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A Novel Reference On Driving AThreePhase Brushless DC Motor With A New Matrix Converter

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Abstract—*This paper presents a novel matrix converter based drive technique for three phase brushless DC (BLDC) machines. In contrast to existing matrix converter based drives, the proposed technique uses a topology that has less number of semiconductors and a unique switching sequence to drive three phase BLDC machines directly from single phase mains supply lines without a DC link capacitor. The paper describes in detail both the topology and the unique switching sequence that is essential for the proposed technique. A model based on Matlab/Simulink is also presented to demonstrate the theoretical performance of the proposed drive system. The performance of the technique is evaluated using a model of 320 W BLDC machine, which is operated in both torque and speed control modes, and simulated results indicate that the performance of the machine is comparable to existing techniques. The proposed technique is simple to implement, cost effective with low component count, and can be easily adapted to applications such as PM synchronous motor drives or loads, which require a single to 3-phase power conversion.*

I. INTRODUCTION

Brushless DC (BLDC) machines has more priority because of their advantages and uses, such as good `speed torque characteristics, high power density, low maintenance, long operating life, high efficiency and noiseless operation. BLDC motors name itself confirms that they never use brushes for the commutation. This process of commutation is done electronically by using an series of switching devices based on the information of the rotor position.

A power electronic converter with a rotor position feedback loop is used to drive a brushless DC motor in practice . In general, power electronic converters can be classified into two sub-categories

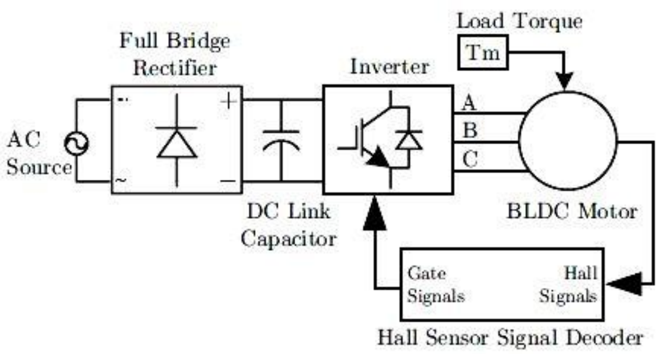


Fig. 1. Brushless DC motor fed by a six step inverter

1) Indirect Converters - The input is rectified, smoothed by an intermediate DC link capacitor and inverted using an array of power electronic switches
2) Direct Converters - The output is synthesized directly from the input by piecewise sampling of input signal using an array of power electronic switches

The various used type is the indirect conversion topology. Indirect converters are variously used because of their easy control as the direct converters requires most complicated techinques. Here in the Fig. 1 A BLDC which is connected with a indirect converter is shown with a rotor position feedback loop. Hence, the rotor position information is obtained by a hall effect sensors.A dc link is used in indirect converters which needs more space for installation, which leads for larger converter housing.

The matrix converter (MC) is the most popular and widely used converter topology in the family of direct converters due to its inherent advantages listed below.

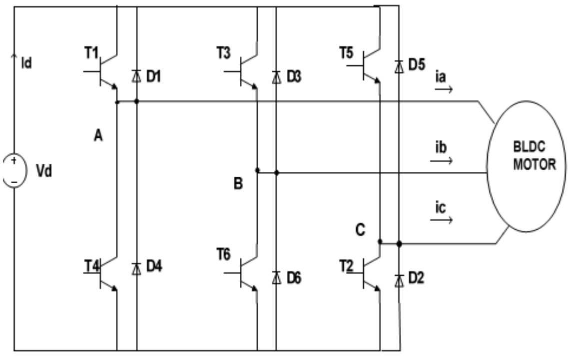
- Ability to generate a load voltage with arbitrary amplitude and frequency.
- Sinusoidal input and output waveforms with unity power factor at any load.
- Regeneration capability, due to the inherent bidirectional nature of the converter.
- Compact and relatively simple power circuitry.

The disadvantages of the matrix converters, which have been reported in literature can be listed as follows.

