



A Variable Speed Bidirectional DC Motor Drive

Ayinde Mohammed Usman^{*}, Ola Ibrahim, Shina Samuel Wuraola, Olayinka Sikiru Zakariyya, Abdulrahman Okino Otuoze, Obalolu Olatunji Mohammed

Department of Electrical and Electronics,
University of Ilorin, Kwara State, Nigeria.

ABSTRACT

The ubiquity of DC motor in industrial, and home applications makes it one of the most important components in various categories of machines. The unending demands for automation in appliances productions have led to continuing efforts aimed at advancing simpler, cost-effective, and efficient DC motor drive to take maximum advantage of its performance. A simple but robust bidirectional DC motor drive has been presented in this work. The PWM technique is used to generate pulses signals which are used to vary the speed of the motor. The device is designed to run bi-directionally, and the H-bridge was used to control the direction of the DC motor.

ARTICLE INFO

Article History

Received: June, 2020

Received in revised form: July, 2021

Accepted: October, 2021

Published online: November, 2021

KEYWORDS

Automation; DC Motor; H-bridge; Microcontroller; Pulse Width Modulation (PWM).

INTRODUCTION

The direct current (DC) motor is ubiquitous in industrial, and home applications. It forms a major component in household and office appliances such as washers, toys, dryers, printers, compressors. In the automotive industry, the DC motor is found in electric windows in cars, fuel pump control, electronic steering control as well as in aerospace where its applications are found in centrifuges, robotics arm control, gyroscope control among others (Ahmad & Taib, 2003; Bensaoud & Tokhmechi, 2020; Sarita et al., 2016). DC motor can also be found in home and office automation systems (Usman et al., 2021; Zakariyya et al., 2017). In these devices, the speed and direction of operation need to be controlled to give the expected output (Al-Sagar et al., 2020; Bensaoud & Tokhmechi, 2020; Sarita et al., 2016). Hence, the DC motor is used to provide the needed speed for the optimal operation of these devices. Its use in almost all types of devices has been largely influenced by the need to replace human efforts of manually carrying out a multitude of repetitive tasks which are hitherto laborious for a human to accomplish with machines.

A DC motor converts DC electrical energy into mechanical energy. It consists of a stator, a rotor, and a commutator. The stator houses the motor and contains magnets, bearing etc. The rotor is the rotating part of the motor, which is also called

armature and consist of coils of wire through which current flows. The function of the commutator is to ensure that current flows in the right direction when the rotor is in operation. DC motors are deployed to control of speed or position required in a device (Bensaoud & Tokhmechi, 2020). The speed can be accelerated or decelerated. It works on the principle of basic magnetism. Details on its principle of operations can be found in (Ahmad & Taib, 2003). Fig. 1 shows a DC motor. Theoretically, the speed of a DC motor increases with an increase in the voltage level. Therefore, the speed is controlled by varying the voltage supply. Besides, the direction of rotation can be changed by reversing the polarity of the current flow through the gate drive. The need for the controller in a DC motor becomes essential to monitor its speed and maintain it as the situation may require in the device where it is deployed. There are different types of DC motors with varying properties.

The essence of the speed controller in a DC motor is to send the required speed needed by a device to operate optimally. The speed can be controlled using one of the following methods: the use of mechanical gears, reducing the motor voltage with a series resistor and the pulse width modulation (PWM) technique in which full voltage is applied to the motor in pulse. As the pulse increases, the speed of the motor increases.

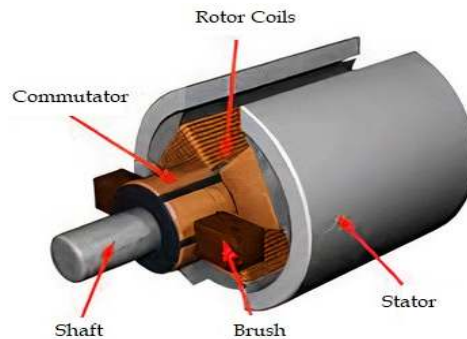


Fig. 1. A DC motor.

