wjert, 2024, Vol. 10 Issue 12, 180-189.
Original Article
ISSN 2454-695X

World Journal of Engineering Research and Technology
WJERT
www.wjert.org
SJIF Impact Factor: 7.029

MODELING OF DC MOTOR PWM CONTROL DRIVE FOR ADJUSTABLE SPEED APPLICATIONS

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Article Received on 04/10/2024 **Article Revised on 24/10/2024** **Article Accepted on 14/11/2024**

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ABSTRACT

This paper adopts Pulse Width modulation technique for speed control of permanent magnet direct current (DC) motor. Separately excited DC motor model is modeled using armature control scheme, and the Dc-Dc Buck converter is designed to control the speed of the motor and the model is implemented in MATLAB/SIMULINK software. This work aim is to investigate the dynamic performance of a separately excited DC motor fed by Chopper for its efficient Speed control. The speed of the motor is feedback and is compared with the reference speed, PID controller is used to evaluate the error, and the Pulse Width Generator block then converts this signal into trains of pulses which trigger the Chopper (IGBT) of buck converter. The Chopper Switching duration determine output voltage of the Buck converter, which also supply voltage to armature winding of the motor, Since motor speed depends on the armature voltage in armature control scheme,. The variable speed operation is implemented and speed of the motor is successfully regulated. The performance of the PWM control method is evaluated using variable load condition, Reference speed tracking is tested with the help of PID controller and transient response to reference speed is evaluated. From the simulation results show that PWM control method provides excellent and efficient control the DC motor and is recommended for Industrial application where variable speed operation is utilized.

KEYWORD: PWM, IGBT, PID controller, Dc-Dc Buck converter, MATLAB/SIMULINK, DC motor.

1. INTRODUCTION

DC machines are electromechanical devices that convert electrical energy into mechanical energy or vice versa. The most common varieties rely on magnetic fields to produce forces. Almost all DC motors contain an internal mechanism, either electromechanical or electronic, that changes the direction of current in a section of the motor on a regular basis. The speed of a DC motor can be varied across a large range by varying the supply voltage or adjusting the current intensity in the field windings. Tools, toys, and appliances all employ small DC motors.[1] They are widely used in various applications such as electric vehicles, industrial machinery, and generators. ADC machine consists of two basic parts: the stator (stationary part) and the rotor (rotating part). The stator contain the field winding, which produces a magnetic field that interacts with the armature winding on the rotor.[2] The armature winding is the winding in which the voltage is induced, It is part of the current carrying motor, which interacts with field flux to create torque. The brush is part of the circuit where the electric current flows to the motor from the power supply, brushes is made of graphite or metal.[3] DC machines can be classified into two types based on the type of field winding: (i) separately excited DC machine, and (ii) self-excited DC machine. In a separately excited DC machine, the field winding is supplied with a separate DC source, while in a self-excited DC machine, the field winding is energized by the current produced in the armature winding. the control of DC motors precise and efficient control techniques to achieve optimal performance in some applications. There are several types of applications where the load on the DC motor varies over a wide range. These applications may demand high-speed control accuracy and good dynamic responses. Higher torques can be obtained by using geared motors. The term geared motor is used to define a motor that has a gear reduction system (or gearbox) integrally built into the motor.[4] There are four (4) main types of DC motors: Permanent Magnet DC Motors, Series DC Motors, Shunt DC Motors, and Compound DC Motors. A Dc motor controller is a device that works alongside a microcontroller, the batteries and motors. Most controllers have under-voltage, over-voltage, short circuit protection, current limit protection, thermal protection, and voltage transients. Without these protections, the motor is exposed to threats that can result in permanent electrical or mechanical damage.[5,6] Many control techniques are used in various industrial applications due to efficient and excellent control operation of separately excited DC motors. Pulse Width Modulation (PWM) uses digital signals to control power applications, as well as being fairly easy to convert back to analog with a minimum of hardware.[7,1] Therefore, the paper aims to investigate the dynamic behavior of a separately excited DC motor using Pulse with control scheme.

