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Performance Analysis and Comparison of Simple Boost PWM and Multi-Reference PWM Technique in Impedance Source Inverters

***Abstract**. In the context of impedance source inverters (ZSI), this work provides a thorough comparison of the sophisticated Multi-Reference PWM (MR PWM) approach and the conventional Simple Boost Pulse Width Modulation (SB PWM) technique. The primary performance metrics that are the subject of the study include total harmonic distortion (THD), switching losses, boost voltages, IGBT voltage stress, and capacitor voltages. The goal of the study is to shed light on the advantages and disadvantages of each PWM method as they relate to the functioning of impedance source inverters. Through simulations and the analytical research, the comparison is conducted, providing insight into how the chosen PWM technology affects the overall dependability and efficiency of the inverter system. Assessing IGBT voltage stress and switching losses provides insights into the stress variables impacting semiconductor devices, while investigating boost voltages helps comprehend their energy transfer capacities. Furthermore, the stability and energy storage features are evaluated by analyzing the voltages of capacitors. In addition, the research includes a comprehensive analysis of THD to determine the harmonic content of the output waveform, which is important for applications requiring high-grade power. The comparative analysis findings enable engineers and researchers to get a better grasp of the consequences of designing and using impedance source inverters with either the conventional SB PWM or the MR PWM technique. This work adds to the continuing advancements in power electronics technology and is a useful tool for anyone looking to maximize the performance of impedance source inverters in a range of applications.*

Streszczenie.** W kontekście inwerterów impedancji źródłowej (ZSI) praca ta zapewnia dokładne porównanie wyrafinowanego podejścia Multi-Reference PWM (MR PWM) i konwencjonalnej techniki Simple Boost Pulse Width Modulation (SB PWM). Główne wskaźniki wydajności, które są przedmiotem badania, obejmują całkowite zniekształcenia harmoniczne (THD), straty przełączania, napięcia podwyższające, obciążenie napięciowe IGBT i napięcia kondensatorów. Celem badania jest rzucenie światła na zalety i wady każdej metody PWM w odniesieniu do funkcjonowania inwerterów impedancji źródłowej. Poprzez symulacje i badania analityczne przeprowadzane jest porównanie, dostarczające wglądu w to, jak wybrana technologia PWM wpływa na ogólną niezawodność i wydajność systemu inwertera. Ocena obciążenia napięciowego IGBT i strat przełączania dostarcza wglądu w zmienne naprężenia wpływające na urządzenia półprzewodnikowe, podczas gdy badanie napięć podwyższających pomaga zrozumieć ich zdolności transferu energii. Ponadto cechy stabilności i magazynowania energii są oceniane poprzez analizę napięć kondensatorów. Ponadto badania obejmują kompleksową analizę THD w celu określenia zawartości harmonicznej przebiegu wyjściowego, co jest ważne w przypadku zastosowań wymagających wysokiej mocy. Wyniki analizy porównawczej pozwalają inżynierom i badaczom lepiej zrozumieć konsekwencje projektowania i stosowania inwerterów źródła impedancji z konwencjonalną techniką SB PWM lub MR PWM. Praca ta przyczynia się do ciągłego postępu w technologii elektroniki mocy i jest przydatnym narzędziem dla każdego, kto chce zmaksymalizować wydajność inwerterów źródła impedancji w różnych zastosowaniach.* (Analiza wydajności i porównanie prostej techniki Boost PWM i techniki Multi-Reference PWM w inwerterze ze źródłem impedancji***)

Keywords: ZSI, simple boost PWM, Switching Losses, Total Harmonic Distortion (THD).
Słowa kluczowe: ZSI, proste wzmocnienie PWM, straty przełączania, całkowite zniekształcenia harmoniczne (THD).

