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A BL-CC CONVERTER-BASED PMSC MOTOR DRIVE WITH FIELD ORIENTED CONTROL CONTROLLER

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Abstract - This paper gives the idea to power factor correction (PFC) - based Canonical Switching Cell (CSC) converter-fed Permanent Magnet Synchronous Motor (PMSM) drive for low-power applications. The speed of PMSM is controlled by varying the dc-bus voltage of Voltage Source Inverter (VSI). The PMSM is electronically commutated for reduced switching losses in VSI due to low-frequency switching. A front-end CSC converter operating in discontinuous inductor current mode (DICM) is used for dc-bus voltage control with unity power factor at ac mains. A sensor less for dc-bus voltage sensing is used for the development of the proposed drive, which makes it a cost-effective solution. In this work, PFC BL-CC converter is operated in discontinuous inductor current mode to attain better power quality. The DIC mode operation requires only one voltage sensor to sense DC-link voltage, whereas in Continuous Conduction Mode (CCM), the sensor requirement increases to three (two voltage sensors and one current sensor). The PFC BL-CC converter also eliminates the diode bridge rectifier stage. The simulation analysis indicates that a smooth control could be realized and the highest efficiency and the smallest current ripple could be achieved.

Index Terms -PMSM, BL-CC Converter, Three Phase Inverter, Canonical Switching Cell, *FOC controller*

I. INTRODUCTION

The contributing and notable features of the presented BL-CC converter-based BLDC motor drive for MEV applications are being listed as follows: The BL-CC converter in BL configuration uses a single-center tapped inductor (shown as two different inductors, i.e., L1 and L2.which conducts partially and fully in different modes of each half cycle of generator output voltage. The usage of this tapped inductance eliminates one extra inductor requirement. BL-CC converter-fed BLDC motor drive uses inbuilt antiparallel diodes of insulated gate bipolar transistor (IGBT) switches for back-feeding during both positive and negative cycle of generator output voltage. So, no separate additional back feeding di- odes are required in the presented scheme whereas conventional BL schemes require separate/additional back feeding diodes.

The CC converter uses three energy storage elements where as other converters such as Cuk, SEPIC, Zeta, Luo, Landsman, Sheppard Taylor uses more number of energy storage elements as compared to CC converter which witnesses the lower-order of CC converter. PFC is achieved with a simple control (voltage follower) technique as both the switches of the BL-CC converter are needed to be fed with same gate pulse. DIC mode operation reduces the sensors requirement to one which reduces the cost of MEV drive with respect to CCM operation which requires three sensors (two voltage sensors and one current sensor).The presence of inductance in output current loop increases the load current profile and the usage of CC converter for both half cycles of DEG output voltage maintains symmetry of BL-CC converter so analysis of any half cycle (either positive or negative) is sufficient to analyze the operation of PF corrected BL-CC converter. This reduces the calculative as well as analysis burden by 50%.

The presented BL-CC converter operating in DIC mode works as inbuilt PF pre regulator of the drive system for obtaining a linear voltage to current profile at generator output voltage (90–260 V). A variable DC-link bus voltage to VSI is used to control the speed of BLDC motor. This reduces the switching losses due to low-frequency electronically commutated switching of VSI. These switching losses at six IGBT switches of VSI shares a significant portion of total losses in BLDC motor drive system.

The composite converter developed by Castaio and Restrepo (2022) enables the integration of high-efficiency converter modules to provide superior efficiency performance, emerging as a leading option for the conversion of electric transport power. This work suggests integrating the adaptable buck-boost dc-dc converter into an electric vehicle composite architecture that needs a wide voltage range in the dc link to increase the electric motor efficiency [1]. Nalli and Subbaro (2022) discussed a sensor less BLDC motor controlling method that is fed by an ib3 converter and is based on power factor adjustment. For a 3-phase BLDC motor, a sensorless control method based on flux linkage has been developed [2].