The unending demands for automation in appliances productions have led to continuing efforts at advancing simpler, cost-effective and efficient DC motor drive to take maximum advantage of its performance. In this work, a simple but robust bidirectional DC motor drive is designed and implemented. The DC motor direction is controlled in either forward or reverse direction through the H-bridge circuit and its speed is controlled using the PWM technique. The DC motor speed is monitored using a proximity sensor, and the speed is displayed using a tachometer LED display. A hardware implementation of the design is carried out to test the workability of the design and it works according to design.

LITERATURE REVIEW

Many research works have been dedicated to how to improve the control of speed and direction in DC motors. Different approaches have been proposed and implemented. Many of them were improved upon to suit a specific need. A review of some related work in this respect are discussed in this section. El-Saadawi *et al* (El-Saadawi *et al.*, 2020) developed a Fractional-order based proportional integral derivative (FOPID) control to control the speed of the DC motor. The conventional PID, though, is popular because of its simplicity and robustness. It is however difficult to achieve the desired performance level due to its long adjustment time, and large overshoot, particularly in multi-input multi-output (MIMO) systems. Fractional control applications, according to them have shown reliable performance against external disorder and parametric ambiguities, thus making them appealing to solving industrial process control issues. The FOPID controller is an extension of PID (a general control loop feedback mechanism) that is popularly deployed in industrial

system control. Three case studies were presented to review the performance of FOPID against conventional PID in their work. The result reported indicated less settling time, rise time and overshoot, thus making the FOPID more adaptable and reliable for controlling higher-order systems compared to conventional PID.

A back-electromotive-force (EMF) voltage approach was proposed in (Ahmad & Taib, 2003) to estimate the speed of a DC motor. The DC motor control is usually achieved using a closed-loop speed sensor, wherein a tachometer or optical encoders are assembled to the motor shaft to provide the feedback speed signal. However, according to their report, the use of a speed sensor or shaft transducers greatly weaken the mechanical efficiency of the drive. The DC motor controller designed used the back-EMF voltage of the DC motor to estimate the motor current. The rise time, settling time and percentage of maximum overshoot were computed from their experimental set-up to analyze the performance of the design. The results confirmed that a back-EMF voltage instead of a speed sensor can be used to control the speed of a DC motor. In the back-EMF sensing scheme, there is no signal attenuation and no high common-mode voltage issue, thus giving a better startup performance.

The direct back-EMF sensing structure has been implemented into a low-cost microcontroller. However, the direct back-EMF sensing scheme needs a minimum PWM 'off' time, the duty cycle is less than 100% which is required in many automotive applications. Shao (Shao, 2006) presented an improved back-EMF detection scheme for DC motor drives in automotive applications. The back-EMF is sampled concurrently during either the PWM 'on' time or the PWM 'off' time to overcome the problem

associated with 'off' time sampling earlier reported. The duty cycle limitation is eliminated by combining the alternative of sensing the back-EMF during the high-side-switch PWM 'on' time. The result from the experimental setup reportedly confirmed the concept and showed a good performance. The limitations on the selection of PWM frequency along with its maximum pulse width for different types of DC motors were investigated by Paul (Paul & Member, 2020). A modest technique to establish the accurate speed of DC motor without the use of any type of sensor was proposed in the work. The back-EMF signal was used as the sensor for the control mechanism rather than using separate sensing or feedback element in the experimental set up. Four experiments were reportedly conducted under different load conditions to confirm the design and it was found from the experimental results that the proposed DC motor controller can be applied for a wide range of control.

Kasim (KASIM, 2021) carried out a study where the gain parameters of the PID controller was optimized to keep the speed value of the DC motor constant under load. The Ziegler Nichols method (ZNM) and the Ant Colony Optimization

method (ACOM) were compared in the experimental set-up to determine the one which gives optimal PID parameters. The ACOM reportedly presented an optimum solution among many parameters in terms of rising time, settling time and overshoot values. Therefore, the PID controller parameters determined from the best ACOM response were used to control the speed of the DC motor.

