is 23.95 Volts with a value of 23.95 Volts. error of 0.08% when in boost mode. So that the speed of the DC motor can be kept constant with an average speed of 478 rpm with an error value of 0.4% in buck and boost modes.

Streszczenie. Silnik prądu stałego to maszyna elektryczna, która jest szeroko stosowana w przemyśle i domu. W swoim zastosowaniu prędkość silnika prądu stałego często zmniejsza napięcie spowodowane obciążeniem odbieranym przez silnik, tak że prędkość nie jest stała. Aby zmaksymalizować wydajność silnika prądu stałego, potrzebny jest regulator prędkości, który służy do regulacji prędkości silnika prądu stałego, aby była stała i zgodna z rzeczywistą prędkością. Metoda sterownika Fuzzy Logic służy do regulacji prędkości silnika prądu stałego tak, aby rzeczywista uzyskiwana prędkość była bardziej precyzyjna, odporna na zakłócenia i miała dokładną reakcję. W ramach tych badań zostanie zaprojektowany przetwornica buck boost wykorzystująca metodę sterownika Fuzzy Logic do sterowania prędkością silnika prądu stałego. W swojej implementacji konwerter buck boost ma średnią wydajność 85,3% dla trybu buck i 86,79% dla trybu boost przy obciążeniu 10-100%. Podczas pracy z silnikiem prądu stałego z obciążeniem, przetwornica buck-boost ma średnio 71,55% w trybie buck i 74,89% w trybie boost. Następnie podczas testowania silnika prądu stałego utrzymywanego na stałej prędkości, przetwornica obniżająca napięcie wyjściowe może utrzymać średnie napięcie wyjściowe wynoszące 23,98 woltów z wartością błędów 0,02% w trybie obniżania, a średnie napięcie wyjściowe wynosi 23,95 woltów o wartości 23,95 V. błąd 0,08% w trybie doładowania. Aby prędkość silnika prądu stałego mogła być utrzymywana na stałym poziomie przy średniej prędkości 478 obr./min przy wartości błędów 0,4% w trybach buck i boost. (Projekt i wdrożenie konwertera Buck Boost do sterowania prędkością silnika prądu stałego w oparciu o sterownik rozmyty)

Keywords: Buck boost converter, DC Motor, Fuzzy Logic Controller, Speed Control

Słowa kluczowe: Przetwornica Buck Boost, silnik prądu stałego, kontroler Fuzzy Logic, kontrola prędkości

Introduction

In the current era, the many developments and advancements in the fields of technology and science have made innovations in the fields of technology and control diverse, including electric machines and their use which cannot be separated from daily needs. One example is the use of DC motors which are often implemented in the industrial and home sectors. However, technological advancements in the industrial and home sectors actually experience a problem related to the instability of the DC motor speed. In fact, DC motors have a more favorable speed torque than other types of motors, so speed regulation is necessary (Saeed et al., n.d.).

In its application, the speed of a DC motor often decreases the voltage caused by the load received by the motor, so that the speed is not constant. In general, to regulate the speed of DC motors still use the PI (Proportional-Integral) method of control. The PI method serves to determine the precision or stability of an instrumentation system with feedback characteristics. PI parameters can be set in the system to be controlled, so that the system output response is in accordance with the desired system input (Dutta et al., 2014). However, consideration of the use of control is very important in regulating the speed of a DC motor. Therefore, we need a control system that has resistance to interference and has an accurate response.

Buck boost converter is one of the many control systems used to regulate speed by increasing and decreasing the input voltage. A DC-DC converter is used to stabilize the DC value of a given voltage to a desired value. This is usually achieved by cutting and filtering the input voltage via a suitable Switch, and is generally applied using

PWM (Jung et al., 2018). There are several methods that have been used to adjust the speed of a DC motor, such as PID and PI. In using the PID Controller, it has a simple structure but the response is not fast with dynamic load conditions and varying set points. Meanwhile, the PI controller has a fast reaction to disturbances but the system is less effective with various parameters (Guo & Mohamed, 2020). With these conditions, this research will design and implement a buck boost converter to regulate the speed of a DC motor. The method of the Fuzzy Logic Controller is used to be able to adjust the speed of the DC motor so that the actual speed obtained is more precise and has resistance to interference and has an accurate response.

Basic Theory

A. Buck Boost Converter

Buck boost converter is one type of power electronic component that is able to produce voltage variations by increasing and decreasing the input voltage based on switching frequency. This converter has an output voltage polarity that is opposite to the input voltage. The components of the buck boost converter consist of a transistor (Q), an inductor (L), a diode (D), and a capacitor (C) (Hernández-Márquez et al., 2018). The working principle of the buck boost converter circuit is divided into two modes, namely when the switch is ON and when the switch is OFF. This topology has the advantage of low voltage ripple on the input and output sides, so the Buck boost converter is the right topology to be used in applications related to DC motors. The following is a series of Buck boost converters.