- No discrete solid state device, which is capable of bidirectional power transfer
- Additional protective circuitry should be employed to avoid input side short circuits and output side open circuits.
- No inherent ride through capability due to the absence of DC link capacitor.
- Maximum achievable voltage transfer ratio between input and output is lower.

OPERATION OF BLDC MOTOR

A BLDC motor employing a voltage source inverter (VSI) is as shown in fig



During the period 0 0 to 60 0, the current I A enter through the phase A and leaves through the phase B. When Tr1 and T r2 are on, terminal A and phase B respectively connected to positive and negative terminal of the dc source Vd. A current will flow through the path consisting of Vd, Tr1,phase A, phase B and Tr6 and rate of change of current IA will positive. When Tr1 and Tr6 are turned off this current will flow through a path consisting of phase A, phase B, diode D 3, Vd and diode D 4. Since the current has to flow against voltage Vd the rate of change of IA will be negative.

CONVENTIONAL TOPOLOGY

Single phase to three phase matrix converter A typical topology of a single phase to three phase matrix converter is shown in Fig. 2. Each bidirectional switch cell is realized by two backto-back solid state switches, since there is no single solid state device, which is capable of bidirectionalpower transfer.

As illustrated in Fig. 2, T1 and T2 resemble one bidirectional switch cell. These switches are controlled in such a way that the voltage output is a sinusoid of the required frequency and amplitude. The concept is validated by using a simulation model developed in Matlab Simulink framework with SimPower Systems toolbox. The SimPower Systems pre-built device models are used for the simulation. Both speed and electromagnetic torque control techniques are simulated and validated using the simulation.

PROPOSED NOVEL METHODOLOGY

The proposed topology for the converter is illustrated in Fig. 3. The analyzing technique is similar to the "Separation and Link" topology, which has already been reported in literature. Both the "Separation and Link" method, and the topology presented here use two single phase to three phase (1×3) inverters for positive and negative half cycles of the input single phase voltage source.

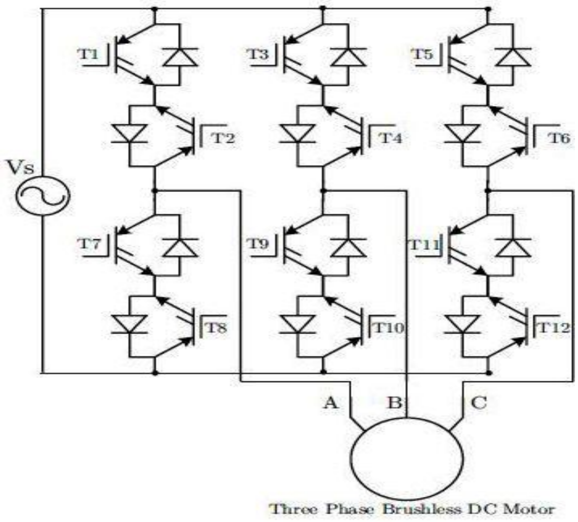


Fig. 2. Single phase to three phase matrix converter

Furthermore, the proposed converter topology requires lesser device count, which leading to an efficient overall design. The switches in the inverter do not need to accompany with the anti-parallel freewheeling diodes as in the method reported as "Separation and Link" and as in conventional converter topologies. The freewheeling paths are provided by forced commutation of the appropriate switching devices at the correct instant in time.

The methodology illustrated in Fig. 3, can be resolved into two single phase to three phase (1×3) inverters. The following nomenclature is used throughout the paper for the ease of explanation.

- The inverter comprised of switches A1, A2, B1, B2, C1,and C2 is named as "inverter-1".
- The inverter comprised of switches A3, A4, B3, B4, C3and C4 is named as "inverter-2".

  When the supply voltage is in its positive half cycle, theinverter-1 supplies power to the load and the inverter-2 provides freewheeling paths. When the supply voltage is in its negative half cycle, the inverter-2 supplies power to the load and the inverter-1 provides freewheeling paths.

