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Modulation Control of Impedance Inverter for Maximum Output

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ABSTRACT

India has seen a notable increase in adoption of the renewable energy, Various policies and schemes had been proposed in India to focalize on renewable energy sector. For solar energy conversion, an AC module that functions as a grid-connected inverter after a PV module is needed. ZSI is being used to alleviate a myriad of issues that VSI and CSI have. An impedance source inverter provided with triggering pulses generated by maximum boost control modulation technique is presented in this paper. The triggering pulses are generated by bringing the input sinusoidal and triangular waves on the same graph. Maximum boosted output can be achieved through this method just by adjusting its modulation index and shoot-through intervals.

Keywords: *Inverter; Boosting; Switching; Transformer-less; Shoot-through States; Parametric fluctuations.*

1.0 Introduction

India places a great deal of reliance on solar energy, which has caused it to concentrate in recent years on using green energy. India has seen a notable increase in adoption of the renewable energy, primarily solar energy, from 2016 to 2022. Just 6.7GW of India's TIC z was devoted to solar energy in 2016, but today that number is closer to 56.95GW, or nearly nine times more [1], [2]. Table 1 displays the rise in the proportion of solar and renewable energy in India's total installed capacity. For the generation of electricity utilizing solar power India was at 5th position in 2018, but after installing 7.3 GW additional solar power nationwide in 2019, India rose to third place. Various policies and schemes had been proposed in India to focalize on renewable energy sector as it is estimated that around 363GW power can be extracted from this sector [4]. In the coming years, northern India might develop into a centre for renewable energy. MNRE had a goal of obtaining 175 GW from green energy sources by 2022, out of which 100 GW will come from solar energy [3]. Based on the newly revised data on 1st June 2022, India has its renewable energy share 166.72GW out of which 56.951GW is contributed by solar energy. The overall installed capacity of the power generation in India, as of 17 June 2022, was estimated to be around 402.817 GW, with renewable energy accounting for roughly 166 GW, or about 41 percent of total utility power generation [2], [5]. 56GW, or 14% of India's total power generation, comes from solar energy [6]. The Indian government has enhanced the nation's capacity for renewable energy in recent years by introducing a number of financial programmes like the UDAY scheme, the rooftop scheme, and the solar energy subsidy scheme. The Government of India launched the National Sustainable Mission (NSM) as a significant project to promote ecological sustainability and address the country's energy security issues.

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Additionally, India's contribution to the global effort to address the concerns of changing climate would be significant.

Table 1: Table Showing Solar Scenario in India

Year	Total installed capacity of India (in GW)	Contribution of renewable energy (in GW)	Contribution of solar energy (in GW)
2019	364.96	83.37	31.69
2020	371	87.67	35.12
2021	391.56	150.4	42.128
2022	402.817	166.729	56.951

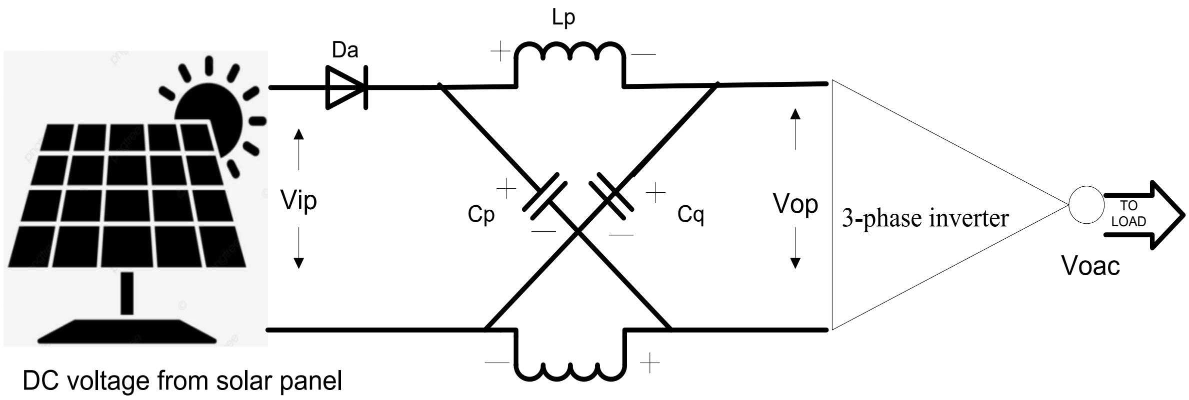
PV systems' modular design makes it simple to boost installed power. In [8], [9], many layouts of an AC module have indeed been explored. The output of PV module which is mostly of lower range must be increased in able to link to the grid due to its inconsistent and fluctuating nature. Transformers are therefore used to achieve this boosting intent, however transformer-less layouts are greatly favored since they offer excellent efficiency, relatively inexpensive, and easy fabrication [10]-[13]. Transformer-less systems can also be subdivided into dual step and single step configurations. In a two-step layout, a PV module's low output is increased using DC-DC choppers before being inverted into AC for a three-phase load. By swapping the chopper or DC-DC boosting step with a straightforward 2-port network made of passive components, this layout is further optimized (L & C). Boosting and inversion can be accomplished via a Z-source inverter in a sole step. The constraints of traditional multi step layouts have been alleviated by ZSI. [15]. As demonstrated in Fig. 3 [14, 15], ZSI is being used to alleviate a myriad of issues that VSI and CSI have, such as the need for double up and dead time to put off the concern of device malfunction and inductor getting disconnected as well as alongside the restrictive output voltage range. It may be able to incorporate buck-boost capabilities without even employing a transformer.