2. (A) MODELLING OF SEPERATELY EXCITED DC MOTOR

The mathematical modeling of the system is done on the actuation model of the SEDC motor shown in Fig.1

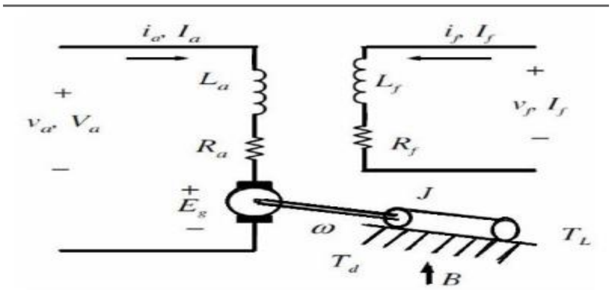

Fig. 1: Circuit Diagram of a Separately Excited Direct Current (SEDC) Motor.

For the armature control scheme shown in figure 1, A fixed voltage Vf is applied to the field and the field current settles down to a constant value. According to the Kirchhoff's voltage law on the field circuit. The Field voltage is given by

$$V_f = R_f I_f + L_f \frac{d\, If}{dt} \quad (1)$$

$$V_a = L_a \frac{dIa}{dt} + R_a I_a + E_g \quad (2)$$

$$E_g = K_b \omega \quad (3)$$

Where, I_a, Ra and La are the armature current, armature resistance and armature inductance respectively. The back electromotive force (emf) or voltage (E_g) is proportional to the angular speed, K_b is the motor voltage constant (in V/A-rad/sec) and ω is the motor angular speed (in rad/sec) I_f , Rf and Lf are the field current, field resistance and field inductance respectively. In addition, the motor generates a torque Td proportional to the armature current,

$$T_d = K_t I_f I_a = K_t I_a \quad (4)$$

Developed Torque is also expressed as

$$T_d = J \frac{d\omega}{dt} + B\omega + T_L \quad (5)$$

Where, B: Viscous friction constant or frictional coefficient. (N.m/rad/sec), Tl: Load Torque (N.m), J: the rotor moment of inertia (Kg.m2), Kt: Torque constant and If is kept constant. Equation (2) to equation (5) together makes up the dynamic equations of the direct current motor used for the simulations. If the input voltage Vs(t)=Vs is a constant, the resulted armature current ia(t)=Ia, angular velocity w(t)= and torque T(t)=T are constant in the steady state.

Taking Laplace transform, the above equations were formulated as

$$E_g(s) = K_b \Omega(s) \quad (6)$$

$$V_a(s) = (R_a + L_a s) I_a(s) + E_g(s) \quad (7)$$

$$T_d(s) = (Js + B)\Omega(s) + T_L(s) = K_T I_a(s) \quad (8)$$

All at zero initial conditions, The angular position is given as

$$\theta(s) = \frac{1}{s}\Omega(s) \quad (9)$$

The transfer function of motor speed with respect to input voltage is expressed as

$$G(s) = \frac{\Omega(s)}{E_a(s)} = \frac{K_T}{(L_a s + R_a)(Js + B) + K_b K_T} \quad (10)$$

$$G = \frac{K_T}{[L_a J s^2 + (L_a B + R_a J)s + (R_a B + K_b K_T)]} \quad (11)$$

The above equations can be represented in block diagram form as shown in figure 2

