Journal of Technological Sciences Volume 1 [June 2023]

مجلة العلوم التكنولوجية
العدد الأول يونيه ٢٠٢٣

Development of Brushless DC Motor Drive System for Teaching Purposes Using Different Speed Control Techniques

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ABSTRACT

In this paper, a test bench was developed for teaching purposes to enhance power electronics and real time control of Brushless DC motor comprehensively, particularly with regard to PWM techniques, signal generation and speed control theoretically and experimentally using Matlab/Simulink environment, assisted with DSP programming kit in practice. First a model was developed under Matlab/Simulink. The control strategies implemented involve two PWM techniques, namely soft and hard switching. The system is built in a way that the students are able to carry out modeling and confirm their results through the testing bench using these techniques. The used approach has been effective in the way that has led to the student satisfaction. It has shown their learning has been improved with regard to the drive control applications either as a variable speed drive or in embedded systems. Brushless direct current (BLDC) motors are mostly preferred for dynamic applications such as automotive industries, pumping industries. Moreover, it is predicted that by 2030, BLDC motors will become mainstream of power transmission in industries replacing traditional motors. A Brushless DC motor electric vehicle is the best solution for green transportation due to their high efficiency and zero greenhouse gas emissions. The increased reliability, flexibility, high efficiency, longer life, reduced friction, faster rate of voltage and current and precision voltage and current applied to field coils could be regarded as the most important advantages of (BLDC) motors.

Keywords: BLDC Motor, Current Control, Pulse Width Modulation, motor drive, Speed Control of BLDC Motors.

1. INTRODUCTION

The world is stepping forward toward the development of technologies to derive energy from sustainable resources and the technologists are thriving hard to mitigate the challenges such as shortage of fuels and clean/renewable energy due to interference, acoustic noise, torque ripple, and flux ripple should be controlled. Thus, the controlling techniques are discussed in this paper. Since BLDC motors are used costs for energy, global warming, and various environmental issues [1]. We will focus

on these storage technologies which form the core of the technological innovations needed to design and develop renewable energy. We have highlighted the salient features of each of these technologies and compared them in terms of their power/energy density, and cost to meet the global challenges, and their ability to manage the scarcity of existing resources and competitiveness in meeting sustainability standards [2].

Brushless DC Motor (BLDCM) has been widely used in industrial automation, household appliances, automotive electronics, aerospace and other fields due to its simple structure, high output torque, long lifetime and high efficiency. However, the key to its control process is how to get the accurate information of rotor position and speed [3]. Some achievements have been made in the research of non-position control technology of brushless DC motor after decades of research by scholars at home and abroad. The counter electromotive force method is the most mature method in application at present, and it can obtain commutation information at a time delay of 300 by detecting the counter electromotive force signal extracted from the terminal voltage of the motor. But it is difficult to detect the counter

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Received [1 Jan 2023 Accepted [13 March 2023]
Manuscript ID [JTS-2023-002]

electromotive force at low speed, at the same time, the existence of filter circuit makes the problem of phase shift more serious at high speed, even may lead to the failure of commutation [4]. Even though BLDC motors are found to have high efficiency, the durability of the machine is less compared to induction motors [5, 6]. the rapid increase in global population, energy consumption owing to lifestyle improvements, high To improve the durability of BLDC motors, the main challenges such as fault tolerance, Electromagnetic in dynamic applications, Reliability control techniques of motor drives are indispensable. Reliability control techniques such as fault-tolerant control (FTC), electromagnetic interference control (EMI), and acoustic noise control improve the feasibility of the motor drive systems in dynamic applications [7]. The generation of EMI and acoustic noises lead to motor failures. Hence, it's essential to control the faults in prior. The various control used to mitigate EMI and acoustic noise generation are discussed. It is predicted that by 2030, BLDC motors will become mainstream of power transmission in industries replacing traditional induction motors [8, 9]. If EMI and acoustic noise lead to the development of fault. The fault-tolerant approach used to work as a backup to continue the operation. The main use of such a technique is to maintain continuity in operations.

In [10] fast fault diagnosis is performed with help of a rapid counter. Whenever the threshold value increases, the fault is detected. The technique is not reliable for high acceleration applications. In [11] EMI of the machine is reduced by analyzing the dc bus voltage at the frequency domain. On analysis, it was found that motor structure can improve or decrease the EMI generated [12, 13]. In Industry, BLDC motors are preferred for various applications such as automation robots, hoists, elevators, conveyor belts, and CNC machines. Since BLDC motor has the advantage of providing fine torque in static applications without any ripples in torque compared to other motors these BLDC motors are preferred a lot. Inherent to the above advantages BLDC motor provides less inertia, high torque, and extensive operating speed [14].

The main challenges facing BLDC motors in the industry are improving fault-tolerant capability, reducing EMI, and torque and flux ripple control. In this section, how the reliability of BLDC motor is affected in industry and torque ripple effects are reviewed. In [15] a sensor less control algorithm for BLDC motor for reciprocating compressors is discussed. The peak current magnitude causes the demagnetization of permanent magnets in the rotor. These demagnetization currents are measured. The control algorithm is designed that commutation depends on the level of phase currents. The proposed technique improves the power and torque characteristics. In [16] scalar controlled BLDC motors for industrial applications are discussed. The realization of PWM signals in the motor controller is done with help of input and output ports in the microcontroller. This simplifies the operation and improves the stability of the operation. In [17] torque developed in BLDC motors is educed by model-based power control schemes. In [18] Figure (1) shows the different applications of the BLDC motor [19].

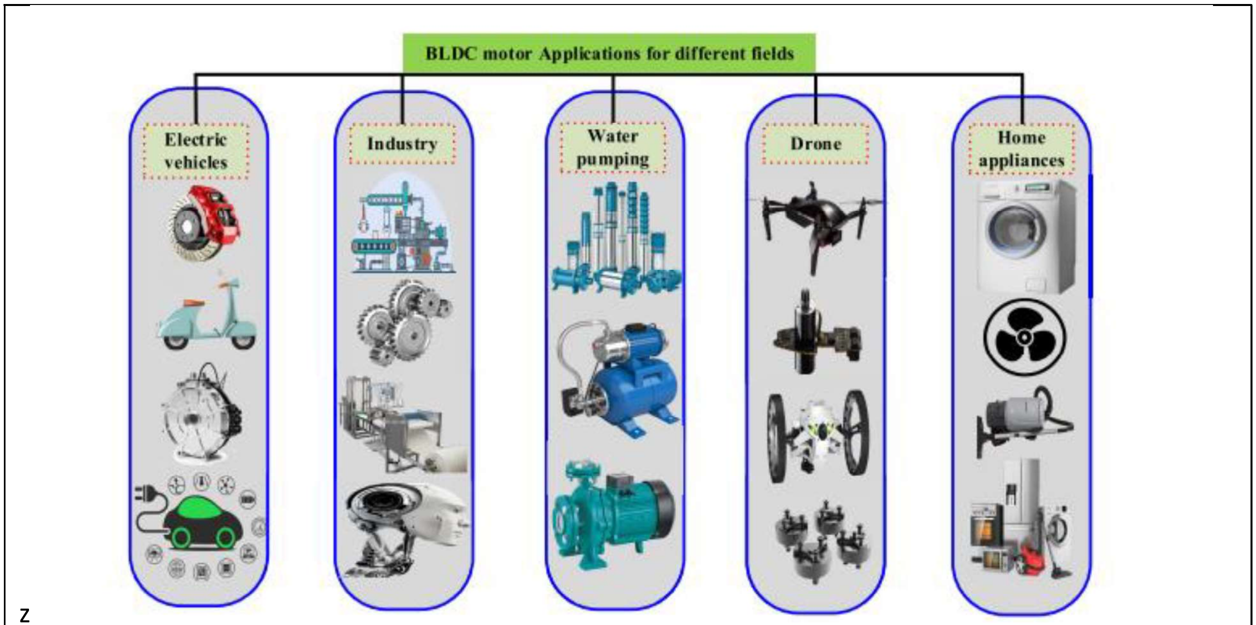

Fig.1: Typical applications of BLDC motor [18]

Velocity feedback can be derived from the position data. This eliminates a separate velocity transducer for the speed control loop. A BLDC motor is driven by voltage strokes coupled by rotor position [20, 21]. The rotor position is measured using Hall sensors. By varying the voltage across the motor, we can control the speed of the motor [22]. When using PWM outputs to control the six switches of the three-phase bridge, variation of the motor voltage can be obtained by varying the duty cycle of the PWM signal where show in figures 2,3. The speed and torque of the motor was depend on the strength of the magnetic field generated by the energized windings of the motor, which hinge on the current through them. Hence adjusting the rotor voltage and current will change motor speed [23].