CIRCUIT DESIGN

This section explains the design concept of each unit of the system. For the speed of the DC motor to be controlled, a circuit is required to generate commands which are passed as input into the DC motor for the speed and direction to be regulated as per set conditions. The block diagram of the proposed bidirectional DC motor drive system is shown in Figure 2. The system comprises five units: speed sensing, power supply, PWM generator, H-bridge, and the DC motor. On the whole, the set-up comprises of different components such as transformer, microcontroller, rectifier, resistor, capacitor, diode, transistor, which are all put together as shown in the electrical circuit in Figure 3.

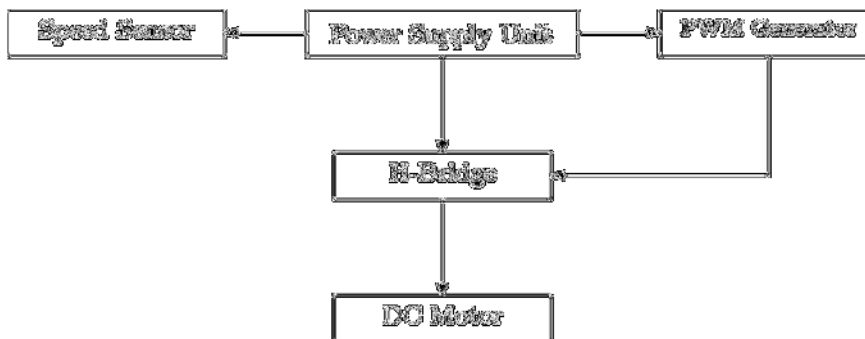


Fig. 2. The block diagram of the proposed variable speed bidirectional DC motor

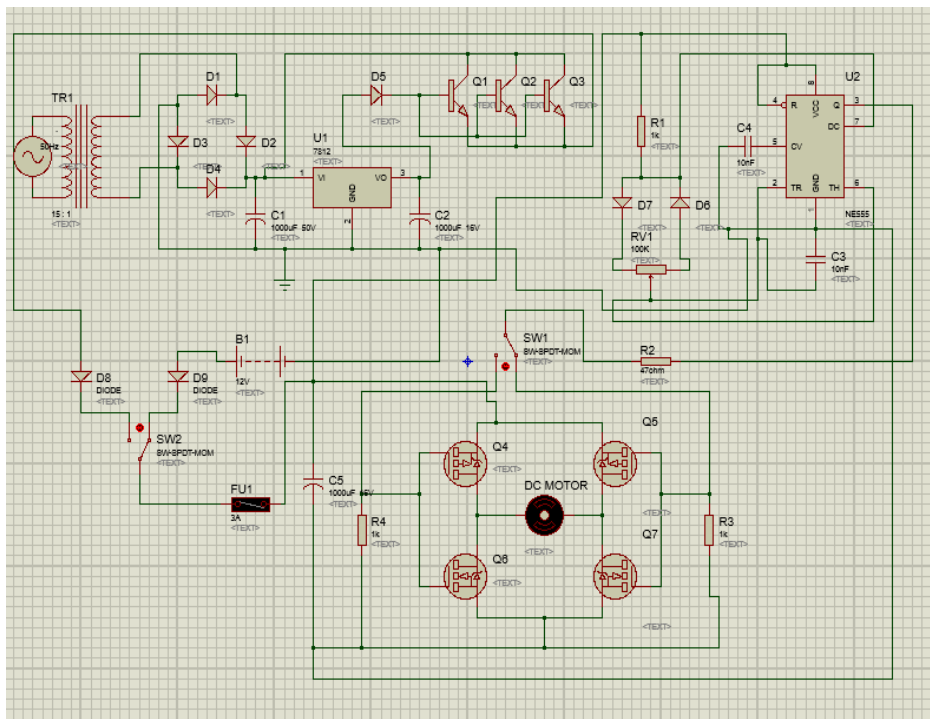


Fig. 3: The circuit diagram of the proposed DC motor drive system

Power Supply Unit

The power supply unit (PSU) provides a regulated power supply to all the constituent parts of the system. The PSU alters the 220 V Alternating Current (AC) supply from the mains to a controlled 15 V. A 220/15 V, 50Hz, I_{rms} 3 A step-down transformer is deployed in this project. The preference for a transformer of these characteristics is opted for to achieve a voltage value that will not go beyond the peak inverse voltage (PIV) of the diode rectifier. The peak voltage of the secondary side of the transformer, V_m is given in Eq. (1):

$$V_m = \sqrt{2} \times V_{rms} = 21.21 V \quad (1)$$

where V_{rms} is the root mean square voltage.

