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EFFECT OF PULSE WIDTH MODULATION ON DC MOTOR SPEED

[1]Cosmas Tatenda Katsambe, [2]Vinukumar Luckose, [3]Nurul Shahrizan Shahabuddin
[1,2,3] Department of Electrical Engineering, Faculty of Engineering, Nilai University, Malaysia
Email: shahrizan@nilai.edu.my

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***Abstract*--**Pulse width modulation (PWM) is used to generate pulses with variable duty cycle rate. The rapid rising and falling edges of PWM signal minimises the switching transition time and the associated switching losses. This paper presents a DC motor speed controller system using PWM technique. The PWM duty cycle is used to vary the speed of the motor by controlling the motor terminal voltage. The motor voltage and revolutions per minutes (RPM) obtained at different duty cycle rates. As the duty cycle increases, more voltage is applied to the motor. This contributes to the stronger magnetic flux inside the armature windings and the increase the RPM. The characteristics and performance of the DC motor speed control system was investigated. In this paper, a PIC microcontroller and a DC-DC buck converter are employed in the DC motor speed controller system circuit. The microcontroller provides flexibility to the circuit by incorporating two push button switches in order to increase and to decrease the duty cycle rate. The characteristics and performance of the motor speed controller system using microcontroller was examined at different duty cycle rate ranging from 19% to 99%.

Keywords*--DC motor, duty cycle, pulse width modulation, motor speed controller, DC-DC converter*

I. Introduction

DC motors are devices that convert electrical energy into rotational energy for numerous applications ranging from printing press (Chauhan & Semwal, 2103), home appliances (Arvind et al., 2014) and industrial application (Arvind et al., 2014). DC motors are widely used for the ease in speed controlling and regulation compared to the other types of motors (Gupta et al., 2012).DC motor offers smooth speed control in both directions without any power switching circuit (Chauhan & Semwal, 2013).In many applications AC motors and vector-control drives are now being used as an alternative to DC motors, but there are many applications where DC motors offer great advantages over AC motors for its reliability, cost effectiveness, and performance (Bansal&Narvey,2013;Gupta et al., 2012). DC motors have a vital role in the modern industry for applications which are speed dependent and the speed might vary over a wide range. There are many different ways to control the speed of motors. Basically three methods are employed for speed control, namely, armature resistance, field flux and armature voltage (Bansal & Narvey, 2013) Pulse Width Modulation (PWM) is a simple method to control the voltage (Kapil & Patel, 2015).

When a specific voltage is supplied to the motor, it rotates the output shaft at some speed.The power applied to the motor can be controlled by varying the width of these applied PWM pulses and thereby varying the average DC voltage applied to the motors terminals(Bakibillah et al., 2104). By changing or modulating the timing of these pulses the speed of the motor can be controlled. The longer time the pulse is "ON", the faster the motor will rotate and whereas, the shorter time the pulse is "ON" the slower the motor will rotate.Microcontrollers have been used to control the DC motor speed due to the low cost and also the use of extra hardware such as the use of timer, RAM and ROM (Arvind et al., 2014). This technology is provides fast response in controlling of multiple parameters and these parameters are field programmable by the user.

In this paper, a DC motor speed controller system using PWM is proposed and its performance is studied. A compact DC motor speed controller system using microcontroller is then applied to provide adjustment mechanism to the circuit.

II. Experimental Setup

Figure 1 shows the proposed block diagram of the DC motor speed controller system consists of DC motor, PWM control unit, DC- Cbuck converter and 12V DC power supply. The driver circuitis used to trigger the power MOSFET in the buck converter. The IRF540 MOSFET has the gate–source voltage of ± 20 V and the maximum drain-source voltage of 100 V. The

MOSFET exhibits the minimum gate–source threshold voltage of 2V. The output pin of the driver circuit is connected to the gate terminal of the MOSFET. The PWM control unit can provide PWM signal with the voltage ranging from 0 to 15 V.

