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Design and implementation of a 350-watt BLDC motor driver using an Insulated Gate Bipolar Transistor (IGBT)

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Abstract. IGBT device was not commonly used as a BLDC motor speed controller. This paper described the successful of using IGBTs in a 350Watt BLDC motor speed controller. Triple bridge configuration with PWM (Pulse Width Modulation) wave signal for power tuning was mainly integrated as a main switching method in order to drive the current commutation cycle. Also, an efficient bootstrap IC was designated to perform as the high and low side driver. The data were measured by using a current sensor and a DC voltage sensor to measure the current and the voltage delivered from the power source. Then, IGBT device was activated based on triple bridge commutation cycle and phase based on motor hall effect sensor triggering signal. The performance was also tested by varying the duty cycle input ratio and its PWM frequency. It can conclude that the BLDC motor controller can be made by using an IGBT and added gate drivers for the IGBT. Meanwhile, to adjust the commutation cycle, a high speed processor was used to generate gate activation and PWM signal. Changing the PWM duty cycle starting from 10% to 90% by turning the setting point, observed that BLDC motor rotates successfully without load and maximum power used was 111.20 watts with 2,32 amperes current at 48 volts supply voltage.

1. Introduction
One type of motor that is currently widely used is an electric motor without brush or which has been popularly known as BLDC (Brushless Direct Current) Motors. The application of this type of motor has been widely used in various fields of industry such as the aviation, automotive, medical, and nowadays industries start to use it as a motorcycle drive on an electric vehicle. BLDC motors have various advantages compared with a conventional DC motor. Some of these advantages includes the speed better than the torque characteristics, dynamic response and high efficiency, life long service, quiet, and higher speed range.

Toyota for example was a successful electric vehicle manufacture which utilize the series/parallel drive which is popular with THS system [1]. Toyota itself also states that in order to develop and commercialize the electric vehicle controller, they would still rely on IGBT [2]. However, it was challenging to implement the BLDC motor controller, beside of the higher cost or expensive controller, speed controller is more complicated than that conventional DC motor. This complicated control is due to the usage of electronic commutator which replaces brush as a mechanical commutator on a DC motor conventional. The manufacturing costs was also quite expensive due to making the system The BLDC motor controller must use industrial grade components which usually must be purchased at higher cost. Therefore, usually people prefer to buy imported BLDC motorbike drivers and controller products although the products available in the market was quite expensive. Also, the reason of more practical reasons and can be used immediately.

However, it was always challenging to build a BLDC motor controller due to the existing components and peripheral which was difficult to be provided. As the real problems could also come from the hardware implementation and selecting appropriate central processing unit (CPU) and perfect configuration of the microprocessor clock speed related to interrupt service routine to serve the commutation cycles. The option also acts for the IGBT devices. A lot of article which says IGBT was a correct device to handle high voltage and high current application as in electric vehicle [3].

In accordance with these problems, this research focuses on design and experiments on some IGBT components that have the highest power rating compared to other thyristor components. IGBT ability was expected to be able to control the switching process of a high capacity BLDC motor [4]. In addition, variations voltage input can be maximized up to 24 Volt DC, with a current rating reach 25A. In this study also was tested on various types of IGBT to find out which type of IGBT has the most optimal performance both in terms of switching time, voltage loss and working temperature.

It was expected that this research could produce an optimal BLDC motor driver, reduced cost, and has a quality that is not inferior from manufacturer products. Also, controller could be mass produced and can be widely marketed. As the end result of this research, a prototype of BLDC controller circuit finally being build and was capable of controlling a 350Watt BLDC motor. Apart from that it was expected to get optimal torque even if the motor rotates at low speed. This prototype will next be used for an electric car controller circuit in an energy-efficient car competition routinely held nationally. With the success of this prototype, it was expected to be able to continuously raise the output power rating of the driver to reach the rated power generally been used in commercial electric cars.

2. Methods

In order to get the data, the experiment was using the real time measurement process. A precision voltage sensor and high current sensing system was used to test the power performance of the controller. The first test was using a low voltage source +12Volt with lowest duty cycle setting point. The next experiment was conducted with +24Volt higher voltage source and identical PWM pulse also used. The highest voltage source was +36Volt and +48Volt resulting fastest rotation in the test bench. Experiment setup was not using any load or coupled bearing, so that program algorithm could be tested to accommodate the current commutation at each cycle.

