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Modeling and Control of Four switch inverter fed Brushless Dc motor Drive Using Low cost controller and Enhanced Buck Boost converter

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ABSTRACT

The paper deals with the speed control of Brushless DC Motor drive by low cost controller and B4 Inverter with new converter design (Four Switch Inverter) rather than conventional inverter (Six Switch Inverter) is proposed. The conventional Six switch Inverter is modified into B4 Inverter in order to reduce the switch leg failure, and Total Harmonic Distortion.This facilitates the operation of voltage source Inverter at fundamental frequency switching by using the Electronic commutation technique rather than Mechanical commutation.In addition we propose single phase Rectifier and Three phase voltage source Inverter, dsPIC controller to generate the multiple carrier PWM pulses for B4 Inverter which is fed to the Permanent Magnet Brushless DC Motor to obtain the desired motor speed. The proposed Research mainly focused on the new topology of Buck boost converter design for B4 inverter,By this new modified buck boost Enhancement converter design motor speed are controlled and voltage imbalance in the capacitors are avoided the capacitor voltage is similar voltage level is obtained during the buck and the boost mode operation of the converter side, So results with improved quality of Boosted up output DC Power is obtained.Simulation Modeling Results are carried out by Matlab/Simulink environment and Portable Experimental Hardware is developed. Results are carried out Sucessfully and Validated for various operating parameter conditions.

KEYWORDS

B4 Inverter, dsPIC Controller, Buck Boost converter, Permanent Magnet Brushless dc Motor, Multiplecarrier PWM Pulses, Simulation.

1. Introduction

The Hybrid Electrical Vehicles (HEVs) instead of fossil-fuel vehicles are preferred as the rapidly growing population increases the demand in energy consumption, increase in oil and natural gas prices and the depletion of fossil fuels. The HEVs are proposed to provide a environmental

POWER = 250W	POWER = 500W	POWER = 800W
VOLTAGE = 24V	VOLTAGE = 48V	VOLTAGE = 48V
BRAND NAME = EVFUTURE ELECTRIC VECHICLES	BRAND NAME = XINGWEI	BRAND NAME = TAIZHOU QUANSHUN MOTOR CO., LTD.
MODEL NO = CY250	MODEL NO = 14inch205	MODEL NO = 800W 48V Bicycle Hub Motor
Max speed = 10 RPM/Volt	Max speed = 35KM/H	Max speed = 45KM/H

friendly operation (noiseless) with the usage of battery in transportation applications [1], [2].

The recently used Brushless DC Motor hub motor[3][4][5] specifications in HEVs are shown in table 1.Generally, the voltage source inverter (VSI) feeding three phase motor is the six-switch three-phase inverter (B6-Inverter). Some applications such as electric and hybrid propulsion systems should be as reliable as possible which cannot be achieved effectively. Within this requirement, the reconfiguration of the B6-Inverter into a four-switch three phase inverter (B4-Inverter) reduces the prospect of a switch/leg failure and also reduce the cost and size of the system avoiding the cumbersome which is currently given an increasing attention [6]–[9] comparison of Six switch and Four switch are show in Table.2.

The Brushless DC Motor is also known as an electronically commutated motor because an electronic commutation based on the rotor position of the motor is used rather than a mechanical commutation which has disadvantages like sparking, wear and tear of brushes and technical hitches in commutator assembly [10], [11]. The speed of the Brushless DC Motor is directly proportional to the applied dc link voltage. Hence the speed control is achieved by varying the variable dc link voltage of B6-Inverter. This allows the fundamental frequency switching of B6-Inverter (i.e., electronic commutation) and offers reduced switching losses [12], [13]. The B6-Inverter fed Brushless DC Motor drive utilizes a pulse width-modulated technique with a constant dc link voltage for the speed control of the motor. This offers higher switching losses in B6-Inverter as switching losses increase as the square function of switching frequency. To overcome this switching losses the modified buck-boost converter for B4 inverter were proposed. Henceforth electric vehicle hub Brushless DC Motor are designed using B6 inverter but the proposed the electric hub Brushless DC Motor is designed by using B4 inverter for the speed control.Proposed Research involves Sensorless too. Performance of Sensorless Brushless DC Motor drive is better than conventional DC drive[14-17]. This Sensorless technique drive is widely used due to its high efficiency and reliability it also have the advantage of wide range of speed control. The Permanent Magnet Brushless DC Motor drive is used various instruments which are used in industry, medical and house hold appliances. Brushless DC Motor are also known as the synchronous motor due to its permanent magnet present on rotor and stator has three phase winding using conventional dc motor with four switch inverter[18-20] has many problems such as noise sparking, occurs in the brushes and maintenance is difficult as brushes require often replacement. Hall Effect sensors for sensing the rotor position these problems can be eliminated by this proposed Research.

