International Journal For Advanced Research In Science & Technology
A peer reviewed international journal www.ijarst.in
ISSN: 2457-0362

Advanced Drive System for DC Motor Using Multilevel DC/DC Buck Converter Circuit

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ABSTRACT

Nowadays, Direct Current (DC) motors are the main horse power of the most of the industrial process operations. These motors find a wide area of applications such as robotic motions, automatic manipulations, electric and hybrid vehicles, traction system, servo systems, rolling mills, and similar applications that require adequate process. The DC motors and their associate control and drive system are classified as the first choice compared to the available Alternating Current (AC) motors and their drive systems. This project presents a new topology of clamped diode multilevel DC/DC buck power converter for a DC motor system. The proposed converter circuit consists of four cascaded MOSFET power switches with three clamping diodes and four voltage sources (voltage cells) connected in series. The main objective of the new topology is to reduce current ripples and torque ripples that are associated with hard switching of the traditional chopper circuit. When the voltage profile of this converter is applied on a DC motor, it positively affects the performance of the DC motor armature current and the generated dynamic torque. The output voltage of the proposed topology shows an adequate performance for tracking of reference voltage with small ripples that are normally reflected into smaller EMI noise. Moreover, it has been shown that the operation of the DC motor with the newly proposed chopper topology greatly decreases the motor armature current ripples and torque ripples by a factor equal to the number of the connected voltage cells.

INTRODUCTION

Nowadays, Direct Current (DC) motors are the main horse power of the most of the industrial process operations. These motors find a wide area of applications such as robotic motions, automatic manipulations, electric and hybrid vehicles, traction system, servo systems, rolling mills, and similar applications that require adequate process. The DC motors and their associate control and drive system are classified as the first choice compared to the available Alternating Current (AC) motors and their drive systems. The DC motor acquires this popularity due to many merits such as simplicity of its control and drive system compared to AC counterpart, linear variation of the torque and speed against applied armature voltage, wide controlled speed and wide controlled torque ranges, compact of size with high power efficiency for Permanent Magnet DC (PMDC) motors, and finally the overall low cost.

To control the DC motor rotor position, rotor speed, or the developed torque, the motor field current or the armature voltage is controlled to achieve the control goal. The armature terminal voltage through power electronic circuits is mostly used in the motor control system especially for the relatively high-power machines.

The application of pulse width modulation (PWM) with a large DC link voltage to the motor windings with hard switching strategy (as the case of traditional chopper circuit) causes an unsatisfactory dynamic behavior. The abrupt variations in the voltage and the associated change in the armature current corresponding to the PWM switching initiate a wide range of voltage and current harmonics, which lead to torque ripples and the associated mechanical vibrations and acoustic noise. The mechanical vibration and noise in electric motors have become one of the most important factors for motor selection to do a certain task. The sound of the noise and the vibration in the motor are aroused mainly due to improper electromagnetic exciting forces that are continuously changed in time and space corresponding to the switching operation. This resultant variable-exciting force causes deformation in the mechanical structure and triggers the motor to vibrate

In a modern industrial situation, DC motor is widely used which is due to the low initial cost, excellent drive performance, low maintenance and the noise limit. As the electronic technology develops rapidly, its provide a wide scope of applications of high performance DC motor drives in areas such as rolling mills, electric vehicle tractions, electric trains, electric bicycles, guided vehicles, robotic manipulators, and home electrical appliances. DC motors have some control capabilities, which means that speed, torque and even direction of rotation can be changed at anytime to meet new condition. DC motors also can provide a high starting torque at low speed and it is possible to obtain speed control over a wide range.

So, the study of controlling DC motor is more practical significance. Control theory is an interdisciplinary branch of engineering and mathematics that deals with the behaviour of dynamical systems. For controlling a motor in any system, a controller is needed which is to give input to gate driver. For motor actuation, the microcontroller does not directly actuate the DC motor. It will have a device that known as gate driver which is function to drive the motor. For this system, it use motor driver as PWM amplifier to provide variable output voltage for controlling the speed of the motor and positive or negative voltage to control the direction of motor rotations. In real world, motor applications not only use the maximum speed of motor.

