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Developing Drive System Using Multilevel DC/DC Buck Converter Circuit for DC Motors

S. Rajasekaran*[1] and MISTE V. Mohan[2]

[1]*Associate Professor Department of EEE, Vignana Bharathi Institute of Technology, Hyderabad, TS, India.*
[2]*PG Scholar Department of EEE (PEED), Vignana Bharathi Institute of Technology, Hyderabad, TS, India.*

ABSTRACT

Direct current (DC) motors serve as the principal power source for the vast majority of industrial process flows today. Rolling mills, robotic movements, automated handling, electric and hybrid autos, traction systems, servo systems, and other related tasks all employ these motors. Direct current (DC) motors and the associated control and drive systems are among the greatest alternatives to the available alternating current (AC) motors and drive systems. This work presents a novel topology for a multi-level diode-clamped step-down DC/DC converter for direct current motor systems. Four cascaded MOSFET power switches, three clamp diodes, and four series-connected voltage sources make up the converter circuit that is being suggested (voltage cells). The major goal of the novel topology is to reduce the current and torque ripple caused by hard switching in conventional chopper circuits. This converter voltage profile improves the performance of the armature current and dynamic torque when used with a DC motor. The output voltage of the recommended design can be used to follow the reference voltage using small ripples, which are typically reflected in low EMI noise. Additionally, it has been demonstrated that the newly proposed chopper architecture reduces armature current ripple and torque ripple by a factor equal to the number of connected voltage cells.

Keywords: Multilevel DC/DC converter, traditional DC/DC converter, and DC drive systems.

I. INTRODUCTION

Today, the majority of industrial process activities use Direct Current (DC) motors as their primary source of horsepower. Robotic movements, automatic manipulations, electric and hybrid vehicles, traction systems, servo systems, rolling mills, and other similar applications that call for proper procedure are just a few of the many uses for these motors. When compared the control and driving systems for the DC motors system are regarded as the first option in comparison to the AC motors that are currently available and their drive systems. The popularity of the DC motor can be attributed to a number of benefits, including the Compared to its AC equivalent, its control and drive system is simpler, and the torque and speed variations are linear with respect to the applied armature voltage the wide range of controlled speed and torque, and the compact size and high power Additionally, the general low cost of Permanent Magnet DC (PMDC) motors and their efficiency [1]–[3]. By adjusting the armature or the motor field current voltage, the rotor orientation, Rotor speed or the DC motor's produced torque can be changed. In the majority of cases, the motor control system uses armature terminal voltages via power electronic circuits, particularly for machines with comparatively high power [4]–[6].
Large pulse width modulation (PWM) moderate circuit voltage applied to the engine windings causes an unfavorable unique method of behaving in a hard exchanging plan (as in typical chopper circuits). PWM switching causes rapid voltage variations and associated changes in armature current, which result in a lot of voltage and current sounds force Ripple and related mechanical vibration and acoustic commotion?

One of the key considerations when choosing an engine for a particular task is the mechanical vibration and noise of electric engines. Engine clamour and vibration are mostly caused by weak electromagnetic excitation powers. These powers fluctuate in reality based on the activity of the exchange, and the resulting fluctuating excitation forces it to bend initially and creates engine vibration. Due to their inexpensive starting costs, excellent driving performance, low maintenance requirements, and minimal noise, DC engines are frequently used in modern settings today. Numerous uses for high-power DC engine drives are now available in the sectors of moving plants, electric vehicle drives, electric trains, electric bikes, programmed directed vehicles, automated controllers, household gadgets, and others thanks to the rapid advancement of electronic innovation. Few research activities Even though many studies have examined the In permanent motors, the causes of sound noise and the modeling and forecasts of these phenomena have been reported [8]–[12]. However, efforts still need to be done to make these motors quieter and more vibration-free.