Introduction

Considering the solar power as the best alternate electrical source is very common these days. The solar power can be converted into electrical power which can be utilised by the DC loads or AC loads. Even that power can be feed into the grid. If the application is DC load, DC to DC converter is required specially a buck boost converter where the irradiance will not be constant throughout the day. In order to maintain a constant DC voltage at the low irradiance levels, the DC-to-DC converter need to be step up or step down the voltage. If the load is AC or if the power needs to be feed into the grid, a controlled AC voltage is required. A conventional voltage source inverter is basically operating like step down converter. It cannot boost the voltage. Hence a boost converter will be used as an intermediate circuit between the solar PV and the inverter module. This increases the cost of the system. Without the need of transformers, the Z-source inverter is a single stage power converter that can convert DC to AC with buck and boost capabilities. This converter as special feature as makes it popular for use in fuel cell, electric vehicle, and adjustable speed drive applications [1]. When the required output voltage needs to be higher than the available dc bus voltage, a Z-source inverter can buck and boost the voltage. Furthermore, because the shoot through induced by electromagnetic interference (EMI) noise can no longer disrupt the circuit, the inverter's reliability is significantly increased. Thus, it offers a single-stage construction for buck and boost power conversion that is inexpensive, dependable, and extremely efficient [2]. Zero states are nothing more than a short circuit that occurs when the upper and lower switches on the same leg are triggered simultaneously, destroying the circuit [3]. The zero states present in the technique are changed into shoot through states in both Impedance Source Inverter and Quasi-Impedance Source Inverter, where switches on the same leg are switched on simultaneously, but the circuit is shielded from damage by the impedance network between the source and the inverter [4]. The study examined and contrasted seven PWM controllers in single-phase and three-phase ZSIs. The comparison reveals that the primary design parameter for ZSI performance that needs to be considered is the dc-link voltage stress. The use of shoot-through state to enhance the dc link voltage is a feature shared by PWM controls [5]. Research is done on the three different types of inverters for fuel cell vehicles: Z-source inverter, dc/dc boosted PWM inverter, and regular PWM inverter [6]. The typical inverter's inability to raise the dc output voltage at the ac end is one of its limitations. The input to the inverter is often the output voltage of the fuel cell, battery, or line conditioning circuit, which requires an increase in voltage to run the AC load. This calls for the need of a dc-to-dc boost converter, which adds to the demand for extra parts, space, and money [7]. When comparing an SL-ZSI to a classical ZSI, the low shoot-through time (T0) needed to reach a specific boosting level accounts for the large voltage boost [8].

Impedance source inverters

The addition of the inductor and capacitor to the input stage of the conventional voltage source inverter will make the VSI to work like a step-up inverter. In conventional step-up chopper the MOSFET is turned on, the inductor will be charged and when the MOSFET is turned off charged inductor discharges the current during which the voltage across the inductor will becomes negative. This reversed voltage will be added to the input source and hence the voltage across the output capacitor is equal to 2 times the input DC voltage. The similar concept it will be used in impedance source inverters. In conventional inverters that means voltage source inverters, 2 switches in a leg should not be turned on simultaneously which may lead to dead short circuit DC link voltage. But in this impedance source inverters case, short circuit need to be created to charge the inductor in the first place. Hence along with the eight possible switching states of 2 level inverter, the 3rd state called shoot through state need to be implemented along with the regular PWM schemes. When the shoot through state occurs then the impedance network will be charged, then after the circuit follows the Impedance network which results the boost or buck the voltage based on the technique used in PWM. The impedance source inverter is shown in the Fig. 1.

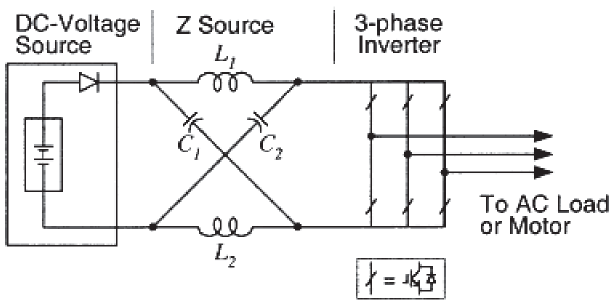

Fig.1. Impedance Source Inverter

Simple boost pwm scheme

In simple boost scheme, the regular sinusoidal PWM will be generated but comparing the sinusoidal signal with the triangular signal. To achieve the boost voltage a shoot through state needs to be introduced at regular intervals. For this purpose, a positive and negative DC voltage lines equal to the maximum value off the reference sinusoidal signals are compared with the same regular carrier signal. They obtained pulses or digitally 'OR'ed to produce the simple boost gate pulses. The three-phase reference sinusoidal signals are given by the equations 1 - 5.

(1) $V_x = A * sin(wt + 0^o)$
(2) $V_y = A * \sin(wt + 120^o)$
(3) $V_z = A * \sin(wt + 240^o)$
(4) KPOS = +A
(5) KNEG = -A

The peak value of the reference signals is A and hence the positive and negative DC lines, KPOS and KNEG are considered as +A and -A respectively.

If the third harmonic injection is preferred [9], another set of sinusoidal signals with one sixth of the fundamental magnitude can be added to the existing PWM as given in the equations 6 – 10.

