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Evaluation on Performances of Carrier Based PWM for Z-Source Five Leg Inverter

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***Abstract*—On the basis of conventional five-phase Z-source inverter (ZSI), this paper presents an analysis for the performance parameter and the design parameter. The study applied a simple boost pulse-width modulation (SBPWM) under specified range of modulation index (0.65 < Mi <1.0). Study found that the five references signals approach provides better performance compared to the three reference signals approach. This study been verified via Matlab/Simulink simulation.**

***Index Terms*—ZSI, SBPWM, modulation index**

I. INTRODUCTION

Z-source inverter (ZSI) overcomes the conventional voltage source inverter (VSI) and current source inverter (CSI) in number of common features such as [1][2]: 1) The effect of electromagnetic interference (EMI) noise can be avoided in terms of the ZSI reliability and circuits operation. This scenario called as anti-noise function [3] . 2) Under similar main circuit study shows that the conversion process for boosting and bucking purpose can be employed either VSI or CSI. This really cut-off the cost and simplify the circuit construction. 3) With single stage conversion circuits operation and listed modulation index, ZSI capable of handling boosting and bucking conversion mode. This can be monitored at the output voltage with specific input (either higher than or lower than the output voltage).

There are a lots of studied been compared for multiphase ZSI [2][4][5][6]. In [2], the study shown that the application of five-phase ZSI with two three-phase alternating current (AC) motors in parallel connection and five-phase purely resistive load. With number of phases increase, it shows that the ZSI constraints decrease. For example lower inrush current at the start up, lower current total harmonic distortion (THD), lower Z-source voltage stress and lower Z-source current inductor ripples. A system for five-phase with nine-switch has been proposed in [4] where the features and advantages capable of improving voltage utility factor (VUF) up to 86.6%. According to the comparative study presented in [5], the carrier-based switching strategy can be implemented in single-phase, three-phase and four-phase ZSI either in continuous or discontinuous conduction mode operation. A five-phase ZSI has also been studied in [6]. Through simulation, it is shown that under simple boost pulse width modulation (SBPWM) the line-line output voltage and the phase output current THD profiles with resistive load comply with the limit of the EN61000-3-2 standard.

This paper reveals another comparison between three reference signals approach and five reference signals approach in five-phase ZSI. The comparison performance parameters and design parameters are investigated. Simulation results on five-phase ZSI topology are given to verify the analysis.

II. FIVE-PHASE SYSTEM OPERATION OF ZSI

A. Basic A. Operation of ZSI Circuit

This paper will elaborate on the ZSI with voltage feed type
since it is generally more reputable and opportune to be constructed using low-cost and high performance insulated gate bipolar transistor (IGBT) modular [5] .

Either in three-phase or five-phase system of ZSI, the basic operation of ZSI can be summarized as shoot-through state and non-shoot-through state. Figure 1 shows the common depiction of N-phase ZSI. N represent number of phases (N = 2 for single phase, N = 3 for three phase and N = 5 for five phase).

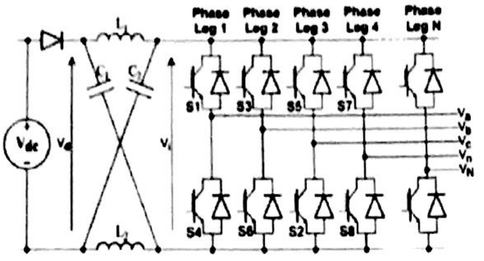


Fig. 1. Common depiction of Z-source voltage type with configuration N-type [5].

The basic operation of this conventional ZSI can be understood with the analysis in Fig. 2. During shoot-through state as shown in Fig. 2 (a), the output of ZSI is short. Thus, based on Kirchhoff Voltage Law (KVL) the derivation of the circuit can be obtained as follows [5]:

$$V_{L1} = V_{L2} = V_L = V_{C1} = V_{C2} = V_C \quad (1)$$
$$V_d = V_L + V_C = 2V_C \quad (2)$$
$$V_i = 0 \quad (3)$$

While in non-shoot-through state as shown in Fig. 2 (b), the power from Z-source network will be transferred to the AC load. The overall circuit analysis can be obtained as follows [5]:

$$V_L = V_{dc} - V_C \quad (4)$$
$$V_d = V_{dc} \quad (5)$$
$$V_i = V_C - V_L = 2V_C - V_{dc} \quad (6)$$

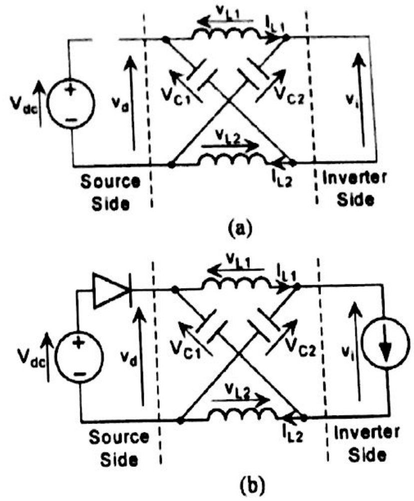


Fig. 2. Simplified circuit operation for understanding ZSI. (a) During Shoot-through state. (b) During nonshoot-through state. [5]