Technically, there are several peripherals being used to evaluate the performance of purposed this BLDC controller. Each was described more detail at the following chapter. More complete block diagram could be seen at Figure 1 below.

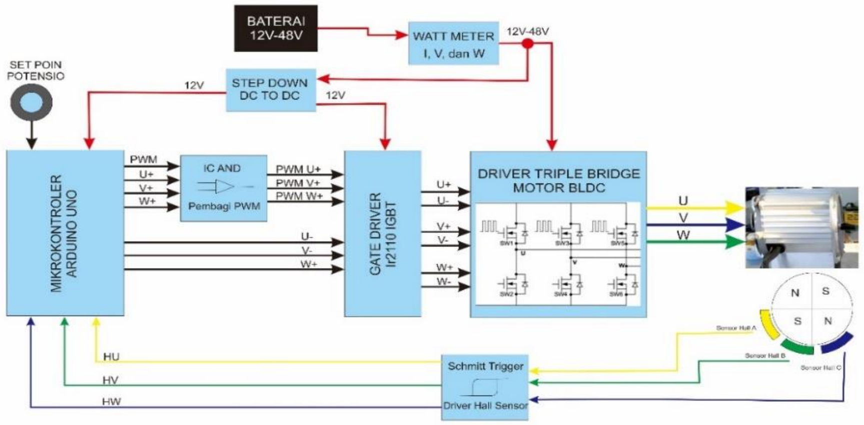

Figure 1. Block diagram of a 350 Watt BLDC controller.

2.1. Gate driver

This gate circuit driver is designed to regulate IGBT component displacement. This is necessary because an IGBT requires a gate voltage between 10V-15V while the working voltage of the microcontroller used is only 5V. For more details, see Figure 2 below:

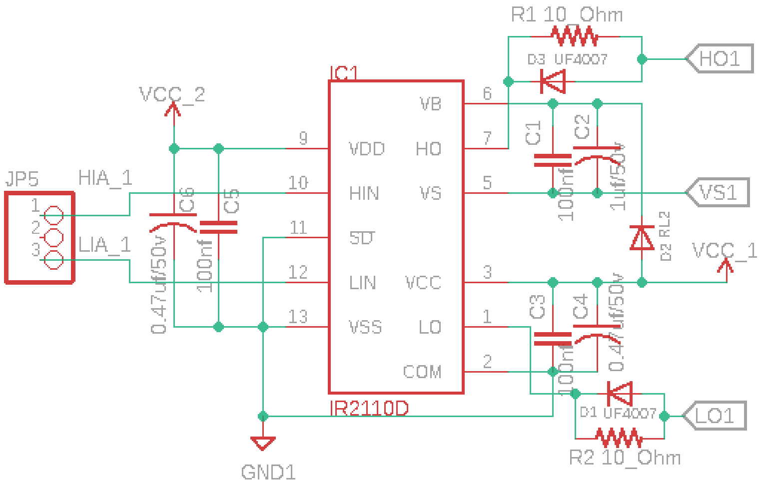

Figure 2. IR2110D IGBT gate driver.

In this IGBT gate driver circuit uses the main components of IR2110 and supporting components in the form of 3 capacitor 1uF and 100nf, 1 ultrafast diode, 2 ultrafast 4007 diodes, and 2 10Ohm resistors. RL2 diodes are installed on the VCC and VB pins then 1uf and 100nf capacitors are added together and then mounted on the VS and VB pin, these two components are the first supporting components for IR2110 which functions as a bootstrap. To activate the HIN pin requires a PWM signal from the microcontroller. When the HIN and LIN pin still get logic 0 from the microcontroller, the HO and LO pin was also logic 0. When LIN is given logic 1, the LO will output 12V voltage which is used to activate IGBT. While if the HIN pin gets a PWM signal, the HO will be active and output a voltage in accordance with the change in the PWM signal that enters the HIN pin. For HO will produce a variable output voltage, even greater than the VCC input voltage depending on the size of the bootstrap capacitor. Whereas the VS pin in this schematic serves as feedback from the IGBT phase output being controlled.

2.2. Triple bridge design

This Triple Bridge series is assembled using 3 pairs of IGBT consisting of 6 components. Basically, between the two switching components has almost the same characteristics. Before conducting research using IGBT, the author first conducted an experiment using MOSFET to ensure the driver can function properly [5].