BLDC motor drives could be controlled using an open loop method, according to Lalhmangaihzuala (2021). A brushless DC motor, also referred to as a BLDC, is a permanent magnet synchronous electric motor that is powered by direct current (DC) electricity and achieves electronic commutation rather than mechanical commutation [3]. Song and Lee (2020), In this study, the design process of a BLDC that uses a dual rotor approach to generate the same amount of torque as a traditional permanent magnet BLDC is analyzed. [4]. Romine and Sundaram (2019), The goal of this study is to optimise the performance of a brushless DC (BLDC) motor driven by a Landsman Converter (LC) and fueled by solar energy. The motor is subjected to simplified indirect field oriented control (IFOC) using the back-EMF estimate approach in order to minimize the torque ripple and achieve precise speed control [5]. Diofode and Suryawanshi (2019) a bridgeless single switch single ended primary inductance converter (SEPIC) is proposed. This converter serves as a better than Buck-Boost and Cuk converters since it does not need a diode bridge rectifier at the front end, which reduces conduction loss [6]. Both elikel and Aydomuş (2019), The brushless direct current (BLDC) motors' commutation time of phase currents is what causes the torque ripple. Using a wide speed control range for high speed BLDC motor applications, an efficient way to eliminate torque ripple is presented in their work [7]. The modelling parameters of the Permanent Magnet Brushless DC (PMBLDC) motor drive are represented in this article using Mat-lab / Simulink software. Permanent Magnet Brushless DC (PMBLDC) motor drive modelling is beneficial in a variety of phenomena such as aeronautical modelling and other applications by Dae et. al.,. [8].

II. BL-CC CONVERTER CONFIGURATION

High-performance and high-efficiency motor drives are frequently made with permanent magnet synchronous motors (PMSM). Smooth spinning over the motor's whole speed range, full torque control at zero speed, and quick acceleration and deceleration are all signs of high-performance motor control. An air gap magnetic field is produced by permanent magnets rather than electromagnets in permanent magnet synchronous motors. Researchers and business are interested in these motors because they offer various benefits that make them useful in a variety of applications.

The six cases/modes arising with BL-CC converter whenoperated in DIC mode are as follows:

Positive half cycle of DEG output voltage.

- Switch S_P is conducting (supplied with gating pulse).
- Switch S_P is not conducting (off).
- Switch S_P is off and also no diode current through diode D_1 vanishes (DIC mode of positive half cycle).

Negative half cycle of DEG output voltage.

- Switch S_N conducts.
- Switch S_N is off.
- Switch S_N is off and also inductor L_2 current vanishes (DIC mode of negative half cycle).

To unfold the CC converter working in BL configuration, different operating modes of presented PF-corrected BL-CC converter, are explicated in present section.

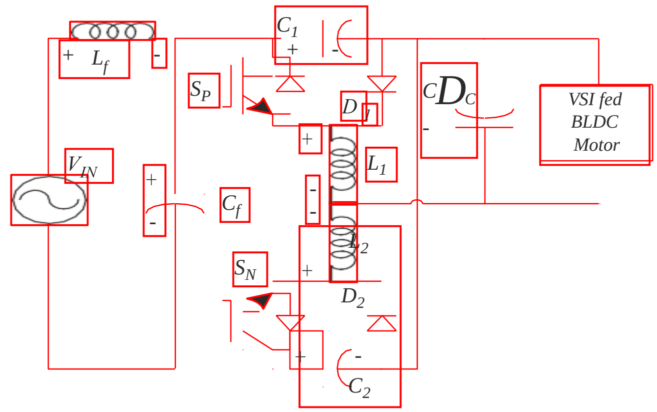

Figure 1 BL-CC Converter

III. FOC CONTROLLER

Field Oriented Control, which is analogous to a DC motor, illustrates how torque and speed are directly controlled depending on the electromagnetic state of the motor. Torque and flux are the first "real" motor control variables that FOC is able to regulate. The torque-producing component of the stator flux can be separately adjusted using decoupling between the stator current components (magnetizing flux and torque). With decoupled control, the motor's magnetic state can be kept at the proper level at low speeds while the torque can be adjusted to manage the speed. Only high-performance motor applications that can function smoothly over a large speed range, provide full torque at zero speed, and have quick switching capabilities have been the focus of FOC's development.

Controlling the stator currents using a vector is what field oriented control is all about. This control is based on projections that convert a three-phase time and speed dependent system into a time invariant two-coordinate (d and q frame) system. These transformations and projections result in a structure resembling a DC machine control. As input references, FOC machines require two constants: the torque component (aligned with the q coordinate) and the flux component (aligned with the d coordinate). AC-motor three-phase voltages, currents, and fluxes can be expressed as complicated space vectors. If we consider ia, ib, and ic to be instantaneous currents in the stator phases, the stator current vector is as follows:

$$\vec{i}_s = i_a + i_b e^{j2\pi/3} + i_c e^{j4\pi/3} \quad (1)$$

where, (a, b, c) are the axes of three phase system. This current space vector represents the three phase sinusoidal system. It needs to be transformed into a two time invariant coordinate system. This transformation can be divided into two steps:

- (a,b,c) ⟶ (α,β) (The Clarke Transformation) which gives outputs of two coordinate time variant system.