The brush DC motor's permanent magnet pole has a copper ring attached to it in [7] by Hong et al. to reduce mechanical vibration; this method successfully reduces vibration brought on by manufacturing errors. A new switching frequency is suggested in another significant research study to lower noise levels and losses that are caused by PWM applied to induction motors [12], which have been used to lessen vibration and noise. This strategy is successful in lowering by 5 dB, the noise level during startup, and overall reductions of up to 15 dB have been seen. The issue has been addressed in part in numerous other pertinent articles, with a particular focus on the effectiveness of the algorithms for controlling DC motors [5], [4] [13]-[27]. [13] Demonstrates a nonlinear observer-based controller for controlling cogging torque disturbances in permanent magnet DC motors.

By reducing tracking mistakes caused by cogging torque, the authors are successful. The data, however, indicate significant Torque ripples and sounds are produced by armature current waves. An innovative DC/DC converter has been created introduced in [14] created for use with an electric car energy storage system. Although the created approach in [14] has a structure with two As a result, the issues with ripples in the motor performance profile for current and torque are not completely addressed despite the use of higher

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voltage sources and improved efficiency. The researchers in [15] have described an algebraic method for quick In a DC motor system powered by a boost converter, the angular velocity trajectory tracking work is fed forward. With the use of noisy observations of the state variables, the same team was able to calculate the load torque perturbations. Comprehensive information on the design and control of the buck converter driving DC motor has been supplied by the authors of [16].

A comparison research conducted by Sira-Ramirez et al. [16] evaluated the effectiveness of numerous controllers. To build a DC motor's DC/DC chopper circuit, they have provided a Lyapunov stability analysis.

Their design's goal is to regulate the motor's speed and current/torque for industrial applications. Much work has gone into designing a smooth beginning in [14], [17], and [18] for a For a DC motor, a DC/DC buck converter. These articles discuss sliding mode and PI controllers, flatness control, and hierarchical control of some controllers, or rejection of disturbances can all be used to directly regulate the rotor speed [17]. When DC/DC power converters are used to power DC motors, the issue of Torque and current pulses are typically produced by disturbances, nonlinearities, and uncertainties in the DC motor characteristics, which must be taken into account. These issues have been covered in a number of articles [20]–[24], either using fuzzy logic or a neural network control system, or to address the uncertainties for DC motors equipped with Multi-level DC-DC converters, the unique perturbation technique of controller design [24], adaptive robust control with extended state observer [22], or buck converters are used in the passivity-based control algorithm used in buck converter-equipped AC motors to handle the uncertainty problem.

To drive the DC motor system, a new Multilevel Converter Circuit (MLCC) is suggested in this research in order to produce quick performance of dynamic torque with little vibration. The suggested technique eliminates the H-multilevel bridge's stage, which eliminates the need for as many switching components in converters with levels more than four [25]. As opposed to current neutral point clamped diode topologies. Small current and torque ripples are guaranteed by the devised technology, and the risks associated with switching very high there is a reduction in applied voltage to the power switches. In order to properly track the reference voltage, the suggested MLCC divides the input voltage into many levels and alternately shifts between two close levels.

II. THE PROPOSED MULTILEVEL CHOPPER STRUCTURE

A multilayer chopper circuit (MLCC), which is utilized in a system for driving a DC motor, is shown in block diagram form in Figure 1. The suggested system consists of the proposed MLCC block, an H-bridge block to regulate the rotational direction of the motor, a PMDC motor, and additional control blocks that coordinate and synchronize the operation of the complete system. The four controlled power switches, which resemble power MOSFETs, make up the five-level multilevel chopper circuit (MLCC) depicted in Figure 2. Three clamped diodes (D1, D2, and D3), which are ideally Scotty diodes, plus a freewheeling diode making up the MLCC (DF). These diodes ensure that the multilayer chopper circuit operates properly, together with the power switches.

The voltage of the sources VDC1, VDC2, VDC3 and VDC4 are similar or dissimilar voltage levels. Solar cell units, storage batteries, or other equal these independent DC voltage sources could be used as DC voltage sources. To get the 5-level voltage values at the converter's output terminals, the suggested switching signals to be applied to the MLCC can be set up as shown in Table 1.