The triple bridge driver circuit uses IGBT components with FGD40N60FD type which are capable of 600V voltage and 40A current [6]. This type of component was chosen because it has suitable specifications for controlling a 1kW BLDC motor without load. The IGBT has a fairly fast switching speed, a high working voltage and a high enough working current, the following is the sequence. Next was the IGBT triple bridge schematic driver.

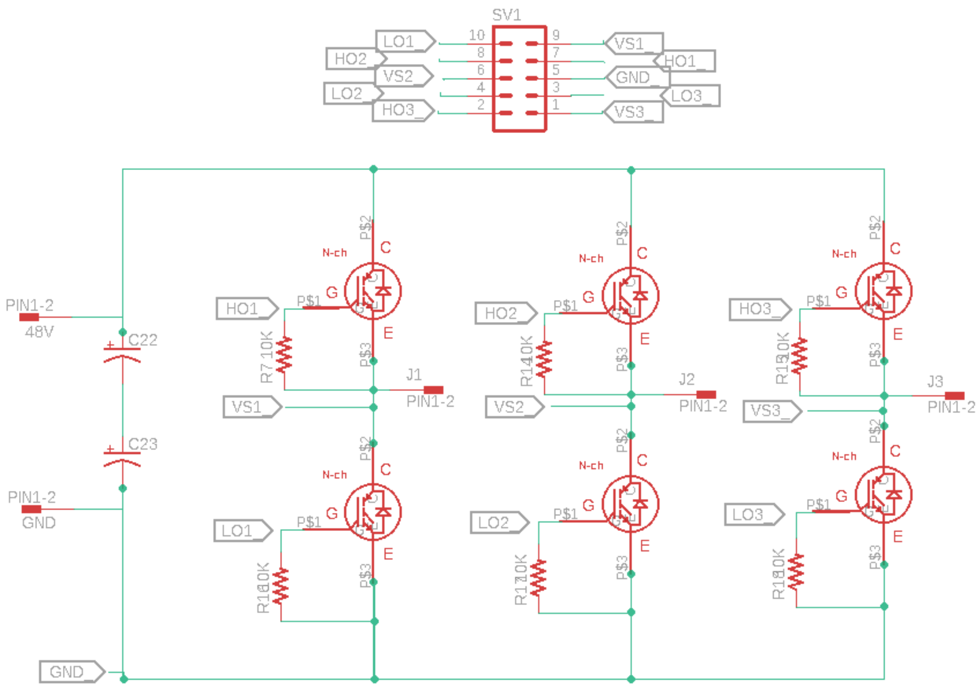

Figure 3. IGBT triple bridge schematic view.

3. Results

In general, the hall sensor of a BLDC motor emits very low voltage resulting output signal was unstable, so the signal cannot be received properly by the microcontroller. To meet the working voltage level of the atmega328 microcontroller, the hall sensor signal from the BLDC motor needs to be conditioned first. The following schematic is the hall sensor conditioning circuit design.

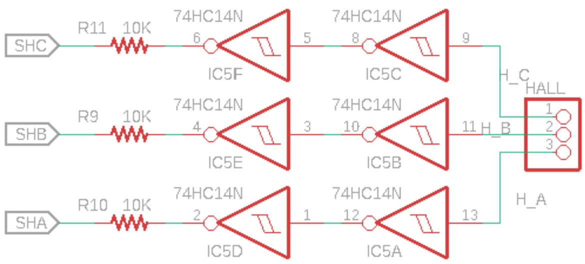

Figure 4. Schmid trigger for hall sensor conditioning.

In this driver uses the 74HC14 Schmitt trigger IC to condition the hall sensor. 74HC14 is an IC logic with 6 trigger inputs. The advantages of 74HC14 can change the weak input signal can be sharper so that it can be received well by the microcontroller. 74HC14 has a high on / off speed making it suitable for hall sensor conditioning. After the hall sensor is processed using the above circuit, the output of the hall sensor can reach a voltage of more than 4.1V and the signal produced is very sharp, so information from the hall sensor can be received by the microcontroller properly.

3.1. PWM signal divider circuit

A PWM signal on each microcontroller pin has a different frequency. For this controller only use one PWM pin, which is taking pin 11 Arduino and has set the frequency at 31.32 KHz. Then the PWM signal is divided into each pin of the gate driver so that each motor phase gets the same PWM signal frequency. For its components using IC AND 74HC08. This component was suitable because it has a fast on / off speed.

4. Discussions

In this section, the experiments setup will be explained and detailed with figures and data results. In order to get full observation, there was several peripherals being tested and measured so the data collected can be then be observed comprehensively.