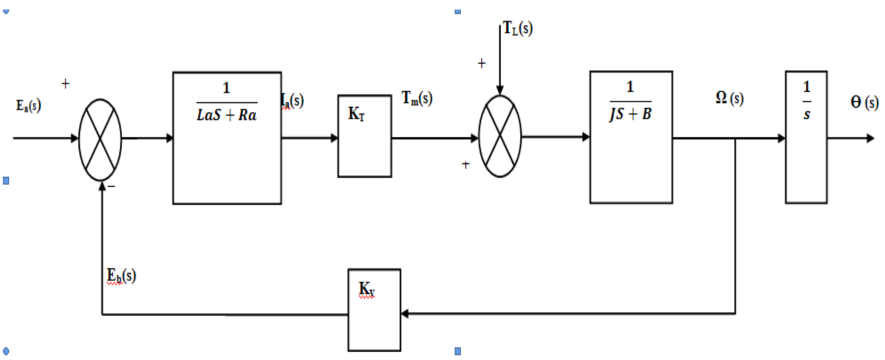

Fig. 2: Block diagram of the armature-controlled DC motor.

(B) DC-DC BUCK CONVERTER (CHOPPER CIRCUIT)

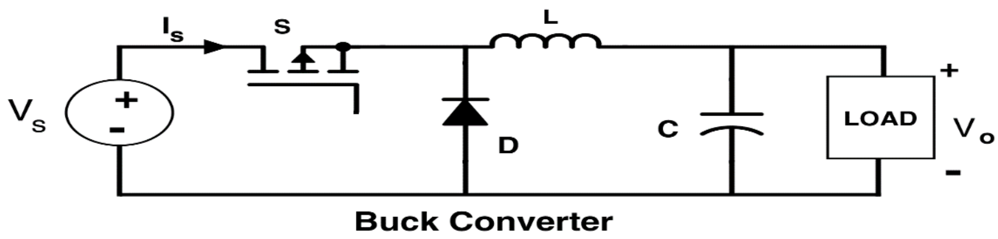

Fig. 3: Block diagram of DC-DC Buck Converter.

A buck converter or step-down converter is a DC-DC converter which steps down voltage (while stepping up current) from its input (supply) to its output (load). Its name derives from the inductor that "bucks" or opposes the supply voltage. Buck converters typically operate with a switching frequency range from 100 kHz to a few MHz. Dc-Dc Buck Converter average voltage is equal to the integral of the voltage waveform. The average voltage (V_o) is given by the following equation

$$V_o = DV_{max} + (1-D)V_{min} \qquad (12)$$

But usually, V_{min} equals to zero and V_{max} is the supply dc voltage (Vs) to Buck converter (Chopper)

$$\text{Thus; } V_o = DV_{max} = DV_s \qquad (13)$$

Where $V_o$is the average or equivalent voltage converter output voltage that power the motor ,$V_s$is the supply voltage (volts) to converter, D is duty cycle ratio (%), Ton is Pulse duration i,e duration in which Chopper switch(IGBT or MOSFET) is turn ON, T = is Switching period ($\frac{1}{F_s}$) in seconds. The recommended switching frequency (F_s) is 300 Hz in most practical circuits.

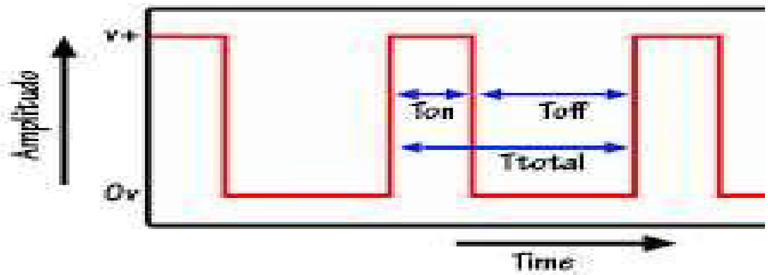

Fig. 4: Dc buck converter output voltage waveform based on (PWM).