The bridge rectifier is used to get a Direct Current (DC) voltage corresponding to the controlled 15 V AC from the mains. Using Eq. (2)

for the full-wave rectification, the IN4001 diode with a 50 V PIV is used to generate the DC voltage.

$$PIV = 2 \times V_m = 2 \times 21.21 V = 42.42 V \quad (2)$$

Nevertheless, there are ripples in the generated DC voltage. The filtering capacitor is used to remove the ripples, consequent upon defining the appropriated capacitor parameter for the application, the rectifier maximum voltage, the output current and the maximum admissible ripple voltage.

Speed Sensor Unit

The speed of the DC motor is detected through the speed sensor. The sensor transistor, which switches 'on' the proximity switch sensor is placed alongside the rotating part of the motor such that, whenever the sensor transistor cut across the proximity switch sensor, it displays the speed of rotation in revolution per minute (RPM) on the LED tachometer RPM speed meter as shown in Figure 4.



Fig. 4: The LED Tachometer RPM speed meter.

H-bridge Unit

The H-bridge fundamentally allows the application of voltage to a load in a circuit in either direction (Williams, 2002). In respect of DC motor application, the H-bridge allows the DC motor to operate in either forward or backward direction. The H-bridge unit is shown in Figure 5. Its configuration is achieved with the following components: FQP27P06 P-channel MOSFET, PSMN022 N-channel MOSFET, and resistors. This H-bridge circuit is for the control of the direction of the motor to operate in either forward or reverse direction such that, when Q4 and Q7

are active, the motor rotates in the forward direction and when Q5 and Q6 are active, the motor rotates in the reverse direction. Q4 and Q5 are p-type MOSFETs while Q6 and Q7 are n-type MOSFETs. R3 and R4 are resistors put in place to pull voltages in gates of the MOSFETS to the ground, whenever there is a switch or change in the direction of rotation of the motor, these resistors are known as pull-down resistors. A reasonable resistor value of 1k was chosen for R3 and R4. The switching pattern used in this project is shown in Table 1.

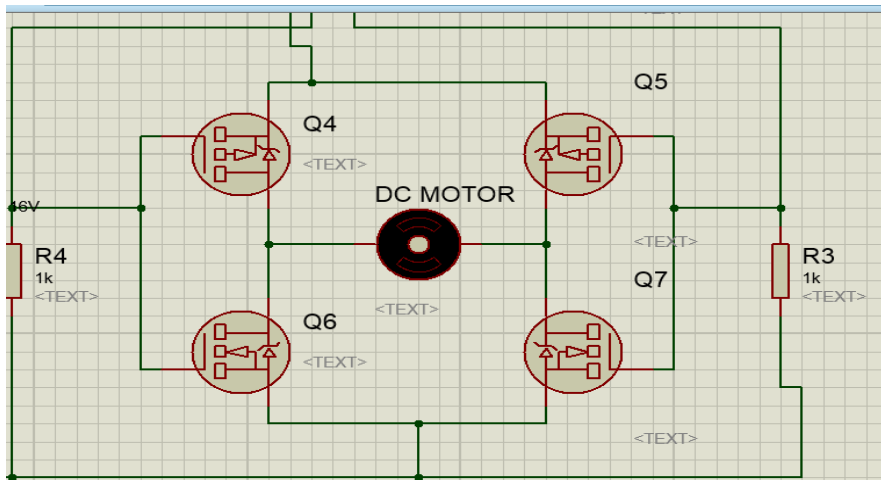


Fig. 5: The H-bridge unit circuit diagram.

