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PID compensated, Stability improved Impedance Source Inverter (ZSI)

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Abstract— This paper presents the design of Closed loop voltage mode control for impedance-source inverter using Proportional Integral Derivative (PID) controller. The control action is performed by regulating the DC-link voltage at the input side. Mathematical model of the inverter is developed and the control parameters are designed using Bode plot. MATLAB – Simulink model has been developed for simulation. From the results, it was shown that the proposed controller is very well capable to regulate the AC output voltage.

Index Terms— Inverters, Impedance-source inverter, PID controller, PID Compensation, Shoot-through state, Stability analysis, Voltage mode control.

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1 Introduction

THE Conventional Voltage Source Inverter (VSI) is a common circuit topology used in converting DC power to AC power. However, it can only produce output AC voltage lower than the input. This is the main drawback for the VSI.

As compared to VSI, impedance-source inverter (ZSI) is a relatively new topology. The main feature of ZSI is that it can boost up its output voltage higher than the input in one stage DC-AC power conversion. Hence, a compact and high efficiency power converter is obtained. In addition, the reliability is improved due to the insertion of shoot-through interval [1]. The structure of the ZSI is depicted in Fig. 1.

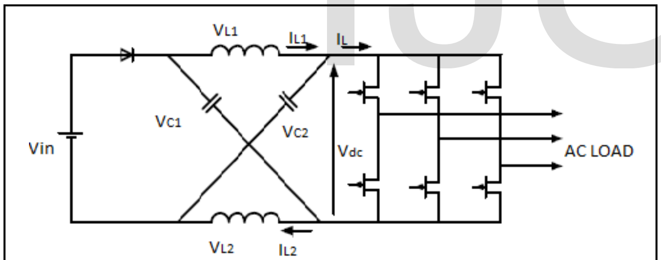

Fig. 1. Z-Source Inverter structure

Numerous control techniques have been proposed for controlling ZSI. In [2], [3], [4] the DC-link voltage is indirectly controlled by the capacitor voltage (Vc) of the impedance network. The capacitor voltage can be kept constant at a desired value through the selection of proper shoot-through duty ratio [2] and Kp and Ki parameters [3], [4] by the controllers. However, when the inverter experiences a step change of input voltage, the DC-link voltage changes though Vc keeps constant and tends to become uncontrollable. This will result in distortion in the inverter's output voltage. The other work proposed in [5] used a PID controller to maintain the peak DC-link voltage directly through direct measurement. It requires additional circuitry for peak detection of the DC-link voltage. Hence the control becomes more complex. In [6], a method for controlling the output voltage of Z-Source Converter (ZSC) is proposed. The output voltage, which is the DC-link voltage, is estimated by the measurement of the input voltage (Vin) and Vc. Two types of controller, voltage mode and current programmed mode, are designed based on the above method. In [7], the design procedure proposed in [6] is utilized to design voltage mode and current mode control for a high-performance z-source inverter.

This paper presents the design of voltage mode control for a conventional z-source inverter using PID controller. The controller regulates the AC output by controlling the DC-link voltage at the input side. The PWM pulses needed for triggering the inverter's switches are generated using modulation method presented in [2].

2 Z-Source Inverter Operation

In the operation of ZSI, the third state called shoot-through state exists together with the null states and the active states. Shoot-through state is a condition where both switches of an inverter leg in PWM inverter conduct simultaneously, which is prohibited in traditional VSI's since they may cause a short circuit condition that could destroy the inverter.

Thus, there are two conditions in the operation of ZSI, the shoot-through state and the non shoot-through state. With symmetric z-source network, i.e. $L_1 = L_2 = L$ and $C_1 = C_2 = C$, the inverter side of z-source network can treated by an equivalent current source with a finite current during non shoot through state and a zero current during shoot through state. The equivalent circuit of the two conditions can be seen in Fig. 2(a) and (b) respectively [1], [8].