Duty cycle (D) is defined as the percentage of digital 'high' to digital 'low' plus digital 'high' pulse-width during a PWM period. D describes the proportion of 'ON' time to the regular interval or 'period' (T) of time. signal information. its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast pace. The longer the switch is on compared to the off periods, the higher the power supplied to the load is. The PWM switching frequency has to be much faster than what would affect the load, which is to say the device that uses the power. The term duty cycle describes the proportion of 'on' time to the regular interval or 'period' of time. A low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent, 100% being fully on. PWM or duty-cycle variation methods are commonly used in speed control of DC.

$$D = \frac{T_{ON}}{T} \quad (14)$$

(C) Pulse Width Modulation (PWM)

Pulse-width modulation (PWM), is a modulation technique that conforms the width of the pulse, formally the pulse duration, based on modulator motors. PWM generators include: Microcontroller circuit, Fuzzy logic circuit, 555 Timer circuit etc. These can provide pulse signal trigger Chopper (DC Buck converter) switch like IGBT, GTO, SCR, MOSFET etc. The Pulses (gating signal) control the turning of the switch (Chopper) between Voltage supply (Vs) and the load (DC motor) ON and OFF at a fast pace. The longer the switch is on compared to the off periods (high duty cycle ratio), the higher the output voltage is supplied to the Dc motor. The PWM switching frequency (Fs) has to be much faster. Typically switching is from few kilohertz (kHz) to tens of kHz for a motor drive and well into the tens or hundreds of kHz in audio amplifiers and computer power supplies. In this study, the average value of Dc buck converter voltage (Vo) is fed to the motor. 20KHz is chosen switching frequency.

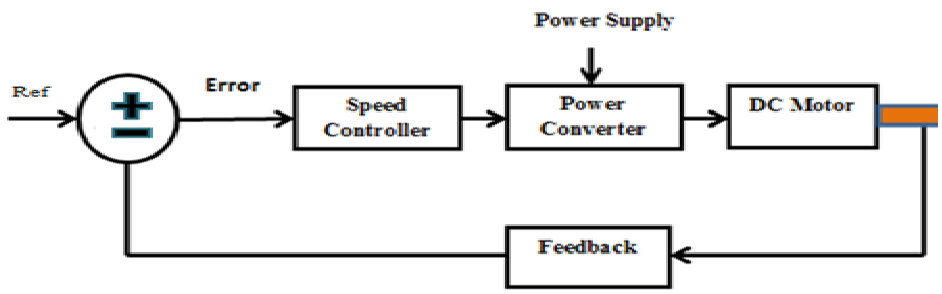

Fig. 5: Block diagram of DC motor speed control system using PWM.

(D) Proportional Integral Derivative (PID) Controller

The PID controller is most widely used in industrial applications. It is implemented to control the speed of DC motor. The error between the reference speed and the actual speed is given as input to a PID controller. The PID controller depending on the error changes its output, to control the process input such that the error is minimized. Main purpose of the PID controller is to adjust all the gain values so as to achieve optimum solution for control application. By tuning the PID gains (K_p , Ki and K_d) enable control Engineers to obtain optimum response using trial and error method. proper tuning of these values can be achieved by using Zeigler-Nichols method.

The Transfer function of a PID Controller output is given in equation (15)

$$u(t) = K_p e(t) + K_I \int_0^t e(t) + K_d \frac{de(t)}{dt} \qquad (15)$$

Where u(t) is control signal and e(t) is an error signal of the system to be controlled.

3.0 SIMULATION RESULTS AND DISCUSSION

SIMULINK toolbox in MATLAB/SIMULINK software program is used for the simulations to produce a number of results with respect to important variables of the DC motor. The full DC motor speed control scheme was digitally simulated using MATLAB/SIMULINK. motor was fed by Dc-Dc Buck converter (Chopper) as field current is kept constant. the Dc motor operates using negative feedback control strategy as the motor runs to track or match the reference speed of 1146 rpm as it is depicted below. After simulation, plots of speed, current against time when using PWM control technique and plots of the responses are presented.