It maybe uses only 50% of its speed. So, the speed of the motor must be control. For some applications, motor is using not only one direction but with alternate direction to control a machine. In industrial field, some machine or robots cannot get in touch according to safety and the location of those things. The new method, which extensively used in motor controller, is pulse width modulation (PWM). PWM switching technique is a best method to control the speed of DC motor compare to another method. The duty cycle can be varied to get the variable output voltage[11]. The concept of this system is same like DC-DC converter which is the output voltage depends on their duty cycle. Digital-to-analog conversion is not necessary because PWM itself is a signal that remains digital all the way from processor to control the overall system. By keeping the signal digital, noise effects are minimized unless there is a change from logic 1 to logic 0, which will make noise affect the digital signal[3]. The Pulse-Width-Modulation (PWM) in microcontroller is used to control duty cycle of DC motor drive. PWM is an entirely different approach to controlling the speed of a DC motor. Power is supplied to the motor in square wave of 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[6]. 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.

PROPOSED SYSTEM

A direct current (DC) motor converts DC electrical energy into mechanical energy. It produces a mechanical rotary action at the motor shaft where the shaft is physically coupled to a machine or other mechanical device to perform some type of work[2]. DC motors are well suited for many industrial applications. For example, DC motors are used where accurate control of speed or position of the load is required and can be accelerate or decelerate quickly and smoothly. Plus, the direction easily reversed

To evaluate the performance of the proposed multilevel chopper circuit, two Simulink models are built. One model is given for the proposed MLCC with the structure given in section II and the other one is given for the traditional chopper circuit with one fixed DC voltage source and one controllable switching element. The traditional chopper circuit works in a step-down mode to achieve the required reference voltage. The results of the output voltage performance is shown where the reference voltage (red) is changed from 40V to 20V then to 30V and thereafter to 6V for a duration of 0.05 s for each voltage level. It is clear from the comparison of these two figures that the proposed system works properly to provide the required level voltage to the load. The system keeps switching only between two consecutive voltage levels,

While the tradition system of Fig must follow hard switching across the ultimate voltage range (0-48V) to provide the required reference voltage. The torque ripple in the steady-state performance is shown in the magnified part of Fig for the both drive systems.

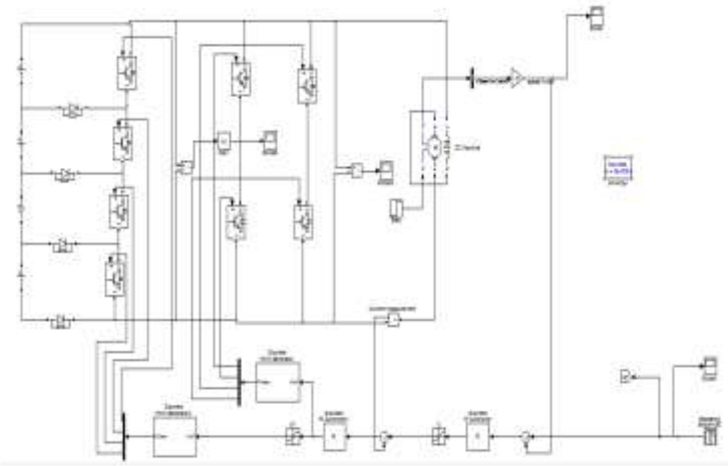

Fig 1 Proposed circuit configuration

The peak to peak torque ripple is approximately 0.7 Nm for the traditional chopper drive circuit and around 0.2 Nm for the proposed MLCC. It can be roughly concluded that with the proposed MLCC, the torque ripple is decreased by a factor of n (equal to the number of the DC voltage source cells). This reduction in the torque ripples eventually reflects on less noise and reduced mechanical vibration. In addition, the armature current in Fig which is like the developed torque performance, shows smaller current ripples for the proposed MLCC. These smaller ripples lead to less ohmic losses, and less harmonics and low EMI noise. The corresponding