Figure 2 shows the DC to DC converter circuit which consists of MOSFET, 150n Hinductor, 47 pF capacitor, diode and a load at the output terminals. In this project the buck converter is operating in continuous conduction mode at different frequency. The buck converter regulates the speed by controlling the average DC voltage which is applied to the armature windings of the motor through the switching element MOSFET.

The output voltage from the converter is fed to the armature windings of the motor and the armature voltage is varied with the use of pulse width modulation technique where by the duty cycle of the pulse is varied and supplied to the converter switch (MOSFET) through a motor driver. The input voltage to a DC-DC converter is an unregulated DC voltage V_s which is equal to 12 V. The converter supplies a variable DC output voltage $V_0$to the DC motor. The DC motor has the rating of 12 V and the maximum speed of 5000RPM. The speed of the DC motor is measured by a tachometer which gives the reading in RPM.

The buck converter has the inductor value of 150nH on the output side act as a filter to provide a smooth continuous output current to the load. The voltage across the inductor is given by

$$V=L\,di/dt \qquad (1)$$

where L is the value of inductor in Henry (H), and di/dt is the rate of rise of inductor current.

The value of inductor is calculated based on the switching frequency, load voltage and load current. The capacitor is connected in parallel to remove the ripple current from the inductor to a stable output voltage. The diode, D conducts current when the MOSFET is OFF and provide a path for the inductor current to flow to the load. The diode has the feature of providing low leakage current to the circuit. The power dissipated by the diode is given by

$$P_D= I_F x\ V_F \qquad (2)$$

whereI_F is the average forward current of the rectifier diode and V_F is the forward voltage of the rectifier diode.

Figure 3 shows the implementation of PIC microcontroller to control the motor speed. The microcontroller is connected to the driver circuit. A microcontroller is regarded as the PWM controller since it is the one which generates and control the PWM signal which is being applied to the gate terminal of the MOSFET (Arvind et al., 2014). As the amount of time that the voltage is on increases compared with the amount of time that it is off, the average speed of the motor increases and vice versa. The PWM frequency is fixed at 1 kHz.PIC16F877A is a 40/44-pin device which can operate at up to 20 MHz clock speed. The microcontroller supplies the PWM pulse about 5 volt DC to the driver circuit. The driver circuit will provide the necessary voltage to turn on the MOSFET. This enables the speed of DC motor to be controlled through duty/PWM cycle supplied by microcontroller.

The PWM signals are the one responsible for turning ON/OFF the power MOSFET in the buck converter hence the armature windings of the motor receives average DC voltage that will determine the motor speed. The time that it takes a motor to speed up and slow down under switching conditions is depends on the inertia of the rotor (basically how heavy it is), friction and load torque (reference). By controlling the T_{ON} and T_{OFF} (duty cycle) the average of output DC voltage can be varied. Two push buttons are applied in the microcontroller circuit to increase and decrease the duty cycle. LCD display is connected to microcontroller to display the duty cycle.

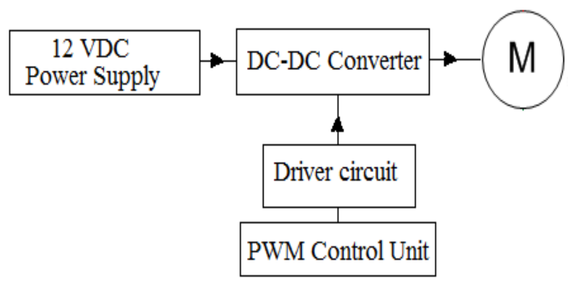

Figure 1: DC motor speed controller system.