Table 1: Voltage Ranges as a Result of the Switching Signal

Switching states Q_1 Q_2 Q_3 Q_4	Voltage Level Code	DC Standard voltage value
0 0 0 0	V0	0
1 0 0 0	V8	V_{DC1}
1 1 0 0	V12	$V_{DC1}+V_{DC2}$
1 1 1 0	V18	$V_{DC1}+V_{DC2}+V_{DC3}$
1 1 1 1	V15	$V_{DC1}+V_{DC2}+V_{DC3}+V_{DC4}$

Any two voltage levels can be divided by the voltage between them by employing a step-down chopper mode derived. For instance, the method finds the first voltage ranges of Vx stage as illustrated in Fig.3 if an abnormal voltage level Vx is required be obtained at sampling instant "k".

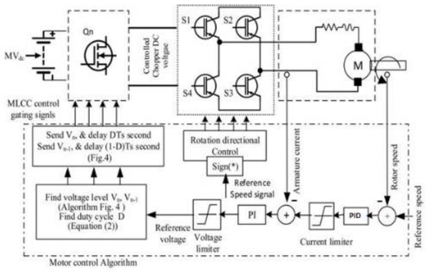

Fig. 1. Shows how MLCC powers a DC motor

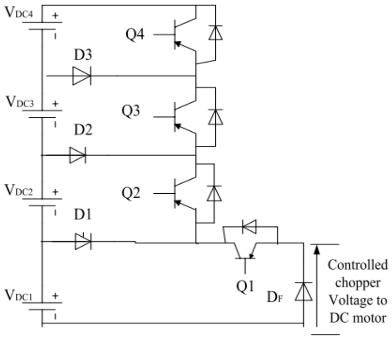

Fig. 2. Circuit setup for a multilevel chopper with five levels of diodes

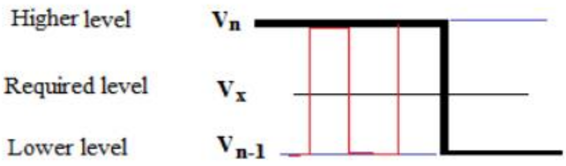

Fig. 3 limits of the necessary voltage Vx

At sampling instant "k," the average voltage Vx can be determined as When Vn (higher voltage level) and Vn1 are separated by the necessary voltage level Vx (lower voltage level).

$$V_x = \frac{T_S D(k) V_n + T_S(1 - D(k)) V_{n-1}}{T_S} \tag{1}$$

Where:
Ts is the sampling period
D is the per unit duty cycle.
When Vn is switched ON, DTs occurs, and Vn1 is turned off (1-D)
Ts is the time at which Vn1 turns on, with Vn off. Using (1), the following is a sampling instant k's duty cycle:

$$D(k) = \frac{V_x - V_{n-1}}{V_n - V_{n-1}} \tag{2}$$

The voltage level Vn must be turned on for DTs seconds before Vn1 is turned on for (1-D) Ts seconds in order to create Vx. Fig. 4 depicts a flow chart of a potential switching algorithm for the suggested topology.