2. PROPOSED BLDC TRAINING KIT

Fast development of power electronics components in recent decades has enabled improvements also in electric drives technology. The current inverter technology has made it possible to accurately control an induction motor, which has previously been complicated. Therefore, inexpensive, robust and low-maintenance induction motors supplied with inverters have replaced more expensive and complicated motors in many industrial applications. Thus, it is important for power electronics engineers to be familiar with the control and phenomena of induction motor drive.

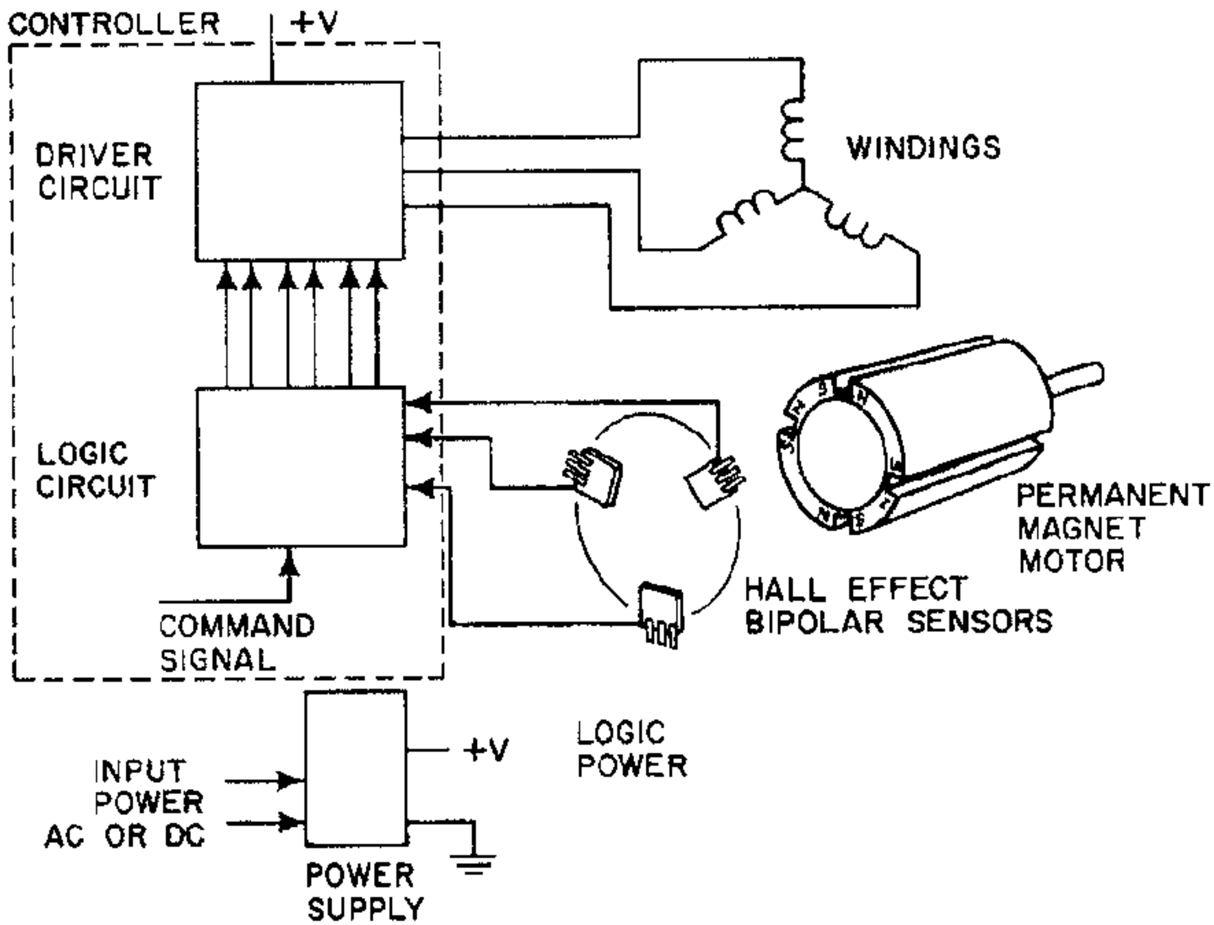

Fig.2: Essential elements of a typical BLDC motor

A typical BLDC motor controller has a half-bridge or half-H bridge circuit. Unlike an H bridge**,** this circuit configuration has only two switches, one high-side and one low-side transistor.

3. Operating principle

Most brushless motors use two or three-phase power systems. So, in a BLDC motor controller circuit diagram, this will look like two or three. half-bridges (depending on the number of phases) with a pair of switches each. Let's take a closer look at a 3-phase brushless DC motor controller with Hall-effect sensors to view the basic principles of its circuit design. The stator has three-phase windings located at 120° to one another. Each winding has a vector representation of voltage and current applied to the stator. The BLDC motor controller Hall sensors identify the rotor's position. Upon receiving the sensor data, the power **MOSFETs** switches the current and injects it into the right winding. In a high-power brushless DC motor controller, **IGBT**s and **GaN** switches can replace MOSFETs. Either integrated or discrete gate drivers can control the transistors. The drivers of a brushless motor controller schematic act as intermediaries between the switches and a microcontroller (MCU), shown in figure 3. The three-phase BLDC motor controller circuit includes six steps necessary to complete a full switching cycle (that is to energize all the three windings of the stator). By turning the high-side and low-side transistors on and off, the current flows through the stator windings in sequence.