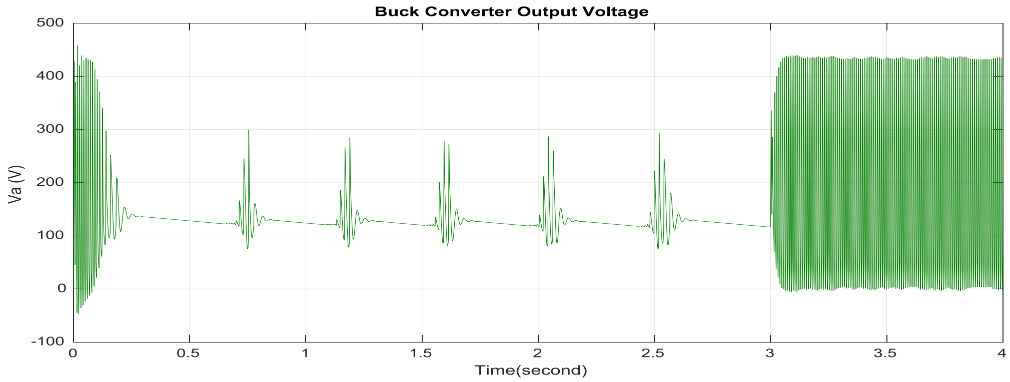

Fig. 6: DC Chopper variable output voltage.

From the dc buck converter average output voltage depicted in figure 6 shows high voltage level from 3 seconds when load torque was applied, this is as a result of high duty cycle (Ton) duration of pulse at this instant. this waveform nature of chopper (dc buck converter) makes its mathematical value be calculated as average output voltage value as in equation.[13]

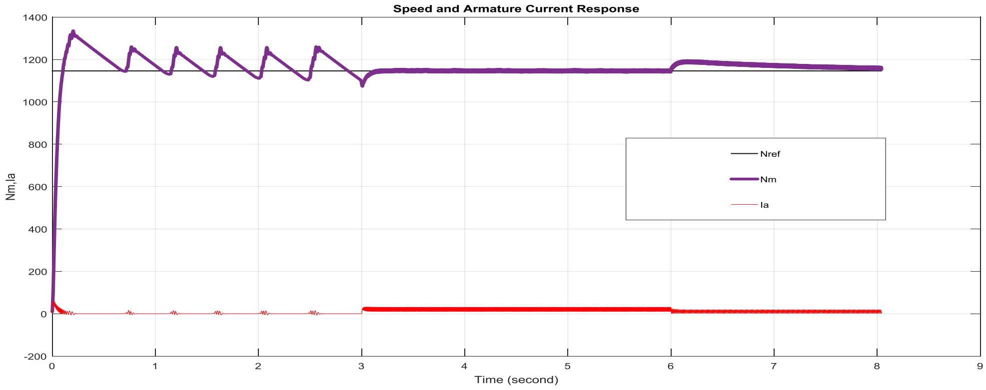

Fig. 7: Speed and armature current response for fixed reference speed under variable load condition.

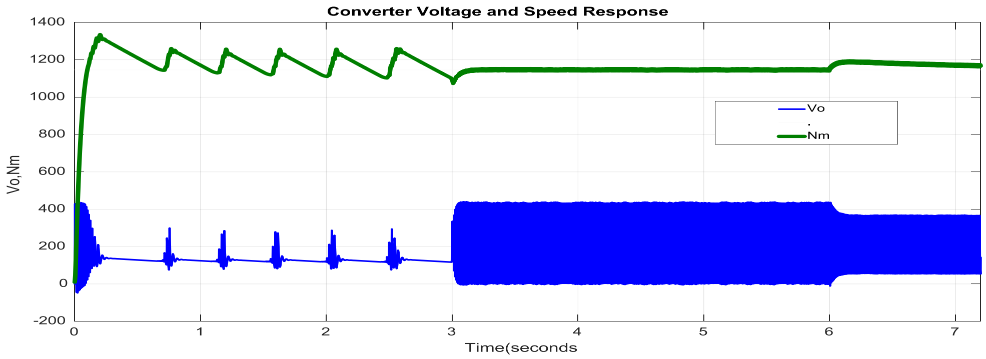

Fig. 8: Speed and chopper voltage response for fixed reference speed under variable load condition.