Materials and Methods ·

Figure 1 demonstrates the modified buck boost converter with B4-Inverter fed Brushless DC Motor drive system. The proposed system includes front end modified voltage balancing converter (buck boost converter) and the rear end B4 inverter fed Brushless DC Motor drive. The front end modified converter includes intermediate capacitor C_1, power switches S_1&S_2, input inductanceL_1, power diodes D_1&D_2 and voltage balancing capacitors C_{01}&C_{02}. On the other hand, the rear end includes a B4 inverter switches $(Q1-Q4)$ and a Brushless DC Motor.

Mode 0

When switch (S_2) is in "ON" state and switch(S_1) is in "OFF" state, the current in input inductance (L_1) drops (discharging) to intermediate capacitor(C_1). Thus the intermediate capacitor (C_1) gets (charging) from an input inductor (L_1). Consequently, voltage across the intermediate capacitor C_1increases. The equivalent circuit of proposed system at an instant of mode 0 is shown in fig 2(a).

Mode 1

When switch () is in "ON" state, the input inductance (l charging from input dc supply. Thus, the current through the input inductance increases. Simultaneously, current in the intermediate capacitor (C and input supply acts as series sources and its energy is transferred to the output capacitor (C_c. As a result, the voltage across the output balancing capacitor C increases as shown in equivalent circuit 2(b).

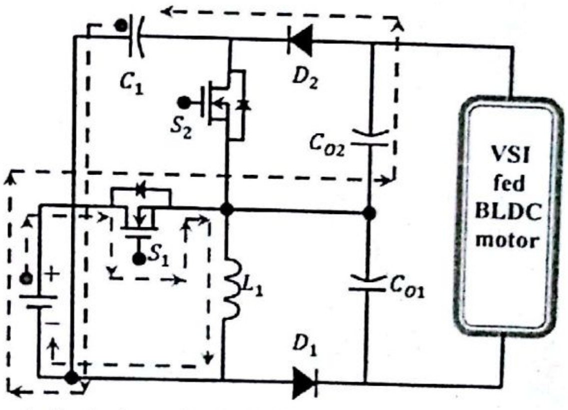


Figure. 1 Equivalent circuit Mode0 Proposed system schematic diagram

Mode 2

When switches (S and () is in "OFF" state, current in inductance (L completely discharging to output balancing capacitor (C_c via diode ( ). Thus, the voltage across the balancing capacitor increases as shown in fig 2(c).

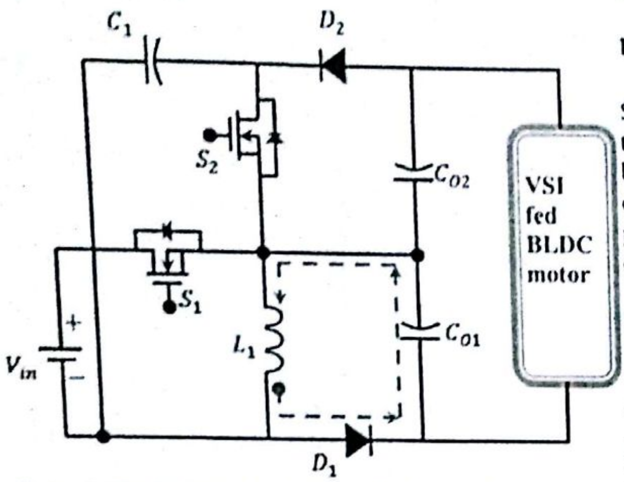


Figure.2 Equivalent circuit Mode() Proposed system schematic diagram

------------- **Represents switch conduction**

------------- **Represents circuit closing**

Control Algorithm of proposed system

The control diagram of proposed system is shown in fig 3. On the basis of voltage follower approach, the enhanced buck boost converter control is employed for the speed control of Brushless DC Motor motor. Here electronic commutation method of B4-Inverter fed Brushless DC Motor is preferred rather than mechanical commutation i.e. pulse width modulated inverter. The switching stress and losses are reduced in the B4-Inverter. The speed control of Brushless Dc Motor motor is effectively attained with dc link voltage control using modified buck boost converter.

A reference dc link voltage (V_{dc}^{*}) is generated as

$$V\_dc^{\wedge *} = k\_volt \times \omega^{\wedge} \qquad (1)$$

where k_{volt} and ω^{*} are the motor's voltage constant and the reference speed, respectively.