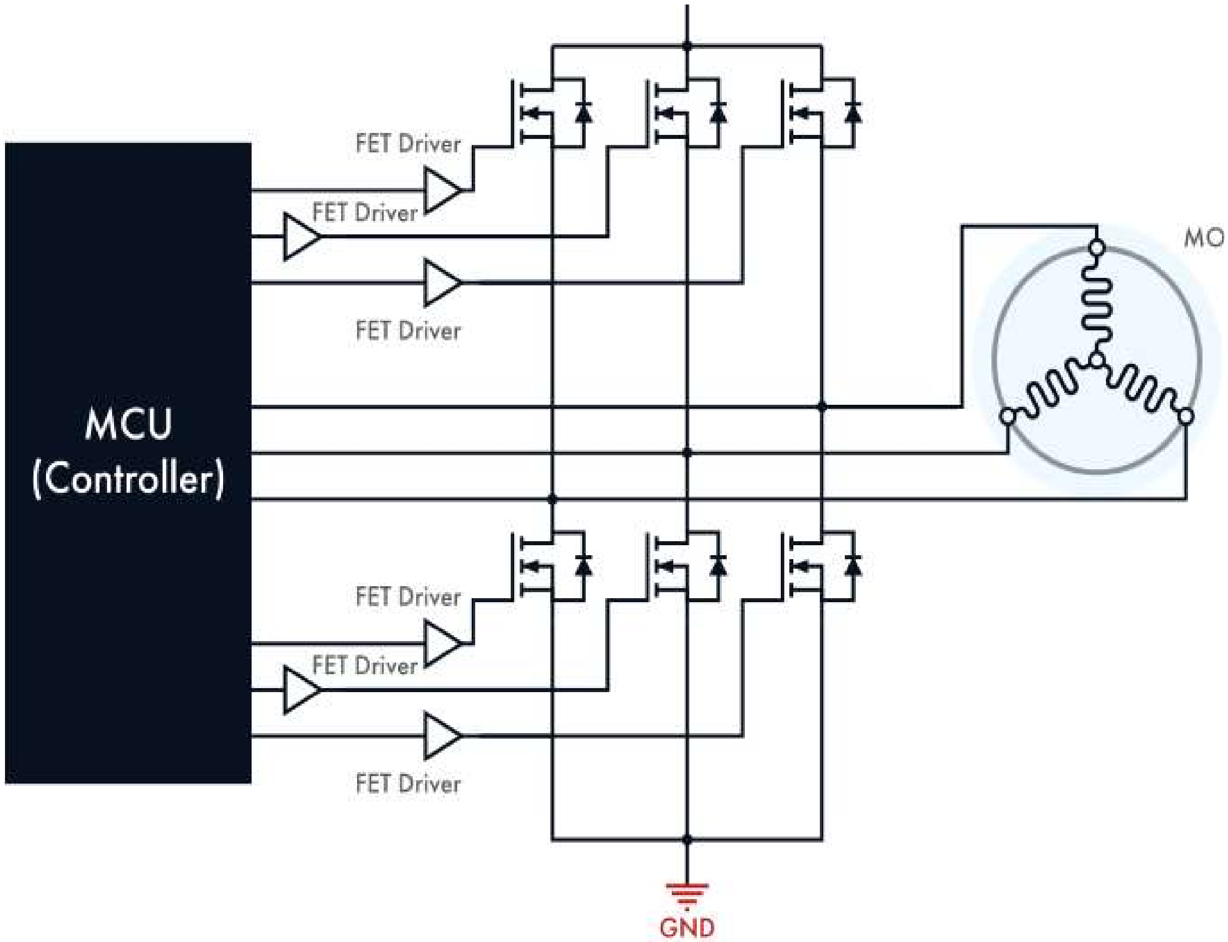

Fig.3: Three-phase BLDC motor controller with Hall-effect sensors

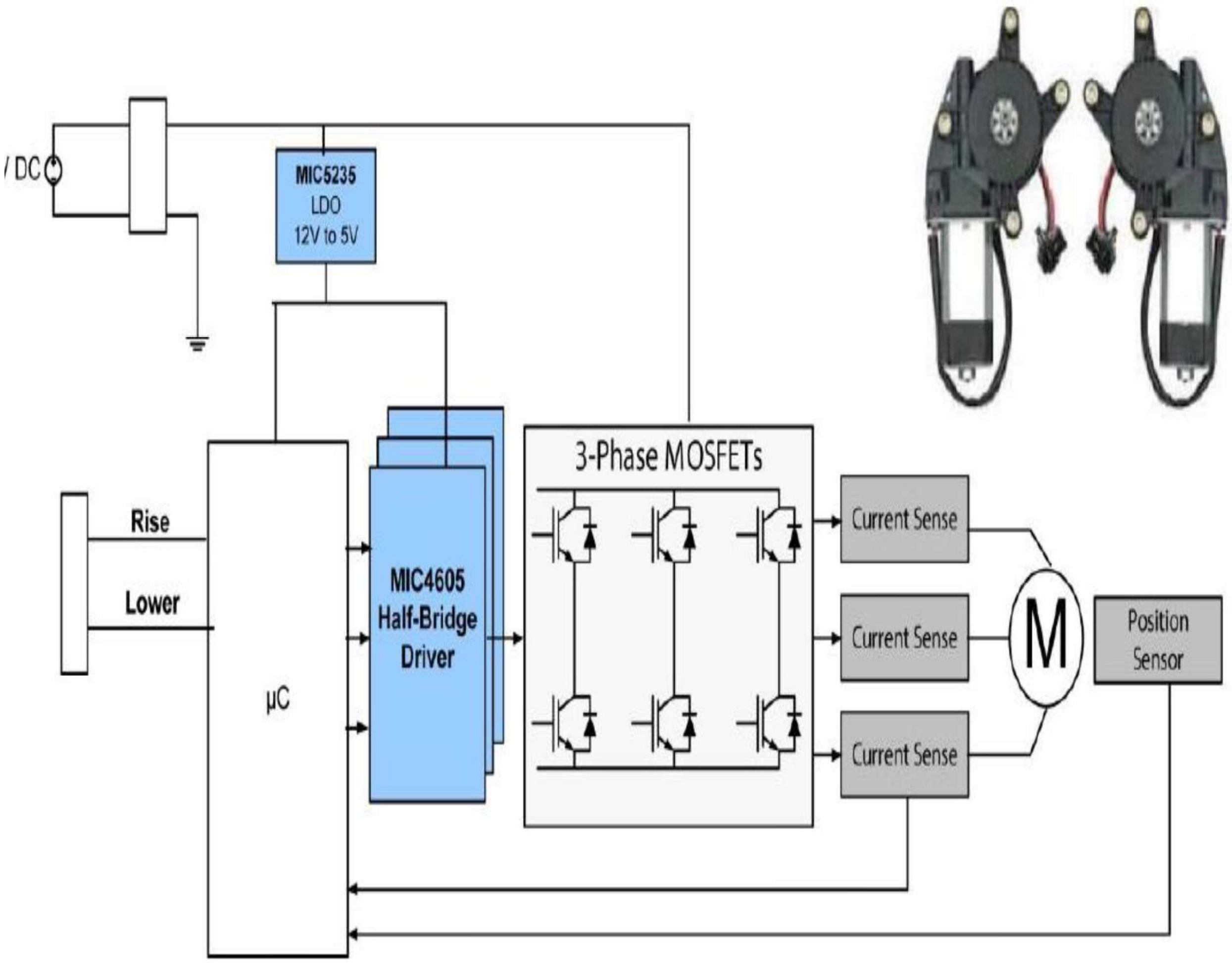

Fig.4: BLDC motor control

Currently, motor manufactures are gravitating towards 3-Phase BLDC motors because they provide more torque for less power and have a longer operating time due to no direct contact from the commutator and electrical terminals such as that is found in the brushed motors. Regrettably, the use of three-phase motor control adds additional complexity compared to brushed DC or AC motors then the relationship between digital and analog components becomes very important. This proposal discusses a summary of the concerns that should be factored in when using analog components and microcontroller in three-phase BLDC motor applications as shown in figure 4. It also covers the BLDC motors. the suitable power management devices and power level shifters that enable the microcontrollers to drive motors form power sources from 12V all the way up to 300V DC voltages. **Home Appliances.** There are quite a few appliances at home application market that can benefit from the use of high efficiency BLDC motors as shown in figure 5. These include pumps, fans, air conditioners, blenders, hand power tools, and other kitchen appliances. **Industrial Systems.** Most pumps, fans, air conditioners, mixers, and HVAC units require a motor drive as shown in figure 6. The EU has issued an edict that requires all new industrial appliances to use the 3-Phase "Inverter Drive" of

