Control of Adjustable Speed Drives Using Z-Source Inverter

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Abstract — This paper proposes a Z-source inverter (ZSI) system and control for adjustable speed drives (ASD) is based on PWM strategy. By controlling the shoot-through duty cycle ratio, the Z-source can produce any desired output ac voltage, even greater than the line voltage. As results, the new ZSI system provides ride-through capability under voltage sags, reduces line harmonics, improves power factor, provides reliable operation and extends output voltage range. The proposed ZSI can effectively reduce the voltage stress across the capacitors in the impedance network. The simulation result verifies the validity of the proposed high-performance ZSI to control the ASD systems.

Keywords**—Z-Source Network, Diode Rectifier, Voltage Source Inverter (VSI), DC Link Capacitor, Adjustable Speed Drives.**

I INTRODUCTION

Z-source inverter has x-shaped impedance network on its DC side, which interfaces the source and inverter H-bridge. It facilitates both voltages –buck and boost capabilities. The impedance network composed of split inductors and two capacitors. The supply can be DC voltage source or DC current source or AC source. Z-source inverter can be of current source type or voltage source type. Fig. 1 shows the general block diagram of Z-source inverter.

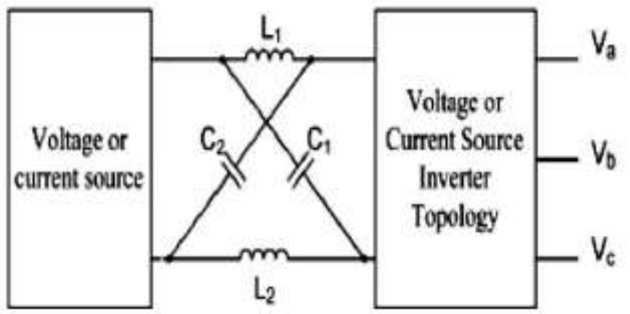


Fig. 1: Block Diagram of Z-Source Inverter

Z-source inverter operation is controlled by multiple pulse width modulation. The output of the Z-source inverter is controlled by using pulse width modulation, generated by comparing a triangular wave signal with an adjustable DC reference and hence the duty cycle of the switching pulse could be varied to synthesize the required conversion. A stream of pulse width modulation is produced to control the switch as shown in the Fig. 2.

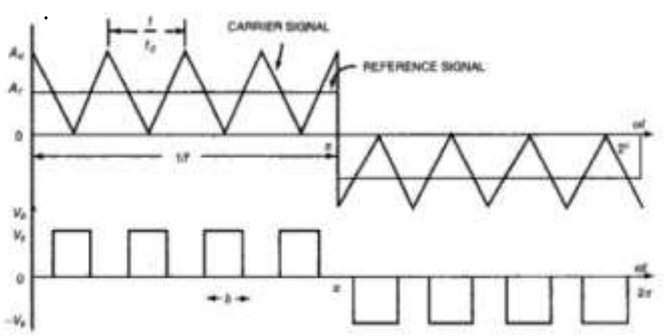


Fig. 2: Pulse Width Modulation

The ZSI is a single stage converter that can either buck or boost the ac output voltage from a dc supply. This topology overcomes the shortcomings of the traditional voltage source and current source inverters, where the output ac voltage is either respectively less or more than the input dc voltage. ZSI employs a unique impedance network to couple the converter to the source [1]. In some applications, the inductance should be minimized in order to reduce cost, volume, and weight. From the design of Z-source network inductor and system control become very complex, and the output voltage becomes incontrollable with small inductor even operate in full load. To enhance the performance in the low speed range of current fed inverter drive, an LC network is proposed to couple the inverter main circuit to the diode front end [2]. ZSI fed by diode rectifier is applied to general purpose drives which reduces line harmonics and improves power factor [3]. The pulse width modulation of the ZSI [4] produces the ac voltage boost by controlling the duty cycle of the switches used in the circuit. The ability of the Z-source system to produce any desired ac output voltage, provide ride through conditions during voltage sags and to minimize the motor ratings to produce the required power enables it to be used for adjustable speed drive systems [5].

The Traditional ASD system is based on a voltage-source inverter (V-source inverter), consisting of a diode rectifier front end, dc link capacitor, and inverter bridge as shown in Fig. 3. Because of the V-source inverter, the ASD system suffers the following common limitations and problems.