The dc link voltage error signal (V_{dce}) is produced by comparing the reference output voltage(V_{dc}^{*}) with the sensed output voltage (V_{dc}) as

$$V_{err}(k) = V_{dc}^{*}(k) - V_{dc}(k) \qquad (2)$$

Where k denotes the kth sampling instant. This error voltage signal (V_{dce}) is given as input to the voltage proportional–integral (PI) controller for generating a controlled output voltage (V_T) as

$$V_T(k) = V_T(k-1) + k_p\{V_{dce}(k) - V_{dce}(K-1)\} + k_i * V_{dce}(k)$$

Similarly the voltage balancing capacitor (C_{01}) is controlled for maintain the constant dc voltage across the balancing capacitors. The balancing capacitor voltage error (V_{ce}) is produced by comparing the reference output voltage (V_{CO1}^{*}) with the sensed output voltage (V_{CO1}) as

$$V_{ce}(k) = V_{CO1}^{*}(k) - V_{CO1}(k) \qquad (4)$$

Where k denotes the kth sampling instant. This error voltage signal (V_{ce}) is given as input to the voltage proportional–integral (PI) controller for generating a controlled output voltage $(V_{\frac{T}{2}})$ as

$$V_{\frac{T}{2}}(k) = V_{\frac{T}{2}}(k-1) + k_p\{V_{ce}(k) - V_{ce}(K-1)\} + k_i * V_{ce}(k) \qquad (5)$$

Where k_p and k_i are the proportional and integral gains of the voltage PI controller.

An electronic commutation of the Brushless DC Motor includes the proper switching of VSI in such a way that a symmetrical dc current is drawn from the dc link capacitor for 120° and placed symmetrically at the center of each phase. A Hall-effect position sensor is used to sense the rotor position on a span of 60°, which is required for the electronic commutation of the Brushless DC Motor

A line current is drawn from the dc link capacitor whose magnitude depends on the applied dc link voltage, back electromotive forces, resistances, and self-inductance and mutual inductance of the stator windings. Table 1 shows the different switching states of the VSI feeding a Brushless DC Motor motor based on the Hall-effect position signals (*Ha* – *Hc*).

The TPC used in a B4-Inverter fed BLDC motor drive system is illustrated as in Figure 3. The system proposed comprises PV powered DOBB converter and battery powered bidirectional BB converter function as a backup supply for BLDC motor that operates under demand condition. The newly introduced TPC converter consists of Buck-Boost switch ( ), power sharing switch ( ), two power diodes ( ), a single buck-boost inductor ( ), intermediate capacitor ( ), and output capacitors ( ). Similarly, bidirectional BB converter comprises the buck switch

( ), boost switch ( ) and battery inductor ( ). However, the rear end B4-inverter is inclusive of the four switches ( ) and a BLDC motor.

The duty of switch ( ) in unidirectional DOBB converter is for the extraction of the maximum power from PV panel using the MPPT algorithm. As the energy conversion efficiency of PV supplies is less, a correct matching between the PV supplies and the electric load have to be taken into consideration. Hence the coupling between the motor load and the PV module is realized through an MPPT algorithm so as to operate the PV system at its maximum output power for any temperature and solar radiation level. The fundamental P&O technique does the tracking of the MPP by raising or reducing the output voltage repeatedly at the MPP of the PV module besides being considerably simple to implement. Furthermore, the control of total output voltage ( ) to preferred value is the responsibility of the power sharing switch ( ) present in DOBB converter.