Figure 7 and 8 depicts the dc motor speed responses, armature current waveform and that of buck converter voltage waveform supplied to the motor, it could be easily seen that from the start of the motor at zero second, the motor accelerates rapidly to attain reference speed value (1150 rpm), as after 0.3 second, the motor speed oscillates it steady state value around the reference speed value. At this instant, the error being the difference of reference speed and motor speed becomes zero, hence, the pulse signal becomes zero, which consequently turn OFF converter switch, from this duration between 0.4 second to 3 seconds, as far as the speed of motor matches reference speed, the PID controller evaluates the error to be nearly zero, the switching of the chopper has high frequency, from 3 seconds where load is applied. The motor draws more power from the chopper, as a result, torque change causes fall in speed level which affect duty cycle of pulse, the width of the pulse changes to cause higher turn ON time which consequently enable chopper to supply higher voltage to motor as seen in figure 8. also, better speed operation is obtained when dc motor is connected with load. From 6 seconds, the applied load value is reduced to 10Nm, this makes decrease in output voltage waveform, PID controller is characterized by overshoot especially where there are no loads at the start of motor.

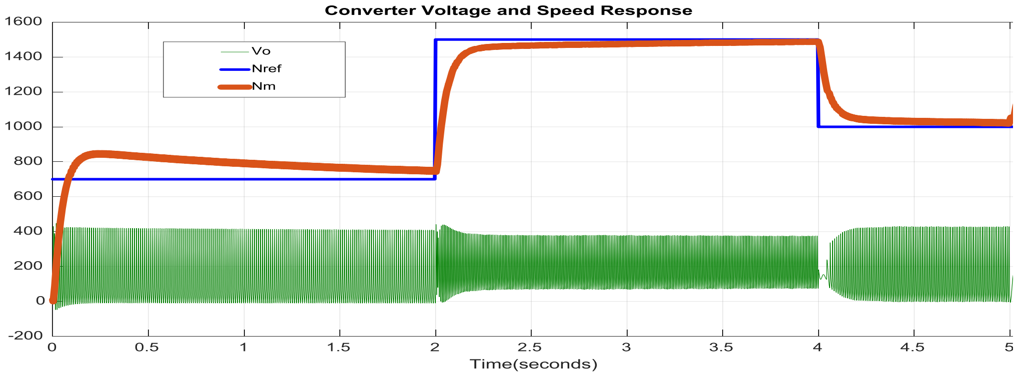

Fig. 9: Variable Speed and input voltage response of SEDCM with Load from the starting time.

Figure 9 shows similar response of that of figure 8, but in this case the motor rotor is connected to load, the motor speed tracks reference speed of 700 rpm. motor start at 0.2 second, as the reference speed changes at 2 seconds and at 4 seconds to 1500 rpm and 1000 rpm respectively, since the motor is connected to load the speed response is improved. also output voltage waveform of chopper is high due to effect of load torque on motor. And the motor with applied load torque draws less power(chopper voltage) when reference speed value (1500 rpm) is close to its motor rated speed value (1700 rpm) as it could be seen from 2 seconds to 4 seconds, where Chopper output voltage waveform amplitude decreases until 4 seconds where reference speed decreases to 1000rpm at this instant.

4.0 CONCLUSION

This paper presents speed control system using pulse width modulation (PWM) technique for industrial application. feedback drive control system technique is employed to control separately excited d motor speed. dc motor speed control system is modeled using PID controller and dc-dc buck converter in MATLAB/SIMULINK environment. the dynamic performance dc motor was evaluated from simulation result. it could be seen that the dynamic response of dc motor speed and the response to change in load condition is very fast and efficient using PWM control strategy. a number of simulation results are presented. based on the simulation results, one can conclude that PWM control scheme of dc motor is suitable for industrial application especially when variable speed operation is utilized as this method offer efficient performance in terms of speed reference tracking as it shows fast operation and robustness.

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