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Z-SOURCE NEUTRAL POINT CLAMPED INVERTER FED MOTOR DRIVE

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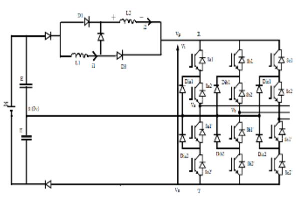
Graphical abstract



Abstract

Z-source inverter is a recently invented new power conversion concept mainly developed for fuel vehicular applications by advantageously utilizing the shoot through states to boost the DC-bus voltage. The impedance network contains two inductors and three diodes and is connected in between the DC source and inverter bridge. This shoot through state provides the unique buck-boost feature to the DC-link voltage and hence the AC output voltage of the inverter. By varying the boost factor and modulation index, the output AC voltage can be maintained at any value between zero and infinity regardless of DC voltage giving a wide range of voltage. Thus Z-source inverter overcomes the conceptual and theoretical barriers and limitations of the traditional inverters and provides high efficiency single stage structure for buck and boost operation. Previous publications have shown speed control of BLDC motor by controlling the DC link voltage of voltage source inverter using bridgeless buck boost converter. This paper presents the speed control of BLDC motor by controlling the shoot through states of Z-source neutral point clamped inverter using a space vector modulation technique which possess advantage of reduced harmonics with boosted output voltage. The proposed technique is demonstrated in simulation by using MATLAB software.

Keywords: z-source inverter, neutral point clamped inverter, space vector modulation technique

1.0 INTRODUCTION

In house hold applications such as fans, pumps, blowers, mixers etc. efficiency and cost of the low power motor drives are the major concerns. Due to high efficiency, low electromagnetic interference problems , low maintenance requirements, high flux density per unit volume (BLDC) motor are very common in applications such as HVAC, medical equipment, transportation etc. Mechanical commutation of brushed DC motor has disadvantages like wear and tear of brushes and commutator assembly and sparking. All the above problems are eliminated in BLDC motor because rotor position is used for an electronic commutation.

The cascaded inverters, diode clamped inverters and the capacitor clamped inverters are the three most common topologies of multilevel inverters. Among these, the neutral point clamped inverter, in medium voltage drives, has become an established topology. For applications such as photovoltaic array, fuel cells, and in order to meet the required output voltage, boost converter is required to boost the DC voltage which increases the system complexity. To overcome the above problem in traditional VSI inverter the Z-source [2] inverter topology has been proposed.

For all sorts of power conversion, the Z-source concept can be applied. In NPC inverter, the Z-source converter can be extended. Between two isolated DC source and a traditional inverter, two additional Z-source networks have been connected. Due to the presence of two Z-source network, the Z-source NPC inverter used for achieving voltage buck-boost conversion is more expensive and for balancing the boosting of each Z-source network it requires complex modulator. Using a single Z-source network the design and control of NPC inverter has been presented to overcome the cost and modular complexity issues.

In renewable energy resources such as wind turbines, PV system, fuel cell stacks, reduced element count Z-source inverter can be applied in grid connected system. Reduced element count NPC inverter reduces the volume and cost in addition to increasing the efficiency and facilitating the control. It is also used in fans, conveyor belts and water pumps applications.

As a means of contribution for this paper, in order to control Z-source NPC [6] inverter, space vector modulation algorithm has been developed. Proposed space vector modulation technique was simulated by using MATLAB software.

2.0 EXISTING SYSTEM

To control the speed of BLDC [1] motor, the existing system uses power factor corrected bridgeless buck boost converter and voltage source inverter. The common limitations and problems of voltage source inverter based adjustable speed drives is its obtainable output voltage is limited quite below the input line voltage.

Performance and reliability are compromised by the V-source inverter structure, because 1) miss-gating from EMI can cause shoot-through that leads to destruction of the inverter, 2) the dead time that is needed to avoid shoot-through creates distortion and unstable operation at low speeds, and 3) common-mode voltage causes shaft current and premature failures of the motor.

