BLDC motor design by applying the control of direct current and analysis of loading mechanism soft starting

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Abstract. In this research, there will be a design driver brushless DC (BLDC), which on the input voltage of the motor driver applying direct current controllers and the implementation mechanism of soft starting the operator of BLDC which uses fuzzy logic controllers. Testing is done with a view of controlling the application of direct current to the BLDC to many conditions, namely the amount of value given fuzzy logic and the load that is given to the mechanics. The design of the driving BLDC has successfully created and implemented by applying a direct current control and the results obtained in the form of efficiency that is better than the previous design. The soft starting mechanism that controls using the fuzzy logic method possible produces a low inrush current and generates steady conditions that are better on BLDC. For values that are applied to the load, the greater the torque load placed on the BLDC, the higher the initial current needed to achieve transient time equally and opposite that the smaller the torque load placed on the BLDC, then the lower torque the load required to achieve the transient time.

1. Introduction

In the use of BLDC, one that must be considered is the large wave in the initial start of the motor because if it does not take into account things like this, it will cause some good problems that result in damage to the BLDC driver and have an impact on energy efficiency problems [1]. Several studies use current protection to control BLDC using both hardware and software. The application by using hardware a method that can protect the wave in a classic way that is by using a rheostat, how to slowly increase the resistance value to the maximum resistance value so that the initial inrush current can be minimized. But this method has several disadvantages; namely, the rheostat still uses a manual shear system, so that the current that is retained is discharged into heat, and the price of the rheostat is still relatively expensive. More conventional hardware current protection by using a start and trip system for BLDC [2].

The induction motor, when turned on, can immediately draw 5 to 7 times the full load current. This large current can result in a decrease in voltage and disrupt other devices on the same channel, so motors with power above 30 or 50 horsepower are not recommended to be turned on immediately. In the research carried out, to achieve the nominal current needed 3 seconds, because the setting at the start and trip time is 3 seconds, if it exceeds the time limit set, then the trip circuit will function. A time tolerance setting of fewer than 3 seconds can be set on IC 555 via the potentiometer. So that the delay system, which consists of a timer configuration start and the trip, will reduce the current, and others are expected to control the current to the motor gradually by following the desired settings.
Current protection research using the software by looking at the BLDC current profile for several variations, namely the height of steps, a time delay between steps, and mechanical load provided by changing the resistor resistance at the BLDC terminal. The greater the time delay between input steps, the lower the maximum start-up wave that occurs at BLDC. When the given delay time is greater than the BLDC transient time for each step, the addition will not decrease the maximum value of the start-up wave but will extend the time needed for the BLDC to reach steady-state [3]. Referring to several references, the researcher got an idea to develop BLDC current protection by using fuzzy logic and made a closed loop to control the current entering BLDC.

2. Literature Review

2.1. Three-phase BLDC motor
The drive is the main part of a vehicle. One part of the drive is the Brushless Direct Current Motor (BLDC). BLDC has many advantages from DC motors, one of which is the commutation that can be released, namely the commutation of 2 connected phase windings and the commutation of 3 connected phase windings. Allowing Intermediate power to occur when 2 phase coil commutations are connected, and maximum power occurs when 3 phase coil commutations are connected [4].

2.2. Hall sensor
The hall-effect sensor was implemented for driving asynchronous three-phase motor with a permanent magnet in the rotor side through the three-phase inverter. In censored driver, hall-effect sensors are generally of three pieces mounted on the stator and separated by 120 electrical degrees or 60 electrical degrees. Noisy hall-effect based rotor position sensor could result in erratic switching patterns if not properly addressed [5]

2.3. Fuzzy logic
Basically, the fuzzy set theory is an extension of classical set theory (crisp). The existence of an element in a set, A, will only have two possible memberships, which are members of A or not members of A [6,7]. The reasoning with the Sugeno method is almost the same as the Mamdani reasoning, it’s just that the (consequent) output of the system is not a fuzzy set, but a constant or linear equation. The stages in the Sugeno method are as follows: the formation of the fuzzy set, application function implications, and defuzzification.