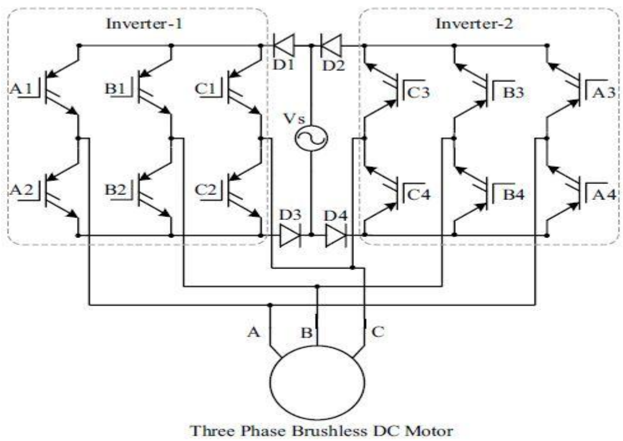


Fig. 3. Proposed matrix converter based BLDC motor drive

It is worthwhile noting that there are no natural freewheeling paths, as in the case of conventional inverter topologies.

Freewheeling current paths are provided by forced commutation of the switches.

The four diodes named as D1, D2, D3 and D4 in Fig. 3, are used to select the appropriate half cycle of the input voltage source to the relevant inverter and avoid the reverse voltages being applied to the switching devices. Also they prevent the
input side short circuits.

The following two conditions will ensure that the converters in its safe operating conditions at all times,hence have to be taken in to account while designing the switching algorithms for the converter.
1) No two switches in a same leg should turned on in at any point in time, which would result in high currents due to the short circuit of input voltage source.
2) No output line left open circuited at any point in time, which would result in high over voltages due to the inductive nature of the load (i.e. due to the absence of apath to flow the inductive current).

Switching algorithm with a three phase brushless DC Machine. The commutation of the switching devices of converter was simulated by processing the Hall effect sensor signals, and energizing the appropriate windings of the machine model accordingly.

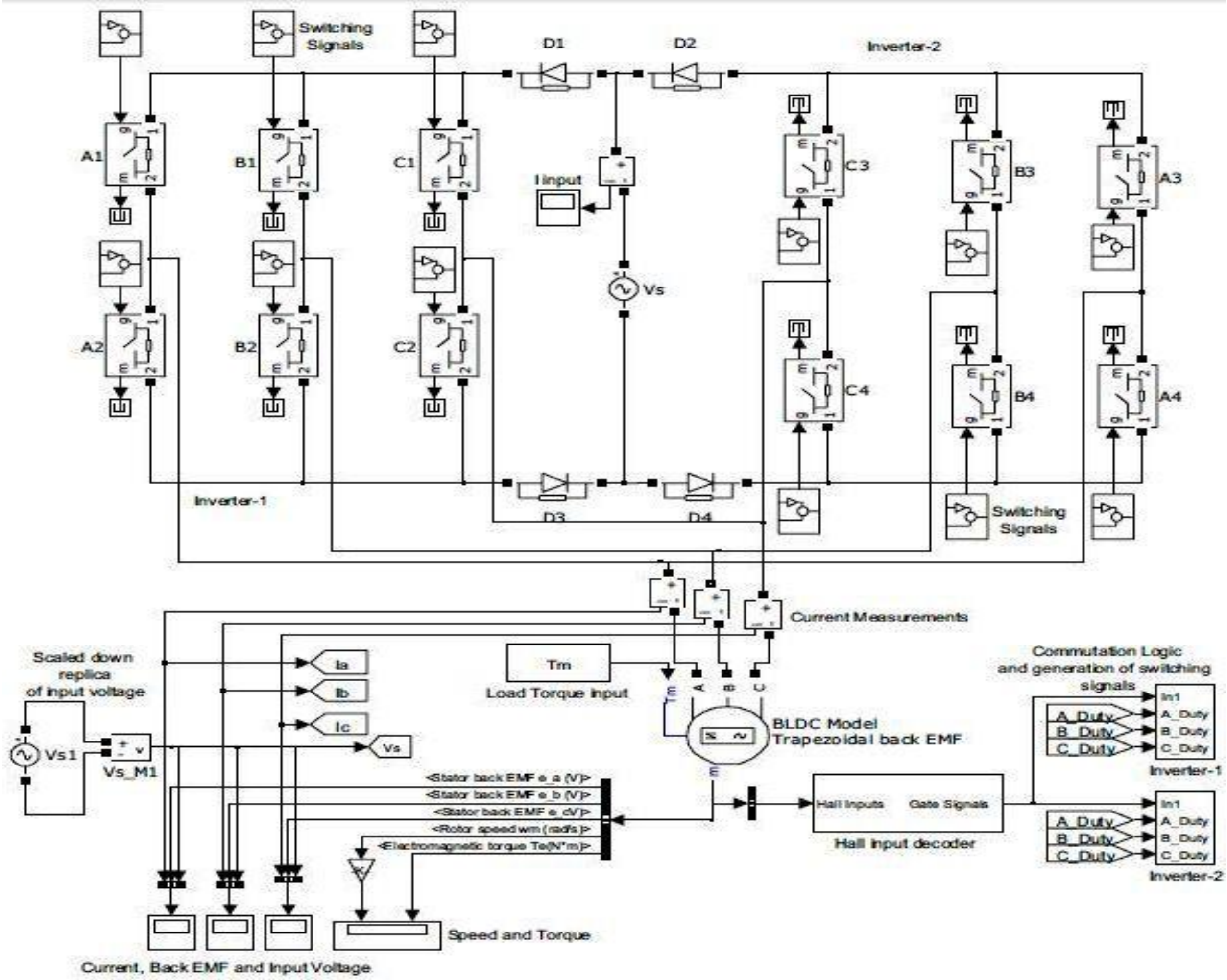
Following switching algorithm tabulated in Table I is derived assuming a trapezoidal back Electromotive Force (EMF) brushless DC machine as the output. The freewheeling paths are provided by firing the relevant switches in the opposite side of the converters tabulated in Table I.

