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Modulation Control of Impedance Inverter to Achieve Simple, Constant and Maximum Boosted Output

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ABSTRACT

In order to provide a sustainable option for the generation of electricity, grid integration of PV panels is becoming more popular in developing nations. A PV module with a grid-coupled inverter makes up an AC module used to capture solar energy. Transformerless single stage AC module layouts are among the most effective configurations. Since its first release in 2003, ZSI, one of these arrangements, has seen a rapid evolution that has seen it adopt new topologies and control and modulation strategies to improve its performance from a variety of angles. This study compares and contrasts the modulation techniques used for 3-ZSI in order to highlight their fundamental differences. It then offers a practical method for obtaining high output voltage with minimal voltage stress on the inverter's switching components.

Keywords: *Inverter; Boosting; Switching; Transformer-Less; Shoot-Through States; Parametric Fluctuations.*

1.0 Introduction

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.

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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].

Figure 1: 2-Step Arrangement

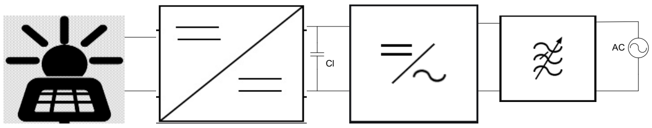

Figure 2: Single Step Arrangement

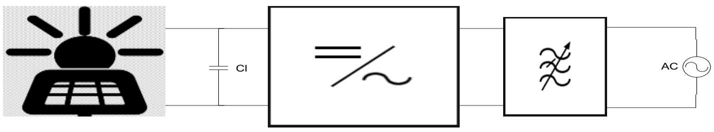

Figure 3: Impedance Source Inverter

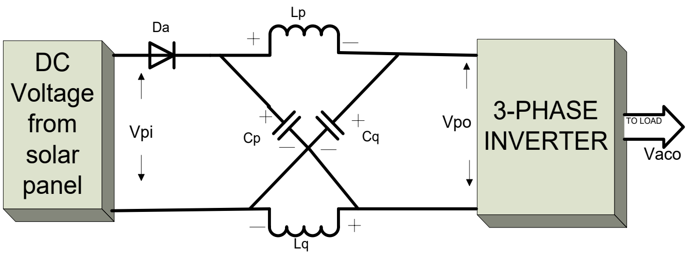

Table 1 displays the rise in the proportion of solar and renewable energy in India's total installed capacity. For the generation of electricity utilizing solar power India was at 5th position in 2018, but after installing 7.3 GW additional solar power nationwide in 2019, India rose to third place. Various 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. Additionally, India's contribution to the global effort to address the concerns of changing climate would be significant.

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2.0 Circuit Framework and Functional Principle of ZSI

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].

Figure 4: Non-Shoot Through Mode of ZSI

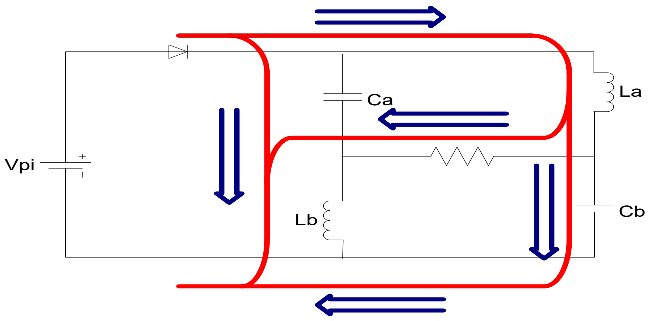
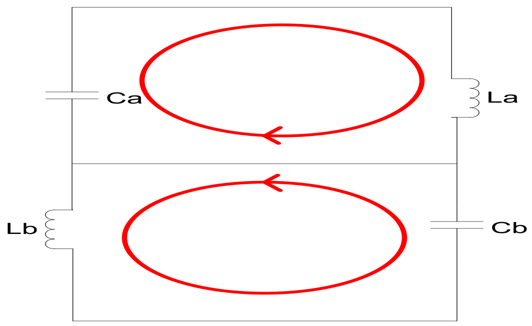


Figure 5: Shoot Through Mode of ZSI



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]. 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.

