

Modeling and Simulation of Renewable Energy Fed Brushless DC Motor Drive Using Improved DC-DC Converter For Reducing Vibration and Noise

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Abstract

The anticipated research involve, Modeling and simulation of Renewable Energy Fed Brushless DC motor Drive using Improved DC-DC Converter for reducing vibration and noise. It consists of buck and boost converter, DC-link module. Compare with conventional converters, the designed system results in reduction of voltage tension across the switches, compact power switches, DC source reckoning and reduced inrush current. In this Enhanced converter DC-link switching is achieved by abridged ripple voltage which results in improved quality of output power is obtained and it also reduces vibration, noise in the drive without affecting mechanical properties. Lessening in switch tot up makes the system more cost effective. A simulation of Buck-Boost converter is designed and its concert is analysed for various functioning factor conditions.

Keywords: B4 inverter; Buck boost converter; dsPIC controller; DTC; Permanent magnet brushless DC motor; Simulation; Vibration and acoustic noise

Introduction

In recent times, permanent magnet brushless DC (BLDC) motors are extensively utilized by several industries like medical, electric traction, HVAC industry, aircrafts, military equipment, road vehicles, hard disk drive, etc., because of their better efficiency, high power density, consistency and extremely uncomplicated to control. One of the most significant categories of instantaneous electromagnetic torque controlled AC drives employed for high-performance applications is Direct Torque Control (DTC) drives Liu Y et al. DTC is a kind of hysteresis or bang-bang control for the purpose of controlling the torque (and as a result speed) of electric motors. The fundamental conception that functions the DTC of AC drive, as its name indicates, is to direct the electromagnetic torque and also the flux linkage directly and autonomously with the ehlp of of six or eight voltage space vectors given in lookup tables. The benefits linked with DTC are ease of use and better dynamic working, moreover there is no vector transformation and quicker torque response. The torque ripple is the foremost complication allied in the process of DTC [1-8] into account, in addition to unconventional inverters [9,10]. In the midst of the unconventional inverters, it is easy to differentiate the B4-inverter result from the reorganization of the B6-inverter in the scenario of switch/leg breakdown. These kind of reorganization is a fundamental requirement in certain category of applications, in particular electric and hybrid propulsion systems, in case of the vehicle consistency is taken into account [11,12]. Managing the BLDC motor control schemes, it is relatively in general considered that they are completely based on the current and torque control techniques [13-15]. One of the most popular is a generalized harmonic injection to discover optimal current waveforms by reducing the torque ripple [16]. On the other hand, since the torque is not directly controlled, a fast dynamic is not consummate. In addition, the implementation of these schemes needs costly position sensors. In Ozturk et al. [17], hysteresis current controllers are employed for the purpose of driving BLDC motors. On the other hand, the proposed control scheme needs quite a lot of transforms for the purpose of synthesizing the abc-frame optimum reference currents, leading to a tricky control scheme with no direct control of the torque. In recent times, several DTC schemes have been effectively put into practice in B6-inverter-fed BLDC motor drives [18-

20]. On the other hand, it has been observed in [21,22] that the two-phase conveyance mode is penalize through high torque ripple at some stage in sector-to-sector commutations. In order to overcome this disadvantage, the three-phase conduction mode has been considered provisionally at some stage in sector-to-sector commutations. Mourad Masmoudi et al. formulated ascheme in the scenario of of B4-inverter-fed BLDC motor drives under DTC [23-25].

Conventional DTC model of B4 inverter based BLDC motor is illustrated in Figure 1. Given that, a variable input power supply like PV panel is employed here, there is a requirement to incorporate a converter with the intention of obtaining the regulated supply voltage. For these functions, various converters, for instance, boost, buck, buck boost, cuk, sepic, zeta etc have been employrd in the literature. However, the most important drawback with these converters for a DTC of B4 inverter based BLDC is the incidence of voltage imbalance across the capacitors. This voltage imbalance is primarily because of the DTC switching model to the BLDC motor as given in [4]. This setting is completely described with a conventional type buck boost converter fed BLDC motor as illustrated in Figure 1. When switch (S_1) is in "ON" condition, the current in inductance (L_1) begins to increase (Charging). In contrast, during switch (S_1) is in "OFF" condition, the energy in inductance (L_1) begins to dropping (discharging). This energy in the inductance is transmitted to the voltage balancing capacitors (C_{01}), and (C_{02}). At some point when these capacitors are about to discharge in accordance with the switching pattern of the DTC, it ends in voltage imbalance because of variation in time period of discharging. This voltage imbalance is a most important complication since it have an effect on the torque ripples in the BLDC motor are shown in Table 1