Equations (1) until (6) leads to the detail derivation for obtaining the peak output voltage of Z-source network as follows [1] [2]:

$$\hat{V}_i = V_C - V_L = 2V_C - V_{dc} = BV_{dc} \quad (7)$$

Where $B = \frac{T}{T_1 - T_0} = \frac{1}{1-2\frac{T_0}{T}} \geq 1$ is the boost factor that determine for shoot-through state. Rearrange back equation (7) we simply can obtain B as:

$$B = \frac{1}{2Mi-1} \quad (8)$$

where Mi is a modulation index.

B. Basic Review of Five-Phase Analysis

Base on the conventional analysis for five-phase under star formation (by assuming the systems are balance for 72^0 for each phase) the five-phase ZSI relation can be obtained as [7]:

Five-phase voltage relation:

$$V_L = \sqrt{1.38}V_{ph} \text{ or } V_L = 1.17V_{ph} \quad (11)$$

Three-phase current relation:

$$I_L = I_{ph} \quad (12)$$

The detail explanation of the above derivation for voltage relation can be explored by referring phase relationship [6] [7] [8] as shown in Fig. 3.

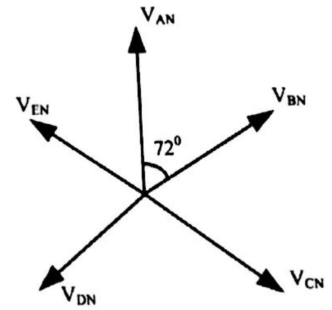


Fig. 3. Phase relationship of five-phase voltage.

III. Carrier-Based PWM

A considerable amount of literature [2][4][9][10][11][12] have been published on the carrier-based PWM using 5 reference signals to apply in the multiphase inverter. There is study by [7] to use 3 reference signals in the conventional VSI for five-phase system. However, there is no study to compare between the 3 reference signals and the 5 reference signals. Hence, this study attempts to show the performance parameter in terms of DC link voltage and capacitor voltage of Z-source network.

The main aim of the SBPWM used in five-phase ZSI is to control the shoot-through time per switching cycle is constant [13] hence having a constant boost factor. Thus, the DC inductor current and capacitor voltage have no ripples. In SBPWM, two constant lines which are equal or greater than the peak value of reference signal. Fig. 4 shows the employment block diagram of the SBPWM [13]. By comparing the constant line with the carrier signal the shoot-through pulse can be generated. The process as in conventional carrier-based PWM (i.e: when Vref > Vtri, the pulse is HIGH and Vref < Vtri, the pulse is LOW).

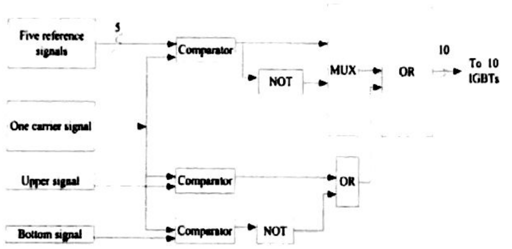


Fig. 4. Block diagram of employment SBPWM using 5 reference signals.

Next, the shoot-through pulses are injected in the product from the above comparison. Then, these shoot-through pulses manipulated with the logical gate. Finally, these become the final PWM that will be sent into the power devices through gate drive circuit. The same process to generate shoot-through signal when using 3 reference signals. The distinguish process is 2 of the reference signals inserted into the gain manipulator. Fig. 5 shows the employment of SBWPM using 3 reference signals.

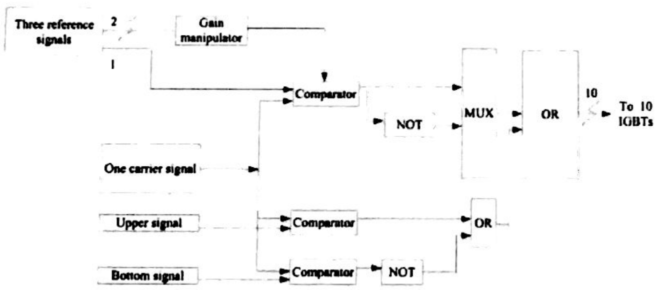


Fig. 5. Block diagram of employment SBPWM using 3 reference signals.