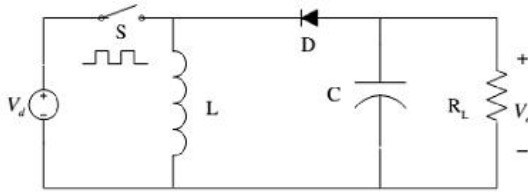


Fig. 1 Buck Boost Converter

When the buck boost converter is switched off, the diode will work in a reverse biased state so that current will flow to the inductor. From the condition of the current flowing in the inductor so that there will be charging on the inductor which causes the inductor current to increase.

When the buck boost converter is switched ON, the diode will work in a forward biased state so that the current stored in the inductor will be empty and will then flow to the load. The direction of the current flowing and the charging process are the same. Then the energy stored in the inductor will experience a state of discharging. Therefore, the buck boost converter can produce an output voltage whose value is inversely related to the input voltage. The output voltage generated by this buck boost converter can be high or low value from the input voltage

The following is the equation used to find the value of the inductor:

$$L = \frac{V_d D}{\Delta I_L f}$$

Then to find the value of the capacitor we get the following equation:

$$C = V_{max} \left(\frac{1-D}{f R \Delta V} \right)$$

Next, when looking for the value of R, we get the following equation:

$$R = \frac{V_o^2}{P_o}$$

From the above equation it can be seen that V_o is the output voltage of the converter, then P_o is the output power of the converter whose conditions are considered ideal. Then the value of the output power P_o sama dengan daya input P_o .

B. DC Motor

A DC motor is an electric machine that converts direct current electrical energy into mechanical energy. The use of DC motors is almost in every aspect of everyday life, such as toys, fans, and car drives. Small DC motors are used in toys, tools and equipment (Sadiq.A.A, 2013). While larger DC motors are used in electric cars, propulsion systems, and elevators. On an industrial scale, high speed control, stable state, and good torque speed characteristics are required for the performance of DC motors.

Motors are classified into several types, namely separate amplifier DC motors (separately excited), Shunt DC motor, Series DC motor, Separate boost DC motor

1) Separate Amplifier DC Motor

A split-amplified DC motor is a motor whose field circuit is supplied from constant voltage power which is separate from the supply. Separate amplifier DC motors have the advantage of generating power and speed because they have a field flux generated by the field coil, which is located separately, besides that this DC motor also has its own generator source in the form of DC voltage. Therefore, this type of DC motor is very possible to generate field flux when compared to permanent magnet DC motors or other types (Taufiq Arif, 2020).

The following is the equivalent circuit of a separate amplifier DC motor:

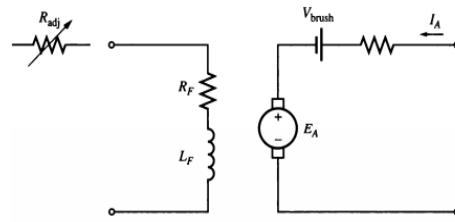


Fig 2 Rangkaian Ekuialen motor DC penguat terpisah

From the DC motor equivalent circuit above, the equation used to analyze the characteristics of a DC motor is obtained:

$$V_t = E_a + I_a R_a$$

$$P = \tau \omega$$

$$\tau_{ind} = K \phi I_A$$

$$E_A = K \phi \omega$$

$$I_f = \frac{V_f}{R_f}$$

$$I_L = I_A$$

2) Shunt DC Motor

A shunt dc motor is a motor whose field circuit gets power directly connected to the armature terminal of the motor. In the Shunt type DC Motor, this is the type of motor that is often used, this is because it has an almost constant speed even though there is a change in load, the speed will decrease when it reaches torque. (torque) certain (Tapia-Olvera et al., 2016).

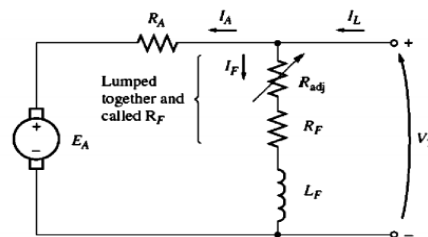


Fig 3 Rangkaian Ekuialen motor DC Shunt

From the DC motor equivalent circuit above, the equation used to analyze the characteristics of a DC motor is obtained:

$$V_t = E_a + I_a R_a$$

$$P = \tau \omega$$

$$\tau_{ind} = K \phi I_A$$

$$E_A = K \phi \omega$$

$$I_f = \frac{V_T}{R_f}$$

$$I_L = I_A + I_f$$

3) Series DC Motor

Series DC motors are a group of self-excited DC motors in which the field winding is connected in series to the armature winding and thus higher current flowing. The working principle of a DC series motor is to convert electrical energy into mechanical energy based on the electromagnetic principle. In this type of DC motor, the power supply terminal is at one end of the armature and field coils. By applying a voltage, power is initiated at this terminal and passes through the armature and field

windings. Since the conductors in this winding are very large, they have minimal resistance.