(6) $V_x = A * \sin(wt + 0^o) + \frac{A}{6}\sin(3wt + 0^o)$
(7) $V_y = A * \sin(wt + 120^o) + \frac{A}{6}\sin(3wt + 120^o)$-
(8) $V_z = A * \sin(wt + 240^o) + \frac{A}{6}\sin(3wt + 240^o)$-
(9) KPOS = +A
(10) KNEG = -A

Multi reference pwm scheme

In this multi reference PWM scheme, the regular PWM scheme is chosen but to produce shoot through state, the turning ON gate pulse of the LOW side switch need to be ahead by certain time. This period decides the boost factor of impedance source inverter. To make the LOW side gate pulse turn ON at an early stage, similar set of reference signals are generated with slightly less amplitude. The two different sinusoidal signals per phase will intersect the triangular signal at different heights. This results in two gate pulses with slightly delayed by turn OFF of high side switch or early turn ON of low side switch. The six reference signals under this multi reference PWM scheme are given by equations 11 – 16. The multireference PWM (MR PWM) logic and RMS output are shown in Fig. 2. and Fig. 3. Respectively.

(11) $V_x = A * sin(wt + 0^o)$
(12) $V_y = A * \sin(wt + 120^o)$
(13) $V_z = A * \sin(wt + 240^o)$
(14) $V_{x1} = m * A * sin(wt + 0^o)$
(15) $V_{y2} = m * A * \sin(wt + 120^o)$
(16) $V_{z3} = m * A * \sin(wt + 240^o)$

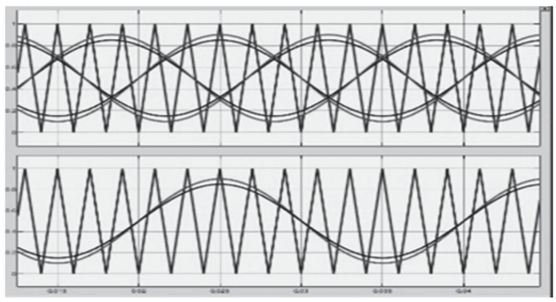

Fig.2. Multi reference PWM

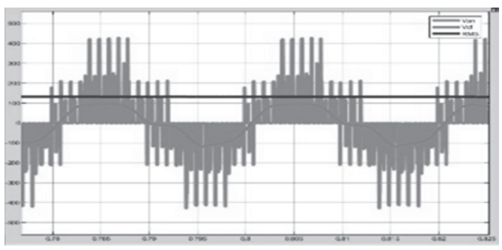

Fig.3. RMS o/p voltage of MR PWM – ZSI

In the equations 14 – 16, 'm' can be considered as modulation index or shoot through factor. The detailed simulation results were discussed in the following section.

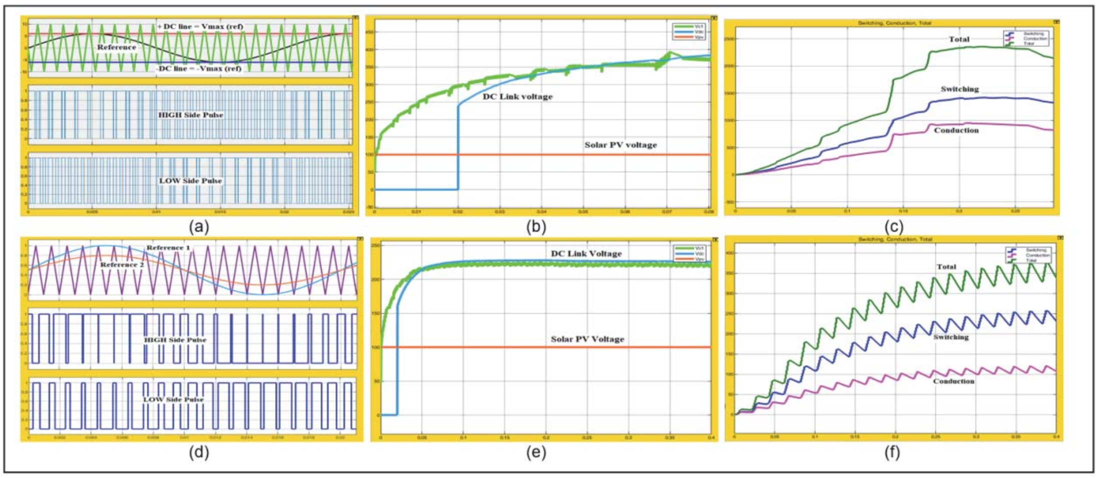

Fig.5. Logic & gate pulses of SB PWM (a) & MR PWM (d); PV voltage & DC link voltage of SB PWM (b) & MR PWM (e); Switching losses of IGBT in SB PWM (c) & MR PWM (f).