3.0 MITIGATION OF PROPOSED SYSTEM

The proposed systems uses Z-source inverter fed three [7] [8] levels neutral point clamped inverter to control the speed of BLDC [1] motor. Z-source inverter overcomes the aforementioned problems. A Z-source inverter based ASD system can

(i) Produce any desired output AC voltage, even greater than the line voltage, regardless of the input voltage, thus reducing motor ratings;
(ii) Provide ride-through during voltage sags without any additional circuits.
(iii) Improve power factor and reduce and harmonic current and common-mode voltage.

The x-shaped Z-source network has the following drawbacks:

(i) Capacitors are used in the Z-source network, which necessitates high-voltage or large capacity capacitors to be used, which may result in large volume, cost expensive, and reduce the life span of system.
(ii) It cannot suppress the inrush current and the resonance introduced by Z-source capacitors and inductors[7] at start up, thus causing the voltage and current surge, which may destroy the devices.
(iii) It regulates boost factor only by adjusting the shoot-through duty-ratio.

To solve the drawbacks in x-shaped network, a new Z-source inverter topology is presented with no capacitor and by reducing the inherent inrush current limitation at start up. It can suppress the resonance thoroughly by removing capacitor and improve the efficiency of power supply.

The unique feature of the three-level Z-source inverter [7] [8] is that the output ac voltage fundamental can be controlled to be any value between zero and infinity regardless of the DC source voltage. Thus, the Z-source inverter [3] is a buck–boost inverter that has a very wide range of obtainable output voltage.

The buck-boost operation [10] of the inverter is based on the boost factor, which in turn is based on the placement of shoot-through time period in between the active states in a switching cycle. The shoot through zero state does not affect the PWM control [4] [5] of the inverter, because it equivalently produces the same zero voltage to the load terminals.

4.0 BLOCK DIAGRAM OF PROPOSED TECHNIQUE

The block diagram of proposed system consists of a DC supply source, an impedance network [9], three-level neutral point clamped Inverter Bridge and BLDC [1] motor. The AC voltage is rectified to DC voltage by the front end rectifier. The DC source can be either a voltage source or a current source.

The DC voltage fed to the Z-source network [3]. This network allows the inverter to be operated in a new state called the shoot-trough state in which the two switching devices in the same inverter leg are simultaneously switched-on to produce the effect of a short circuit to the DC-link.

These networks also act as a second order filter and it requires less inductance and less capacitance. The output of Z-source inverter is fed to neutral-point clamp inverter. The Neutral Point Clamped topology offers advantages such as reduced switching losses, smaller output current ripple, and split of total +/- supply voltage. Only half of the voltage has to be switched, and this also cuts the switching losses in the transistor by half. This will lead to further reduction of the switching losses.

The NPC topology will have lower ripple in the output current and half of the output voltage transient. This will reduce the effort for filtering and isolation in the filter inductor. The DC voltage is divided into positive and negative voltage, which supports the serial connection of DC capacitors without the need for leakage current compensation. Output of neutral point-clamped inverter is fed to BLDC [1] motor. Speed of BLDC motor is sensed by using hall sensor and its output is fed to the pulse generator of NPC circuit. Space vector modulation[2] technique is to control the DC link voltage of NPC inverter. Through this paper, the Power factor at AC mains is improved, the overall efficiency is increased and the Total Harmonic Distortion (T.H.D) is achieved up to 6 %. The block of L-ZSI diagram is shown in Figure 1.