2.0 Impedance Source Inverter

An impedance network is incorporated into the ZSI circuit layout to link with the circuit constituting inverter and the power supply in order to offer distinct features that are unavailable from standard CSI and VSI [16]. The impedance connection is made by an X-shaped connection between two capacitors (C_N & C_T) and a split inductor (L_N & L_T). After this impedance network, a 3-phase inverter is used to change the increased Direct Current voltage to Alternating Current. A certain input DC voltage is fed to the inverter, and by manipulating the on/off switch time period of the switches of inverter, a regulated output AC voltage could be derived from this. For such approach, a triangular carrier signal of high frequency and a three-phase sinusoidal wave as modulating signal with a 120-degree phase shift are selected, and the time between the meeting sites of these signals determines the pulsing or turning on period of modulated pulses and commutation. Unusually, ZSI permits continuous conduction of an inverter phase leg, that is made to happen only and only possible by tweaking the duty-cycle (T_0/T), leading to enhanced AC output voltage. [14].

Typically, there are 8 switching states in commonly used VSI and CSI, with 6 of them being actively functional states and the other 2 are null positions where shorting of end terminals occur). The 0- shoot through (ST) state, when sustained conductivity via up and down switches in different inverter legs is carried on, is one of the ZSI's supplementary switching states. ZSI has nine switching states altogether. Buck and boost features are permitted in ZSI inside this zone [16].