3.0 Calculation of Parameters

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,

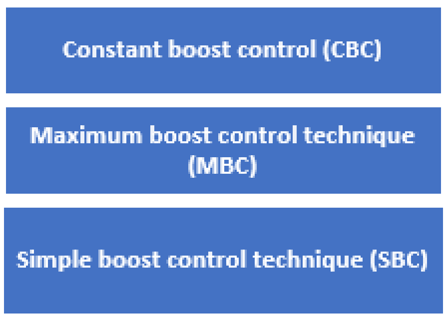
T_{st} = time for shoot through,

T_{sw}= time for switching.

4.0 Methods for the Control of Shoot-Through

The control approach that is used to insert shoot-through has a direct bearing on the impedance network capacitor voltage, the controlled range of AC output voltage, the voltage stress across the switching devices, or the boost in the voltage of the dc link, as well as the harmonic profile [10]. In ZSI, the insertion of ST states is the fundamental requirement that has resulted in the development of a variety of control approaches. In the research done up until this point, 3 distinct solutions have been suggested as shown in figure.

Figure 6: PWM Control Approaches



Using simulation findings, an in-depth examination of these control approaches is given in [11], [12]. The classification of these various control mechanisms can be broken down into two distinct categories. Those that properly level shift the modulation signals of the VSI and insert ST states at each and every state change fall into the first group. The second type of situation falls into the category of situations in which the null states (111 and 000) are directly substituted by the ST states [13]. When comparing the two categories mentioned above, it has been demonstrated that the second

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category is superior to that of the first category [14]. The second group includes techniques that are simple to execute, such as control over the boost.

4.1 Simple boost control technique

Two straight lines with values equal to the peak of the modulating sinusoidal signal are used to generate the ST standards in this manner. The values of these lines are equivalent to the signal's crest. OR gates serve as the connecting mechanism for merging these lines into the standard switching patterns. When the upper straight line is below the top triangular carrier waves or the lower straight line is higher than the bottom triangular carrier waves, the circuit enters ST mode; in all other circumstances, it operates as a conventional PWM circuitry [14]. ST mode is triggered when either Straight lines below or above the bottom triangle carrier waves are used to represent these two possible states of matter. Hiking is a phenomenon that occurs in an SBC system when in all switching devices there is an increase in voltage stress.

With an increase in M (z), D z will decrease, resulting in a maximum limit of (1-M z). As a result, when M z=1, the ST duty ratio will be zero, indicating that no voltage gain or boost has occurred. The selection of 'M z' in ZSI has a few restrictions. Low output voltage at the load side is evident when M z is high, while high voltage stress on the switches occurs when M d is low. The high voltage gain that can be attained with a high M z if the interdependence between D z and M z becomes insignificant [14].

4.2 Maximum boost control

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 minimize 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 utilized 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.

4.3 Constant boost control

In MCBC, the majority of the blank states are used to provide ST, hence the width of the zone encircled by ST envelopes is maintained almost constant throughout the basic period to ensure maximal boosting and a stable ST duty cycle. 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. Dz is kept constant in this fashion. Dz determines the boosting factor, yielding as in maximum constant boost. This method fixes the line frequency-related ripple issue, allowing for the use of smaller L & C.

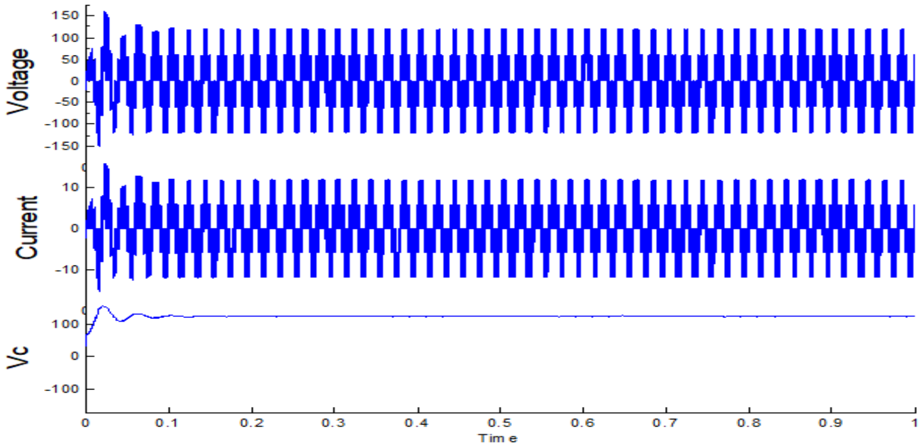
5.0 Modelling and Simulation Results

Table 1: Calculation Tables

PWM Method	When V_{pi} =90V and $\widehat{V}_{aco}$ =86.7V	
	Voltage stress ($\widehat{V}_{po}$)	*Modulation index* (M_i)
Simple Boost	**256.6 V**	0.676
Maximum Constant Boost	**210 V**	0.823
Maximum Boost	**196 V**	0.88