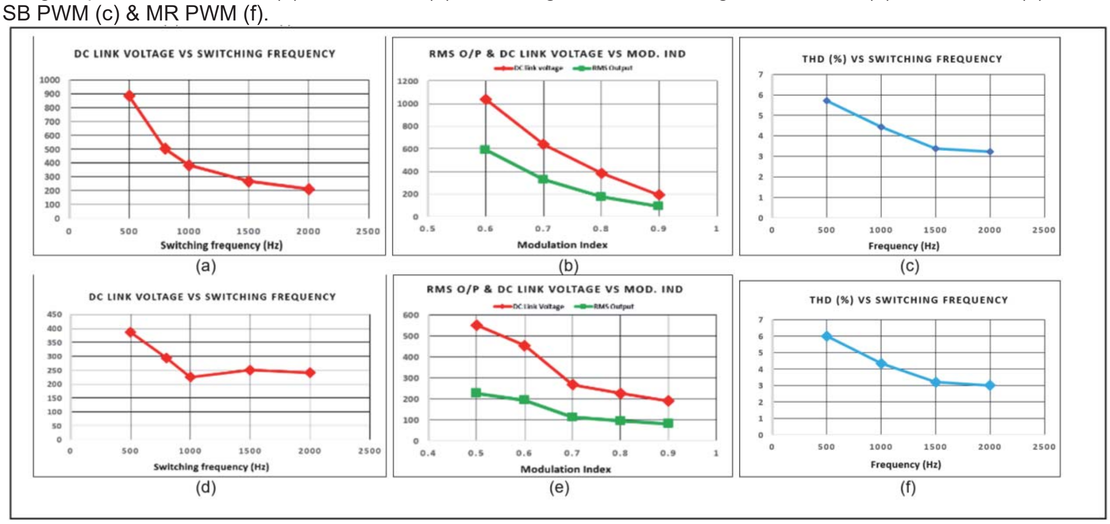

Fig. 6. DC link voltage Vs Fsw of SB PWM (a) & MR PWM (d); RMS output voltage & DC link voltage Vs modulation index of SB PWM (b) & MR PWM (e); Total Harmonic distortion – THD of SB PWM (c) & MR PWM (f).

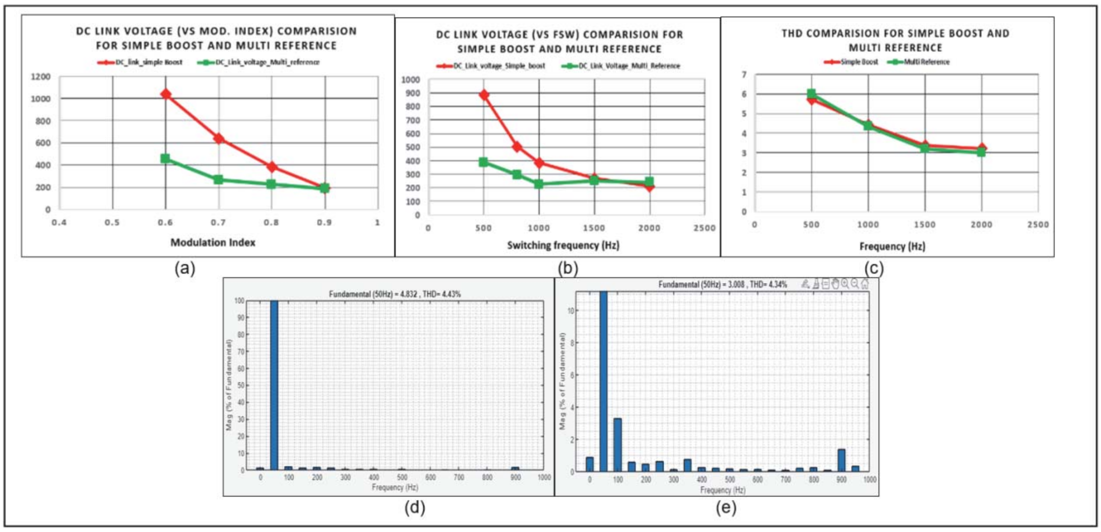

Fig. 7. SB PWM & MR PWM – comparison (a) DC link voltage Vs Mod. Index (b) DC link voltage Vs Switching frequency (c) Total Harmonic Distortion (e); THD of SB PWM (c) & MR PWM (f).