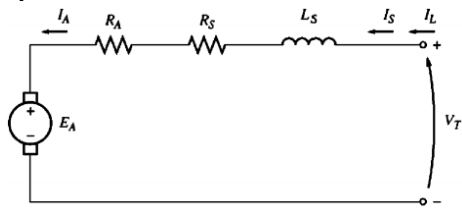


Fig. 4 Rangkaian ekuivalen motor DC seri

From the DC motor equivalent circuit above, the equation used to analyze the characteristics of a DC motor is obtained :

$$V_t = E_a + I_a(R_a + R_s)$$

$$P = \tau\omega$$

$$\tau_{ind} = K\phi I_A$$

$$E_A = K\phi\omega$$

$$I_s = I_a$$

4) Permanent magnet DC Motor

In this DC motor, the state of the main field flux is generated by a permanent magnet, so it is called a permanent magnet DC motor. In this type of DC motor, only one external DC supply source is required, to supply electrical power to the armature. Permanent magnet DC motor is a type of DC motor whose poles are made of permanent magnets.

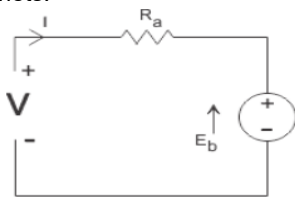


Fig 5 Rangkaian ekuivalen Motor DC permanen magnet

From the DC motor equivalent circuit above, the equation used to analyze the characteristics of a DC motor is obtained

$$V_t = E_a + I_a R_a$$

$$P = \tau\omega$$

$$\tau_{ind} = K\phi I_A$$

$$E_A = K\phi\omega$$

$$I_f = \frac{V_T}{R_f}$$

$$I_L = I_a + I_f$$

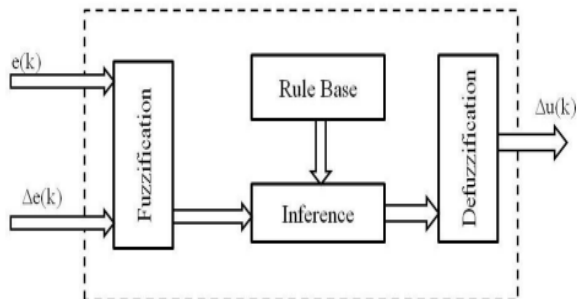


Fig. 6 Diagram Fuzzy Logic Controller

C. Fuzzy Logic Controller

In its application fuzzy logic can be applied in various applications and uses. One application of fuzzy logic in industry is as a DC motor speed controller. So that the buck boost converter can control the speed of the DC motor. The results obtained are that when a DC motor is given a

varying load, its speed can be kept constant or stable. In this research, the process of determining fuzzy logic to control the buck boost converter, the first thing that will be made is the membership function or membership function. By specifying the input and output parameters, which here are given that the inputs are error and delta error. Meanwhile, the output is duty cycle, which will be regulated by the input value of error and delta error. The output of the duty cycle will set the switch on the buck boost converter. The following is a diagram of the Fuzzy Logic Controller:

1) Fuzzyfication Process

In the fuzzification process, the crisp input variable value will be converted into a linguistic label where the condition is in accordance with the predetermined membership functions (MFs). For fuzzy input that produces verbal decisions, it has gone through a conversion process from linguistic labels. The next process aims to change the fuzzy input into fuzzy output through the rules (If-Then) that have been determined in the fuzzy knowledge base. The last stage is fuzzyfication, which will change the fuzzy output obtained from the inference into a firm value using a membership function that is in accordance with the fuzzyfication process. The following is the input variable used :

$$Error = V_{reff} - V_{aktual}$$

$$\Delta Error = Error(t) - Error(t - 1)$$

$$Error(k) = V_{reff} - V(k)$$

$$\Delta Error = e(k) - e(k - 1)$$

For the application of the buck boost converter, two inputs are given, namely error and delta error which will produce one output, namely the duty cycle which is used for the MOSFET switching process in the converter circuit.

2) Inference Engine

In this process the inference engine will receive the results of the calculations in the fuzzification process so that it can produce a value which will later be processed on a linguistic variable that refers to the membership function. The membership function used in this study consists of several members including PB (Positive Big), PS (Positive small), ZO (zero), NS (Negative Small). Eriikut is the logic of fuzzy logic:

Table 1 Table of Fuzzy Logic

E/dE	NB	NS	Z	PS	PB
NB	NB	NB	NB	NS	Z
NS	NB	NB	NS	Z	PS
Z	NB	NS	Z	PS	PB
PS	NS	Z	PS	PB	PB
PB	Z	PS	PB	PB	PB

3) Defuzzyfication

This process is called defuzzyfication, where the output from the inference engine stage which has the form of a linguistic variable will be converted back into a numeric value (crisp). The following is an equation to find the center of gravity (ΔD) :

$$\Delta D = \frac{\sum_{j=1}^n \mu(\Delta D_j) \times \Delta D_j}{\sum_{j=1}^n \mu(\Delta D_j)}$$

The following is the equation to get the actual value of the duty cycle:

$$D(k) = D(k - 1) - \Delta D \cdot \Delta D(k)$$

4) Rules

This process is used to store and manipulate the knowledge that has been determined in the membership function and then used to solve problems. By using rules, rules can be used to show the form of knowledge in semi-natural language in the fuzzy Rule-Based System algorithm.

Methodology and System Model

A) System Block Modeling

In this study, there is a part of the system that works, namely the buck boost converter system with the Fuzzy Logic Controller algorithm to control the speed of the DC motor by changing the duty cycle value so that the converter output voltage and DC motor speed will also change. Meanwhile, for the next system, that is by maintaining the output voltage of the buck boost converter so that the speed of the DC motor will be maintained constant when a variable load is given..