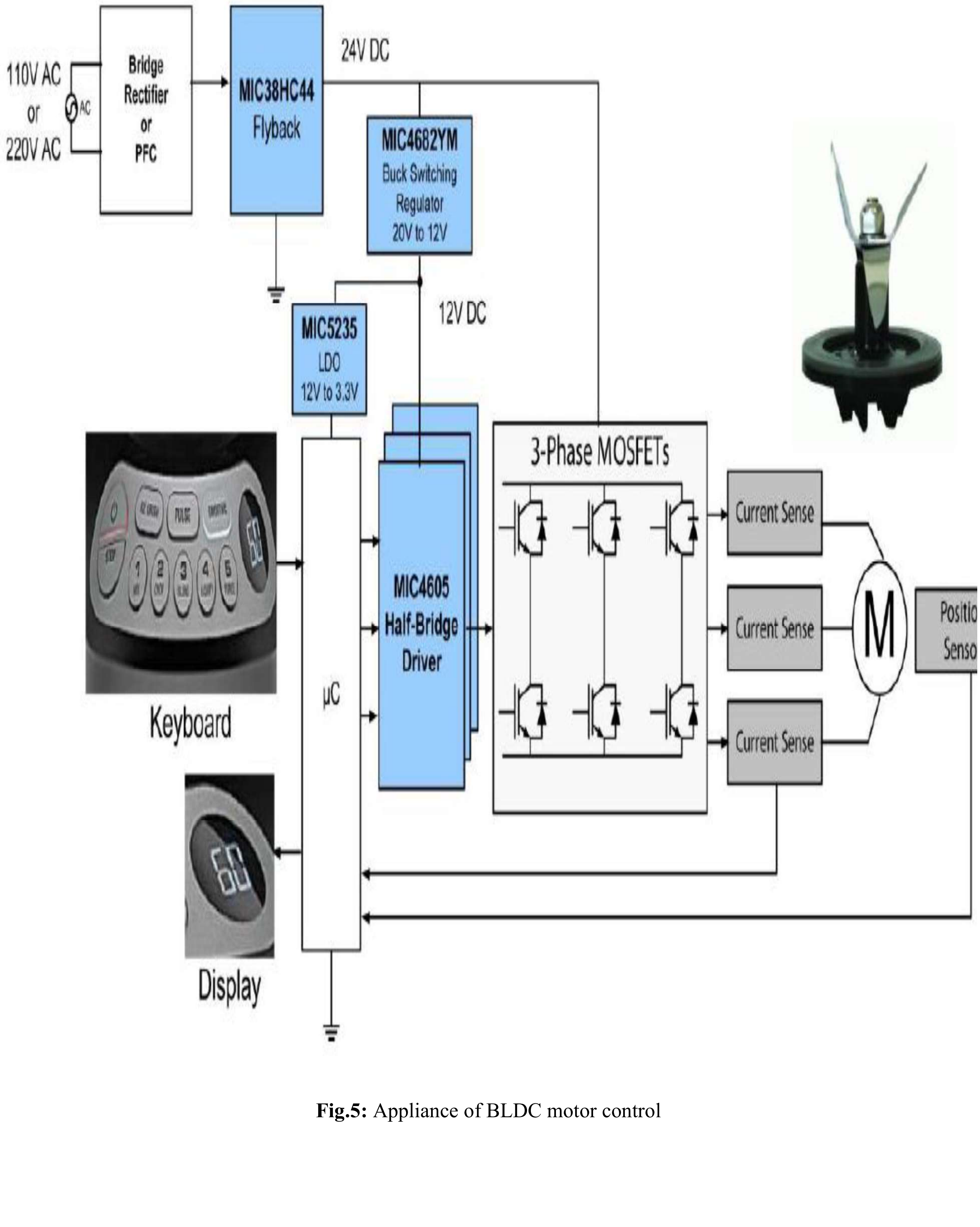

Fig.5: Appliance of BLDC motor control

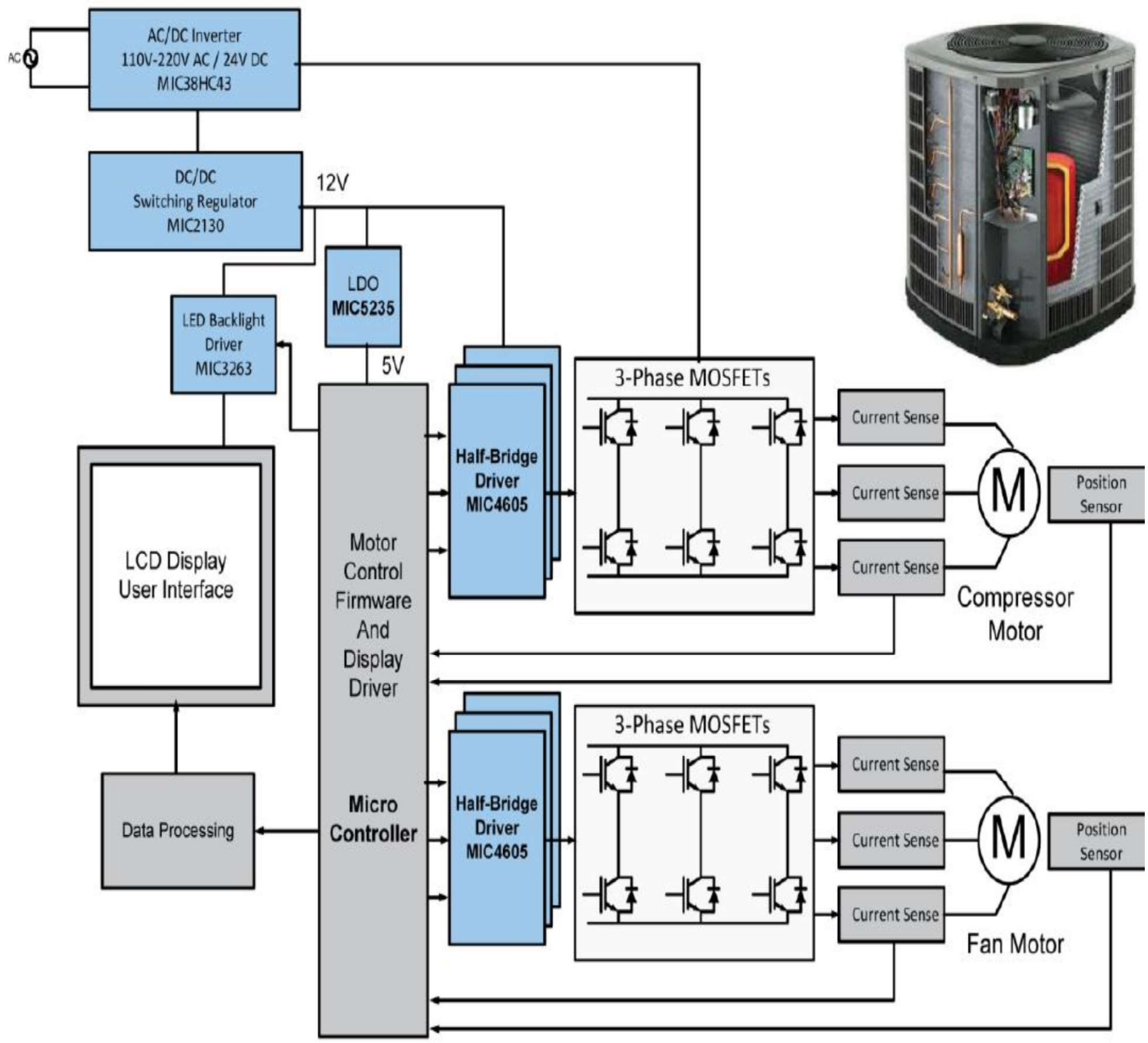

Fig.6: Air conditioning functional block diagram

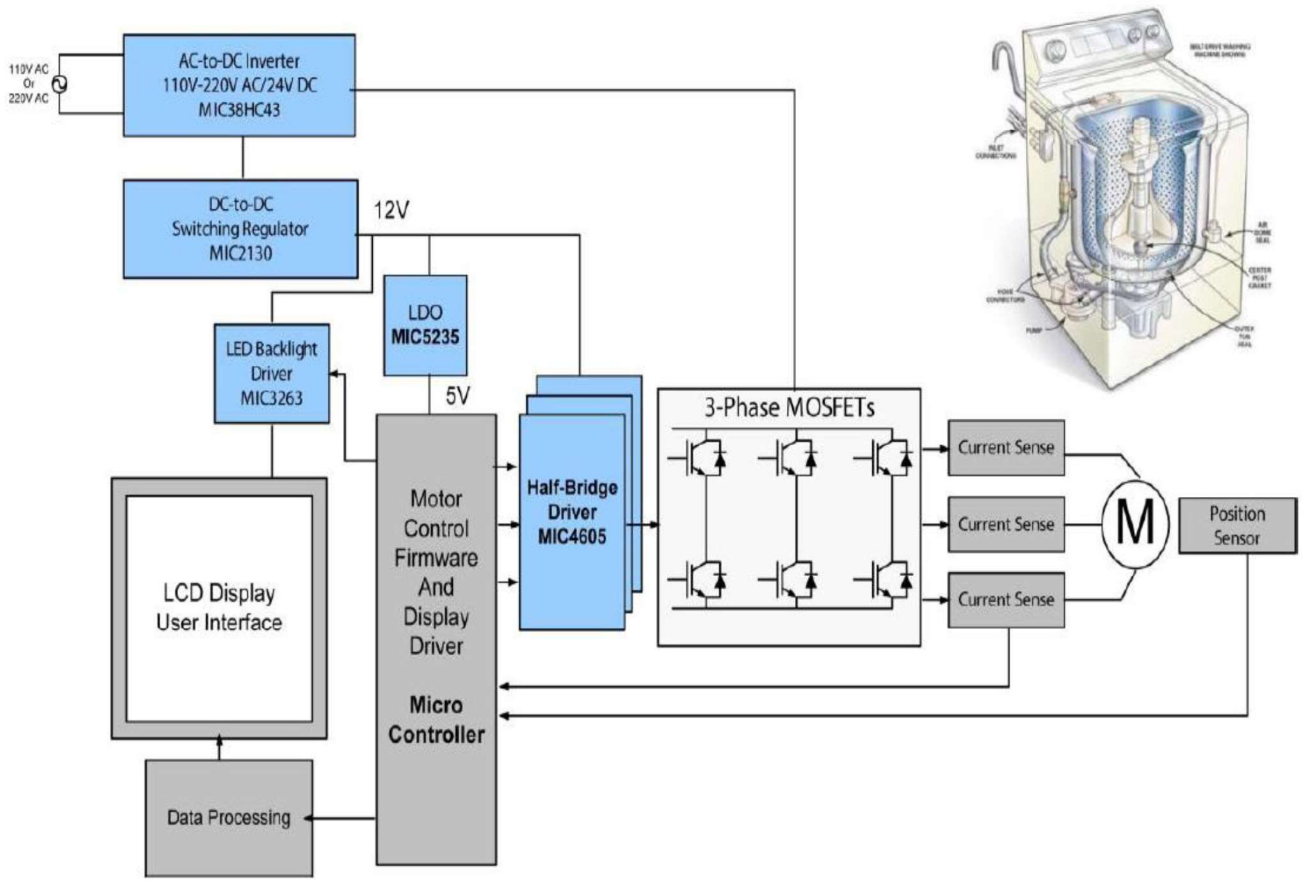

Fig.7: Washer Motor Functional Diagram

4. Experimental Implementation of BLDC Motor Drives

In designing a BLDC motor controller, you can consider different approaches to current switching, including trapezoidal and sinusoidal commutation.

The names of these methods relate to the signal waveforms. With the trapezoidal commutation, two windings out of three can stay energized at the same time. In the sinusoidal control method, the phase shift complies with the law of sines. It provides smoother current switching between the phases. The trapezoidal commutation is simpler, but it may cause motor's vibration at low speeds. Implementation of sinusoidal current waveforms can ensure flawless operation of your motor. However, this type of commutation becomes challenging at high speeds.

represents the switching pulses of the inverter of 50% duty cycle and to show the phase shift and the inversion of PWM pulses for the switches as shown in figure 8.

Typically, a sinusoidal brushless motor controller circuit uses pulse-width modulation **(**PWM**)**. It helps to regulate the current injected into the rotor's windings and to run the commutation process more to closed-loop controllers that get feedback on the output signal and adjust the input power by varying the duty cycle. A duty cycle is the percentage between the current pulse and the complete cycle of the current signal. A BLDC motor speed controller changes PWM duty cycles to create sinusoidal signals.