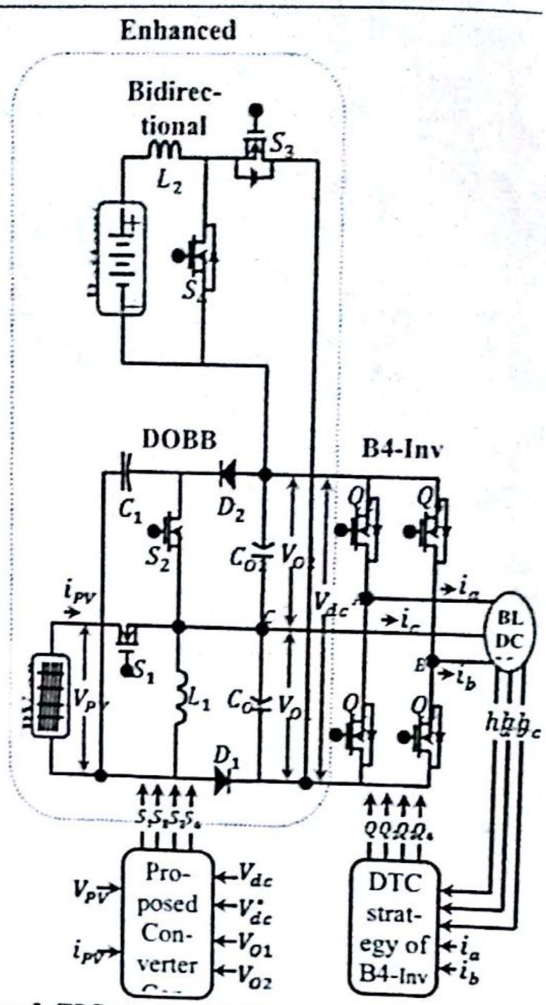


Figure 3 TPC employed B4-inverter fed BLDC motor drive system

A BLDC motor contains three phase windings on the stator and permanent magnets on the rotor. The BLDC motor is also referred to as an electronically commutated motor as an electronic commutation is dependent on rotor position utilized in place of a mechanical commutation that has drawbacks such as sparking and wear and tear of brushes and commutator assembly.The TPC proposed also tackles the DTC of BLDC motor drives driven by B4-Inverter in comparison with the B6-Inverter in traditional drives. The B4-Inverter will be considered to be a reconfigured topology of the B6-Inverter if a switch/leg failure that indicates the advantage of critical reliability for several applications, particularly in electric and hybrid propulsion systems.

When partial shading occurs in the PV array, battery in the form of energy storage device and a bidirectional DC-DC converter are used to satisfy the demand for power. Among the various configurations of PV technology, a stand-alone PV-battery powered back-up system could be utilized in various types of applications. A rechargeable battery is usually exploited in the system for energy saving when the solar energy generated exceeds the energy needed by the load. In this the buck switch (   ) is in an active state. The energy saved can be helpful in maintaining the system operation while the shading to the PV panel is carried out. Hence the boost switch (   ) also is in an active state. Two power switches (   ) present in the converter structure act as the chief controllable elements controlling the power flow of the converter.

The important accomplishments of the proposed work are below.

1. The DOBB converter is developed to work in discontinuous conduction for boosting the battery life time. Moreover, the dual output capability of this converter is appropriate for B4-inverter, and therefore the expense of this new system is reduced considerably.
2. Due to the two stage power conversion present between PV and load ports or between battery and load ports, the power flow associated with the converter is largely enhanced.
3. The DOBB converter design along with reduced number of components is proposed for minimizing the current conduction losses. The DOBB converter is utilized for tracking maximum power from PV and it yields preferred voltage to DC link.
4. Based on the three-domain load voltage control technique, the load voltage is always controlled with high quality in every power flow scenario.

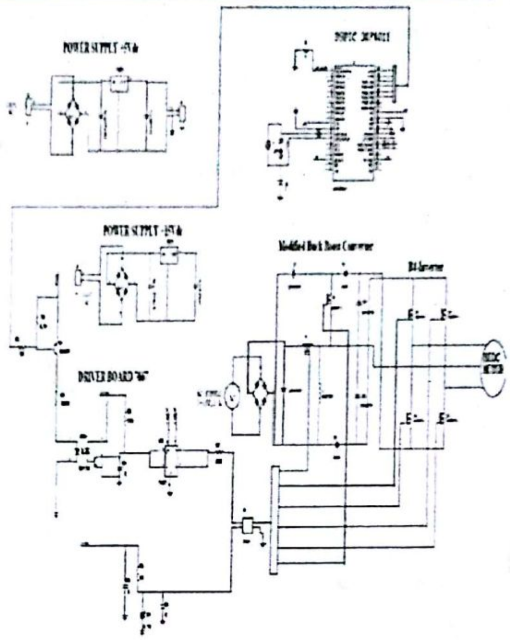


Figure. 4 Structure of Brushless DC Motor Unit

Mathematical Modeling of Modified Buck Boost Converter after the capacitor voltage is balanced

Input Voltage across the capacitor C_1 is expressed as

$$Vdc_1 = C1\int(I_2 - I_1)/T_{ON1} \qquad (6)$$

At this instant, the energy input to the capacitor C_1 from the source

Vdc_1 is expressed as

$$Ei_1 = Vdc_1 \cdot Is_1 \cdot T_{ON1} \qquad (7)$$

At $t = T_{OFF1}$, the Modified Buck-Boost converter across switch S_1, switch S_2 is turned OFF and the current through the inductor L_1 falls linearly from I_2 to I_1.