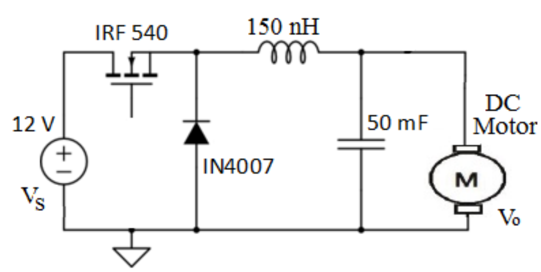

Figure 2: DC-DC Converter

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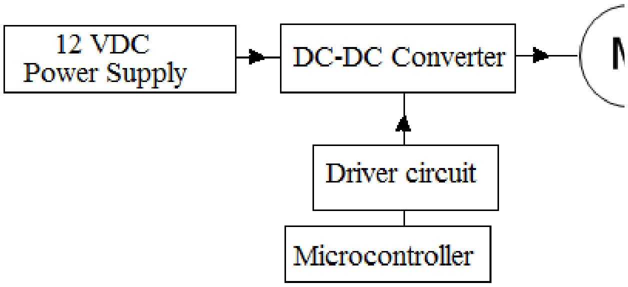

Figure 3: DC motor speed controller system with microcontroller.

III. Result and discussion

Figure 4 shows the pulses at different duty cycles. The pulse with higher duty cycle turns 'ON' at longer time than that of lower duty cycle. The duty cycle, d is governed by equation

$$d = \frac{t_{on}}{T} \tag{3}$$

where T is the duration of one period and t_{on} is the 'ON' time. The ratio of ON to OFF time is called as duty cycle which determines the speed of the motor. The desired speed can be obtained by changing the duty cycle. The PWM pulse is used to control duty cycle of DC motor drive. Power is supplied to the motor in square waveof constant voltage but varying pulse-width or duty cycle. Duty cycle refers to the percentage of one cycle during which duty cycle of a continuous train of pulses. Since the frequency is held constant while the on-off time is varied, the duty cycle of PWM is determined by the pulse width. Thus the power increases duty cycle in PWM.(Srivastava). The PWM ON period at 60 % of duty cycle is higher than at 40 % duty cycle. This contributes to higher motor speed at 60 % duty cycle compared to 40 % duty cycle.

Figure 5 shows the pulses at switching frequency of 500 Hz and 1500 Hz. The frequency of operation, f is defined as

$$f = \frac{1}{t_{on}+t_{off}} = \frac{1}{T} \tag{4}$$

Where t_{on} is the ON time of the PWM pulse, t_{off} is the 'OFF' time in which the value of PWM pulse is at zero level and T is the total time period of one duty cycle. Higher switching frequency increases the output voltage.

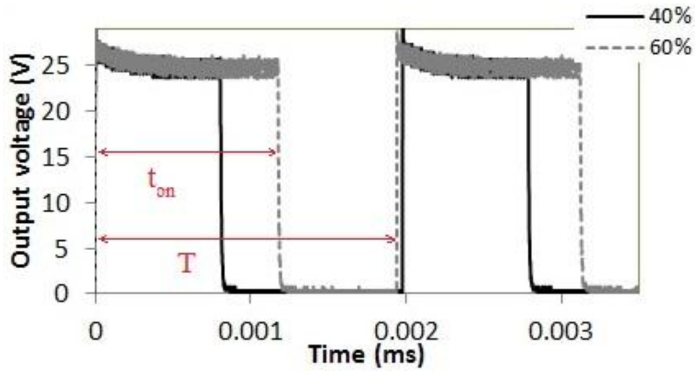

Figure 4: Pulse at different duty cycle.

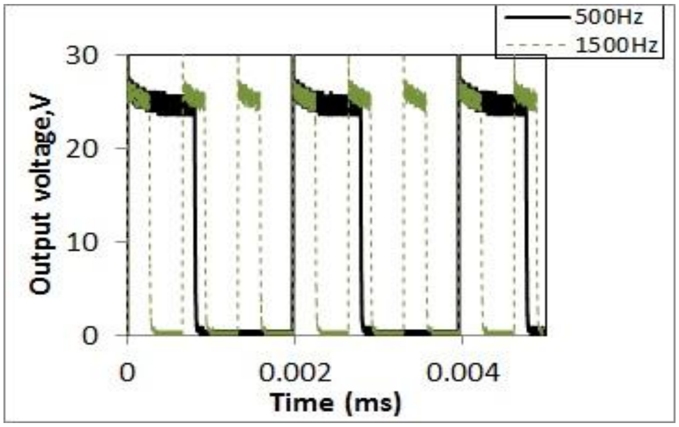

Figure 5: Pulse at different frequencies.