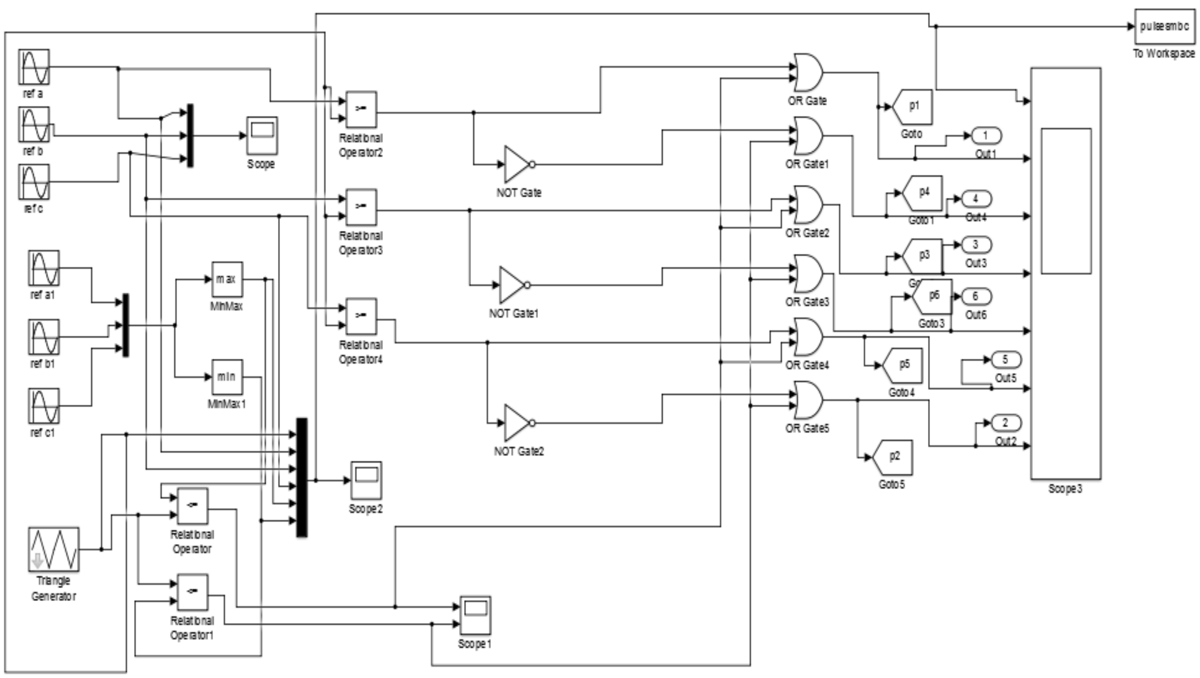
Figure 2: Impedance Source Inverter



2.1 ZSI consists of two components: ST & NST

Power is delivered without a cessation to the load by the input DC voltage source and inductors throughout NST (Non-Shoot Through) phase as a continuous pathway is offered by a forward biased diode. Additionally, capacitors were being charged concurrently. To prevent the circuit from harm caused by short circuiting of devices within the same leg, a detachment resulting from a reverse biased diode causes the DC input source to be disconnected from the load in ST condition. To ensure continuous transmission, the charged capacitors will now start transfer energy to maintain the continuity.

Figure 3: To Generate Pulses in MBC



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3.0 Mathematics Included in ZSI

Mathematical equations can be used to illustrate how ZSI parameters are interdependent, with $\hat{V}_{os}$ standing for the highest amount of DC link voltage, V_c for the capacitor attained voltage, and $\hat{V}_{os}$ for the output AC peak phase voltage.
So,

$$V_c = \frac{V_{is}}{1-D_z} \quad \ldots(1)$$

$$\hat{V}_{os} = B_z.V_{is} = \frac{V_{is}}{1-2D_z} \quad \ldots(2)$$

$$\hat{V}_{os} = M_z.\frac{\hat{V}_{os}}{2} = M_z.B_z.\frac{V_{is}}{2} \quad \ldots(3)$$

$$B_z = \frac{1}{1-2D_z} \quad \ldots(4)$$

$$G_z = B_z * M_z \quad \ldots(5)$$

Where, B_z= boosting factor,
M_z= modulation index,
G_z= overall gain in ZSI
D_z=$\frac{T_{st}}{T_{sw}}$ is ST duty ratio,
T_{st} = time for shoot through,
T_{sw}= time for switching.

The relationships outlined above lead to the conclusion that altering M z and shoot-through time can control $\hat{V}_{os}$.

Table 2: Formulae to Calculate Different Parameters for Different Control Schemes

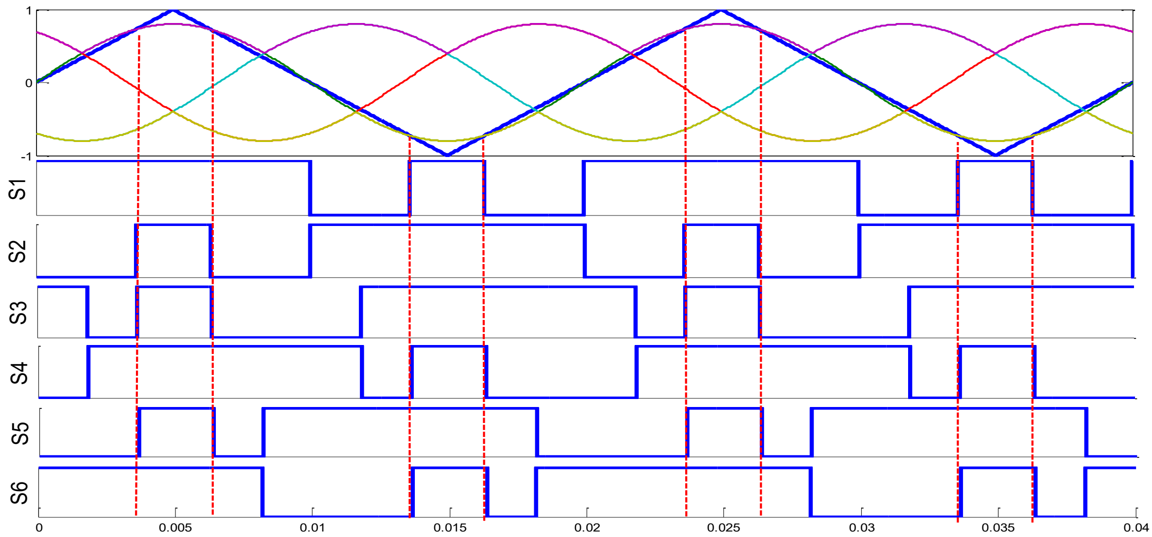
	MBC
Boost factor	$\frac{\pi}{3\sqrt{3}M_d - \pi}$
Duty ratio	$\frac{2\pi - 3\sqrt{3}M_d}{2\pi}$
Modulation index	$\frac{\pi G_f}{3\sqrt{3}G_f - \pi}$
Voltage stress	$(\frac{3\sqrt{3}\,G_f - \pi}{\pi}).V_{ip}$

4.0 Maximum Boost Control Scheme (MBC) for Shoot Through Generation

It outperformed the Simple Boost Control method, which places considerable voltage stress on the inverter switches. By maintaining a certain range for voltage gain, it can be decreased. Therefore, to maintain their product at a target value and reduce stress on the switches for a specified voltage gain, we must improve modulation index and minimise boosting factor [20]. The ST duty cycle is not continuous, therefore maximal exploitation of zero states yields additional boosting. But to obtain a greater degree of voltage gain, the boosting factor couldn't be too minimal.