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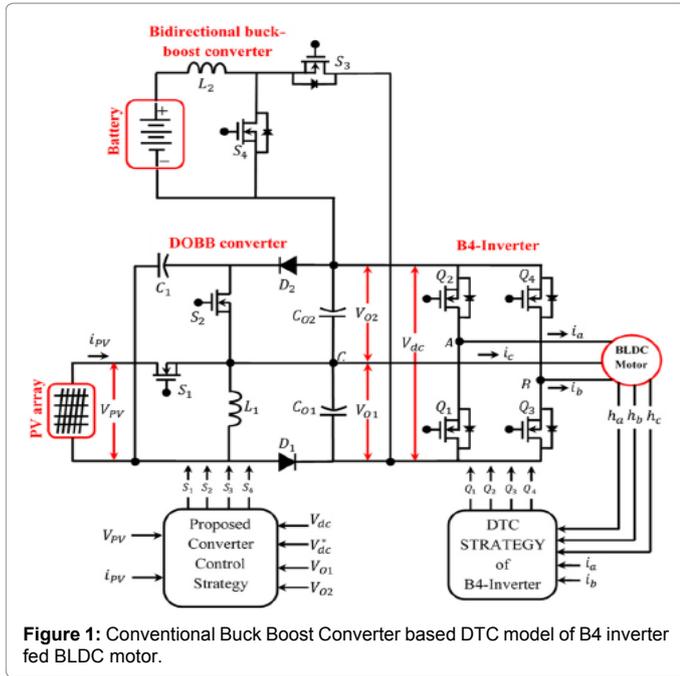


Figure 1: Conventional Buck Boost Converter based DTC model of B4 inverter fed BLDC motor.

S ₁	S ₂	S ₃	S ₄	status	
				V _{co1}	V _{co2}
1	0	0	0	V _{dc} /2 ↓	V _{dc} /2 ↑
0	1	0	0	V _{dc} /2 ↓	V _{dc} /2 ↓
0	0	1	0	V _{dc} /2 ↑	V _{dc} /2 ↑
0	0	0	1	V _{dc} /2 ↑	V _{dc} /2 ↓
1	0	0	1	V _{dc} /2	V _{dc} /2
0	1	1	0	V _{dc} /2	V _{dc} /2

Table 1: Torque ripples in the BLDC motor.

In order to handle this voltage imbalance problem, a modified converter is required which is the major focus of this research work. Comparison carried out conduction of switches for B4 and B6 inverter for the proposed DOBB fed BLDC Motor Drive are show in Table 2 [26-30].

Materials and Methods

Figure 2 demonstrates the projected system model with front end modified voltage balancing converter and the rear end for DTC of B4-Inverter-based BLDC Motor Drives. The system model includes fed DC motor. The enhanced converter consists intermediary capacitor C₁, power switches S₁ & S₂, input inductance L₁, power diodes D₁ & D₂ and voltage balancing capacitors C_{o1}, & C_{o2}. On the other side, the rear end includes a B4 inverter (S₃-S₆) and a BLDC motor. The DTC of BLDC motor results in voltage imbalance state across capacitors C_{o1} and C_{o2}, which consecutively results in elevated torque ripples. With the intention of managing this complication, a modified converter is incorporated with the B4 inverter in the front end. The method of

managing the charging and discharging time period of capacitors C_{o1} & C_{o2} in accordance with the (ON/OFF) position of the modified converter switches S₁ & S₂. The operation of the converter is categorized as three modes which are clearly given in the following section.

Mode of Operation

Mode 0

When switch (S₁) is in “ON” condition and switch (S₂) is in “OFF” condition, current in inductance (L₁) drops (discharging). As a result, the intermediary capacitor (L₁) gets (charging) energy from an input inductor (L₁). Consequently, voltage across the intermediary capacitor C₁ boosts as given in Figure 3.

Mode 1

When switch (S₁) is in “ON” condition, current in supply voltage drops (discharging). Consequently, the energy is transmitted to the inductance (L₁). (charging). Therefore, voltage across the intermediary capacitor C₁. boosts as given in Figure 3.

Simultaneously, current in the capacitor C₁ and the supply current V_{dc} drops (discharging). As a result, the energy is transmitted to the capacitor (C_{o2}) (charging) with the help of diode D₂. Consequently, voltage across the intermediary capacitor C_{o2} boosts as given in Figure 3.

Mode 2

When switches (S₁) and (S₂) is in “OFF” condition, current in inductance (L₁). drops (discharging). As a result, the intermediary capacitor C₁ gets (charging) energy from input inductor (L₁) with the help the diode D₁ Figure 4.

Sector	Operation of switches for B6-Inverter	operation of switches for B4-Inverter
0-60	S1, S6	S1, S4
60-120	S2, S3	S2
120-180	S3, S6	S4
180-240	S4, S5	S3
240-300	S1, S4	S1
300-360	S2, S5	S2, S3
Total number of switches operate at 0-360°	12	8
Switching losses for 300 Watt system	2.48 Watt	1.36 Watt

Table 2: Comparison of conduction of switches for B4 and B6 inverter for the proposed Enhanced DOBB fed BLDC Motor Drive.