Figure 6 shows the motor voltage and speed at different frequencies. The voltage increases steeply from 9.56 V to 10.74 V as the frequency is increased from 500 Hz to 1500 Hz. However, the voltage increases gradually as the frequency is beyond 2000 Hz. This is due to the higher loss at higher frequency (Obed, 2011). It is obvious that the speed increases with increasing of switching frequency. For instance, the speed increases from 4213 to 4722 RPM as the frequency is increased from 500 Hz to 3000 Hz. The average output voltage is governed by

$$V_{av} = \frac{t_{on}}{T} V_{in} \tag{5}$$

where, t_{on} is the ON period of PWM pulse, T is the total time period of the one duty cycle and V_{in} is the input voltage.

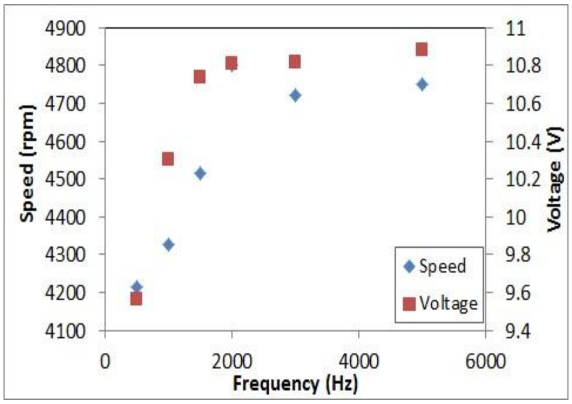

Figure 6: Motor speed and voltage at different PWM frequency

Figure 7 shows the motor speed and voltage at different duty cycle for the configuration shown in figure 3. The duty cycle was set from 20 % to 99 %. When the duty cycle is increased the motor speedis also increased. At 20 % duty cycle, the motor speed is 2332 RPM and the converter output voltage is 5.4 V. As the duty cycle increased to 40 %, the motor speed is 2470 RPM and the converter output voltage is 5.82 V. The motor speed and converter output voltage increasing as the duty cycle increases to 60% and 80 %. The maximum speed of 2892 RPM and the maximum voltage were achieved at 99 % duty cycle. This shows that the speed increases as the duty cycle increases.

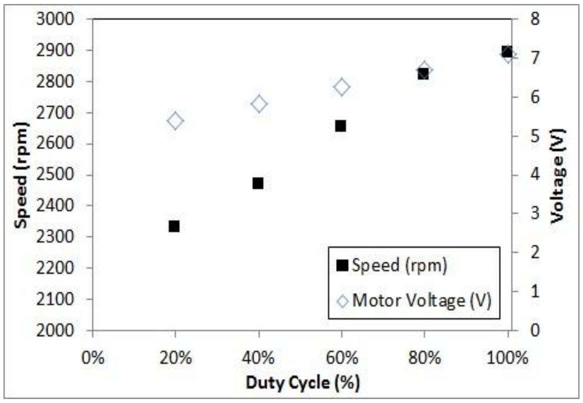

Figure 7:Motor speed and voltage at different duty cycle

IV. Conclusion

The motor speed controller system using PWM technique was developed. The relationship between the duty cycle and the converter output voltage has been investigated. It is found that the wider the pulse width, the more average voltage applied to the motor terminals. This leads to the stronger the magnetic flux inside the armature windings. Hence, the faster the motor will rotate. The microcontroller provides flexibility in controlling the speed by changing the duty cycle of the PWM pulse. The effect of the PWM pulse width on the motor voltage and speed has been studied.

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