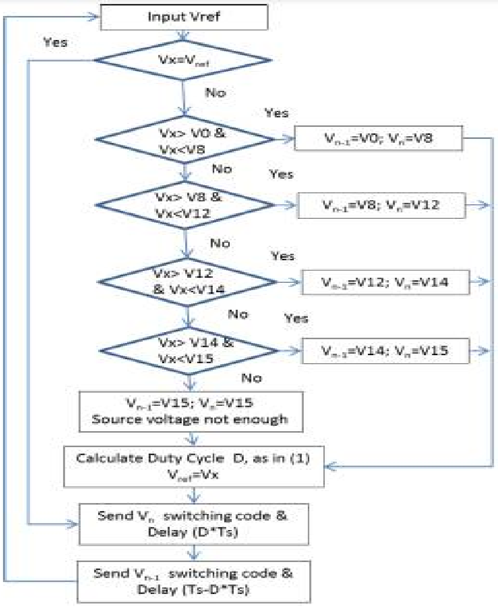

Fig. 4 Diagram of the proposed MLCC's control algorithm

III. ELECTRIC ANALYSIS OF THE MLCC-DC MOTOR SYSTEM

This study presents a non-isolated multilevel For use in high voltage applications, buck dc-dc converter. Fig. 5 depicts the generalized the proposed multilayer converter's structure. Some of this converter's important features are reduced voltage across switches and diodes, minimum switching losses, a smaller output filter, and low voltage across inner capacitors. The multilayer dc-dc converter's most important parts are the capacitors C1 and C2, which are exposed to high voltage (a half of input voltage). Conversely, the majority of high voltage converters also offer this feature.

Capacitors may need to be connected in series based on the amount of input voltage. The suggested converter must operate safely, which requires achieving voltage equilibrium across the capacitor. The voltages of the switches will be greater than they were intended to be because of the uneven voltage across the capacitors. As a result, this converter needs a control that actively balances capacitor voltage. In this text, this subject is covered. This work will analyze and describe a proposed Buck converter's five-level (5L) construction, which is depicted in Fig. 1. Theoretical analysis, capacitor voltage balancing active control, and simulation findings are presented in this work.

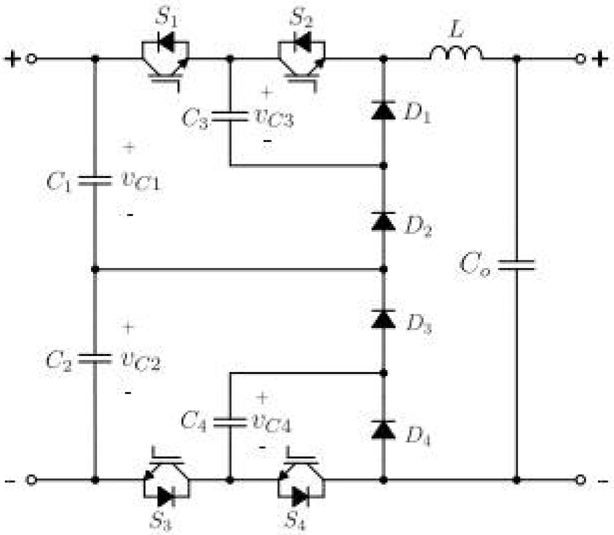

Fig. 5 Five-level Buck dc-dc Converter

The electrical equivalent circuit of the MLCC driving a DC motor can be created as depicted in Fig. 6 if a permanent magnet DC (PMDC) motor with constant field excitation and unidirectional rotation is present. The PMDC motor dynamic equations for the circuit in Figure 6 can be created using the MLCC equations from section 2.

$$\left.\begin{array}{l} V_{in} = E_a + R_a i_a + L_a \frac{di_a}{dt} \\ E_a = K_g \omega \\ T_e = J\frac{d\omega}{dt} + B\omega + T_L \\ T_e = K_t i_a;\ \ K_t = K_g \end{array}\right\} \qquad (3)$$

In this instance, Kg and Kt represent the motor's generated voltage and torque constants, respectively. Vin is the MLCC's applied DC voltage pattern. The produced torque and load torque of the motor are indicated by the letters Te and TL, respectively. The angular speed of the rotor is represented in rad/s, with J being the inertia constant, La being the friction constant, and Ra being the armature winding resistance.

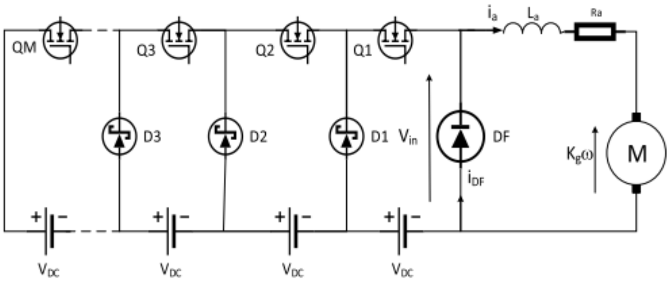

Fig. 6 DC motor driven via MLCC

The aforementioned circuit can be redrawn as a lumped circuit as illustrated in Fig. 6 if all power switches Q1-QM and the Schottky clamped diodes are taken to be ideal. Three switching modes can be used to operate this comparable circuit; two of the modes are related to the two input lumped voltage sources (nVDC and (n-1) VDC), while the third mode suggests using the freewheeling diodes DF.