- (α,β) → (d, q) (The Park transformation), which gives outputs of two coordinate time invariant system.

IV. APPLICATION OF EFFECTIVE SPEED CONTROL SYSTEM

The older technique designed for speed control had some of the following shortcomings:

- Existing drive system torque ripple, speed control, voltage stress and Current THD is higher when compared to the proposed system.
- Reliability of the system is less when compared to proposed system.
- High voltage & current ripples when compared to proposed system.
- High Distortion when compared to proposed system.

The earlier methodology presents a BL-CC converter-based reduced component count drive for BLDC motor for MEV application. The BLDC motor drive for MEV application is divided into three parts in addition to two controlling loops. The filter is connected to DEG output, which is input to the BLDC motor drive (VIN). The filter is made of filtering inductance (Lf) and capacitance (Cf). Next stage to filter is PF correction stage, which incorporate BL-CC converter. The third stage consists of voltage source converter-fed BLDC motor. The rotor position of BLDC motor is sensed by Hall-effect sensors. These sensed signals are then used to generate the gating pulse of VSI. The gating pulses to switches of BL-CC converter are generated with a simple voltage follower controlling technique using proportional-integral controller.

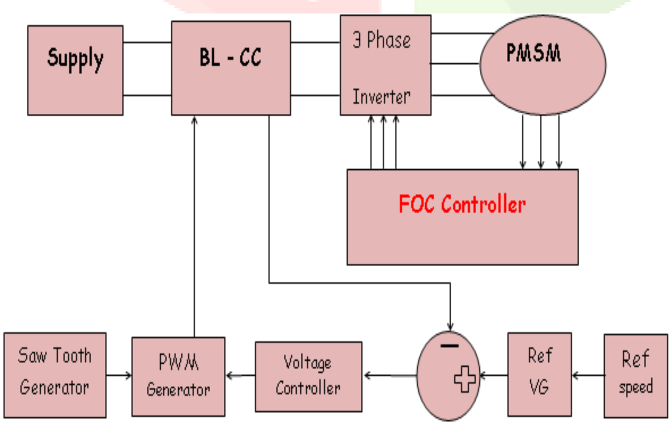

Figure 2. Block diagram of Proposed System

The present studies the application of effective speed control system based on a general full-bridge inverter for PMSM with surface-mounted magnet. Theoretical analysis and Simulation results have verified that the torque, and reliability can be improved effectively with good power factor.

In speed controller, the stator phase currents are measured and converted into corresponding complex vector. Then the currents vector is transformed to a d-q coordinate system rotating with the rotor of the machine. The real y-axis component of the stator current vector qi can be used to control the motor torque. For the surface-mounted PMSM, the maximum torque current control can be achieved by controlling current id = 0.

The PMSM has a sinusoidal back EMF, so the armature is usually energized by the sinusoidal current. Although the motor is characterized with a sinusoidal back EMF, the speed control methods based on sensor less system applied and achieved satisfactory performance. The proposed system overcomes the existing system

- Proposed drive is very better with less torque ripple, smooth speed control, less voltage stress and low Current THD.
- Another advantage of this method is that due to two sources, reliability of the system increases.
- Low voltage & current ripples when compared to proposed system.
- Improves THD.

V. RESULTS AND DISCUSSION

This project is simulated using the user-friendly MATLAB R2011a programme. MATLAB is an interactive environment and high-level language for numerical calculation, visualization, and programming. We can use MATLAB to analyze data, design algorithms, and build models and applications. The language, tools, and built-in math functions allow you to experiment with different techniques and arrive at a solution faster than spreadsheets or traditional programming languages like C/C++ or Java.

PMSM DC motor is a permanent magnet synchronous motor which is powered by dc-voltage through the inverter that produces the ac electric signal to drive the motor. The commutation is done in PMSM is electronically instead of brushes. It is easily controlled through the rotor position sensors and performs well especially in speed/torque. With these advantages, the motor will spread to more applications. The applications of PMSM are increased and its competing with the induction motors and dc motors. The output voltage and output frequency of the inverter are dependent on the switching state of the inverter. The controlling of the inverter switches is done by using various PWM techniques.

To evaluate the performance of the proposed PMSM drive system, simulation models have been developed and the simulation is carried out using MATLAB/ SIMULINK. Figure. 3 shows proposed MATLAB/SIMULINK model of closed loop speed control of a BL-CC Converter -Based PMSM Motor Drive with FOC controller. Figure. 4 show the simulation diagram of PFC Subsystem. Figure. 5 depicts the simulation diagram of control loop system. Simulation diagram of PWM and speed control system is shown in Figure 6.