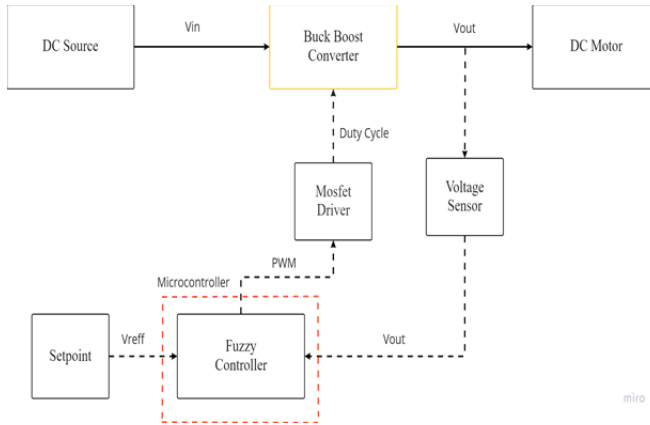


Fig. 7 Diagram Blok Sistem

B) DC motor specifications

For the design needs of the buck boost converter, it is necessary to have a specification or rating of the DC motor used. Then so that the design can be appropriate, it must look at the parameters listed on the DC motor. In accordance with the datasheet listed on the PG45 DC motor, it can be determined the parameters needed in the design of this research. The specifications of the PG45 DC motor used can be seen in the following table:

Table 2 DC motor specifications PG45

No.	Parameter	Value
1.	Type	Motor Brush DC
2.	Model	PG45 Series 775
3.	Motor Capacity	100 watt
4.	Nominal Voltage	24 Volt
5.	Maximum Current	5 Ampere
6.	RPM	480 ±10%
7.	Maximum Torque	2 Nm

C) Buck boost converter design

In designing a buck boost converter there are several things that must be determined and considered. The first step in designing the converter is to determine the electrical parameters based on the load and source specifications to be used. The electrical parameters of the converter to be used such as the value of the input voltage (V_{in}), output voltage (V_o), frekuensi Switching (f_s), Power output P , inductor current ripple (ΔI_L), capacitor voltage ripple (ΔV_C).

Table 3 Buck boost converter specifications:

No.	Parameter	Value
1.	Daya Output (P)	120 Watt
2.	Frekuensi Switching (f_s)	20.000 KHz
3.	Ripple Arus Induktor (ΔI_L)	5 %
4.	Ripple Tegangan Kapasitor (ΔV_C)	1 %
5.	Tegangan Input (V_{in})	22 Volt & 28 Volt
6.	Tegangan Output (V_o)	24Volt

Table 4 Converter component parameters

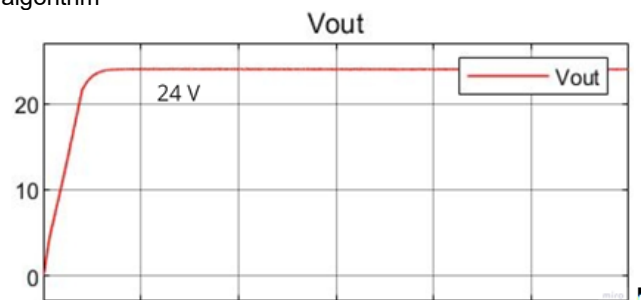
No.	Parameter	value
1.	DC Power Supply	22 V & 28 V
2.	Microcontroller	Arduino NANO
3.	MOSFET	IRFP4227
4.	Driver MOSFET	TLP250
5.	Power Supply Driver Mosfet	12 V
6.	Diode	MUR1560
7.	Inductor	1391,72 μ H
8.	Core Inductor	Toroid Ferrite Core
9.	Input Voltage Capacitor	Elco 1000 μ F 50 V
10.	Output Voltage Capacitor	Elco 2000 μ F 50 V
11.	Resistor Load	4,8 R
12.	DC Motor	PG 45 100 Watt
13.	Frekuensi Switching	20 kHz
14.	Output Voltage	24 V
15.	Voltage Sensor	Multiturn 100k Ω
16.	Current Sensor	ACS 712

The parameter values of each component for the manufacture of tools are adjusted to the availability on the market. The value of the component in the implementation is a value that is greater than the value of the component that has been designed. It aims to anticipate the converter in a state of DCM. The table below is the components used in the implementation:

From the design results in the table above, before carrying out the implementation stage, a simulation is carried out using Matlab software. After the simulation results are in accordance with the design made, the implementation stage of the converter is carried out.