The average output voltage of Modified Buck-Boost converter across switch S_1can be expressed using (8)

$$Vob1 = Vdc_1 + c_1 \cdot dIs_1 \cdot T_{OFF1} \qquad (8)$$

At this instant, the energy released by the inductor L_1 to the LOAD is given by (9)

$$Eo_1 = (Vob_1 - Vdc_1)Is_1 \cdot T_{OFF1} \qquad (9)$$

Considering the system to be lossless, the average output voltage of Modified Buck-Boost converter across S_1 is obtained using (10)

$$Vob_1 = Vdc1_1 - K_1 \qquad (10)$$

The change in voltage across the capacitor C1 can be expressed by (11)

$$dV_{C1} = Io_1 \cdot Vob_1 - L_1 \cdot (I_2 - I_1)Vob_1 \cdot f \; *C_1 \qquad (11)$$

where Vdc_1 is the DC source voltage I, Is1 is the DC source current I, K_1 is the duty cycle of boost chopper I, Vob_1 is the output voltage of Buck Boost converter and f is the switching frequency of Buck Boost converter. Modes 2 and 1 operations: In modes 2 and 1 operations, the source voltage Vdc_2 is boosted to Vob_2 by activating the Buck Boost converter switch S_2 and the conducting switches are S_1 and S_2. The respective equivalent circuit for these operating modes is given in Figs.2 a,b and c. At t = T_{ON2}, the Buck Boost converter switch S_2 is turned ON and the current through the inductor L_2 raises linearly from I_3 to I_4. The voltage across the inductor L_1 is expressed as

$$Vdc_2 = L_2 \cdot (I_4 - I_3) \cdot T_{ON2} \qquad (12)$$

At this instant, the energy input to the inductor L_1 from the source can be calculated using (8)

$$Ei_2 = Vdc_2 \cdot Is_2 \cdot T_{ON2} \qquad (13)$$

At t = TOFF$_2$.

Buck-Boost converter across switch S_1 is turned OFF and the current through the inductor L_2 falls linearly from I_4
to I_3.

The average output voltage Modified Buck-Boost converter across switch S_2 is obtained using (14)

$$Vob_2 = Vdc_2 + L_2 + dIs_2 \cdot T_{OFF2} \qquad (14)$$

At this instant, the energy released by the inductor L_1 to the DCLM is given by (15)

$$Eo_2 = (Vob_2 - Vdc2)Is_2 \cdot T_{OFF2} \qquad (15)$$

Assuming the system to be lossless, the average output voltage of Modified Buck-Boost converter across switch S_2 is obtained using (11)

$$Vob2 = Vdc21 - K_2 \qquad (16)$$

dSPIC controller

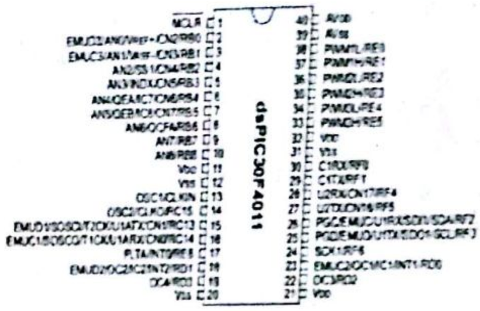


Figure. 5 dspic Controller Pin configuration

Technical Core Features for considering the controller:

- It has a modified Harvard architecture.
- It has a 16 x 16-bit working register array.
- Two, 40-bit wide accumulators with optional saturation logic.
- 30 interrupt sources
- 3 external interrupt sources
- 8 user selectable priority levels for each interrupt source.

Table.3 Technical Pin Details of proposed research:

S.NO	PIN NO
1	Memory clear
2	dsPIC (5V)
3	Ground
4	Crystal oscillator
5	Sequence
6	dsPIC controller output
7	Speed selection and input speed

Port RB and RC are bidirectional I/O port.

Controller Unit :

The dsPIC30F module has a 16-bit (data) with modified Harvard architecture with an upgraded instruction set, including efficient support for DSP. The most important advantage of dsPIC is that the instructions are executed in a single cycle. The working registers in the controller can act as a data, address, or address offset register.The instructions are generally associated with a predefined Addressing mode group depending upon its functional requirements.

Driver Unit (IC 7667)

The ICL7667 is a dual high-power CMOS inverter whose inputs respond to TTL levels while the outputs can swing as high as 15V.The ICL7667 is well suited for driving power MOSFETs in high frequency power converters.The ICL7667can be directly driven by common pulse-width modulation control ICs.

Optocoupler:

The optocoupler is generally present between the controller unit and the driver unit. The optocoupler normally isolate these two units incase of any occurrence of a short circuit.The 6N135, 6N136. and HCPL4502 optocouplers each consists of a light-emitting diode and an integrated photon detector composed of a photodiode and an open-collector output transistor.Separated connections are provided for the photodiode biasing and the transistor-collector output connection.

MOSFET:

The metal–oxide–semiconductor field-effect transistor (MOSFET. MOS-FET. or MOS FET) is a type of transistor which has four terminals namely Gate(G), drain(D),source(S) and body terminals. The main advantage of a MOSFET over a regular transistor is that it requires a very little current for turning on whereas it delivers much higher current for turn off process. In enhancement mode MOSFETs, a voltage drop across the oxide induces a conducting channel between the source and drain contacts via the field effect.