2.4. Current sensor
The ACS712 current sensor is a hall-effect based current sensor. This type of sensor can be used to measure AC or DC currents and is commonly used to control motors, detect electrical loads, and detect overload. This sensor has a reading with high accuracy because, in the sensor, there is a series of the low-offset linear hall with a path made of copper. The workings of this sensor are by reading the current through the copper pathway to produce a magnetic field that is captured by the integrated hall and converted to a proportional voltage [8].

3. Method

3.1. Design scheme
The architecture and initial data of the system to be used can be seen in Figure 1. System design in this research consists of 5 main parts, i.e., Selection of microcontroller, BLDC switching design, current sensor design, speed calculation design, and software design.
3.2. Selection of microcontroller
This research uses two Arduino Uno microcontrollers which are used as a master and as a slave where the microcontroller “used as a master is used to acquire data from the sensor and run the controller algorithm” that has been made while the microcontroller used as a slave is “used to regulate the combination of commutations based on the rotor position”. By using the master and slave configuration, it is expected to function to optimize the performance of the microcontroller and to accommodate the limitations of clock speed, number of timers, and the number of ports needed in the system.

3.3. BLDC switching design
BLDC uses a switching circuit consisting of MOSFET transistors with type IRF3205, which has the advantage of a large current rating and is used as an electronic switch to represent the phase of BLDC and uses IC IR2110 which is used as a commutation to trigger the gate as controlling MOSFET. Each IC has two outputs that are used to trigger the activation of the MOSFET.

BLDC drivers require three voltage inputs: 5V input, is used to supply the hall sensor, 12V input, is used to supply the IR2110 IC as an electronic component to trigger the gate, or as a MOSFET driver, and 24V input is used to supply power to the BLDC motor. This research uses a combination of two connected switches, where only two phases are supplied for each combination of commutation, and one other phase is not connected.

3.4. Current sensor design
How to find the value of the current on the current sensor is to convert the voltage (sensor output) into an electric current. The form of a mathematical equation for conversion from the sensor output voltage to the current can be written:

\[ v_{out} = 2.5 + (0.185 \cdot l_{out}) \]  

(1)

The sensor output current equation is:

\[ l_{out} = \frac{512 - \text{data} \ ADC}{1023} \times \frac{5}{0.815} \]  

(2)

The conversion calculation above is done by the master controller by adding an average algorithm to reduce the ripple of current measurement data. Noteworthy in the algorithm is the determination of the ADC value to represent a voltage of 2.5 volts.

3.5. Speed calculation design
To calculate the speed of a BLDC motor, the first thing to do is find out the rotational speed information of the hall sensor. In this research, the motor used had four pairs of poles, and the smallest speed measurement obtained was 50 rpm or 12.5% of the maximum speed of the BLDC.

3.6. Software design
In making an algorithm, the program is inseparable from the design of the algorithm. Therefore, the form of the overall system algorithm can be seen in Figure 2. In the implementation of the BLDC speed algorithm, the calculation is performed by the master controller, and the input bit position from the Hall Sensor is carried out by the slave controller. Every time an interrupt occurs, the number of counters will increase, and each time interval that has been determined, the counter value is taken to calculate the BLDC speed.

![Figure 2. Implementation of the overall system algorithm.](image)

In the implementation of 2 phase switching connected to be used to play BLDC, the switching model used by the slave controller is used, whereas the order of commutation logic will always be the same for all types of BLDC. In general, the design of fuzzy logic controllers is divided into three stages, namely the fuzzification stage, the stages determining the implication function (fuzzy rule base), and the defuzzification stage (fuzzy inference).

- a. BLDC current without load and load is used as the first fuzzy input.
- b. Delta's current BLDC is used as the second fuzzy input.
- c. The step value is used as a fuzzy output.

3.6.1. Fuzzification
Figure 3. Shows the steps that must be made in the form of determining the Input and Output functions, where the input function is the current and output values in the form of the current delta value of the BLDC and the output function in the form of step values. After fuzzification, the next process is determining the implication function. As previously designed, the output of the fuzzy logic controller is in the form of adding or subtracting step values. Fuzzy inputs and outputs are linked based on rules called if-then rules.
3.6.2. Defuzzification

The method used during defuzzification is the Sugeno method. To implement the fuzzy logic, a program is created on the Arduino Uno master microcontroller, where the flow diagram is used to control the speed with fuzzy logic, which can be seen in Figure 4.