From Fig. 2, the voltage across z-source capacitor is

$$V_C = \left(\frac{T_{ns}}{T_{ns}-T_{sh}}\right)V_{in} = \left(\frac{1-\left(\frac{T_{sh}}{T}\right)}{1-2\left(\frac{T_{sh}}{T}\right)}\right)V_{in} = \frac{1-D_0}{1-2D_0}V_{in} \quad (1)$$

Peak DC-link voltage across the inverter bridge is given by

$$\hat{V}_{dc} = 2V_C - V_{in} = BV_{in} \quad (2)$$

The output peak phase voltage is defined as

$$\hat{v}_{ac} = \frac{m\hat{V}_{dc}}{2} = \frac{m(BV_{in})}{2} = B\left(\frac{mV_{in}}{2}\right) \quad (3)$$

T_{sh} : shoot-through period
T_{ns} : non-shoot-through period
T : switching period
m : modulation index
D_0 : shoot-through duty ratio
V_{in} : inverter's DC input voltage

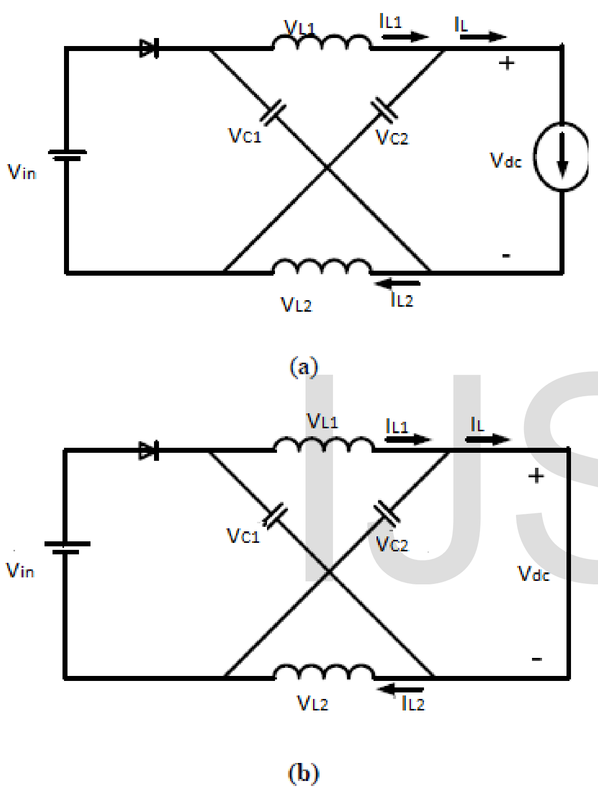

Fig. 2. Equivalent circuit of z-source inverter (a) Non-shoot-through state (b) Shoot-through state

3 Controller Design

The complete system configuration for ZSI connected to a three phase load is shown in Fig. 3. The average output voltage of ZSI depends on the DC-link voltage and the modulation index. The control strategy is to control the ZSI from the DC side only. The modulation index is adjusted using the relationship $m + D_0 = 1$.

The DC-link voltage, *Vdc*, is taken as the control target and the control algorithm is shown in Fig. 7. The control (duty ratio) to peak DC-link voltage transfer function can be expressed as (4) [7].

TABLE 1
Simulation Parameters

Vin (V)	210
L (micro H)	160
C (mF)	1
fs (KHz)	10
R_1 (ohm)	1.2
L_1 (mH)	80
D_0	0.12

Units: V = volts, micro H = micro henry, mF = milli farad, mH = milli henry. D_0 represents duty ratio

Using parameters listed in Table 1, the transfer function (4) can be rewritten as

$$G_{vd}(s) = \frac{2.06\times10^{-7}s^2+216s+32920}{5.4\times10^{-8}s^3+8.23\times10^{-6}s^2+0.0948s+14.34} \quad (5)$$

The magnitude and phase asymptotes of the ZSI's loop gain without compensator is sketched in Fig. 8. The phase margin is 0.00328^0. It is inadequately too small for power converter application which usually needs 25^0 – 60^0 phase margin. A controller is needed to increase the phase margin.