A separate method is used to create a new wave when the maximum boost control is in place. The greatest crest curve of each sinusoidal modulating wave is tracked to create the upper ST envelope, and the lower ST envelope is created in an analogous manner by joining the lower peak curves of each sine wave [18]. Rather than using straight lines, envelopes generated from the sine curves' peaks are utilised to generate shoot through, which transforms all of the null states into ST zero states without affecting the active states that are already present. In this case, any desirable output voltage can be obtained by using the maximum M_d. The ST duty cycle is not continuous, therefore maximal exploitation of zero states yields additional boosting.

Figure 4: Pulses Generated for Maximum Boost

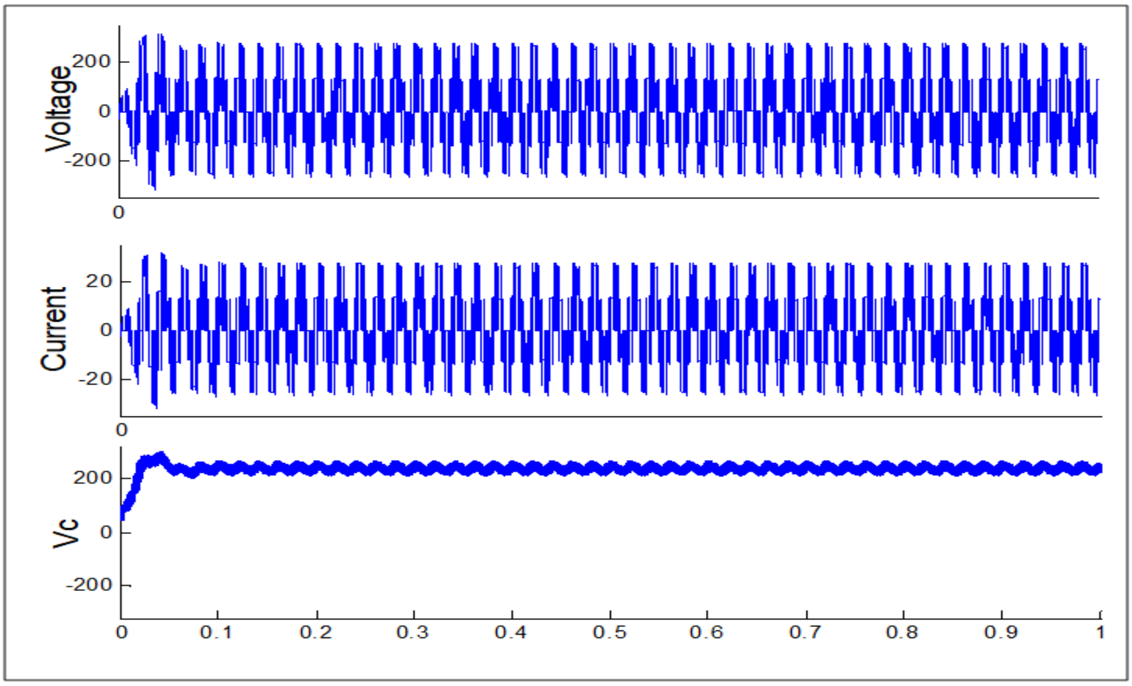


5.0 Results

Tab.3: When $V_{is} = 43V$ and $M_z = 0.65$ Kept Constant

PWM method	V_{is}	M_z	V_c	V_{os}	V_{rms}
MBC	43V	0.65	568.2	**184**	**222.5**

Figure 5: Voltage Obtained after Simulation



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6.0 Conclusion

ZSI output is influenced by modulation index and input voltage. Thus, while maintaining a fixed input voltage and modulation index, parametric fluctuations are investigated. As a result, MBC proves to be the most effective modulation approach for producing the highest possible output AC voltage. Maximum boosted output can be achieved through this method just by adjusting its modulation index and shoot-through intervals. This study describes and illustrates the operation of a Z-source inverter with a modulation method using MATLAB modelling. Numerous factors, including the modulation index (M_z), the boosting factor (B_z), and the overall gain (G_z), determine the ZSI's output. In order to explore the aforementioned parametric fluctuations while maintaining constant input and output voltage levels, an appropriate modulation approach must first be identified.

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