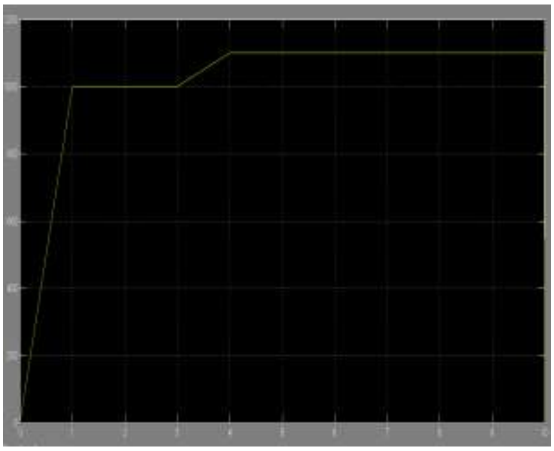

Fig 2 Reference speed vs time

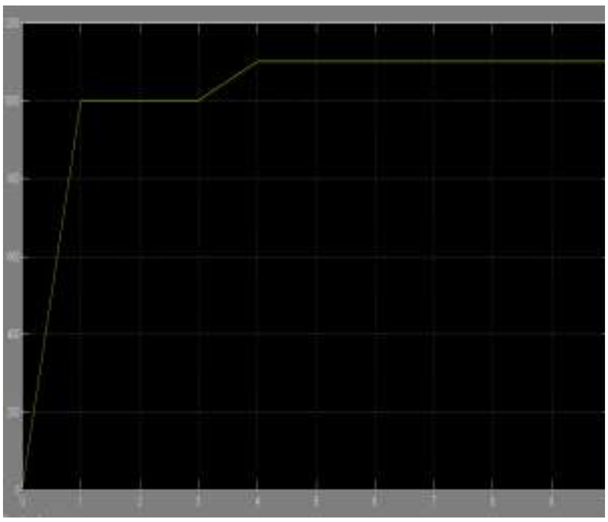

Fig 3 Actual speed vs time

speed pro_le in Fig.13 shows that for the same applied average voltage, the proposed MLCC gives a relatively higher speed level. In addition, the magnified part of the Fig.13 shows that the speed pulsation is higher in the case of the traditional chopper. To accurately evaluate the proposed topology, the MLCC is simulated in closed loop control mode.The detailed speed and torque performances are shown in Fig respectively. The controlled speed performance for the both methods (the proposed in red and the traditional in blue) shows almost the same general performance at starting and at steady state. However, the magnified parts of the Fig.14 show that the proposed MLCC has smaller speed ripples and relatively smaller overshoot during the load change at time D 6 second. On the other hand, the corresponding torque profile shows an outstanding performance of the proposed MLCC as can be seen in the magnified parts of the Fig.15. Although the average dynamic time response is almost the same, the torque overshoot at load torque change point is higher than the proposed MLCC, in addition the torque ripples of the traditional chopper circuit are extremely high.

CONCLUSION

This project presents simulation results and experimental validation of a new topology of the multilevel chopper DC/DC converter for a DC motor system. The main objective of the propounded topology is to reduce current ripples and torque ripples that are associated with hard switching of the traditional chopper circuit. The proposed configuration provides constant _ve values of standard cell voltage and has the ability to generate the required nonstandard voltage within the cell voltage ranges. The generated voltage pattern of this topology has relatively smaller switching ripples compared to the traditional step-down DC/DC power converters. It has been shown that the operation of the DC motor with the new proposed chopper topology can efficiently decrease the motor armature current ripples and torque ripples by a factor equal to the number of the connected voltage cells. As compared with the operation of the motor with traditional chopper circuit,

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International Journal For Advanced Research In Science & Technology
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