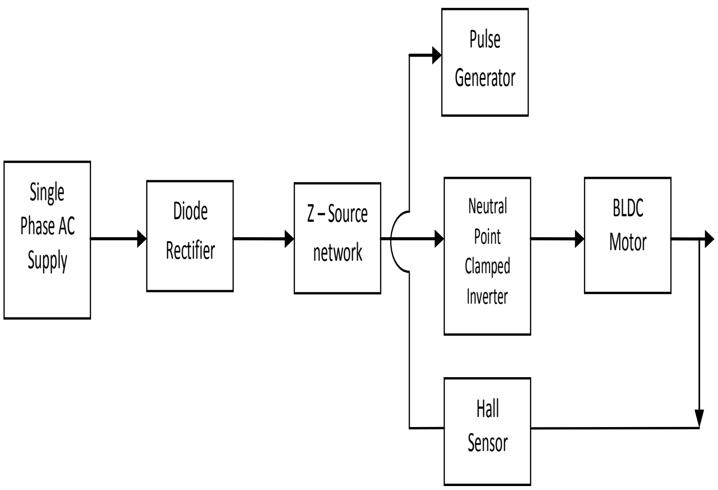


Figure 1 Block diagram

5.0 SPACE VECTOR MODULATION FOR NPC INVERTER

In a traditional three-level NPC inverter [3], only switching transitions between the "R" state and the "S" state or the "T" state and the "S" state are permitted. Switching directly between the "R" state and the "T" state is not allowed because it results in all four switches changing state, which results in unequal dynamic voltage and double the switching loss. Theoretically, a shoot-through state can be introduced on any phase which is switched to the zero level (S) without affecting that phase voltage.

However, the effect on the line-to-line voltages must also be taken into account. It is to be noted that when any phase has UST applied, the positive rail (R) is at the same potential as the DC mid-point (S). Similarly, during LST, the negative rail (T) is at the same potential as the DC mid-point (S). Consequently, it is only possible to use the UST state on a given phase when it is connected to S and the other two phases are connected either to S or T in order to get the correct line-to-line voltages. Similarly, an LST state can only be used when the other two phases are S or R.

Figure 2 shows the topology of proposed system. Comparing the sequences shown in Figure 2, it is observed that the only difference between them is the insertion of a UST state in phase A to the left of the E-active state {RTT} and the insertion of an LST state in phase C to the right of the E-active state {RST}, respectively, within half switching period, *T/2*. Insertion of shoot-through states at these instants will not result in additional switching since, for example, the transition from {STT} to {RTT} can be achieved by switching devices {Sa1,Sa2,Sa1',Sa2'} from {OFF, ON, ON, OFF} through {ON, ON, ON, OFF} to {ON, ON, OFF, OFF} .The process is reversed in the remaining half switching period. In Figure 3 and Figure 4, modulation of Z-source NPC inverter in triangle 3 and triangle 2a are shown.

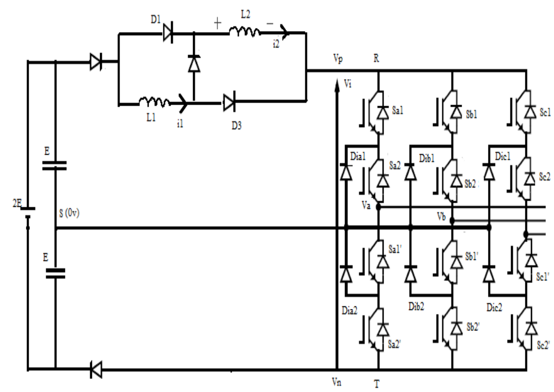


Figure 2 Topology of proposed system

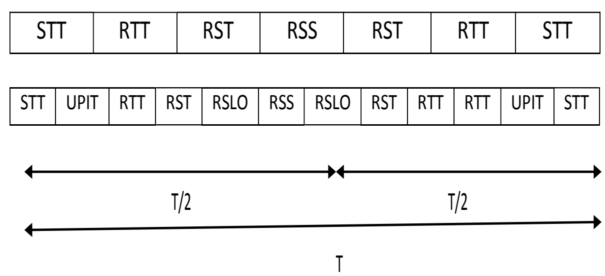


Figure 3 Modulation of Z-Source NPC Inverter in Triangle 3

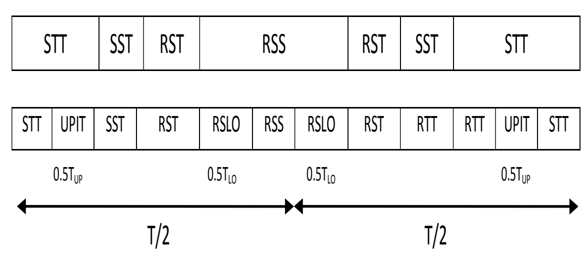


Figure 4 Modulation of Z-Source NPC inverter in Triangle2a

Table 1 Switching sequences and insertion of shoot-trough states in Triangle 2-4

Triangle	Switching Sequence
2a	{STT} → {UPTT} → {STT} → {RST} → {RSLO } → {RSS}
2b	{RRS} → {RRLO} → {RSS} → {RST} → {UPST} → {SST}
3	{STT} → {UPTT} → {RTT} → {RST} → {RSLO} → {RSS}
4	{SST} → {UPST} → {RST} → {RRT} → {RRLO} → {RRS}