IV. SIMULATION RESULTS

Two Simulink models are created in order to assess how well the suggested multilevel chopper circuit performs. Two models are provided: one for the traditional chopper circuit, which has a variable switch and a fixed DC voltage source, and the other for the recommended MLCC, which has the structure described in section II. The conventional chopper circuit operates in a step-down mode to generate the necessary reference voltage.

TABLE -2: PMDC Motor Specifications Used For Simulation

Parameter	Value
Rated power	3.2kW
Rated torque	$.35Nm
Rated speed	6724rpm
Rated voltage	48V
Raated current	75A
Ra	0.48ohm
La	1.4mH
J	0.0117
Km	0.0631Nm/A

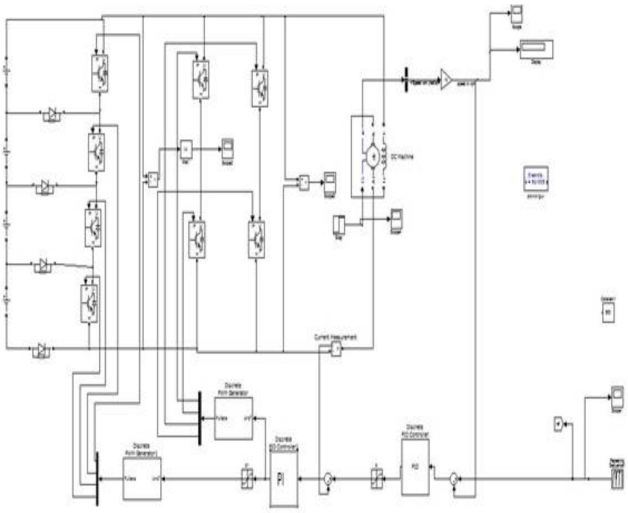

Fig. 7 Proposed circuit configuration

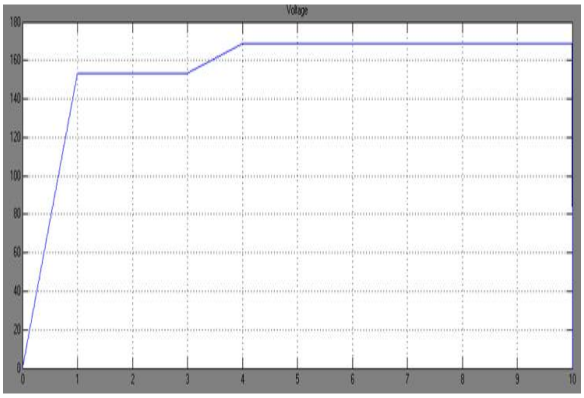

Fig. 8 Output Voltage

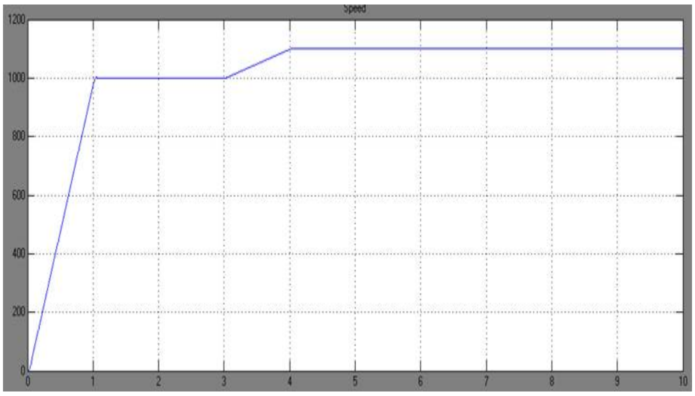

Fig. 9 Reference speed

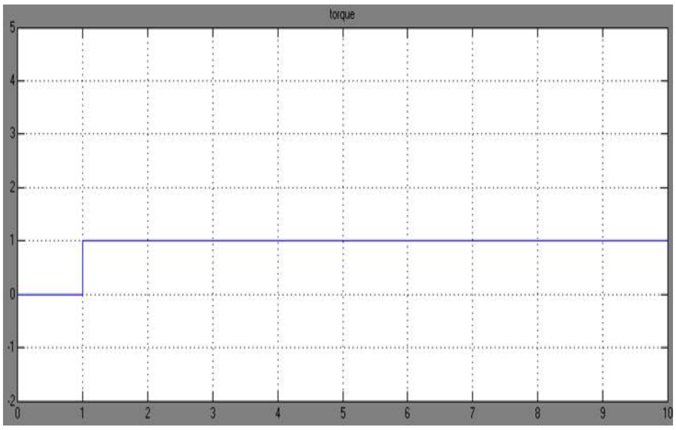

Fig. 10 Torque

Two Simulink models are utilized to assess how well the proposed multistage chopper circuit is presented. A appropriate DC voltage supply and controllable exchange components are used in one of the two variants for the classic chopper circuit and the other for the suggested MLCC with the construction specified. To achieve the ideal reference voltage, you can use conventional chopper circuits that operate in buck mode. When Results of the yield voltage execution are shown as the reference voltage (red) lowers for 0.05 seconds at each voltage level from 40V to 20V, 30V, and finally to zero 6V. By comparing these two figures, it is clear that the suggested architecture is operating as intended to provide the heap with the desired voltage level. The framework has two successive voltage levels that it can change between.

The enhanced part of the figure shows the constant state force swell for both drive frameworks. In relation to the conventional chopper drive circuit and the suggested MLCC, the top to top force swell is around 0.7Nm and 0.2Nm, respectively. We may conclude that applying the suggested MLCC results in an n-fold reduction in the force swell (equivalent to the quantity of DC voltage source cells). There are fewer clamours and mechanical vibrations as a result of