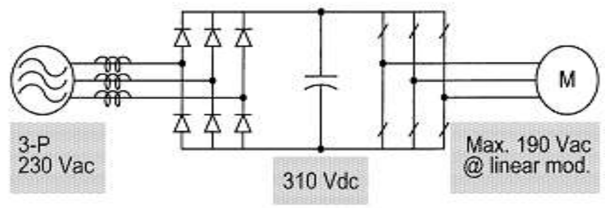


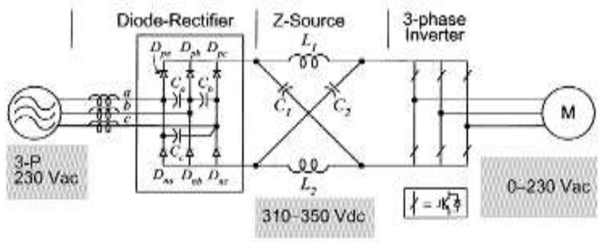
Fig. 3: Traditional Variable Speed Drive System Configuration

Obtainable output voltage is quite limited below the input line voltage. The V-source inverter is a buck (step-down) inverter. For example, Fig. 3 illustrates voltages of a 3-phase 230 V drive system, where the diode rectifier powered by the 230–V ac line produces about 310–V dc, under which the inverter can only produce a maximum 190–V ac in the linear modulation range. For a 230–V motor, the low obtainable output voltage significantly limits output power that is proportional to the square of the voltage. This is a very undesirable situation for many applications where the motor and drive system has to be oversized. Voltage sags can interrupt an ASD, thus shutting down critical loads and processes. Over 90% of power quality related problems are from momentary (typically 0.1–2 s) voltage sags of 10–50% below nominal. The dc capacitor in an ASD is a relatively small energy storage element, which cannot hold dc voltage above the operable level under such voltage sags. Lack of ride-through capacity is a serious problem for sensitive loads driven by ASDs. Inrush and harmonic current from the diode rectifier can pollute the line.

A recently developed new inverter called Z-source inverter has a niche for ASD systems to overcome the above problems. A Z-source inverter-based ASD system can produce any desired output ac voltage, even greater than the line voltage; provide ride-through during voltage sags without any additional circuits; reduce in-rush and harmonic current. This paper presents the basic idea of an ASD system using the Z-source inverter, its main circuit configuration, an equivalent circuit, and control. Simulation results are included to demonstrate the idea and features of the new ASD system.

II Z-SOURCE ASD SYSTEM

Fig. 4 shows the main circuit configuration of the proposed Z-source inverter ASD system. Similar to that of the traditional ASD system, the Z-source ASD system's main circuit consists of three parts: a diode rectifier, dc-link circuit—Z-source network, and an inverter bridge.



network: C_1 and C_2 and L_1 and L_2) and small input capacitors (C_a, C_b, and C_c) connected to the diode rectifier. Since the Z-source inverter bridge can boost the dc capacitor (C_1 and C_2) voltage to any value that is above the average dc value of the rectifier, a desired output voltage is always obtainable regardless the line voltage. Using the 230 V ASD system as an example, the dc capacitor voltage is boosted to 350 V in order to produce 230–V ac output as shown in Fig. 4. Theoretically, the dc capacitor voltage can be boosted to any value above the inherent average dc voltage (310 V for 230V ac) of the rectifier, by using shoot-through zero switching states when a higher output voltage is needed or during voltage sags. The maximum dc capacitor voltage will be limited by the device voltage rating in practical use, however.

III EQUIVALENT CIRCUIT OPERATING PRINCIPLE AND CONTROL

In the proposed ASD system in Fig. 5, a diode rectifier bridge with input capacitors (C_a, C_b, and C_c) serves as the dc source feeding the Z-source network. The input capacitors are used to suppress voltage surge that may occur due to the line inductance during diode commutation, thus requiring a small value of capacitance.