Table 1 shows switching sequences and insertion of shoot through states. Applying the same analysis and moving on to the second transition ({RTT} to {RST}), where phase B switches from the "T" state to the "S" state, no shoot-through state is inserted. Moving forward again to the third transition ({RST} to {RSS}) where phase C switches from the "T" state to the "S" state, an LST state is inserted since the switching of devices {Sc1,Sc2,Sc1',Sc2'} from {OFF, OFF, ON, ON} through {OFF, ON, ON, ON} to {OFF, ON, ON, OFF} do not affect phases A and B, which remain clamped to points R and S.

The phase C voltage during the LST state is equal to that of the "S" state since the voltage *E* is dropped across inductor *L2* and the voltage seen by phase C is 0V. This means that the {RSLO} and {RSS} states can supplement each other for voltage boosting without modifying the produced volt–second average (normalized by taking the boost factor into account). When the previous methodology is applied to another distinct triangle, triangle 2a, a similar state sequence is derived and shown in Figure 2. It is noted that although it is possible to insert a UPST state at the ({STT} to {RST}) transition, no shoot-though state is inserted at this transition since doing so will result in an inferior output voltage.

The shoot through duty ratio of space vector modulation[2] technique is

$$D_R=3/4*2\Pi-3\sqrt{3}M/2\Pi \qquad (1)$$

where M is the modulation index.

Boost factor can be found as

$$B_F = 4\pi / 9 \sqrt{3}M - 2\pi \qquad (2)$$

The voltage stress across the device can be

$$\upsilon_s =9\sqrt{3}G - 4\pi / 2\pi V_{DC} \qquad (3)$$

The corresponding voltages across inductor in non-shoot through state are *V1_nst* and *V2_nst*, respectively.

$$V1\_nst+V2\_nst+Vi=Vdc \qquad (4)$$

$$V1\_nst=V2\_nst \qquad (5)$$

From (4) and (5), (6) and (7) can be concluded

$$V1\_nst=1/2Vdc-1 \qquad (6)$$

$$V2\_nst=1/2Vdc-1/2Vi \qquad (7)$$

6.0 EXISTING MODEL

Figure 5 shows the existing model. The existing system simulation output for 120v input supply is shown above in Figure 6.

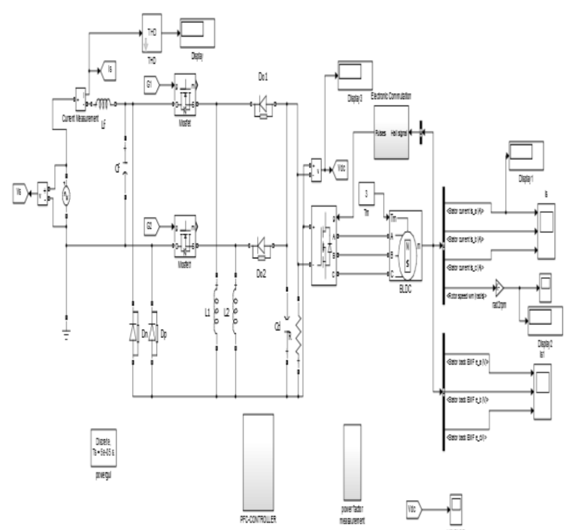


Figure 5 Existing system model

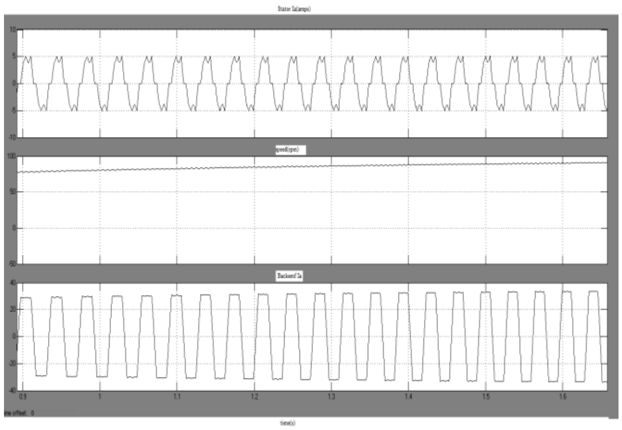


Figure 6 Existing system model output

7.0 PROPOSED SYSTEM SIMULATION MODEL

The simulated output for the proposed model is shown in Figure 7. The proposed technique is simulated in MATLAB/Simulink. The performance of speed for different input voltages are tabulated in Table 2 and its corresponding THD and power factor values are noted.