these reductions in force swell. Similar to this, Fig. 7's armature current, which depicts a small current wave in the proposed MLCC, looks to be the produced force limit. This more subdued wave decreases music and EMI disturbance as well as resistant problems. According to the corresponding speed profile in Fig. 8, the suggested MLCC provides a substantially increased degree of speed for a comparable applied typical voltage. The expanded portion of Figure 8 also demonstrates how the speed throb is larger for a conventional helicopter. By simulating the MLCC in a closed circle, the proposed geography can be evaluated precisely.

The circuit reproduction is configured as shown in Figure 7. The tuning boundaries of the speed regulator are (Ki D 16 and Kp D 1:6, and current cutoff 90V) amperes, while the tuning boundaries of the continuing regulator are (Ki D 0:2 and Kp D 2, and upper voltage limit 48V). At time tD 3 seconds, the The initial speed reference of 100 rad/s is changed to (As 100 60/2 to 120 60/2 in rpm) 120 rad/s The load force changes from its initial value of 4 Nm to its final value of 2 Nm at time t D 6 s.

V. CONCLUSION

The validation of a new through simulation For DC motor systems, this project proposes a multilevel chopper DC/DC converter topology. The major goal of the proposed topology is to reduce the current and torque ripples due to strong switching in conventional chopper circuits. The suggested configuration generates any necessary non-standard voltage within the cell voltage range while maintaining a constant value for standard cell voltages. Compared to traditional buck DC/DC power converters, the voltage waveform produced by this architecture has relatively less switching ripple. It is shown that a newly proposed chopper topology for driving a DC motor successfully increases the motor's armature current ripple and torque ripple while reducing the number of connected voltage cells. Compared to turning the motor with a conventional chopper circuit.

FUTURE SCOPE

In the future, DC/DC converters will be updated with new control techniques such as ANN and AINN schemes to give better results and reduce voltage ripple.

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