A PID controller is then designed. The final PID transfer function is obtained and given by

$$G_c(s) = 6.107\,\frac{(s+1000)(s+1000)}{s(s+30200)} \quad (6)$$

The magnitude and phase asymptote of the system compensated by this PID controller is depicted in Fig. 9. It is observed from Fig. 9 that using PID controller, the phase margin increases to 25^0 at crossover frequency 471 Hz, somewhat adequate to ensure stable operation under disturbances.

So, a PID controller is designed to improve phase margin. This PID controller is used to provide switching pulses. The modulation method is modified from conventional modulation method.

Equation (4) is given by,

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$$G_{vd}(s) = \frac{(-2I_L + I_l)L_l L s^2 + [(-2I_L + I_l)R_l L + (1 - D_0)(2V_C - V_{in})L + (1 - 2D_0)(2V_c - V_{in})L_l]s + (1 - 2D_0)(2V_c - V_{in})R_l}{L_l L C s^3 + R_l L C s^2 + [2L(1 - D_0)^2 + L_l(2D_0 - 1)^2]s + R_l(2D_0 - 1)^2}$$

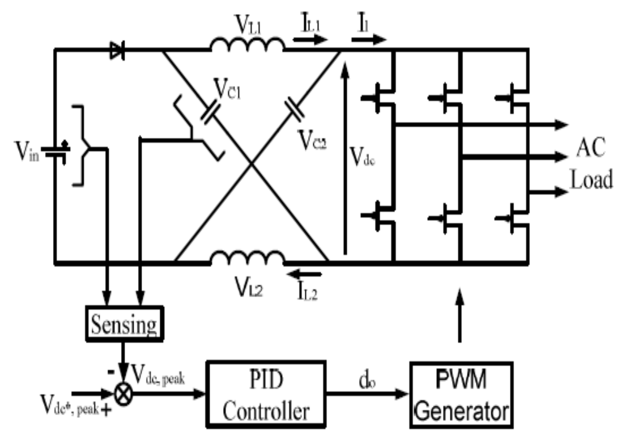

Fig. 3. Voltage mode control of z-source inverter using PID controller

The modified pulse width modulation is employed here to achieve shoot through state. It can be understood as using the following figures

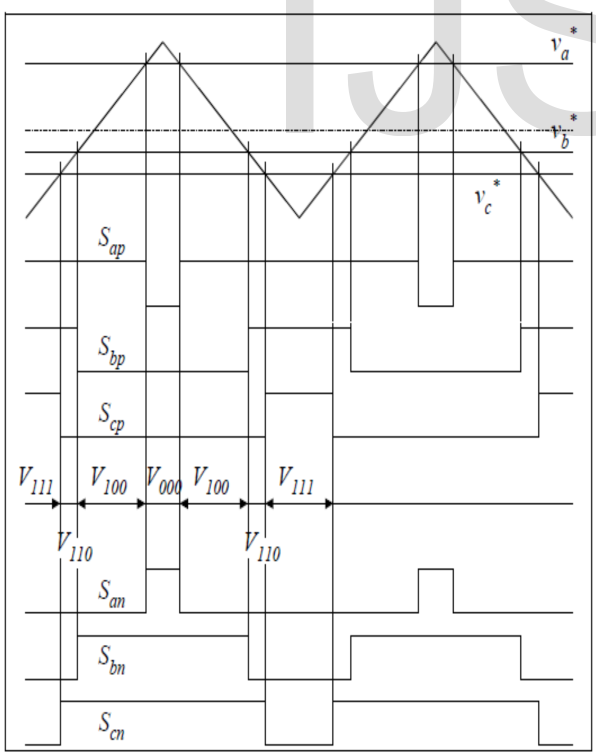

Fig. 4. Traditional carrier-based PWM control without shoot-through zero states, where the traditional zero states (vectors) V111 and V000 are generated every switching cycle and determined by the references

The switching method which produces shoot-through state is shown in the following figure which can be easily understood.