D) Buck Boost Converter Simulation on DC motor with FLC

In this section, a simulation of a buck boost converter is carried out by maintaining the speed of a DC motor when a load is applied. This simulation aims to determine the converter's ability to maintain the speed of the DC motor. Note that the speed of the DC motor can be controlled by the output voltage of the buck boost. So that from the simulation the voltage is kept constant so that the speed of the DC motor can also be maintained stable. To get a constant voltage, close loop control is carried out so that the duty cycle of the converter can be controlled. In this system, the output voltage from the converter is used as feedback which will be compared with the setpoint value. Then from the comparison, an error signal is generated which will be processed by the controller with the Fuzzy Logic Controller algorithm



(a)



(b)

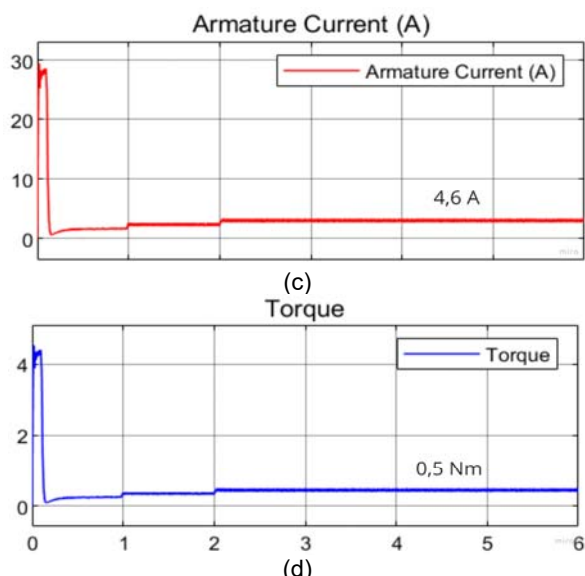


Fig. 8 Simulation Converter with motor speed kept constant when buck mode

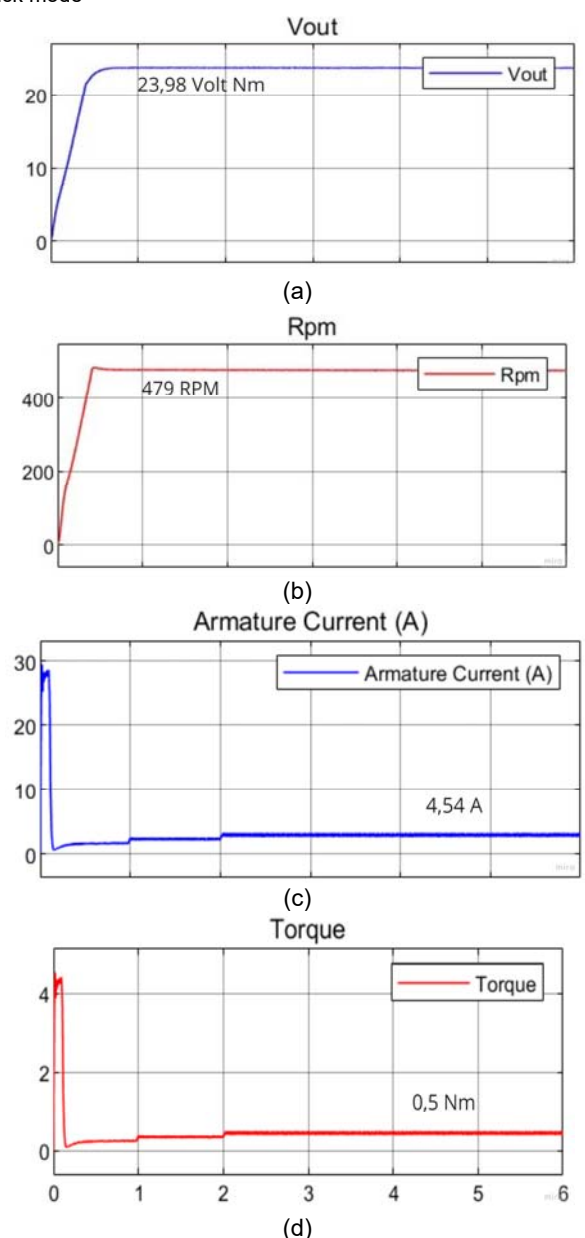


Fig. 9. Simulation Converter with motor speed kept constant when boost mode

Based on the simulation results, the given loading value is 0 to 0.5 Nm when the maximum load condition. Then for the set point value of the daturator voltage with a value of 24 volts in both buck and boost modes. So that the output value of the converter is kept constant, which is 24 Volts during buck mode and 23.98 during boost mode so that the DC motor speed is also stable at 480 RPM in buck mode and 479 RPM during boost mode where the speed value when in boost mode is still different from a predetermined value, but within the tolerance limit because the difference is not too far away. Furthermore, the results obtained for the average current value of the DC motor, which is 4.6 Ampere when in buck mode, while for boost mode, the average value is 4.54 Ampere. From these results, it can be concluded that the converter can maintain the speed of the DC motor when given various loads.

E) Converter Implementation and Testing

The results of the converter implementation can be seen in Figure 11. The converter tests carried out included switching tests, inductor current signals, capacitor voltage signals, input-output voltage signals, current and voltage sensor tests, and efficiency. From the test results of the converter, it can be concluded that the converter can work according to the design with several parameters such as current and voltage ripples that have values above the calculation. This is because the components used in the implementation of the converter are not ideal, causing losses. The converter can achieve efficiency. when operating in buck mode, it can achieve a maximum efficiency of 85.30% at 50% loading and a minimum efficiency of 80.38% at full-load loading. Meanwhile, when the converter operates in boost mode, it can reach a maximum efficiency of 90.33% at 50% loading and a minimum efficiency of 81.81% at full-load loading. So from the efficiency test, the converter has an average efficiency of 85.3% when in buck mode and an average efficiency of 86.79% when in boost mode.