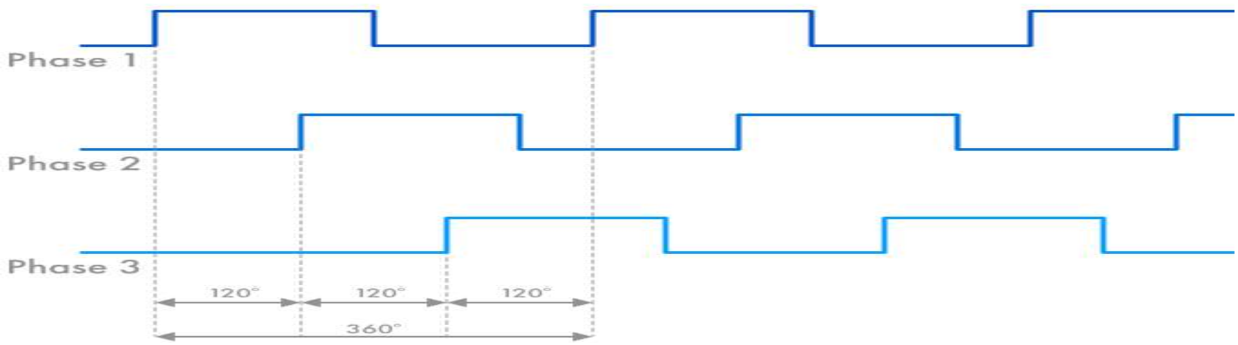

Fig.8: Three-phase pulse-width modulation (PWM)

PWM switching frequency can be different for various applications. Although it should be high enough to prevent power loss. The physical limitations of the stator determine the maximum frequency level. However, there are also the specifications of the control unit itself. So even if the stator allows you to increase the PWM frequency, you will not be able to do that because of the limited capabilities of your DC brushless motor controller.

As an option, you can employ hysteresis to control the operation of a BLDC motor. This method relates to the sinusoidal commutation too. It allows you to establish the upper and lower limits of the current supplied to the motor. As soon as the current reaches its upper or lower range, the transistor switches turn off or on respectively and change the average current using the law of sines.

You can implement a BLDC motor controller half-bridge as either an integrated circuit (IC) or as discrete components. This is one of the most common dilemmas you might face as you start figuring out how to design a BLDC motor controller. A discrete circuit can be less reliable since the components should be assembled and soldered onto the board separately. A brushless DC motor controller IC has a smaller size, low production costs and simplifies the design process. However, integrated circuits have some power limitations. Above that, the failure of one component will lead to the replacement of the entire BLDC motor controller IC, not just this component.