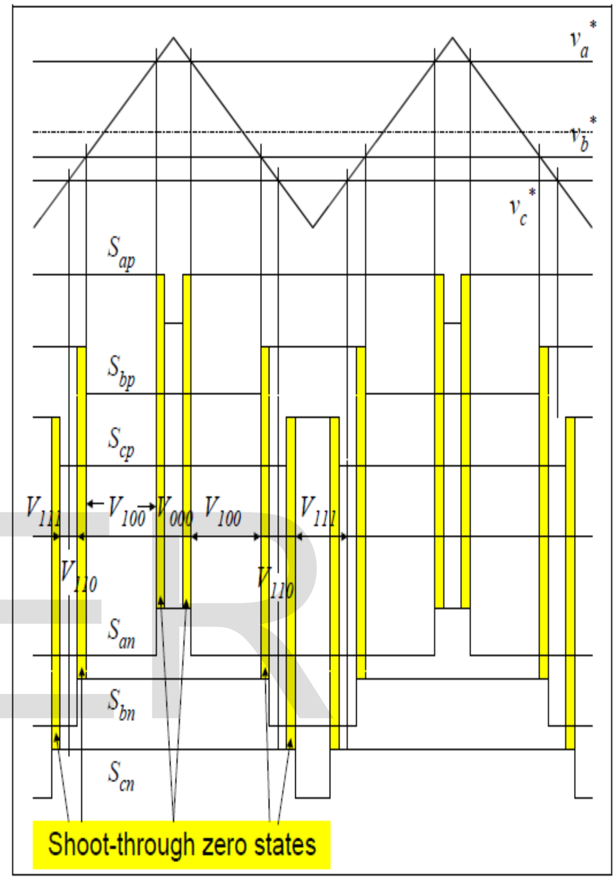

Fig. 5. Modified carrier-based PWM control with shoot through zero states that are evenly distributed among the three phase legs, where the equivalent active vectors are unchanged

4 MODIFIED MODULATION METHOD

Fig. 6 shows the modulation strategy for creating the shoot through duty cycle d_0 to control the dc-link boost voltage. In order to obtain the transfer function of d_0/v_m to design the controller, we have to modify the traditional modulation method. All the boost control methods (simple boost control, maximum boost control, and constant maximum boost control, etc.,) can modify with this method. The shoot through duty cycle d_0 can be expressed as

$$D_0 = 2\left(1 - \frac{T_{ns}}{T}\right) = 2\left(1 - \frac{V_{tri} - V'_m}{V_{tri}}\right) = \frac{2V'_m}{V_{tri}}$$