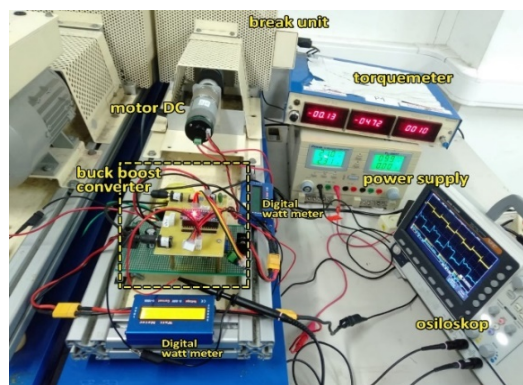


Fig. 10. Implementasi Buck Boost Converter untuk kontrol kecepatan motor DC

Results and Discussion

A) Testing Converter with DC motor for constant speed

Testing with a DC motor that aims to keep the speed constant when the load given varies. This test is carried out to determine whether the converter can work properly or not when the DC motor is given a varying load. In addition, this test is also carried out to determine whether the Fuzzy Logic Controller algorithm has worked well or not when receiving a response from the speed and voltage of the changing voltage.

5) Mode Buck Test

Based on the table below, the buck boost converter can maintain the output voltage so that the speed can be stabilized when given a varying load. It can be seen that the

voltage value is kept constant with the highest value being 24.03 Volts, while the lowest value is 23.95 Volts. It can be seen that the average value of the voltage is 23.98 Volts. From this value it can be seen that the converter is able to maintain the voltage even though the motor is given a varying load. Only a difference of 0.02 from the given set of voltage points so that an error of 0.08% is obtained

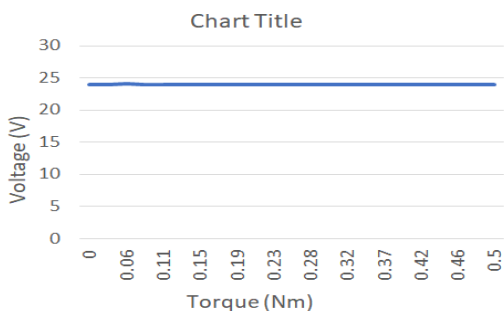


Fig. 11. Torque and Voltage Graph in Buck mode

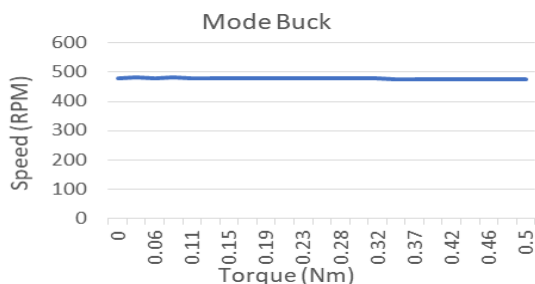


Fig. 12. Torque and Voltage Graph in Buck mode

Then based on the data below, it can also be seen that the speed of the DC motor can be kept constant even though it is given a varying load. The highest value of DC motor speed was found at 483 rpm and the lowest value was 476 rpm. Then for the average value of DC motor speed is 478 rpm. From the predetermined value, there is only a difference of 2 rpm, so an error of 0.4% is obtained.

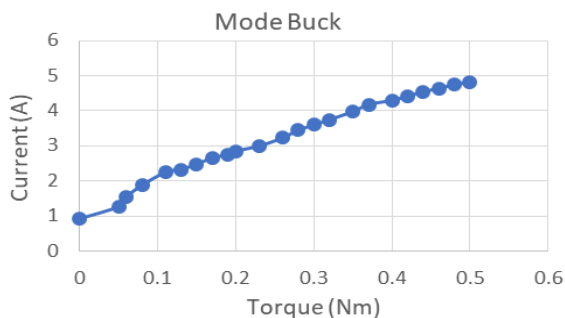


Fig. 13. Torque and Flow Chart in Buck mode

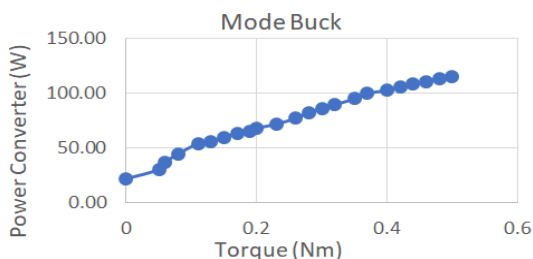


Fig. 14. Torque Graph and Converter Power in Buck mode

Based on the graph above, that the current value increases when the torque is increased. The data obtained that the maximum current value is 4.82 A with a torque of 0.5 Nm. The current value is still safe and below the rating of a DC motor, which is 5A. The relationship between current and torque is directly proportional

Based on the graph above, it shows that the output power value of the converter increases when the load value is increased. In this condition, the voltage is kept constant so that the current will increase more than when the voltage is not kept constant. So that the increase in current results in a larger output power. The output power of the converter is obtained at a value of 115.44 Watt when given a load of 0.5Nm. This value is still within safe limits, because the buck boost converter is designed with a capacity of 120 Watts.