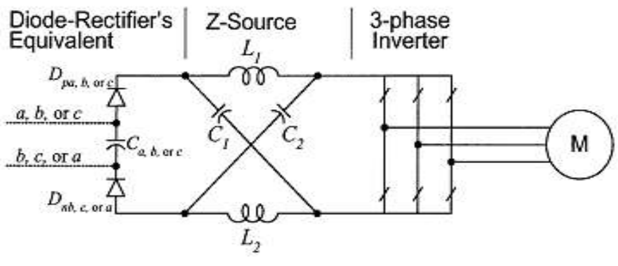


Fig. 5: Equivalent Circuit of the Bridge Viewed from the Z-Source Network

At any instant, only two phases (of the three-phase diode bridge) that have the largest potential difference (i.e., the two phases cross the one of the input capacitors that has the highest voltage) may conduct, carrying current from the ac side to the dc side. Therefore, viewed from the Z-source network the diode bridge can be modeled as a dc source (i.e., one of the input capacitors) in series with two diodes as shown in Fig. 5. The two diodes ($D_{pa,\ b\ or\ c}$ and $D_{na,\ c\ or\ a}$) conduct as a pair with the capacitor ($C_{a,b,or\ c}$). Note the suffix combinations that indicate diodes D_{pa} and D_{nb} form a pair with capacitor C_a when voltage cross capacitor C_a (i.e., the voltage cross phases "a" and "b") is the highest; and with D_{pa} and D_{nc} with C_b when voltage cross capacitor C_b (i.e., the voltage cross phases "b" and "c") is the highest; D_{pc} and D_{na} and C_c when voltage cross capacitor C_c (i.e., the voltage cross phases "c" and "a") is the highest, respectively. Further, the two diodes conduct in a pair and in series acting as one when viewed from the Z-source network. Therefore, the proposed Z-source ASD system is reduced to a Z-source inverter. The traditional three-phase V-source inverter has six active states in which the dc voltage is impressed across the load and two zero states in which the load terminals are shorted through either the lower or upper three devices, respectively. However, the three-phase Z-source inverter bridge has additional zero states when the load terminals are shorted through both the upper and lower devices of any one phase leg (i.e., both devices are gated on), any two phase legs, or all three phase legs. There are seven different shoot-through states: shoot-through via any one phase leg, combinations of any two phase legs, and all three phase legs. The shoot-through zero states boost dc capacitor voltage while producing no voltage to the load. It should be emphasized that both the shoot-through zero states and the two traditional zero states short the load terminals, produce zero voltage across the load, and thus preserve the same PWM properties and voltage waveforms to the load. The only difference is that shoot-through zero states boost the dc capacitor voltage, whereas the traditional zero states do not. When a higher output voltage is required or when the line voltage sags, the shoot-through zero states are employed to boost the dc capacitor voltage. The longer time the shoot-through zero states are used, the higher the voltage one gets. By controlling the shoot-through zero state intervals, a desired dc voltage can be maintained.

IV SIMULATION VERIFICATION OF THE ASD SYSTEM

Simulations have been carried out to confirm the operating principle of the new ASD system. In order to show clearly the output voltage obtained from the inverter, an LC filter with 1 kHz cutoff frequency is placed in-between the inverter bridge and the motor.

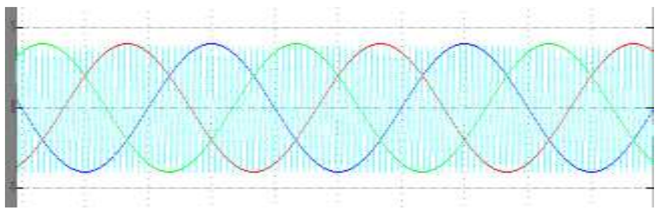
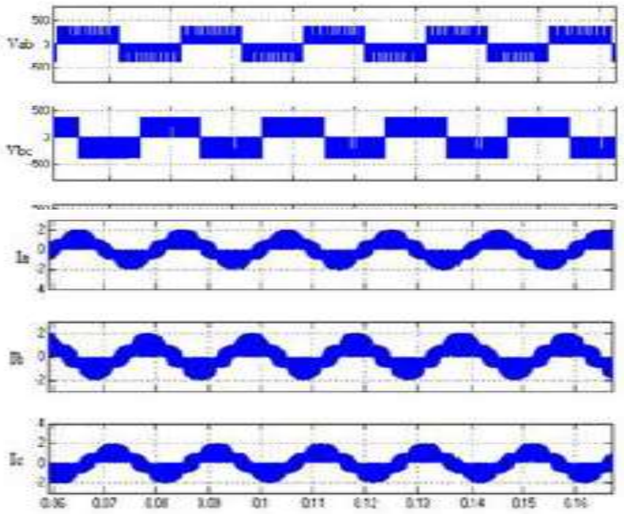


Fig. 6: PWM Gate Pulse Generation



V CONCLUSIONS

This paper has presented control of ASD system using ZSI is proposed. The proposed ZSI based ASD system can operate at light–load with small inductor which is very suitable for adjustable speed drive system and several unique features that are very desirable for many ASD applications.

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