4.1. Gate driver testing

The first test that needs to be done is the IGBT gate driver circuit. The gate driver components are arranged on the prototyping board, High Side Output and Low Side Output are connected to the IGBT gate pin with resisted by a 10 Ohm resistor, then High Side Input was connected at PWM source signal and Low Side Input is given “0” and “1” logic alternately. To visualize the current flow and simulation of currents commutation of BLDC motor, the project was using three +12 DC bulb load with 25 Watt each. The next step was injected a variation of PWM source signal from Signal Generator, also an increasing of signal period of PWM was accommodated to force the IGBT frequency capability.

The result could be observed in detail of table below:

Table 1. Gate driver test result.

No	High Side Input f (Hertz)	Low Side Input f (Hertz)	Phase Different(π)	High Side Output f (Hertz)	Low Side Output f (Hertz)
1	200	200	0.25	200	200
2	400	400	0.5	400	400
3	600	600	1	600	600
4	800	800	1.25	800	800
5	1000	1000	1.5	1000	1000
6	5000	5000	0.25	5000	5000
7	10000	10000	0.5	10000	10000
8	50000	50000	1	50000	50000

The data results show the performance of the IGBT gate driver during light load but forced at higher frequency. Input and output frequency can be concluded with identical value, so that the gate driver performance was considered normal and optimal. But there was significant role of changing the value of bootstrap capacitor. The experiment was optimal when the value of capacitor being varied with the variety of frequency. The IGBT temperature also consider within normal.

4.2. IGBT triple bridge testing

This testing was conducted aiming to determine the ability of the IGBT that had been selected for this study. The test was conducted using only two IGBT with 255Watt DC +12 Volt lamp loads. The second test was conducted using four IGBTs with as if acting H-bridge DC converter. A DC Power window motor was used to test current commutation. The DC motor then also being controlled with variation of the PWM duty cycle. The last experiment was conducted using six IGBT, which was commonly described as a triple bridge commutation. This test was the final purpose of this research using a high power 350W and 1kW BLDC motor loads [7].

The satisfy result was shown from the first and second testing. Both 255 Watt +12 Volt and Power Window are able to be controlled and the IGBT was only operated at normal state. The current flow was only 2.32 amperes maximum. The last test using an actual BLDC motor also was measured by power meter showed 111Watt peak power at maximum rotation. This was considered as the optimal value for the motor without any additional load. Actual data was shown at Table 2 below.

Table 2. Current and voltage measurement for 350Watt motor.

Duty Cycle (%)	12 Volt		24 Volt		36 Volt		48 Volt	
	Current (A)	Power (W)	Current (A)	Power (W)	Current (A)	Power (W)	Current (A)	Power (W)
10	0,12	1,40	0,13	3,04	0,15	5,40	0,19	8,96
20	0,21	2,56	0,27	6,40	0,34	12,24	0,39	18,88
30	0,33	4,00	0,44	10,48	0,55	19,68	0,64	30,88
40	0,45	5,40	0,61	14,64	0,78	28,20	0,94	44,96
50	0,58	7,00	0,79	18,96	1,01	36,48	1,21	58,24
60	0,71	8,56	1,01	24,16	1,25	44,88	1,47	70,72
70	0,86	10,28	1,18	28,40	1,46	52,44	1,77	84,96
80	1,00	12,00	1,36	32,56	1,70	61,08	2,02	96,96
90	1,15	13,84	1,57	37,76	1,95	70,32	2,32	111,20