The Power Factor of proposed technique is 0.996 which is nearer to the Unity Power factor, which does not cause Power Quality issues at AC mains. For 240v input supply voltage, speed reaches 1710rpm value which is nearer to its rated rpm i.e. (2000rpm). Compared to the existing system, proposed system has less total harmonic distortion and improved power factor.

8.0 CONCLUSION

The Z-source inverter based NPC fed BLDC motor drive has been proposed. By proper control of NPC inverter using space vector modulation technique advantages like voltage boosting, better output spectral quality are achieved. For speed control, a satisfactory performance has been achieved and variation in supply voltage is within the acceptable limits of IEC61000-3-2 power quality indices at AC mains.

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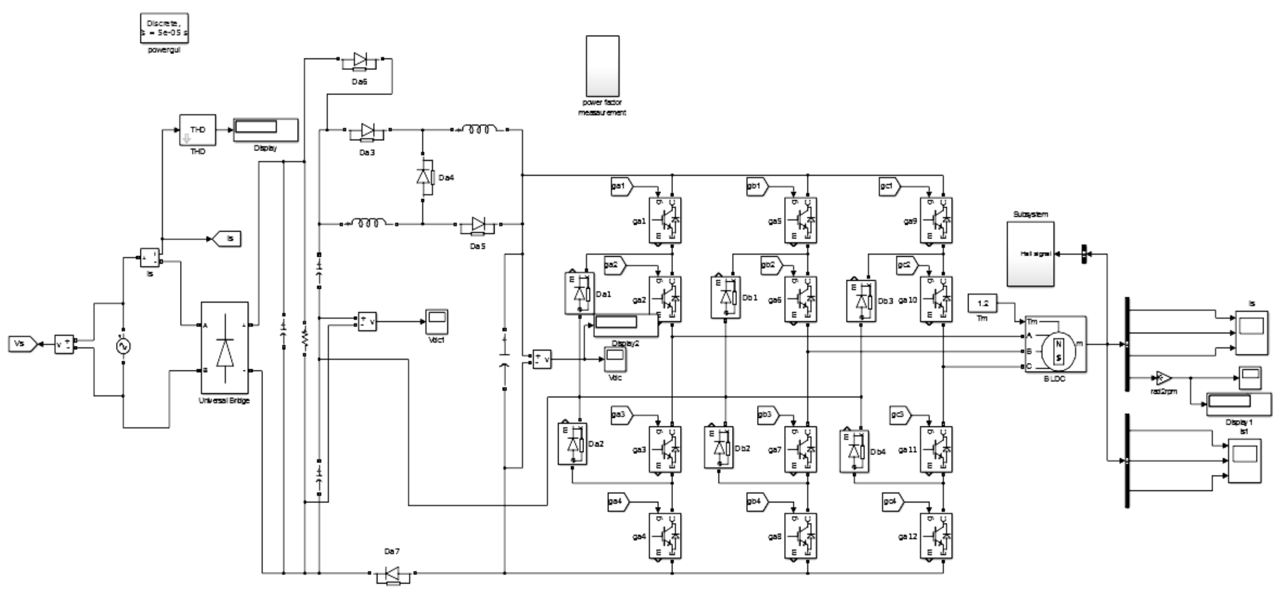

Figure 7 Proposed system model

Table 2 THD and power factor analysis of existing system

Input voltage	Existing System		Proposed System	
	THD	**PF**	**THD**	**PF**
50	25%	0.912	9%	0.996
70	25%	0.912	11%	0.996
120	25%	0.912	8%	0.996
160	25%	0.912	7%	0.996
200	25%	0.912	7%	0.995
230	25%	0.912	6%	0.995

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