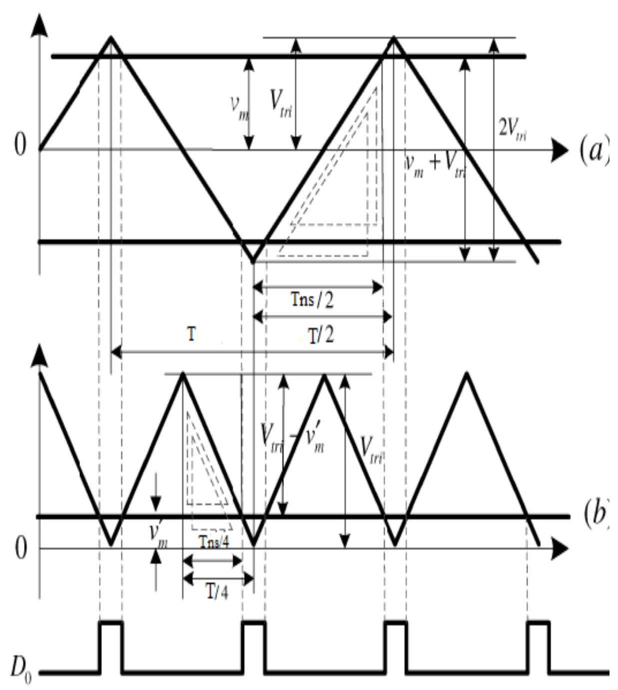

Fig. 6. Modulation method; (a)Simple control method; (b)Modified modulation

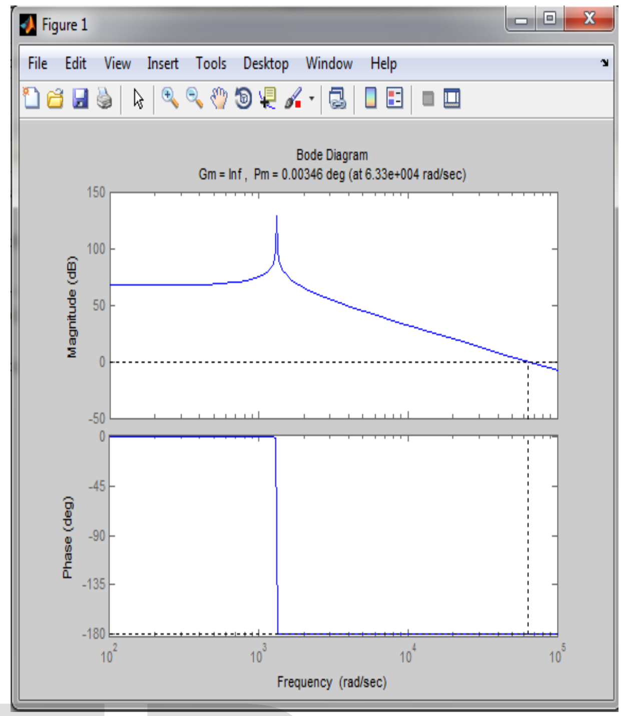

Fig. 8. Bode plot of open loop or uncompensated ZSI

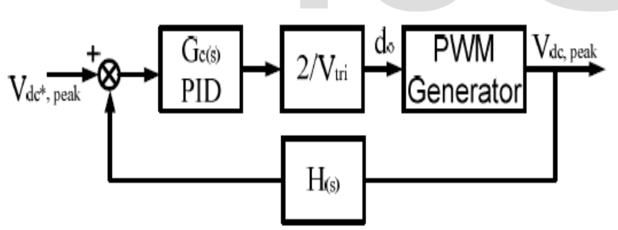

Fig. 7. Control algorithm of z-source peak DC-link voltage

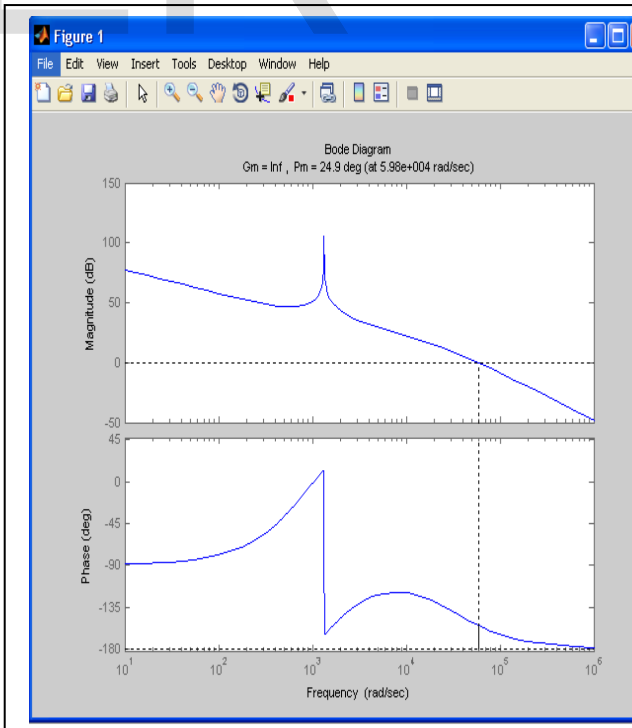

Fig. 9. Bode plot of PID compensated ZSI

5 Simulation Results And Discussions

The above discussed method of designing a PID Compensated ZSI is simulated in Matlab/Simulink software. The stability analysis of open loop or uncompensated ZSI along with closed loop or PID compensated ZSI is compared using Bode plot. From the improved phase margin of closed loop system it is shown that PID compensated system is more stable the uncompensated system.