B4 Inverter:

The operation basis of the B4-inverter-fed Brushless DC Motor drive. Figure.6 shows the connections of the drive with two phases (phase-aand phase-b) of the Brushless DC Motor motor supplied through the B4-inverter legs, while the third one (phase-c) is linked to the middle point of the dc-busVoltage.

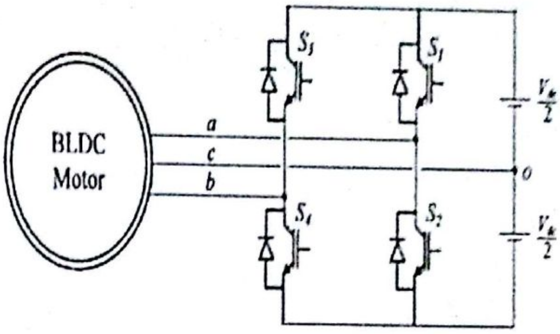


Figure.6 Operation of structure topology of B4 inverter

Operation under Two-Phase Conduction Mode: Let us call V1, V2, V3, and V4 the four active voltage vectors generated by the B4-inverter under the two-phase conduction mode. The corresponding switching combinations (S1, S2,S3,S4) are equal to (1000), (0010), (0100), and (0001), respectively, where, from left to right, the binary values denote the state of the upper and lower switching signals, corresponding to phase-a and phase-b, respectively. These combinations yield four operating sequences characterized by the conduction of phase-c.The two remaining sequences are characterized by the simultaneous conduction of phase-a and phase-b, and inevitably of phase-c, leading to a three-phase conduction mode.

Table No. 4 Case of the B4-inverter under the two-phase conduction mode.

S(1234)	Va	Vb	Vc
(1000)	Vdc/4	0	-Vdc/4
(0010)	0	Vdc/4	-Vdc/4
(0100)	-Vdc/4	0	Vdc/4
(0001)	0	-Vdc/4	Vdc/4

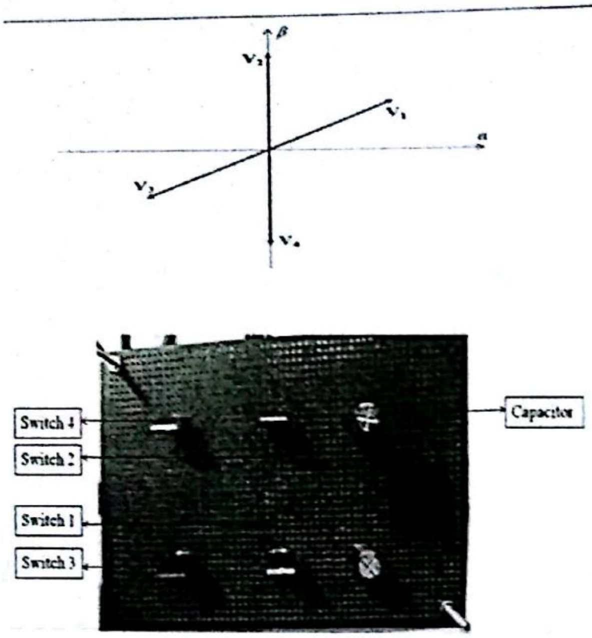


Figure No.7 Active voltage vectors generated by the B4- inverter in the two-phase conduction mode and B4 inverter switches.

HARDWARE IMPLEMENTATON RESULTS AND DISCUSSION:

The controller unit consists of the dsPIC controller which controls the whole process. The supply is given to the unit with the help of step down transformer through the rectifier and voltage regulator. The dsPIC controller gets the feedback from the feedback circuit and controls the speed of the Brushless DC Motor motor according to the set speed with the help of the high level language C.Figure ... describes the implementation of the controller unit.