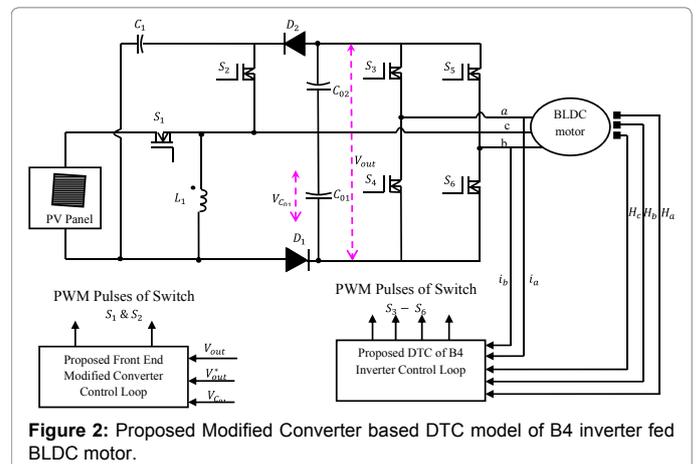


Figure 2: Proposed Modified Converter based DTC model of B4 inverter fed BLDC motor.

Control Loop of The Proposed System and Front End Converter Control Loop

This proposed system includes two control loops, specifically, Front End converter control loop and the rear end DTC of B4 Inverter Control Loop. Major contribution of this research work is based on the converter, this work chooses to utilize a conventional Proportional Integral (PI) for the purpose of a control loop feedback mechanism. In case of industrial process, a PI controller tries to accurate that error among a measured process variable and preferred set point by means of calculating and subsequently provide accurate output that can regulate the process consequently Figure 5.

The actual voltage in the capacitors ($V_{dc} = V_{c01} + V_{c02}$) and the set voltage V_{dc}^* is deducted and the error is provided as key to the PI controller. At this point, set voltage V_{dc}^* is taken as 540 V.

V_{c01} = voltage across the capacitor C_{01}

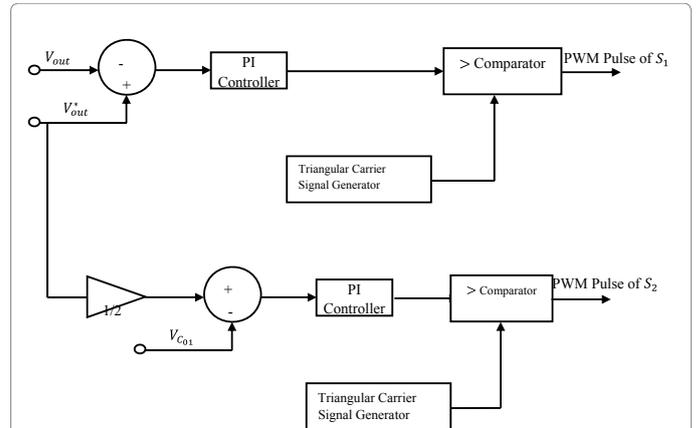


Figure 5: Proposed Front End Modified Converter Control Loop.

V_{c02} = voltage across the capacitor C_{02}

The functioning of the PI controller is discussed briefly as follows.

The PI controller computation engages two distinct modes, they are, proportional mode and integral mode. In case of the proportional mode, the reaction to the current error is determined, however, in case of the integral mode, the reaction based recent error is determined. The weighted sum of the two modes output as corrective action to the control element. PI controller is extensively employed in industry because of its simplicity in design and uncomplicated structure. PI controller algorithm can be executed as follows:

$$output(t) = K_P \text{err}(t) + K_I \int_0^t \text{err}(\tau) d\tau$$

Where ;

$\text{err}(t) = \text{set voltage} - \text{actual voltage}$

The output of the PI controller which is the controlled error is evaluated against the triangular carrier signal of frequency 5 KHz to produce PWM pulses of switch S_1 .

In the same way, with the aim of controlling Switch S_2 , actual voltage taken here is $V_{dc}/2 = V_{c01}$. The output of the PI controller which is the controlled error is evaluated against the triangular carrier signal of frequency 10 KHz to produce PWM pulses of switch S_2 as illustrated in Figure 3.

Proposed DTC of B4 Inverter Control Loop

Here, introduced a new DTC strategy which shows the sign of a potential of dropping the torque ripple at some stage in sector-to-sector commutations. Zhu and Leong [28], concentrate the scenario where the BLDC motor is supplied by a B6-inverter. Finally Zhu et al. formulated a system consisting in the use of active power vectors in line with the three-phase conduction mode, at the origination of every sector with the objective of forcing the current in the curved-off phase to flow through a convenient IGBT fairly than an uncontrollable permissive diode. Therefore, the rising rate $|di/dt|$ of the current in the curved off phase is prohibited in an endeavor to make it similar to the one of the current in the curved-on phase.