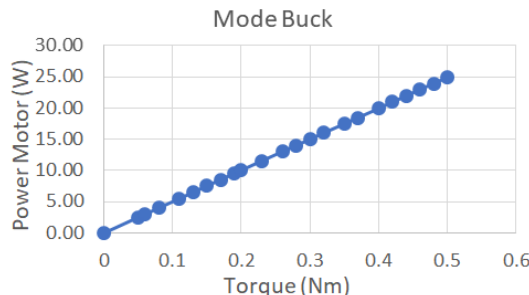


Fig. 15. Torque and Motor Power in Buck mode

The value of the DC motor output power increases with the addition of loading. The value of the output power on the DC motor is 24.91 Watt when it is given a load of 0.5Nm. The value of the motor's output power is a quarter of the motor's rating, which is 100 watts. Because the datasheet is known to achieve this power must be given a maximum load of up to 2Nm. When the load is condition the motor will be stationary and not rotating

6) Mode Boost Test

The DC motor used has a specification of 100 Watt. Where the set point value has been set according to the converter voltage calculation in boost mode. Then the DC motor in this test will be given a load from the break unit, by increasing the torque starting from 0-0.5 Nm. Then see whether when given a load, the speed of the DC motor can be stable or not.

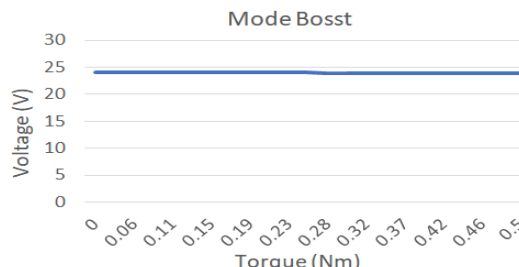


Fig. 16. Torque graph and connection in Boost mode

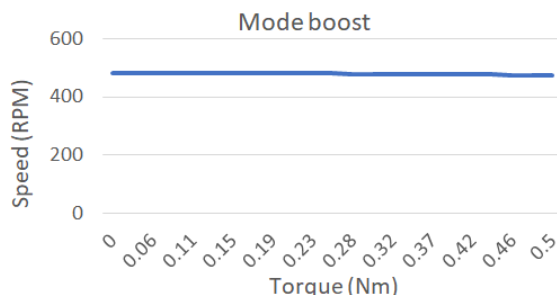


Fig. 17. Torque graph and connection in Boost mode

Based on the graph above, it can be seen that the output voltage can be kept constant so that the speed of the DC motor can be stable when given a varying load. This condition is also the same when testing in buck mode. The load given in this test is a break unit by setting the load torque from 0 to 0.5 Nm.

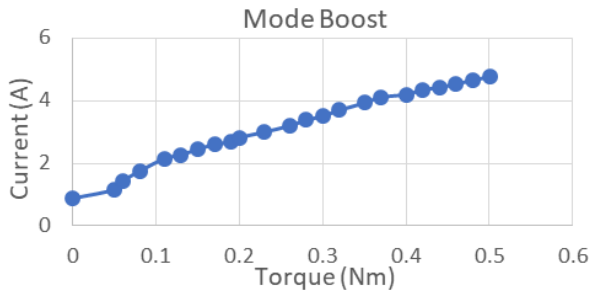


Fig. 18. Torque and current graph in Boost mode

Based on the graph above, that the current value increases when the torque is increased. So that the data obtained that the maximum current value is 4.77 A with a torque of 0.5 Nm. The condition of the motor is still in a safe condition because the current value is below the rating of a DC motor, which is 5A. The relationship between current and torque is directly proportional.

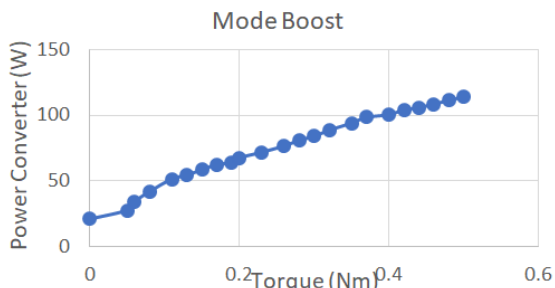


Fig. 19. Torque graph and Power converter when in Boost mode

Based on the graph above, it shows that the output power value of the converter increases when the load value is increased. In this condition, the voltage is kept constant so that the current will increase more than when the voltage is not kept constant. So that the increase in current results in a larger output power. The output power of the converter is obtained at a value of 114.19 Watt when given a load of 0.5Nm.

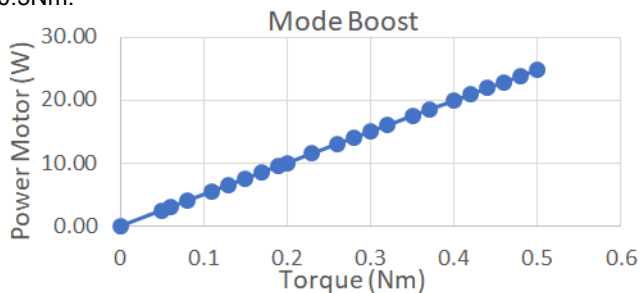


Fig. 20. Torque and Motor Power Graph in Boost mode

Based on the graph above, the value of the DC motor output power increases with the addition of loading. This condition can be analyzed from the equation of power equal to torque multiplied by omega. The results for the output power and torque are directly proportional. The value of the output power on the DC motor is 24.86 Watt when it is given a load of 0.5Nm. The value of the motor's output power is a quarter of the motor's rating, which is 100 watts.