DRIVER UNIT

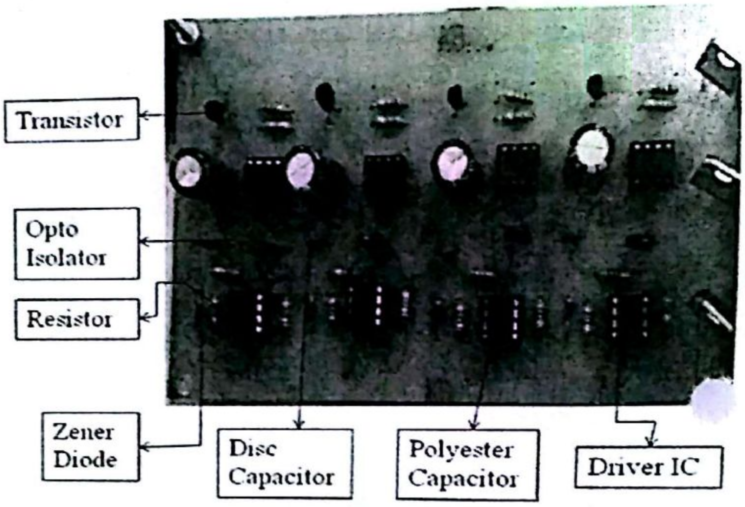


Figure No.8 Front view of Driver unit for proposed research

The driver unit consists of the MOSFET drivers connected in series and optocouplers are implemented to prevent the drivers. The driver unit acts as a voltage controller unit and the MOSFET driver sends the controlled sequence to the controller unit. It also gets +5V supply from the controller unit for the resistors.

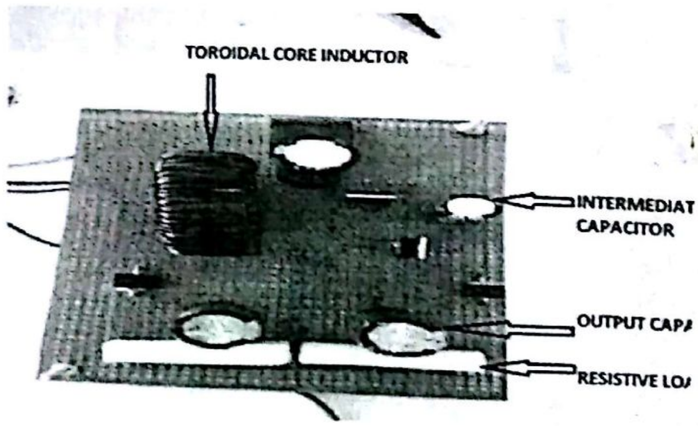
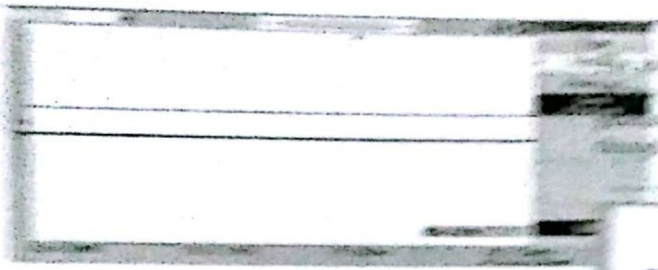
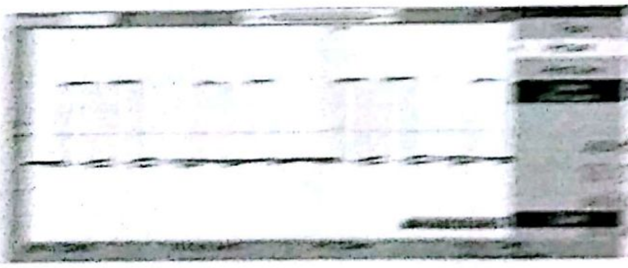
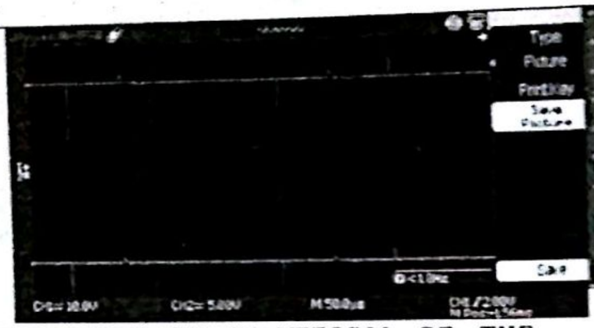


Figure No.9 Front view of Hardware design of the converter image for proposed research







OUTPUT VOLTAGE WAVEFORM OF THE CONVERTER

Figure 15 Output Voltage Waveform During Boost Mode

The above graph denotes the performance of the converter during boost mode to produce a voltage output of about 48V.The 48V generally appears to be as 24V and another 24V across each capacitors. The variation in voltage level also appears to be same across the two capacitors.