Table 1: The H-bridge switching pattern

| Q4 | Q5 | Q6 | Q7 | RESULT |
|----|----|----|----|---------|
| 1 | 0 | 0 | 1 | Forward |
| 0 | 1 | 1 | 0 | Reverse |

| | | | | |
|---|---|---|---|-------------|
| 0 | 0 | 0 | 0 | Motor Free |
| 0 | 1 | 0 | 1 | Motor Brake |
| 1 | 0 | 1 | 0 | Motor Brake |

The Pulse Width Modulation (PWM) Unit

The PWM technique is used to control speed in DC motors because of its advantage over other DC motor speed control techniques (Paul & Member, 2020). This unit is used to control the duty cycle of the DC motor drive. The power is supplied to the motor in a square wave of constant voltage but varying pulse-width or duty cycle. The NE555 IC timer, 1N4007, potentiometer and other peripherals like resistors, capacitors are deployed to achieve this unit.

The DC Motor Unit

The permanent magnet DC motor (Liu et al., 2000) is used in this work due to its small and compact size besides the fact that it is good in speed varying. The rotor winding is electrically linked to the commutator. The rotation occurs with the axle and the commutator with respect to the stator. Its commutator comprises conductive sections that characterize the execution of individual coils of wire spread around the armature. A 12 V 3A 2900RPM PM DC motor is used in this work.



Fig. 6: A 12 V 3 A 2900RPM Permanent Magnet brushed DC motor

IMPLEMENTATION AND TESTING

This section discusses the implementation process and testing of the project. The different units are implemented using the designed circuit as discussed in the previous section. This process includes the physical assembly of the units on a breadboard and then printed circuit board (PCB), soldering, testing for continuity of the various components and units, and programming of the microcontroller.

After the design, the entire circuit was first tested on a breadboard to check the flow of the connection and see if there is a need for any modification in the design. The construction of the units of the system was done in a modular manner. This involves the implementation and testing of functional units in the design. However, the components needed for the construction were purchased according to the design specification and tested to ensure proper functioning, the polarities and pin arrangement of some

Testing of the Components

components such as the transistor, NE555 timer, capacitor, and diode were identified.

Implementation

Upon certifying that all the components worked as expected on the breadboard, they were transferred to appropriate points on a printed circuit board (PCB). Also, terminal leads of every component were soldered correctly along the path of conduction. Figure 7 shows the implementation stage. The LM7812 voltage regulator is used to obtain the 12 V DC needed to power the driving circuit. As a precaution, an IC socket was used for NE555, so that excessive heat does not harm it. Also, the PCB was checked carefully for continuity and soldering bridging.

The PCB is used against the Vero board because it offers a better method of constructing electronic circuits. The Proteus PCB layout software was used for the circuit diagram. The artwork of the design was printed out on paper and then printed on the copper board by the lithographer. Afterwards, the board was etched in a tank containing Ferric Chloride and washed. Finally, the board was drilled at appropriate points. The device was put into a plastic casing to serve as the housing unit. The casing is to make the device to be able to survive mechanical shocks and vibration as a result of moving from one place to another.



Fig. 7: The implementation phase

Testing

A continuity test was carried out on various components on the PCB using a multimeter. Each constituent unit making up the system were tested, to ensure they work according to the design. The whole system was then tested. In testing the whole system, a visual check was carried out to ascertain whether all components were properly connected and had an appropriate

link(s) of right polarity. All Vcc was read to the ground using a digital multimeter to check if the supply voltage is getting to the ICs used and to ensure that the expected voltage and current path were maintained within all parts of the circuit. The speed of the DC motor was controlled, and it operated bi-directionally which is the aim of the work. Figure 8 shows the display of the working system.