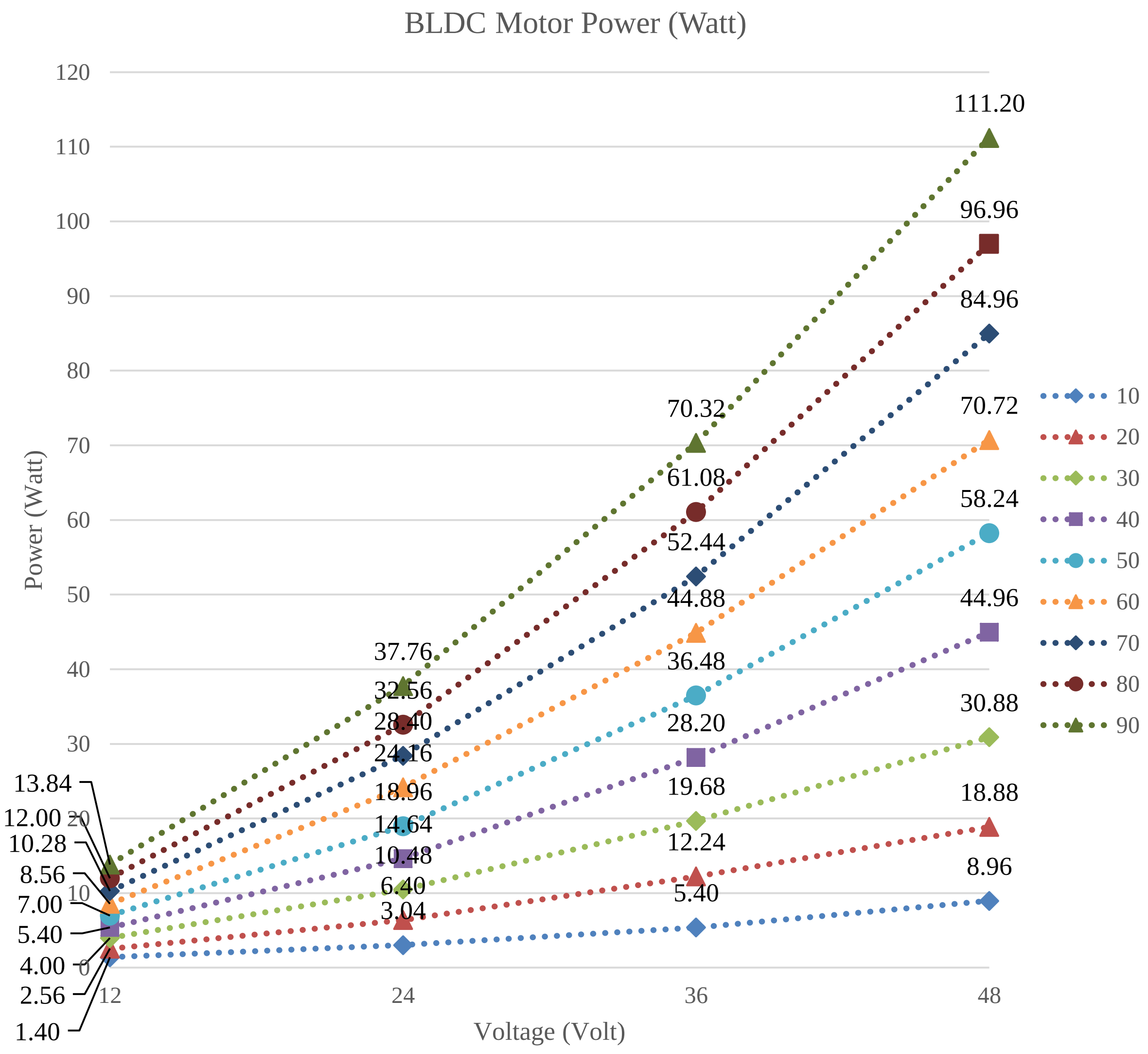

Figure 5. Voltage vs power output.

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Figure 5 shows the experiment result during controller performance test and evaluation. The test was conducted using four different power sources includes 12 Volt, 24 Volt, 36 Volt, 48Volt. The lowest power consumed by controller was produced by 12 Volt power sources, and the highest power derived was resulted by 48 Volt power sources. Higher duty cycle means more current was deliver during controller operation.

5. Conclusions

Based on the research that has been done, there were some conclusions to answer the problem formulation, as follows:

- BLDC motor drivers can be made using the IGBT and added gate drivers for the IGBT. Meanwhile, to adjust the commutation cycle, a high-speed processor was used. This BLDC controller successfully be installed on a 1kW motor with a battery input voltage of 12V to 48V.
- To test the performance of a BLDC motor controller using an IGBT, the driver is mounted on a 1kW BLDC motor, then a 12V to 48V battery is installed. Changing of the PWM duty cycle starting from 10% to 90% is done by turning the setting point. BLDC motor rotates successfully without load. The test results are obtained in the form of:
  - The maximum power needed by a 1kW BLDC motor is 111.20 Watt at 48V voltage and 90% duty cycle.
  - The minimum power needed by a 1kW BLDC motor is 1.40 Watt at 12V voltage and 10% duty cycle.

  So that, lower energy needed by the motor when the maximum duty cycle at a 48V battery voltage on the same motor, it can be said that the controller is more efficient and it saves battery consumption.

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