SWITCHING ALGORITHM FOR A BRUSHLESS DC MOTOR WITH TRAPEZOIDAL BACK EMF

Supply Voltage Vs	Hall Sensor Output	Switches in the main path	Switches in the freewheeling path
Positive	1 0 0	A1 C2	A4 C3
Positive	1 1 0	B1 C2	B4 C3
Positive	0 1 0	B1 A2	B4 A3
Positive	0 1 1	C1 A2	C4 A3
Positive	0 0 1	C1 B2	C4 B3
Positive	1 0 1	A1 B2	A4 B3
Negative	1 0 0	A4 C3	A1 C2
Negative	1 1 0	B4 C3	B1 C2
Negative	0 1 0	B4 A3	B2 A2
Negative	0 1 1	C4 A3	C1 A2
Negative	0 0 1	C4 B3	C1 B2
Negative	1 0 1	A4 B3	A1 B2

SIMULATION AND RESULTS

Simulations were extended to BLDC machine models, which have sinusoidal back EMF with different numbers of pole pairs for various load torque values. The proposedconcept herein was validated by interpreting the promising results, which were obtained by the simulations.



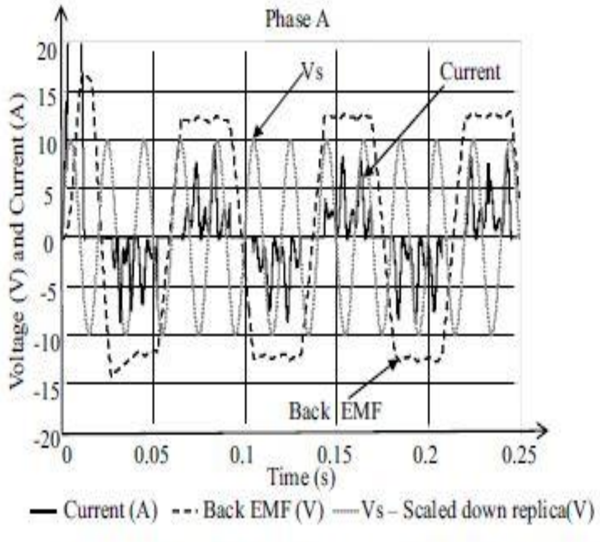


Fig. 5. Phase A current and back EMF waveform with a scaled down replica of supply voltage