Conclusion

In its implementation, the buck boost converter has an average efficiency of 85.3% for buck mode and 86.79% for boost mode at 10-100% loading. While on a DC motor with a load, the buck boost converter has an average of 71.55% for buck mode and 74.89% for boost mode. Then in testing the DC motor which is kept at a constant speed, the buck boost converter can maintain its average output voltage of 23.98 Volts with an error value of 0.02% when in buck

mode and the average output voltage is 23.95 Volts with a value of 23.95 Volts. error of 0.08% when in boost mode. So that the speed of the DC motor can be kept constant with an average speed of 478 rpm with an error value of 0.4% in buck and boost modes.

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REFERERNCES

- Ajiatmo, D., & Robandi, I. (2018). Analisis Pengendalian Kecepatan DC Motor Berbasis Buck-Boost Konverter. *Jurnal Intake : Jurnal Penelitian Ilmu Teknik Dan Terapan*, 9(2), 74–79. <https://doi.org/10.32492/jintake.v9i2.777>
- Caricchi, 17, Crescimbin, F., Giulii Capponi, F., & Solero, L. (1998). *Study of Bi-Directional Buck-Boost Converter Topologies for Application in Electrical Vehicle Motor Drives*.
- Dutta, V., Scholar, R., & Borkakati Student, S. (2014). *PI-Fuzzy rule based controller for Analysis and performance evaluation of dc motor speed control PI-Fuzzy rule based controller for Analysis and performance evaluation of dc motor speed control* Victor Dutta Deepjyoti Bora. <https://doi.org/10.13140/2.1.3635.7922>
- Fitzgerald, A. E. (Arthur E., Kingsley, C., & Umans, S. D. (2003). *Electric machinery*. McGraw-Hill.
- Guo, Y., & Mohamed, M. E. A. (2020). Speed Control of Direct Current Motor Using ANFIS Based Hybrid P-I-D Configuration Controller. *IEEE Access*, 8, 125638–125647. <https://doi.org/10.1109/ACCESS.2020.3007615>
- Hernández-Márquez, E., García-Sánchez, J. R., Silva-Ortigoza, R., Antonio-Cruz, M., Hernández-Guzmán, V. M., Taud, H., & Marcelino-Aranda, M. (2018). Bidirectional tracking robust controls for a DC/DC buck converter-DC motor system. *Complexity*, 2018. <https://doi.org/10.1155/2018/1260743>
- Jung, H. Y., Kim, S. H., Moon, B., & Lee, S. H. (2018). A new circuit design of two-switch buck-boost converter. *IEEE Access*, 6, 47415–47423. <https://doi.org/10.1109/ACCESS.2018.2866886>
- Lin, B.-R., & Hua, C. (1993). *BUCK/BOOST CONVERTER CONTROL WITH FUZZY LOGIC APPROACH*.
- Muruganandam, M., & Madheswaran, M. (2009). Performance analysis of fuzzy logic controller based DC-DC converter fed DC series motor. *2009 Chinese Control and Decision Conference, CCDC 2009*, 1635–1640. <https://doi.org/10.1109/CCDC.2009.5192235>
- Rashid, M. H. (Muhammad H. (2014). *Power electronics : devices, circuits, and applications*.
- Sadiq, A.A. (2013). *A Fuzzy-Based Speed Control of DC Motor Using Combined Armature Voltage and Field Current _ Elsevier Enhanced Reader*.
- Saeed, R. A., Mokhtar, R. A., IEEE Sudan Subsection, & Institute of Electrical and Electronics Engineers. (n.d.). *2017 International Conference on Communication, Control, Computing and Electronics Engineering (ICCCCEE) : proceedings : 16th-17th January 2017, Khartoum, Sudan*.
- Siahan, F. (2018). *Universitas Sumatera Utara*.
- S.J.Chapman. (2005). *ELECTRIC MACHINERY FUNDAMENTALS*.
- So, W. C., Tse, C. K., & Lee, Y. S. (1994). *A Fuzzy Controller for DC-DC Converters*.
- Tapia-Olvera, R., Beltran-Carbajal, F., Aguilar-Mejia, O., & Valderrabano-Gonzalez, A. (2016). An adaptive speed control approach for DC shunt motors. *Energies*, 9(11). <https://doi.org/10.3390/en9110961>
- Taufiq Arif, D. (2020). *Kendali Kecepatan Motor DC Penguat Terpisah Berbeban Berbasis Arduino*. <http://ejournal.unp.ac.id/index.php/jtev/index>
- Tir, Z., Malik, O., Hamida, Med. A., Cherif, H., Bekakra, Y., & Kadrine, A. (2017). *Implementation of a Fuzzy Logic Speed Controller For a Permanent Magnet DC Motor Using a LowCost Arduino Platform*.