There are several methods for driving a BLDC motor. Some fundamental system requirements are listed below:

a. **Power Transistors.** These are usually MOSFETs or IGBTs that can tolerate high voltages (matched to the requirements of the motor). Most home appliances use motors that produce half to three quarter of a horsepower (1hp = 734W). Hence, typical current capabilities of up to 10A are utilized. For a high voltage system (>350V typically), IGBTS can be used.

b. **MOSFET/IGBT Drivers.** Generally, a set of MOSFET or IGBT drivers are utilized. One could choose either three “Half Bridge” drivers or three-phase drivers. These solutions must be able to handle two times the motor voltage to manage the back-electromotive force (EMF) generated from the motors. Moreover, these drivers should provide protection of the power transistors via timing and switching controls that ensure the top transistors are turned off before the bottom transistors turn on.

c. **Feedback Elements/Control.** Designers should have some sort of feedback element in all servo control systems. Examples include optical sensors, hall effect sensors, tachometers, and sensor-less EMF sense, the least costly of all. Various feedback methods are useful, depending upon the precision required, RPM and torque needed. Many consumer applications generally seek to use the sensor-less technique of back-EMF sense.

d. **Analog to Digital Converter.** In many situations, an A/D device is needed in order to convert the analog signals to digital code, which are then sent to the system MCU.

e. **MCU.** All closed-loop control systems (BLDC motors are nearly always in this group) require an MCU, which handles the servo loop control, calculations, corrections, PID controls and sensor management. These digital controllers are usually 16-bit, but less sophisticated applications can use 8-bit controllers.

f. **Analog Power/Regulators/References.** In addition to the above-mentioned components, many systems contain axillary power, regulation, voltage conversion and other analog devices such as supervisors, LDOs, DC-to-DC converters and OP amps.

5. RESULTS AND DISCUSSION

With the increasingly wide use of the brushless DC motors, BLDC driving has become the contents of some training courses and one of the most important research topics for electrical engineering. The circuit is used to control speed of DC motor by using PWM technique. Series variable speed DC motor controller 12V uses a PWM pulse generator to regulate the motor speed DC12 Volt as show in figure 9. In a brushless DC motor, the relationship between the applied voltage and the load torque determines the rotational speed. This means that, when using the motor, you can control the rotational speed of the motor by changing the applied voltage. An experimental prototype was implemented in this study in order to verify the simulation results with adopting the same circuit parameters used for simulation. The gate pulses are generated with a time delay so that avoiding short circuit for switches operation. In accordance with the circuit parameters, the required system has been implemented in the laboratory.

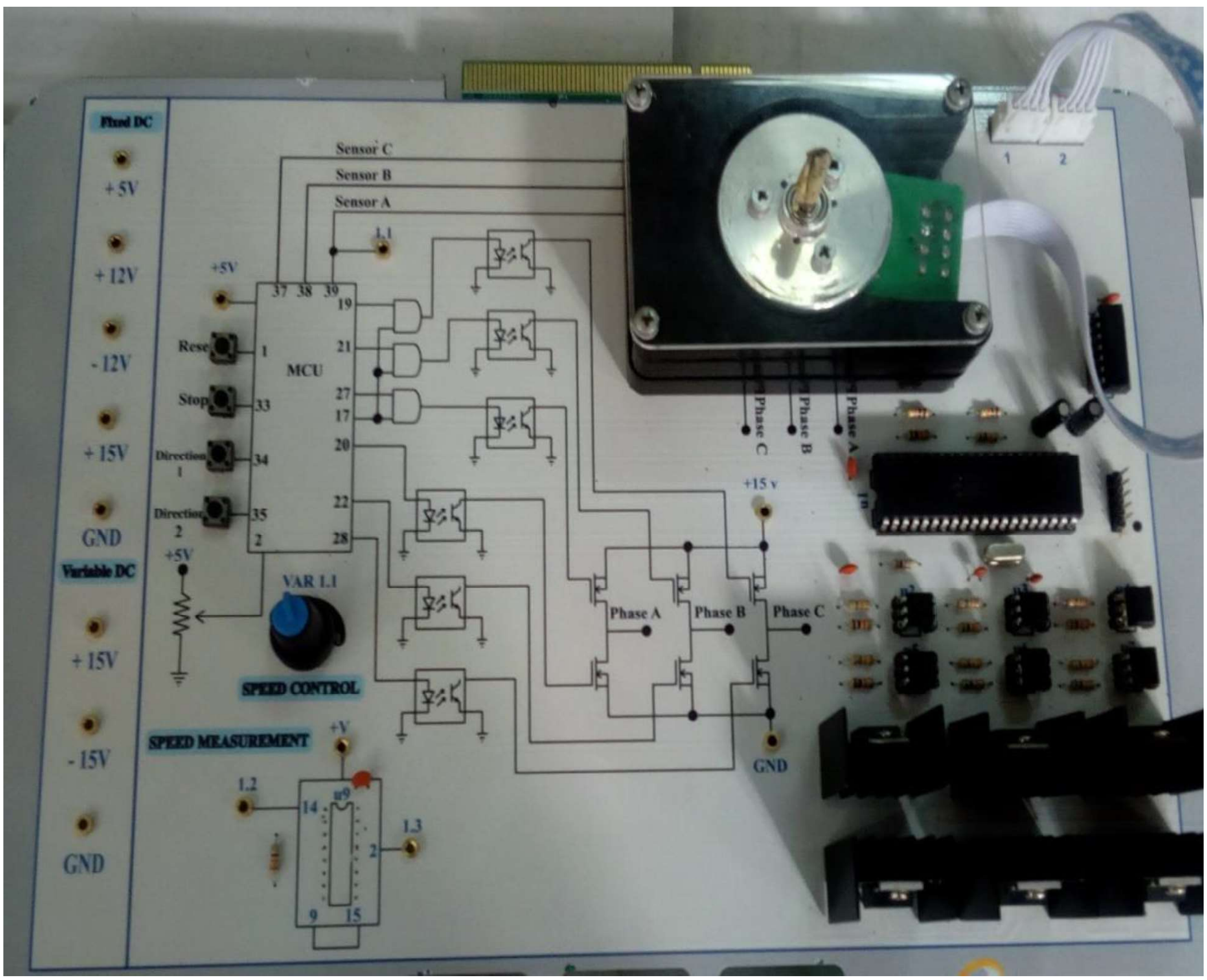

Fig.9: Developed prototype for controlling BLDC

The experimental Mode 1 (variable speed) phase A pulse is shown in Fig. 10, where the experimental results agree to some extent with the simulated results. The experimental Mode 2(constant speed) phase A pulse is shown in Fig. 11, where the experimental results agree to some extent with the simulated results. The experimental Mode 3 (on – off) duty cycle phase A is shown in Fig. 12, where the experimental results agree to some extent with the simulated result. The experimental phase A&B pulse at mode1 and mode 2, where there is a shift approx.120°, are shown in figures 13,14. The experimental results agree to some extent with the simulated result.