4. Result and Discussion

This test is done by combining the whole system and testing, which basically, each block is assembled into one to see the results of the system that is made to run as it should. Testing and data collection conducted in this study are aimed at seeing as current protection (soft starting) using a microcontroller which contains a fuzzy logic method that can run well and compare with the response of the system without using current protection so that it is expected that this control method can be used as a reference for the use of BLDC soft starting.
4.1. System response without overcurrent (soft starting)

In this section, the system is tested without current protection and uses current protection. This test is carried out using 24v and 6A currents sourced from the power supply and with a sampling time of 50ms. This test is also carried out in several stages, namely using load and without load and with different PWM values. The results of testing this system can be seen in Figures 5 and 6.

![Figure 5. System response current and speed without using a load.](image)

![Figure 6. System response current and speed with using a load.](image)

By looking at the whole system response graph without using current protection. Initially, BLDC shows a large inrush current to reach 2A at a load of 100ohm; this is not resolved, so it might cause damage to the BLDC driver.

4.2. System response with overcurrent (soft starting)

At this stage, the system testing is carried out using current protection. In this test, the fuzzy logic system is applied to protect the inrush current with the input in the form of current and delta current obtained from the sampling steps that have been taken previously and the output of the input in the form of steps whose data has been previously taken. This test is also carried out in several stages, namely by using a load and no-load and with different PWM values. The results of testing this system can be seen in Figures 7 and 8.
Figure 7. System response current and speed without using a load.

Figure 8. System response current and speed with using a load.

By looking at the system response graph using current protection. The current at the start of BDLC shows a very small surge in current and by using several types of load current can be protected properly and minimize the impact of damage that occurs in the BLDC driver.

5. Conclusion
After testing and analysis, BLDC speed without using fuzzy logic in protecting currents reaches a steady-state faster than using fuzzy logic. When given PWM 255 without a current protection speed of 0.95 seconds is obtained, and a current protection speed of 1.1 seconds is obtained to reach a steady-state so that the difference obtained is 0.15 seconds.

Before using fuzzy logic for current protection with PWM 255, obtained a wave of 1.67A and after using a damped current to 0.43A to obtain a difference of 73.53%. By using fuzzy logic to protect the current with PWM 255 and given a load of 100 Ohm, an attenuation current of 50.25% from 1.97A and 200Ohm can be obtained from the current attenuation of 57.15% from 1.75A.

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References
[1] Lü Z and Sun F 2011 Soft-start circuitry for DC motor 2011 International Conference on Electrical and Control Engineering (IEEE) pp 3151–3
[2] Tukananto A Rancang Bangun Sistem Proteksi Arus Lebih Motor 3 Fasa dengan Timer Start dan Trip J. Tek. Elektro Univ. Tanjungpura 2

[3] Irsyadi F 2016 Controller design and analysis of the influence of variations in input ladder and loading on the current profile on the soft starting motor mechanism of direct current without brush (LAPAN)

[4] Amalia S 2018 Implementation of 2 phase winding and 3 phase winding connected to voltage in brushless direct current (BLDC) outdoor rotor motors with ANOVA analysis J. Ipteks Terap. 12 167–76

[5] Wicaksono R, Firmansyah E and Isnaeni B S M 2016 Current control and protection of block commutated for 3 phase inverter BLDC motor 2016 8th International Conference on Information Technology and Electrical Engineering (ICITEE) (IEEE) pp 1–6

[6] Nauck D, Klawonn F and Kruse R R 1997 Foundations of Neuro-Fuzzy Systems

[7] Lastomo D, Widodo W and Setiadi H 2018 Optimal power flow using fuzzy-firefly algorithm Proceeding Electr. Eng. Comput. Sci. Informatics 5 210–5

[8] Microsystems A 2017 ACS712 Fully Integrated, Hall-Effect-Based Linear Current Sensor IC with 2.1 kV-RMS isolation and a low-resistance current conductor Datasheets