The multi reference gate pulses were generated from F28069 controller. The code snippet for generating two reference signals is shown below. It is a part of EPWM interrupt service routine of F28069. The program is written code composer studio. The gate pulses are shown in Fig. 4.

```
{
count_A++;
if(count_A>20) count_A=0;
else count_A = count_A;
Va = 0.8*sin*(2.0*3.14*count_A/samples);
Vb = 0.6*sin*(2.0*3.14*count_A/samples);
}
```

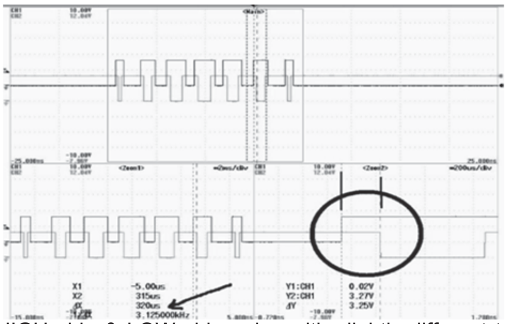

Fig.4. HIGH side & LOW side pulse with slightly different turn ON and turn OFF states.

Simulation work

An impedance source inverter is designed in Simulink / MATLAB, with L1 = 500µH L2 = 500µH; and C1 = 470 µF C2 = 470 µF; The ZSI with both the PWM schemes are discussed and simulated on inductive load of 10mH inductance with an ESR of 10 Ω. The reference and carrier signals along with DC lines (KPOS & KNEG) of SB PWM are shown in Fig. 5(a) and multi reference PWM logic is shown in 5(d). The DC link voltages and the input solar PV voltages are shown in Fig. 5(b) and 5(e) of SB and MR schemes respectively. It is observed that, for similar system specifications, SB produces 350V boost voltage whereas MR produced 200V. A dual IGBT model is taken as reference from MATLAB resources to evaluate IGBT losses including switching and conduction losses[10]. The model consists of thermal models of dual IGBT and its heat sink. The default ambient temperature is set to 25 degrees in simulation. It is observed that SB PWM scheme generates relatively more switching losses compared to MR PWM. The switching losses and conduction losses of IGBT for both SB and MR PWM are shown in Fig 5(c) and 5(f) respectively.

Simulation results and Analysis

The simulation work was carried out on simple boost and multi reference PWM schemes. The performance of the impedance source inverter is studied by observing the simulations results. The DC link voltage Vs switching frequency of SB PWM and MR PWM are shown in Fig. 6 (a) and (d) respectively. SB PWM produced more boost voltage compared to MR PWM. RMS output voltage and DC link voltage of SB and MR PWM schemes are shown in Fig. 6(b) and Fig. 6(e). THD comparison is also shown in Fig. 6(c) and 6(f) of SB and MR PWM schemes.

Table 1. SB PWM experimental results

Modulation Index(K)	$V_{dc\ (V)}$	Psw (WATT)	P_{CON} (WATT)	P_{TOTAL} (WATT)
0.9	197.8	21.88	3.595	25.48
0.8	384.6	117	35.89	152.9
0.7	607.1	412.8	169.9	582.7

Table 2. MR PWM experimental results

Modulation Index(K)	$V_{dc\ (V)}$	Psw (WATT)	P_{CON} (WATT)	P_{TOTAL} (WATT)
0.9	189.6	4.8	1.8	6.7
0.8	225.7	24.9	8.8	33.7
0.7	245	46	14	60

The results shown in Fig. 6 are compared with respect to SB and MR PWM schemes and are briefly shown in Fig 7(a) to Fig. 7(e). It is observed that the multi reference PWM scheme is developing less voltage compared to simple boost. Both the PWM schemes showing the similar results at high modulation index and high switching frequency conditions. Whereas the total harmonic distortion is almost similar for both the modulation schemes.

Conclusion

This paper presented a comparative analysis on the performance of impedance source inverter with respect to the simple boost and multi reference PWM schemes. An RL load with 10-ohm resistance and ten milli Henry inductance is considered as the load for the simulation work. The DC link voltage, switching loss, conduction loss and total losses of an IGBT (HIGH side) for SB PWM are tabulated in table 1 with respect to different modulation index. The similar experiment results for MR PWM are given in table 2.

It can be concluded that the multi reference PWM scheme slightly shows better performance in generating the quality sinusoidal voltage and relatively produces less boost voltage compared to the simple boost PWM technique.

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