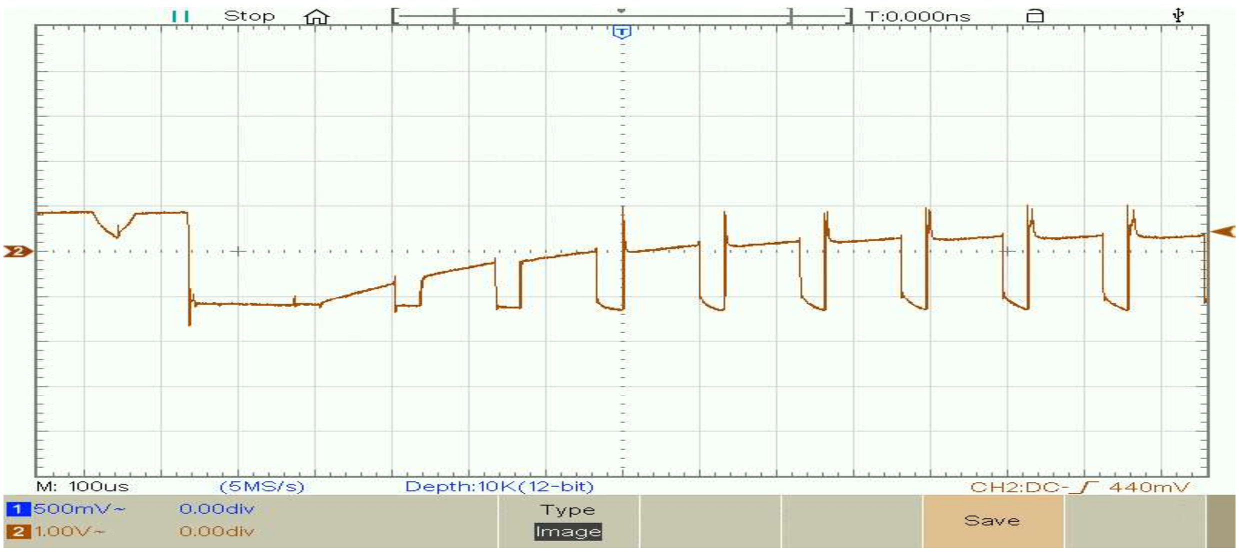

Fig.10: Mode 1 (variable speed) phase A

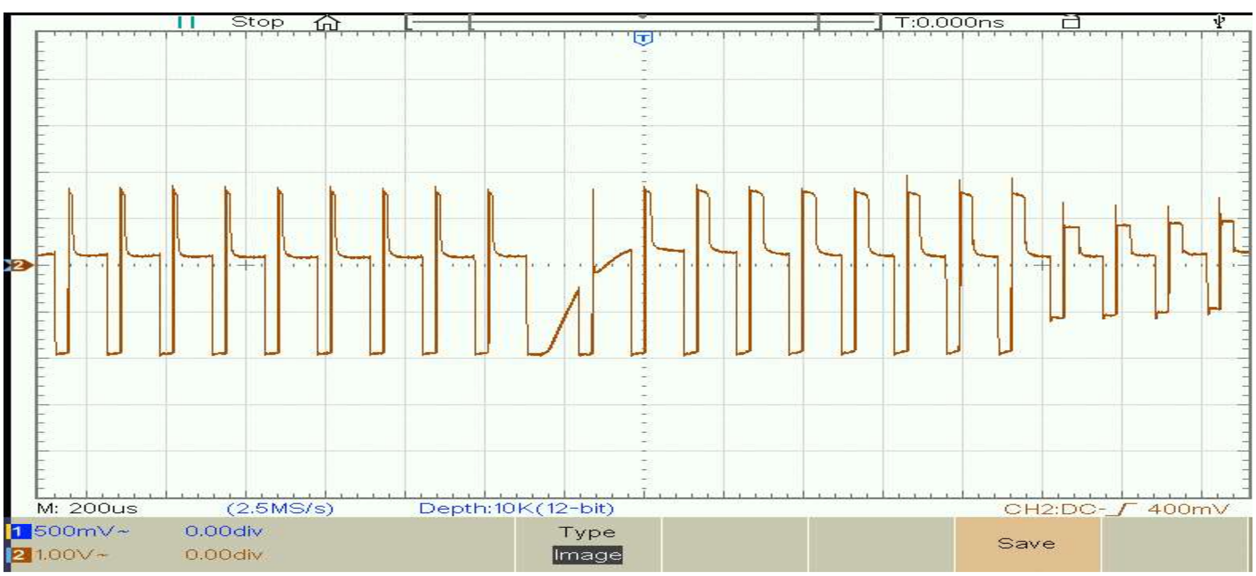

Fig.11: Mode 2 (constant speed) phase A

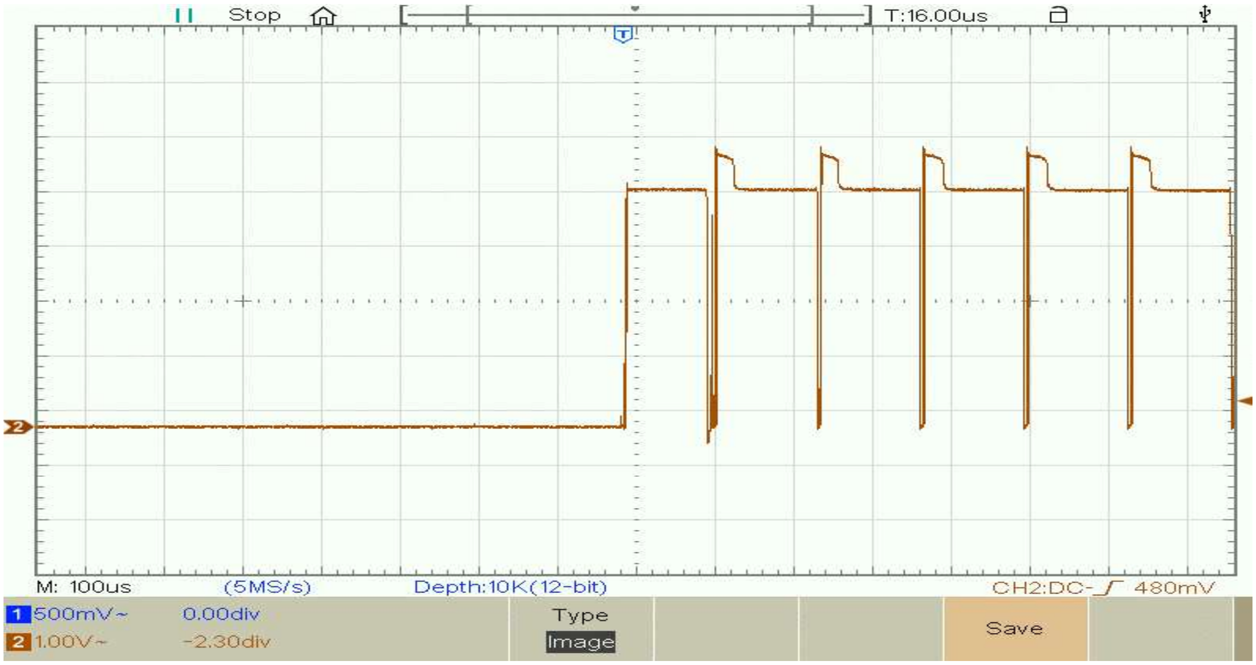

Fig.12: Mode 3(on-off) duty cycle phase A

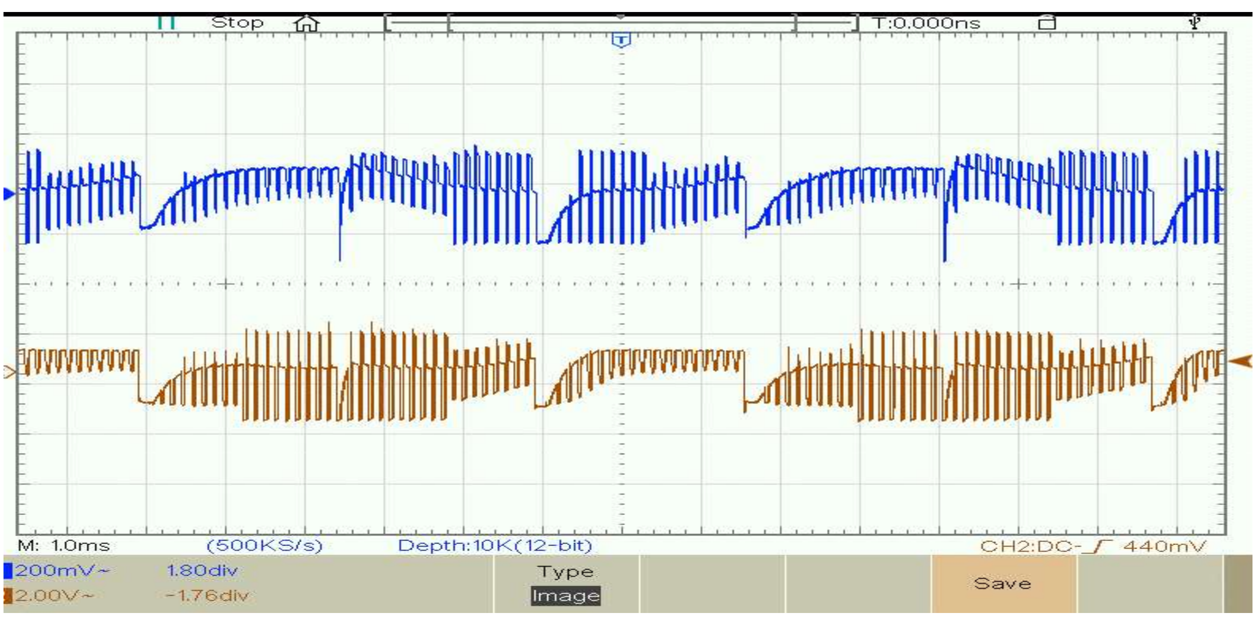

Fig.13: Phase A&B at mode 1

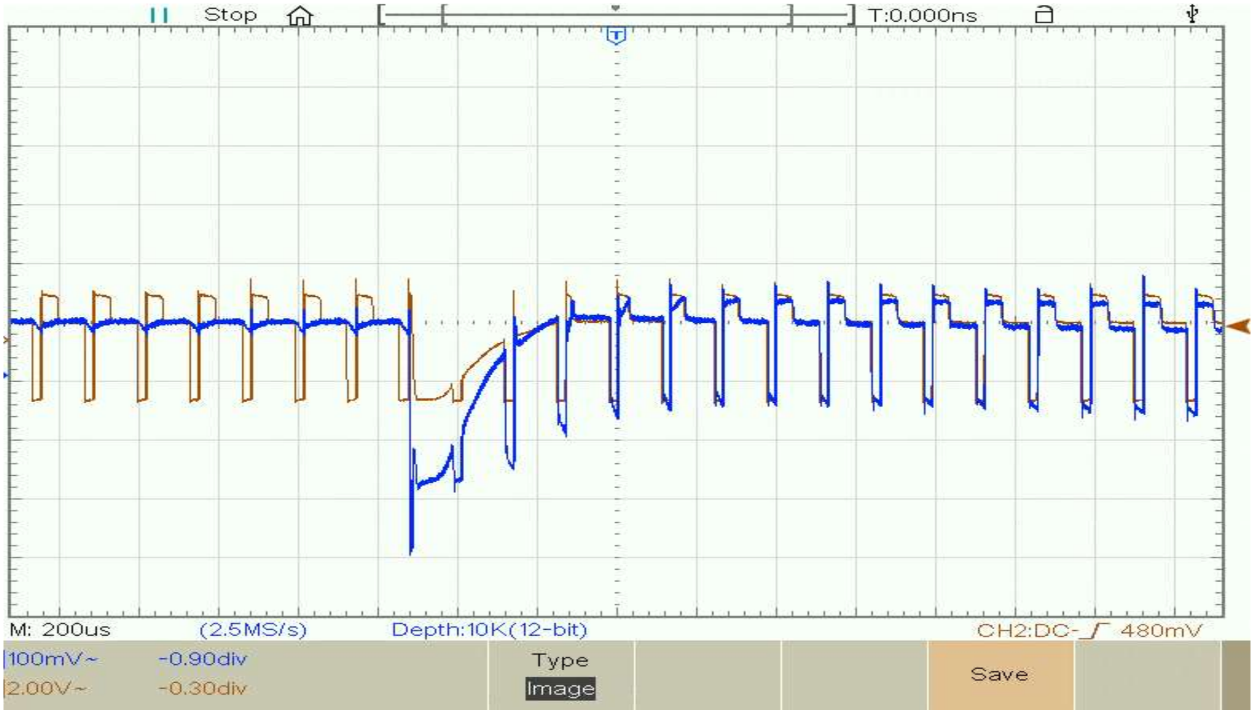

Fig.14: Phase A&B at mode 2

٦. Conclusion

Brushless DC motors have been in use for over fifty years. Their application area ranges from a small-sized consumer device to a complicated industrial automation system. The all-electronic control system increases torque, improves wide-range speed regulation, and enhances other characteristics of the motor.

Despite the reliability and high efficiency, such motors are not universal. First of all, they have a high price and a complex controller's implementation. Thus, for some projects, a brushed DC motor controller could become a reasonable option.

One of the key design challenges of a BLDC motor controller lies in determining the position of the rotor. You can accomplish this in different ways, such as:

- using a suitable sensing device;
- measuring back electromotive force created in the stator's windings;
- combining various methods to achieve the desired result.

Therefore, it is expected that this simple control system for BLDC motor drives will help reduce the complexity of motor control hardware.

By using the BLDC motor in key sub-systems, the overall weight can also be reduced. This means that the application can offer better fuel economy in vehicles. As the BLDC motor is entirely commutated electronically, it is much easier to control the torque and RPM speed of the motor and at much higher speeds. Around the world, many countries are facing insufficient power due to electrical power grid deficiencies. To be certain, a small number of countries are now either giving subsidies or getting ready to provide subsidies for the more efficient use of BLDC motors. The BLDC deployment is but one of the many trends addressing the green initiative to save the world's precious resources without adversely impacting our way of life.

Also, the method of measuring voltage drop on MOSFET can provide over-current protection for the circuit but without current sensing resistor.