IV. SIMULATION RESULTS AND DISCUSSIONS

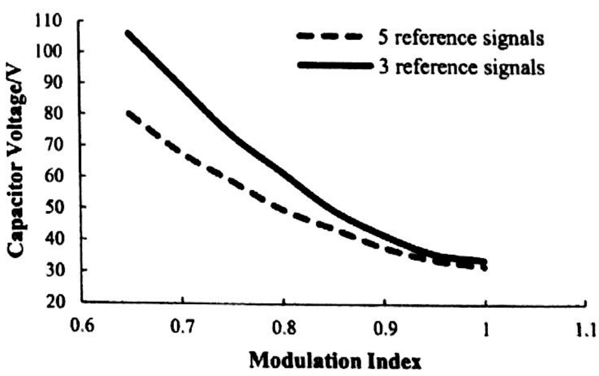
In order to verify the effectiveness of the system a five-phase ZSI is simulated to validate the performance parameter and design parameter relationship. This study define the performance parameter refers to capacitor voltage, DC-link voltage and total harmonic distortion (output line-to-line voltage and output phase current). The modulation index and voltage gain are refer as design parameter which is varied. Table I shows the system parameters used in MATLAB/Simulink. The harmonic profile of the output line-to-line voltage and output phase A current of five-phase ZSI for different type of reference signals are given in Table II. In this comparison, 5 reference signals give fewer harmonic in output line-to-line voltage compare to 3 reference signals. The condition in output phase current harmonic content is also fewer harmonic in 5 reference signals compare to 3 reference signals.

TABLE I. SYSTEM PARAMETER

Parameter	Specification
DC Power Supply	30V
Output frequency	50Hz
Switching frequency	5kHz
Z-source capacitor	1000uF
Internal resistance Z-source capacitor	0.95mΩ
Z-source inductor	1000uH
Internal resistance Z-source inductor	0.3Ω
Filter capacitor	150uF
Filter inductor	3mH
Load resistance	100Ω

TABLE II. HARMONIC PROFILE

Mi	Method	Harmonic Profile	
		THD_v% (line-line)	*THD_i%* (phase)
0.75	3 reference signals	6.16	5.21
	5 reference signals	2.77	1.8
0.85	3 reference signals	7.2	5.24
	5 reference signals	5.08	3.18
0.95	3 reference signals	5.26	6.37
	5 reference signals	7.13	4.43



Graph between capacitor voltage and modulation index

The graph between capacitor voltage and modulation index are depicted in Fig. 6. This chart shows that, using 5 reference signals produce less capacitor. Less value of capacitor voltage means that less weight and capacitance will be used in the Z-source network.

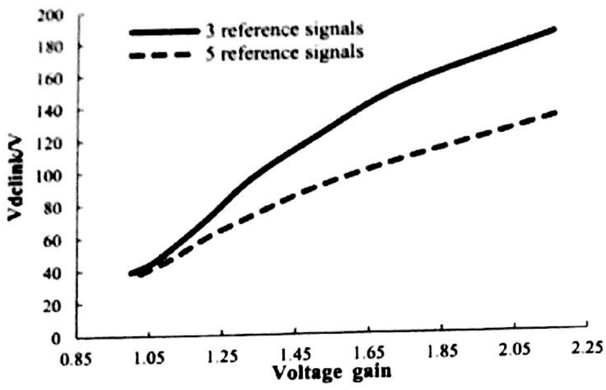


Fig. 6. Graph between DC link voltage and voltage gain

Figure 7 displays a graph between DC link voltage and voltage gain for the five-phase system. It shows that under similar value of voltage gain 3 reference signals attain higher DC link voltage. DC link voltage is presents the voltage stress among the power devices. This also shows that by using 3 reference signals more power need to sustain across the leg compare using 5 reference signals. Figure 8 shows the chart between DC link voltage and modulation index. As can been seen in Fig. 8 the 3 reference signals has a higher DC link voltage than the 5 reference signals. In this system DC link voltage signifies for the cost that ZSI has to pay to achieve voltage boost [13].

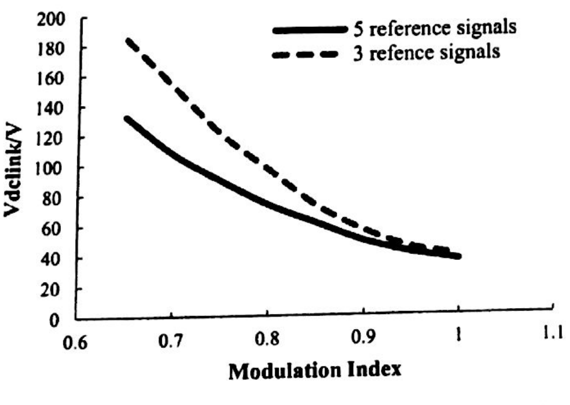


Fig. 7. Graph between DC link voltage and modulation index.

V. CONCLUSION

The investigation of the effect using 3 reference signals and 5 reference signals for five-phase ZSI has been presented in this paper. The evaluation consists of observing into the performance parameter (i.e. DC link voltage, capacitor voltage, THD) versus design parameter (i.e. voltage gain, modulation index). Under the range of modulation index (0.65 – 1.0) the performance of five-phase ZSI can be analyzed. Extension of this paper under experimental setup is under investigation.

VI. ACKNOWLEDGMENT

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