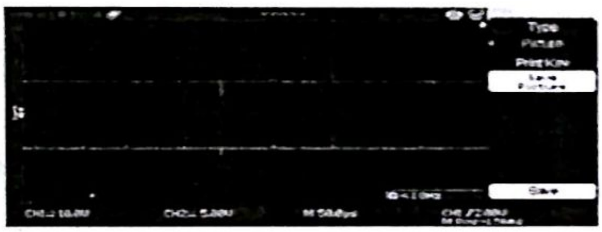


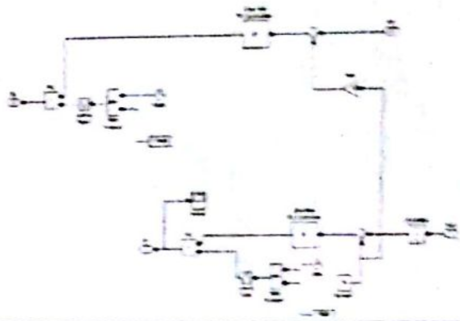
Figure.16 Output Voltage Waveform During Buck Mode

The converter produces a voltage level of about 18V during the buck mode operation. A selection switch is generally present to make the converter work during the buck mode operation.

simulations Results and Discussions

Simulation Diagram of the Controller

The simulation of the controller is listed separately inorder to denote the looping and the unit time constant of the controller. The Gain constants and the lookup tables are also clearly listed below in the diagram.



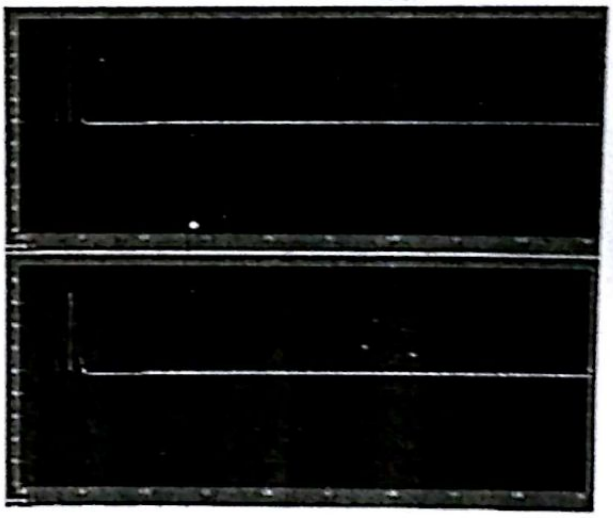


Figure.17 Simulation Diagram of the Controller, Comparison of Modified buck and boost converter, Modified buck Converter Operation operation

Prototype Modified Buckboost converter with Brushless DC Motor motor Unit for different speeds

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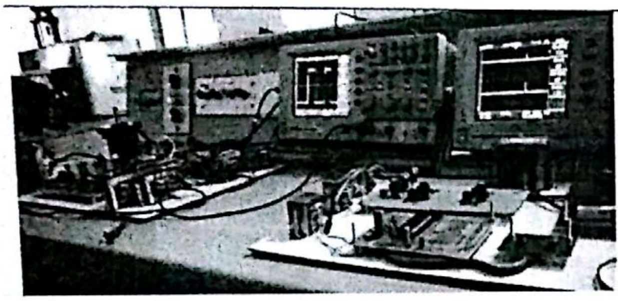

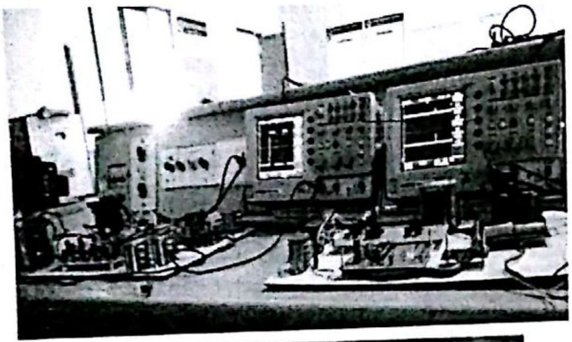

Figure .18 Comparison of Modified buck and boost converter operation

BLDC MOTOR SPECIFICATION

Rated voltage	: 24 V
Rated power	: 40 W
Ratedcurrent	:1.6 A
Rated rpm	: 5000rpm
Operatingtemperature	:-30°C -90°C
Insulation resistance	: 1.34Ω
Motor size	: 46 mm long

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 hardware implementation 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.In this research we significantly uses Sensorless control so for angle position hall sensing fully avoided. 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 simulation results were carried out. The simulation of the Brushless DC Motor is done using the software MATLAB/SIMULINK Whose back EMF, phase voltage phase current, rotor speed waveform are analyzed and incorporated the speed of rotor is 1400 rpm,800 rpm,200 rpm were analysed.The converter used less number of Insulated Bipolar Switches which Evaluate the Conventional Converter. The Back Electromotive force compensating and direct current controlling for Brushless DC Motor drives analyzed and switch leg failure are avoided. In this scheme, the Pulse width modulation is applied to high side switches of the converter, 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 insulator and also increase system efficiency by reducing the conduction loss is achieved. 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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