7. FUTURE WORK

The possibilities of continuing the work that has been done will be summarized here as possible future work. Even though the results were mostly promising there are of course some parts that can be made even better, and which can be considered as possible future work. An example of a part like this, is the temperature dependence. The temperature dependence would be seen in the hydraulic pressure from the pump, since the properties of the hydraulic oil in it depends on temperature. An example of one such property is the viscosity, which behaves differently at different temperatures. the BLDC are also temperature dependent, which was not compensated for in this paper.

ACKNOWLEDGMENTS

This work was supported by Science, Technology and Innovation Funding Authority (STDF), (Project No. 45039).

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تطوير محرك تيار مستمرعديم الفرش لأغراض التدريس باستخدام تقنيات مختلفة للتحكم في السرعة

الملخص:

في هذا البحث ، تم تطوير منصة اختبار لأغراض التدريس لتعزيز إلكترونيات القوي والتحكم في الوقت الفعلي لتشغيل محرك عديم الفرش بشكل كامل خاصة فيما يتعلق بتقنيات تعديل عرض النبضة (PWM)، وتوليد الإشارات والتحكم في السرعة نظريًا وعمليا باستخدام محاكاة الماتلاب و بمساعدة مجموعة برمجة معالجة الاشارة الرقمية (DSP) في البحث. أولاً تم تطوير نموذج باستخدام محاكاة الماتلاب.وتضمنت استراتيجيات التحكم المطبقة تقنيتين : وهما التبديل الناعم والثابت. ثم تم بناء النظام بطريقة تمكن الباحث من تنفيذ النموذج وتأكيد نتائجه من خلال منصة الاختبار باستخدام هذه التقنيات. كان النهج المستخدم فعالاً في الطريقة التي أدى بها إلى رضا الباحث. مما أظهر تحسن فيما يتعلق بتطبيقات التحكم في القيادة إما كمحرك متغير السرعة أو في أنظمة الدمج. تُفضل محركات التيار المستمرعديم الفرش (BLDC) في الغالب للتطبيقات الديناميكية مثل صناعات السيارات وصناعات الضخ. ومن المتوقع بحلول عام ٢٠٣٠ ، ستصبح محركات التيار المستمر عديم الفرش BLDC هي السائدة في نقل الطاقة في الصناعات التي تحل محل المحركات التقليدية.يعتبر محرك التيار المستمر عديم الفرش للسيارات الكهربائية هو الحل الأفضل للنقل الأخضر نظرًا لكفاءته العالية وقدرته علي عدم الانبعاثات للغازات. حيث تتمثل مزايا محركات (BLDC) في زيادة الموثوقية والمرونة والكفاءة العالية والعمر الأطول وتقليل الاحتكاك والمعدل الأسرع للجهد والتيار والجهد الدقيق والتيار المطبق على ملفات المجال.