In [28], the DC-link voltage V_{dc} being lesser than four times the maximum value E of the back EMF waveform ($V_{dc} < 4E$). With this situation, the following drawbacks have been observed:

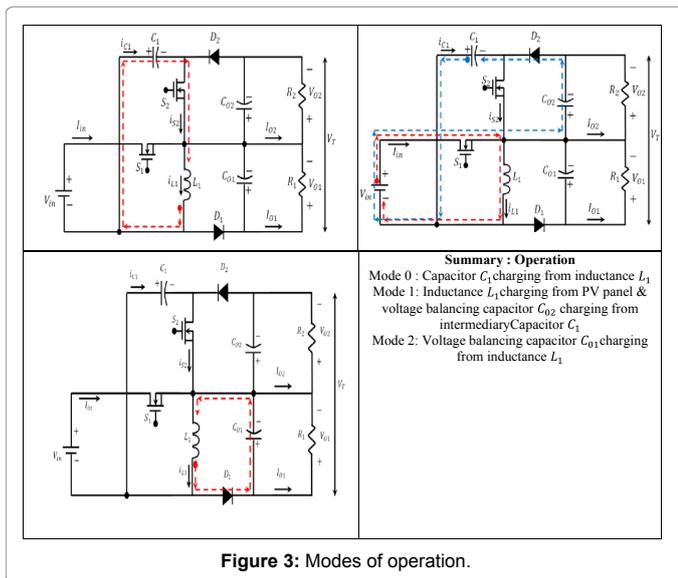


Figure 3: Modes of operation.

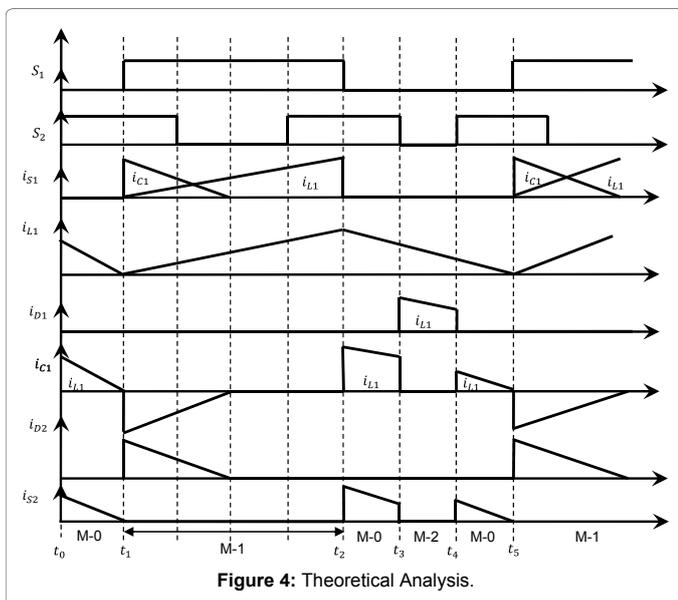


Figure 4: Theoretical Analysis.

The rising rates ($|di_a/dt|$, $|di_b/dt|$, and $|di_c/dt|$) of the phase currents rely on three variables, specifically: i) the DC-link voltage V_{dc} , ii) the back-EMF peak value E , and iii) the self-inductance L . As a result, the getting higher and the diminishing times Δt of the phase currents rely on their highest value I which is openly related with the consignment torque T_r . Even though at high-speed operation ($V_{dc} < 4E$), an unequal incident is related with the waning of the electromagnetic torque at various step in sector-to-sector commutations, predominantly at low values of the crest current I and the self-inductance L . In accumulation, its found that, at a few stage in torque acceleration or deceleration, the maximum and minimum times Δt of the phase currents are variables which have an effect on the electromagnetic torque by outstanding dips, at conventional one instantaneous measurement of the V_{dc} , particularly in electric and hybrid propulsion systems where the DC-bus is accomplished by means of a battery pack. The proposed system is formulated, it includes the replacement of the two-level torque controller with a four-level one. In this system, the positive high level $c_r = +2$ of the torque hysteresis controller is methodically triggered when the torque drops at some point in sector-to-sector commutations in the scenario of an anticlockwise rotation ($T_{em} > 0$), while its negative high level $c_r = -2$ is methodically triggered when the torque drops at some point in sector-to-sector commutations in the scenario of a clockwise rotation ($T_{em} < 0$). The lowlevels $c_r = \pm 1$ are applied at the time of the complete cycle not including the torque dips taking place at some stage in sector-to-sector commutations Figure 6.