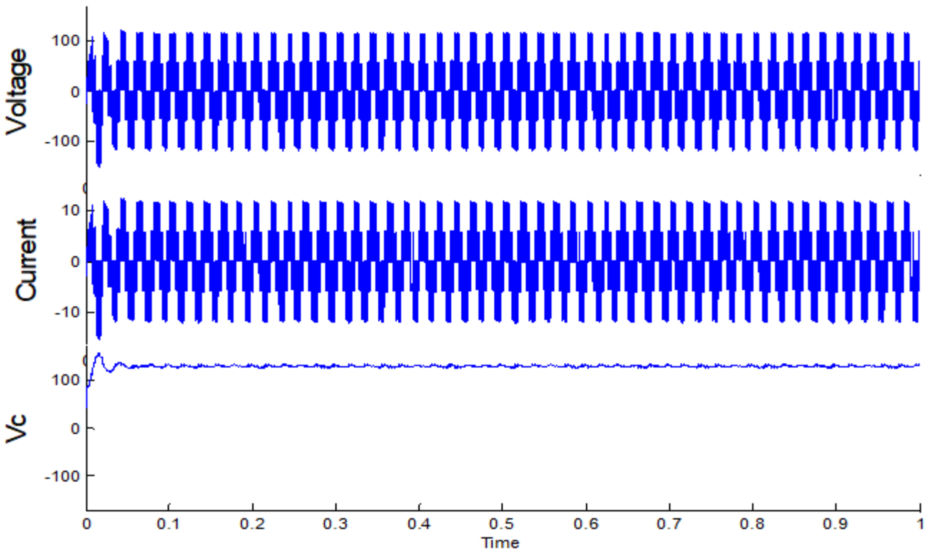
5.1 SBC method

Figure 7: SBC Output Voltage



5.2 MBC method

Figure 8: MBC Output Voltage



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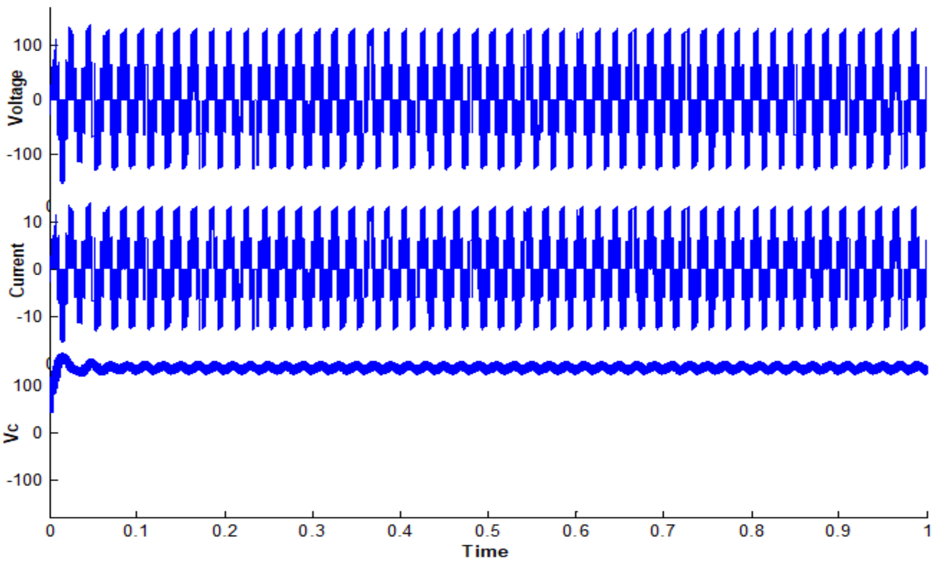
5.3 MCBC Method:

Figure 9: MCBC Output Voltage



6.0 Conclusion

This study describes and illustrates the operation of a Z-source inverter with three alternative modulation methods using MATLAB modelling. Numerous factors, including the modulation index, the boosting factor, and the overall gain, 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. It turns out that the maximum boost control (MBC) scheme is the one that results in higher voltage gain for inverter operation while delivering the same voltage boost as other schemes because voltage stress on the switching devices is relative considerably lower in MBC than in other schemes.

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