The voltage mode control of ZSI is alone taken into consideration. This control strategy can be extended for current mode control also.

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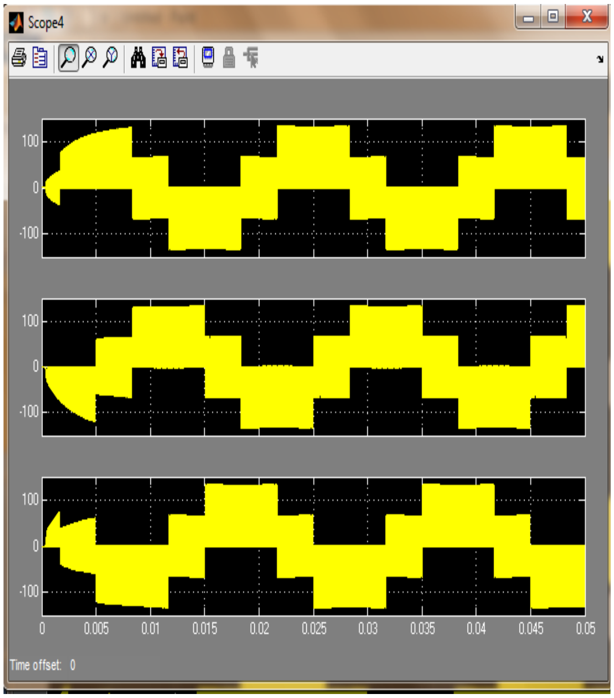

Fig. 10. Output voltage of ZSI for an input of 210V

6 Conclusion

Since the usage of solar energy for domestic appliances is upcoming, the conversion of variable DC voltage to constant AC voltage becomes area of interest for scholars and researchers. The one of the best method for the above mentioned power conversion is using Impedance Source Inverter (ZSI). The proposed control strategy for voltage mode control is effective and capable of regulating output AC voltage very well with improved stability. The control strategy can be extended for current mode control also.

References

[1] F. Z. Peng, "Z-source inverter", *IEEE Transactions on Industry Applications*, vol. 39, pp. 504-510, Mar-Apr 2003.

[2] X. Ding, Z. Qian, S. Yang, B. Chu, and F. Z. Peng, "A PID control strategy for DC-link boost voltage in z-source inverter", in *Proc. IEEE APEC, 2007*, pp. 1145-1148.

[3] X. Ding, Z. Qian, S. Yang, B. Chu, and F. Z. Peng, "A dircet peak DC-link boost voltage control strategy in z-source inverter", in *Proc. IEEE APEC,* 2007, pp. 405-411.

[4] M. J. Rastegar Fatemi, S. Mirzakuchaki, S. M. J. Rastegar Fatemi, "Wide-range control of output voltage in z-source inverter by neural network", in *Proc. IEEE ICEMS, 2008,* pp. 1653-1658.

[5] X. Ding, Z. Qian, S. Yang, B. Chu, and F. Z. Peng, "A dircet DC-link boost voltage PID-like fuzzy control strategy in z-source inverter", in *Proc. IEEE PESC, 2008,* pp. 405-411.

[6] G. Sen and M. E. Buluk, "Voltage and current-programmed modes in control of the z-source converter", *IEEE Trans. on Ind. Appl.,* vol. 46, no. 2, pp. 680-686, March/April 2010.

[7] O. Ellabban, J. V. Mierlo, and P. Lataire, "Voltage mode and current mode control for a 30 kW high-performance z-source inverter", in *Proc. IEEE EPEC, 2009,* pp. 1-6.

[8] C. S. Thelukuntla and M. Veerachary, " Resonant controller based single-phase z-source inverter with LCL-filter", in *Proc. Joint Conference on Power Electronics, Drives, and Energy System and Power India, 2010,* pp. 1-6.

[9] B.Y. Husodo and S.M. Ayob, "Design of Proportional Integral Derivative (PID) Controller for Impedance-Source Inverter", in *Proc. IEEE ICCAIE, 2011,* pp. 121-125.

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