As illustrated in Figure 1, the position phase currents should be emphasize that the anticipated scheme either ineffective through the commutations from Sector I to Sector II and from Sector IV to Sector V in the scenario of an anticlockwise rotation, and from Sector III to Sector II and from Sector VI to Sector V in the scenario of a clockwise rotation, owing to the truth that $|di_c/dt|$ is out of control. Proposed DTC strategy shows the sign of capability of reducing the torque ripple at the time of sector-to-sector commutations without any dependence of V_{dc} , I , Δt , and L . The resultant transformations in the designed scheme concern just the blocks surrounded by the dashed line in Figure 7. These turn to be as illustrated in Figure 8. By considering both anticlockwise and clockwise rotations, the proposed vector selection subtables are given in Tables 3 and 4 respectively.

Results and Discussion

The performance of the Proposed Modified Converter based DTC model of B4 inverter fed BLDC motor is simulated in MATLAB/Simulink environment using the Sim- Power-System toolbox. The

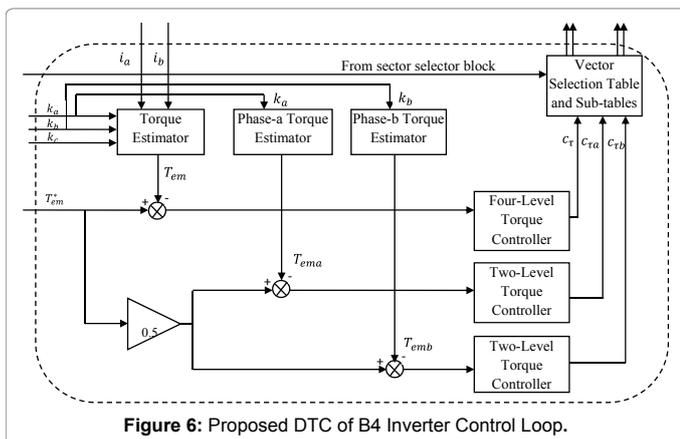


Figure 6: Proposed DTC of B4 Inverter Control Loop.

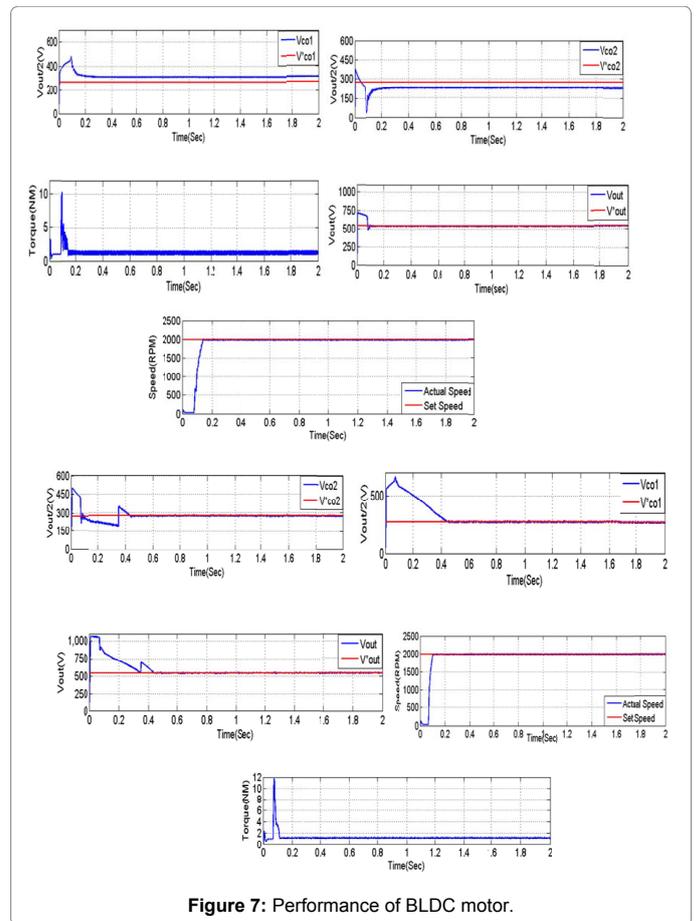


Figure 7: Performance of BLDC motor.