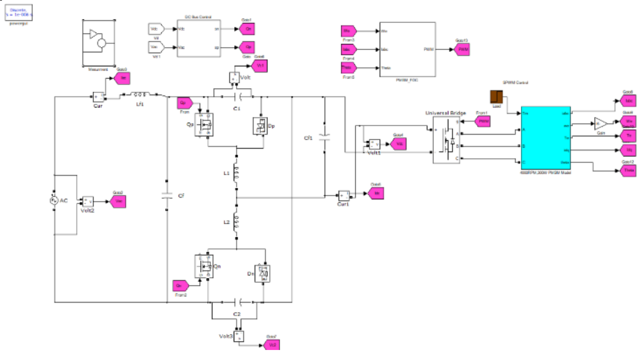

Figure 3 Simulation Diagram of a BL-CC Converter -Based PMSM Motor Drive with FOC controller

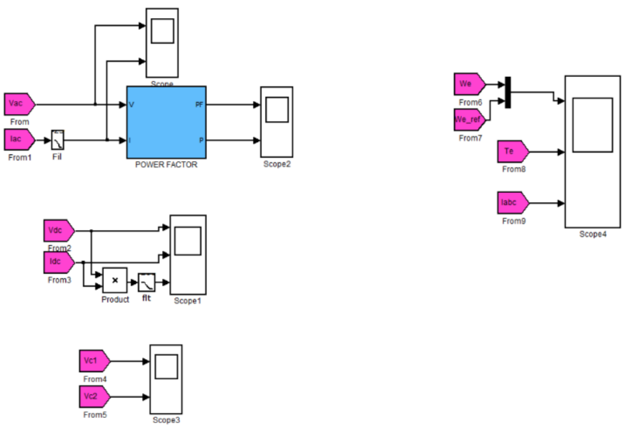

Figure. 4 Simulation Diagram of PFC Subsystem

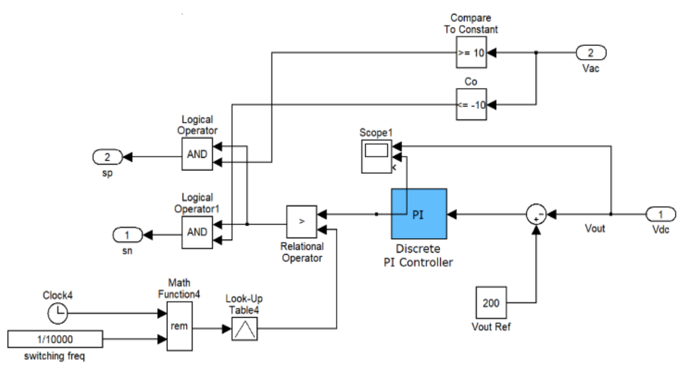

Figure. 5 Simulation Diagram of Control Loop System

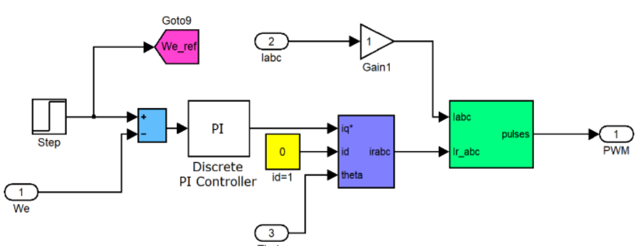

Figure.6 Simulation Diagram of PWM and Speed control System

The simulation work is carried out extensively for both the cases with constant speed with variable load condition and with variable speed with constant load torque condition. It is observe that proposed method has so many advantages when compared to the existing system. In proposed method voltage stress across stator winding is reduced to half, second one is reliability of the drive increase due to the presence of two sources, third one is the torque ripples are going to reduced, fourth one is low cost as number of switches are reduced and current sensors are also reduced, fifth one is that in current % THD is less.