Fig. 8: Pictorial view of the testing stage

CONCLUSION

The ubiquity of DC motor in industrial, and home applications makes it one of the most important components in various categories of machines. In this work, a simple but robust speed bidirectional DC motor drive has been presented. PWM technique is used to generate high and low pulses to control the speed of the DC motor. The PWM generated signals are sent to the motor driver to vary the voltage supply to the DC motor to maintain a constant speed. The control of the

direction of the DC motor- to run in either direction is carried out using the H-bridge. The developed device is tested, and it can control the speed and direction of the DC motor. The device is implemented to control the DC motor bidirectionally. This project is economically viable for running a DC motor efficiently, reliably, and accurately. A future area of improvement in this work includes the use of the wireless network to access and control the DC motor drive. Another



area of future research is the provision of an alarm system to indicate the overload of the DC motor.

Acknowledgement: The authors acknowledge the University of Ilorin, Ilorin, Nigeria for the support in carrying out this research work.

REFERENCES

- Ahmad, A. Z., & Taib, M. N. (2003). A study on the DC motor speed control by using back-EMF voltage. *2003 Asian Conference on Sensors, AsiaSENSE 2003*, 359–364. <https://doi.org/10.1109/ASENSE.2003.1225047>
- Al-Sagar, Z. S., Saleh, M. S., Mohammed, K. G., & Sameen, A. Z. (2020). Modelling and Simulation Speed Control of DC Motor using PSIM. *IOP Conference Series: Materials Science and Engineering*, 745(1). <https://doi.org/10.1088/1757-899X/745/1/012024>
- Bensaoud, O., & Tokhmechi, A. (2020). *Speed Control of DC Motor Using PICAXE Microcontroller*. <http://dSPACE.zu.edu.ly/xmlui/handle/1/902>
- El-Saadawi, M. M., Gouda, E. A., Elhosseini, M. A., & Essa, M. S. (2020). Identification and Speed Control of DC Motor Using Fractional Order PID: Microcontroller. *European Journal of Electrical Engineering and Computer Science*, 4(1), 1–8. <https://doi.org/10.24018/ejece.2020.4.1.170>
- KASIM, Ö. (2021). Speed Control of DC Motor under reverse torque disturbance with Ant Colony Optimized PID Controller. *Aksaray University Journal of Science and Engineering*, 5(1), 8–19. <https://doi.org/10.29002/asujse.892979>
- Liu, X. Q., Zhang, H. Y., Liu, J., & Yang, J. (2000). Fault detection and diagnosis of permanent-magnet DC motor based on parameter estimation and neural network. *IEEE Transactions on Industrial Electronics*, 47(5), 1021–1030. <https://doi.org/10.1109/41.873210>
- Paul, A. K., & Member, S. (2020). Robust PMDC Motor Control for Accurate Wire Feeding in GMAW Using Back EMF. *IEEE Transactions on Industrial Electronics*, 67(1), 413–420. <https://doi.org/10.1109/TIE.2019.2896131>
- Sarita, M., Umadi, S., & Patil, D. (2016). Dc Motor Speed Control Using Microcontroller. *International Journal of Engineering and Techniques*, 2(6), 70–74. <http://www.ijetjournal.org>
- Shao, J. (2006). An improved microcontroller-based sensorless brushless DC (BLDC) motor drive for automotive applications. *IEEE Transactions on Industry Applications*, 42(5), 1216–1221. <https://doi.org/10.1109/TIA.2006.880888>
- Usman, A. M., Ibrahim, O., Muhammed, Y. S., Otuoze, A. O., Zakariyya, O. S., & Afolayan, M. A. (2021). Design and Construction of an Automatic Home and Office Power Control System. *FUOYE Journal of Engineering and Technology*, 6(2). <https://doi.org/10.46792/FUOYEJET.V6I2.597>
- Williams, A. (2002). Microcontroller Projects Using the Basic Stamp. *Microcontroller Projects Using the Basic Stamp*. <https://doi.org/10.1201/9781482280777>
- Zakariyya, O. S., Salami, A. F., Alabi, O. O., & Usman, A. M. (2017). Design of a Bimodal Home Automation System using ESP8266 and ATMEGA328 Microcontroller. *Computer Engineering and Applications*, 6(3). <https://uilspace.unilorin.edu.ng/handle/20.500.12484/4631>