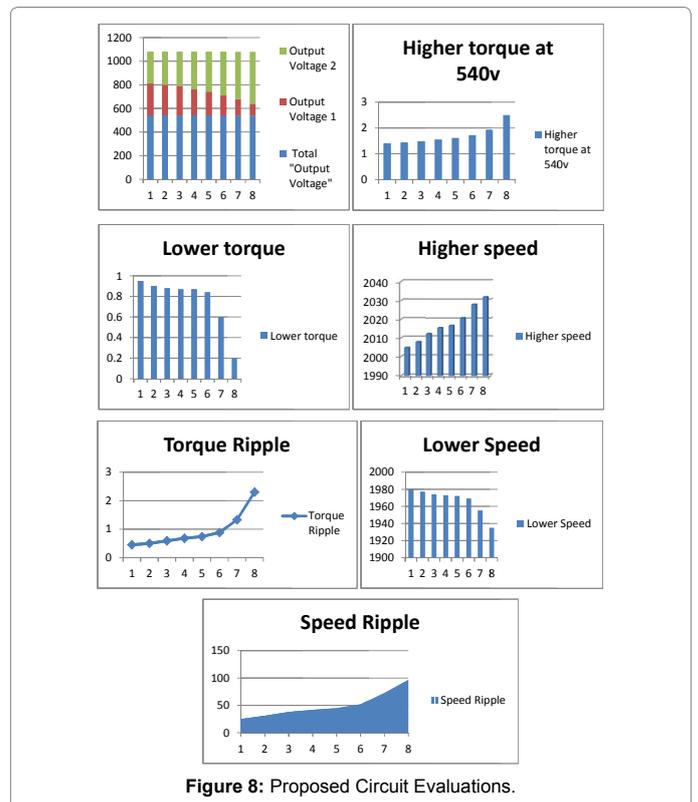


Figure 8: Proposed Circuit Evaluations.

performance evaluation of the proposed system is categorized in terms of the voltage balancing performance of the front end Converter as well as the sudden change in torque and speed in the rear end B4 Inverter. The parameters associated with the proposed system such as voltage across the balancing capacitors V_{co1} and V_{co2} , Expected voltage across the balancing capacitors V^*_{co1} and V^*_{co2} are analyzed for the proper functioning of the front end Converter Table 5.

The conventional buck boost converter based DTC model of B4 inverter fed BLDC motor response which is termed as ‘Exist’.

C_{ra}	+1		-1	
C_{rb}	+1	-1	+1	-1
Sector II	$U_3(0110)$	$U_4(0101)$	$U_2(1010)$	$U_1(1001)$

Table 3: Vector selection adopted subtable for vector selection [27] to reduce the harmonics for the BLDC Motor Phase Current in Sectors II and V.

C_1	-2
Sector II → Sector I	$U_1(1001)$
Sector I → Sector VI	$U_4(0101)$
Sector V → Sector IV	$U_3(0110)$
Sector IV → Sector III	$U_2(1010)$

Table 4: Vector selection subtable during Sector-To-Sector Communications in the Case of a Clockwise Rotation.

Components and Symbols	Parameters
Input inductor (L_i)	389.4 μH
Intermediate capacitor (C_i)	50 μF
Output capacitor (C_{o1} and C_{o2})	1000 μF , 100 V
Operating Switching frequency (F_{sw}) of switches	$S_1 = 5kHz$, $S_2 = 10 kHz$
Load resistance (R_1 and R_2)	28.8 Ω

Table 5: Simulation parameters for proposed converter.

It is observed that, the existing buck boost converter model results in voltage unbalanced condition across the capacitors $co1$ and $co2$. This voltage unbalancing condition results in higher torque and speed ripples. The capacitor voltages V_{co1} and V_{co2} , are varied sequentially to attain the respective torque and speed ripples as shown in Table 6.

From the Table 5, it is clearly observed that, an efficient voltage balancing capacitor is essential to handle this voltage unbalancing condition. The proposed modified converter based DTC model of B4 inverter fed BLDC motor is designed to handle this problem and its response is termed as ‘Proposed’ in the simulated result. The specifications of the BLDC motor for this simulation study is given below. BLDC Motor Rating: four poles, Prated (rated power) = 251.32 W, Vrated (rated dc link voltage) = 200 V, Trated (rated torque) = 1.2 N·m, ω rated (rated speed) = 2000 r/min, Kb (back EMF constant) = 78 V/kr/min, Kt (torque constant) = 0.74 N·m/A, Rph (phase resistance) = 14.56 Ω , Lph (phase inductance) = 25.71 mH, and J (moment of inertia) = 1.3×10^{-4} N·m/A². Back EMF constant = 78 V/kr/min; thus a minimum of $78v_{peak} * 4 = 312v$ for b4 inverter is required. Here, 540 V is considered as V_{out} .