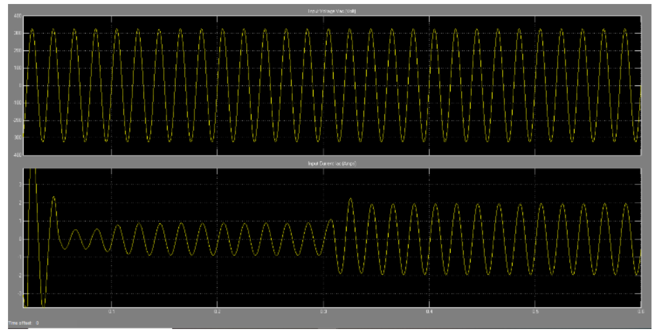

Figure. 7 Output Waveform of Input Voltage/Current

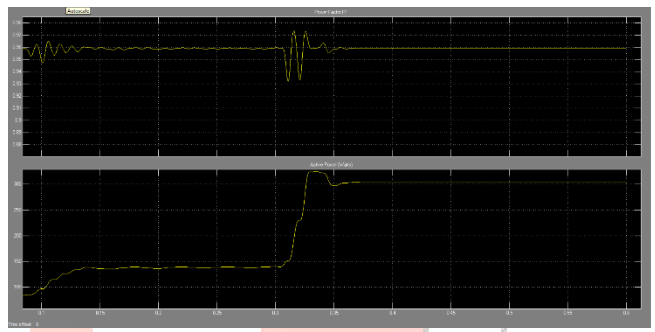

Figure. 8 Output Waveform of Power Factor/Active Power

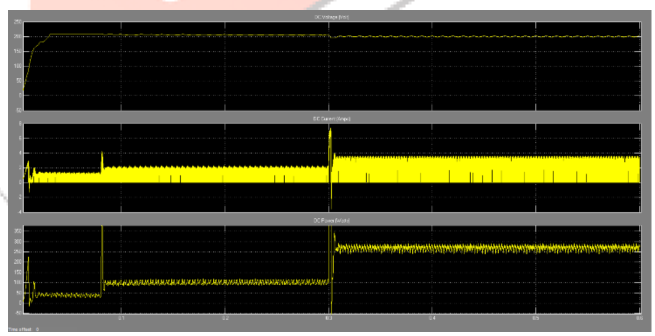

Figure 9. Output Waveform of DC Voltage/Current/Power

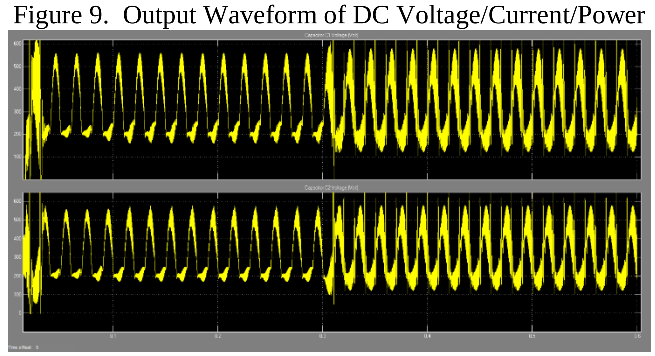

Figure 10. Output Waveform of Capacitors Voltage

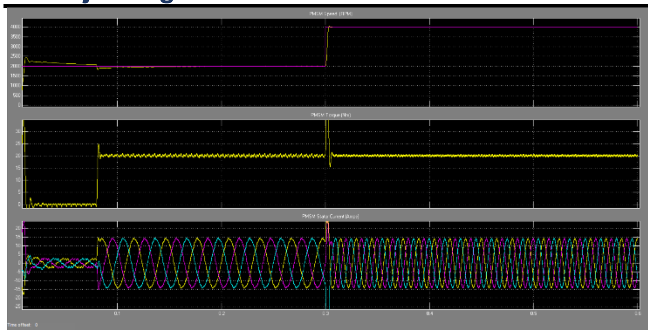

Figure 11. Output Waveform of Speed/Torque/Current

Variable speed drive systems are essential in many industrial applications. In the past, DC, are require to high speed synchronous circuit because these improved efficiency of induction motor, since their control flux and armature current of induction motor. Dc motors have certain disadvantage they are totally depends for brushes and large current loss. That is, they have require for large periodicity of torque; they cannot be used in explosive or corrosive environments and they have limited commutator these properties are high speed and higher alternate current and rugged Structure of motor. That is providing high maintainability and good economy.

VI. CONCLUSION

PMSM drives are very preferable for compact, minimal effort, low maintenance, and high reliability system. In this work, a mathematical model of PMSM motor is developed. The simulation of the Permanent Magnet Synchronous motor is done using the software package MATLAB/SIMULINK and its phase voltage, phase current speed and torque waveform are analyzed. A PI controller has been employed for position control of PMSM motor. Effectiveness of the model is established by performance prediction over a wide range of operating conditions. Power Factor Correction based CSC converter-encouraged PMSM drive has been proposed for focusing on low-control family unit applications. A front-end CSC converter working in DICM has been utilized for double destinations of dc-link voltage control and accomplishing a solidarity power component at air conditioning mains. The execution of the proposed drive has been found entirely well for its operation at variety of velocity over a wide range.

VII. REFERENCES

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