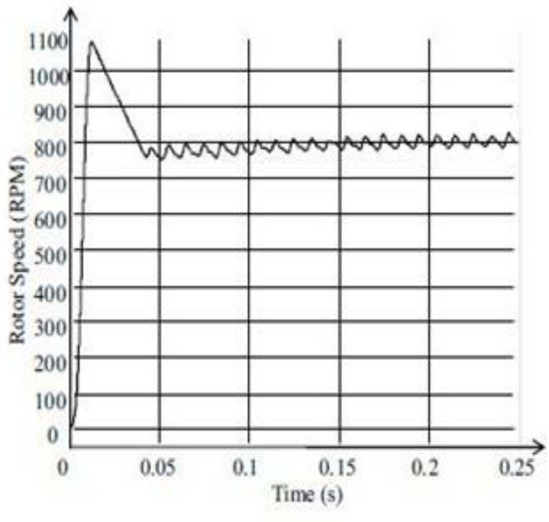


Fig. 6. Rotor speed

Those signals are used to trigger the switching devices adhering to the switching algorithm, which is presented in Table I.
The simulation results for the current control are illustrated in Fig. 8 and 9. The reference current was set to 6 Amperes. The torque ripple is due to the zero crossing points (zero current points) in input voltage

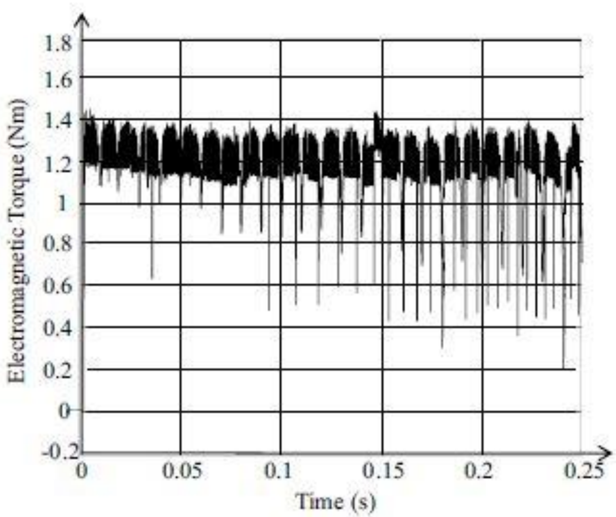


Fig. 9. Electromagnetic torque

source Vs. The stator current waveform shape is caused by the commutation of the phases, zero crossing points of the input waveform and PWM switching. A scaled down supply voltage Vs of 10 Vpk−pk is used in Fig. 8, instead of the actual 325 Vpk−pk waveform, which is used for the simulation, for easy comparison of the output waveforms.

CONCLUSION

A novel matrix converter based drive technique for three phase BLDC machines has been described. This topology allows the machine to be driven directly from the single phase mains without an intermediate DC link capacitor and with lesser number of semiconductor devices, in contrast to the conventional matrix converter based drive topologies. The safe operating conditions and modular switching algorithms with the potential expansions to various applications are included and explained.
The simulation model has been tested extensively for trapezoidal back EMF brushless DC machine models with different machine parameters and load conditions to verify the theoretical performance of the proposed drive system. The simulated results indicate that the performance of the machine is comparable to the existing driving techniques. The speed and torque ripples are inherent with the method due to the zero crossing points of the input power supply in speed and current control modes, respectively.
The presented technique is reliable in operation, cost effective with low component count and can be integrated easily to applications such as PM synchronous motor drives or loads, which require a single to 3-phase power conversion.

ACKNOWLEDGMENT

TABLE I
BRUSHLESS DC MACHINE PARAMETERS

Parameter	Value
Stator Phase resistance	2 Ω
Stator phase inductance	5 mH
Torque constant	0.2 Nm$(A_{peak})^{-1}$
Inertia (J)	0.0008 kgm^2
Friction factor (F)	0.001 Nms
Back EMF	Trapezoidal
Rated power	320 W
No. of pole pairs	4

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