The PM-BLAC motor fed by sinusoidal AC sources and produces an essentially constant torque, or so-called smooth torque. On the other hand, the PM-BLDC motor fed by rectangular or trapezoidal AC waves and has a significant torque pulsation. However, due to interaction between a rectangular field and a rectangular current, the BLDC motors can produce higher torque than the BLAC motor. Torque ripples issue is major problem for ripples causes torsional vibration and also acoustic noise. Due to vibration systems, mechanical parts of the system can be damage reduction of the torque ripples in many kind of methods have been proposed Direct torque control (DTC) is the name of reliable and energy efficiency vector control method. Although the DTC was

Proposed Circuit Evaluation								
V_{out}	V_{co1}	V_{co2}	Higher Torque Value (HTV)	Lower Torque Value (LTV)	Torque Ripple (TR) (TR=HTV-LTV)	Higher Speed Value (HSV)	Lower Speed Value (LSV)	Speed Ripple (SR) (SR=HSV-LSV)
540 V	270 V	270 V	1.4 Nm	0.95 Nm	0.45 Nm	2005 Rpm	1980 Rpm	25 Rpm
540 V	260 V	280 V	1.43 Nm	0.9 Nm	0.5 Nm	2008 Rpm	1977 Rpm	31 Rpm
540 V	250 V	290 V	1.47 Nm	0.88 Nm	0.59 Nm	2012 Rpm	1974 Rpm	38 Rpm
540 V	220 V	320 V	1.55 Nm	0.87 Nm	0.68 Nm	2015 Rpm	1973 Rpm	42 Rpm
540 V	200 V	340 V	1.61 Nm	0.87 Nm	0.74 Nm	2017 Rpm	1972 Rpm	45 Rpm
540 V	170 V	370 V	1.72 Nm	0.84 Nm	0.88 Nm	2021 Rpm	1969 Rpm	52 Rpm
540 V	140 V	400 V	1.93 Nm	0.6 Nm	1.33 Nm	2028 Rpm	1955 Rpm	73 Rpm
540 V	100 V	440 V	2.5 Nm	0.2 Nm	2.3 Nm	2032 Rpm	1935 Rpm	97 Rpm

Table 6: Proposed Circuit Evaluation.

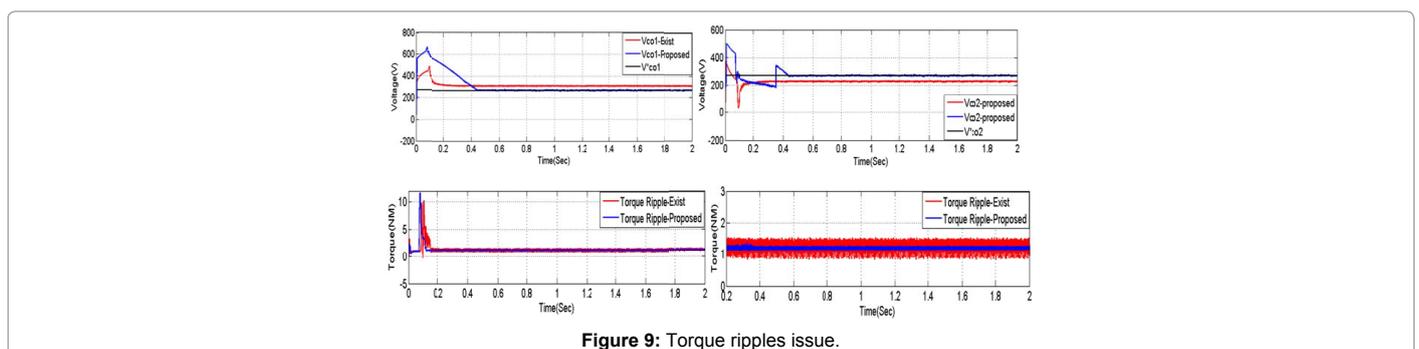


Figure 9: Torque ripples issue.

originally over the years, it has been applied and also PM motors Figure 9 [10-12]. Conventional DTC scheme for AC motors is given in Figure 2 Another vector control method which field oriented control (FOC). Almost half a century ago, the FOC method was also firstly proposed for asynchronous motors has been implemented for many given in Figure 3.

Sudden change in torque

Sudden change in torque shown in Figure 10.

Sudden change in speed

Sudden change in speed follows in Figures 11, 12 and Table 7.

Substances	Various Dual output converters		
	Converter accessible by Nami et al.	Converter accessible by Boora et al.	Anticipated converter for DTC
Switch count total	2	3	2
Total number of Diodes count total	2	3	2
Total number of Capacitors count total	2	2	3
Total number of Inductors count total	1	1	1
Total number of components count total	7	9	8
conversion	Buck	Buck-Boost	Buck-Boost
Switching states convolution	easy	multifarious	easy
Driver circuit convolution	average	multifarious	easy

Table 7: Performance Comparison of the conventional and proposed DTC Converter with various objects.

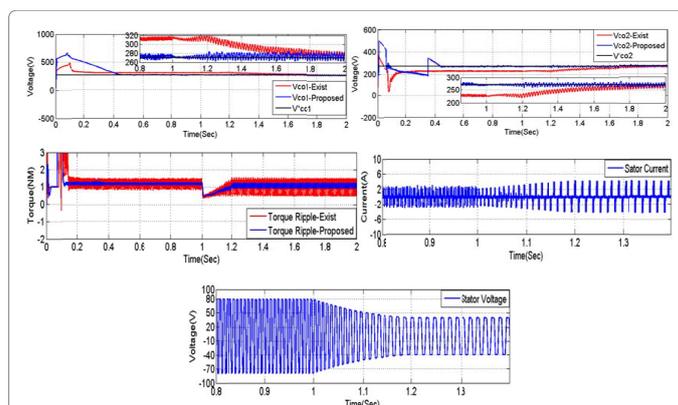


Figure 11: Performance of Parameters.

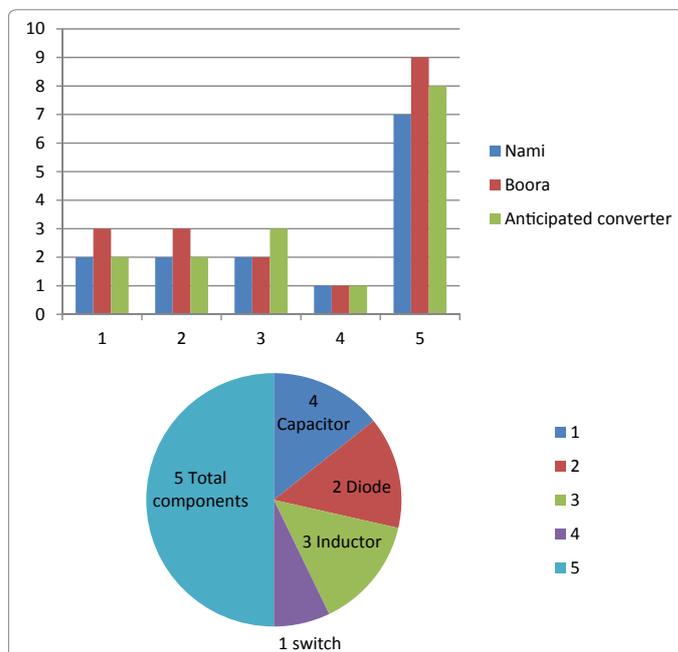


Figure 12: Performance comparison of the conventional and proposed DTC converter with various objects.

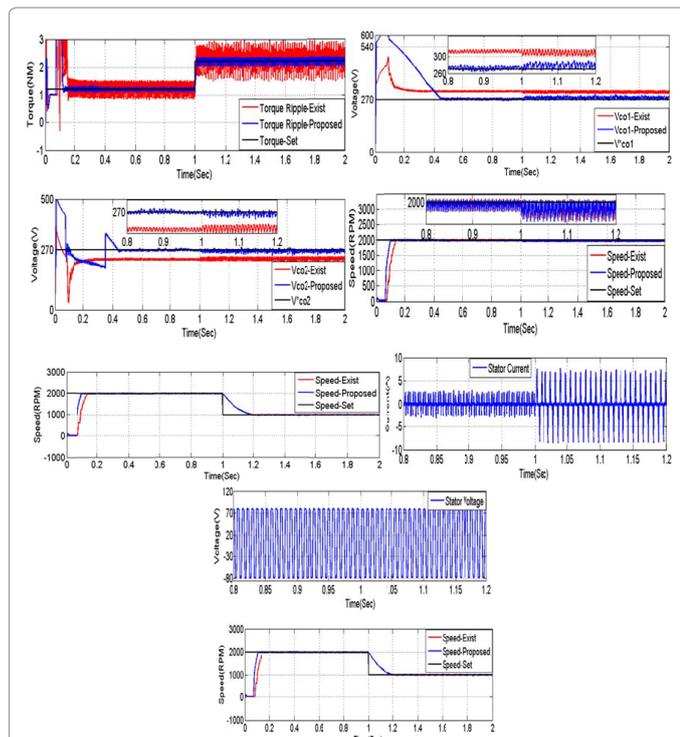


Figure 10: Sudden change in torque.

Conclusion

In this proposed research presents in the dsPIC microcontroller (dsPIC30F4011) based 120 degree mode is used for gate pulse generation in the B4 Inverter fed brushless DC Motor drive. Brushless DC drives which is preferable for compact, low maintenance and high reliability system in order to reduce the mechanical strength so it proposed and convenient results were carried out. In this scheme, the Pulse width modulation is applied to switches of the B4 Inverter, This Pulse width modulation scheme can eradicate the offset voltage in the back Electromotive force signal caused by the voltage drop of the Insulated bipolar transistor and also increase system efficiency by reducing the conduction loss is achieved compared to conventional converter. The simulation results are verifying the feasibility of the system. The concept of the capacitor voltage balancing is also done to obtain equal voltage across the capacitors. Since converter used Sensorless control operation no hall sensors, therefore, the system becomes robust, optimized design of the Brushless DC Motor achieved higher efficiency and better speed, current were formulated.

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