Sliding-Mode Control of Z-Source Inverter

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***Abstract*- In this paper, sliding-mode control (SMC) is applied to a z-source converter to control output dc voltage of impedance network. The converter is assumed working in continuous conduction mode (CCM). First a comprehensive review of the literature for z-source inverter (ZSI) and use of sliding mode control in switched converters are performed. The procedure of SMC design used in ZSI is presented. The simulations for the application of SMC in z-source inverter are made and the results are illustrated. The results verify the effectiveness and robustness of the controller.**

I. INTRODUCTION

Conventional pulse width modulation (PWM) inverters have been used widely for dc-to-ac or ac-to-dc power conversion. There are two types of PWM traditional inverters, voltage source and current source inverters (VSI and CSI), both of which have some limitations and theoretical barriers. The most important of these limitations are:

1- VSI and CSI act as a buck and boost inverter respectively for dc-to-ac power conversion.
2- Electromagnetic interference (EMI) noise problem. In VSI both of switches in a leg cannot be switched on and in CSI cannot be switched off simultaneously. So because of EMI noise, a dead time should be considered in switching rules.

To overcome the limitations of conventional inverters, a new type of inverters (Z-source inverter or ZSI) has been introduced by F.Z. Peng in 2003 [1] (Fig.1). Steady state and transient models of ZSI are derived in [2]-[4]. In order to use shoot-through vector to control the dc boost of this new type of inverter, PWM methods are modified and discussed comprehensively in [5]-[7]. Applying Z-source inverter to adjustable-speed drives(ASD) systems [8]-[11] can eliminate some problems of conventional ASD systems, such as influence of voltage sag on ASD system, inrush currents transmission and harmonic injection to power network and low reliability of system because of sensitivity to shoot-through. Because of voltage suppression during output power increment of fuel cell stacks, nonlinear P-V characteristic of photo voltaic(PV) model and ability of ZSI to boost and adjust the dc voltage to a desired level, applying this new type of inverter to fuel cell and PV systems has been widely investigated[1],[12]-[16]. As shown in [1], ZSI can boost the dc input voltage and therefore one of the control objects is controlling the dc boosted voltage. Some strategies to maximize voltage gain of impedance network voltage are proposed in [1],[17]-[18]. The algorithms to control linearly the capacitor and ac output voltage of Z-source are suggested in [4]. Early papers on control of ZSI have used open-loop nature [1],[5],[8], but newer papers have designed closed-loop controllers to control dc boosted voltage and ac output voltage of the inverter[4],[14],[19].

Sliding mode control (SMC) was proposed initially to control nonlinear and variable structure systems (VSS)[20]. This type of closed loop controller is well known for stability and robustness towards system input, output variation and parameters uncertainties. SMC is an effective approach for the control of power converters because of switching nature of these systems. SMC cannot be applied ideally, because of limited switching frequency of power converters so all of them act as quasi-sliding-mode controllers. So many papers proposed and discussed several sliding surface to control output voltage of dc-dc converters especially buck, boost and cuk converters [21]-[26]. In order to fix the frequency of switching, equivalent control and is applied to SMC [24]-[26]. Conventional SMC does not take into consideration dynamic of the system, [25] and [26] employ the Ackermann's Formula for designing static controllers [27]. This basically concerns with the selection of sliding coefficients on the desired dynamic properties.

In the applications which dc input voltage of the converter varies in different circumstances or dc voltage which is needed for inverter varies due to the load, ZSI seems to be suitable because of capability of controlling the dc voltage and SMC is an appropriate control approach because of robustness towards system input, output variation. In this paper SMC is employed to control and regulate the dc output voltage of ZSI impedance network.

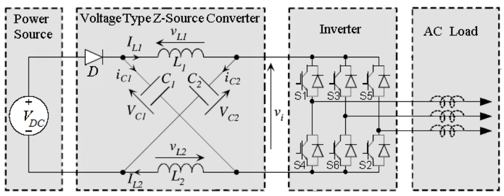

Fig.1 Schematic configuration of a z-source inverter

II. CONFIGURATION, SPECIFICATIONS, AND BASIC OPERATION PRINCIPLES OF Z-SOURCE INVERTER

The impedance network which is made of an X shape LC network can boost the dc input voltage (V_o) in respect to the interval of shoot-through zero state (T_0) during a switching cycle (T). In conventional VSI there are eight permissible switching states: six active and two zero states, while during the zero states there is no difference for the load if the upper three, the lower three or all the six switches are gated on (all the states short the output

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terminal of the inverter and produce zero voltage to the load), as discussed in [1] in ZSI, during the zero states all the switches are gated on (shoot-through state) and this state is used to achieve boosting dc input voltage. Therefore in ZSI, there are six active states and two zero states which are the same as conventional inverter and an addition shoot-through state (it is forbidden in conventional inverters) which is utilized advantageously to boost the dc-bus voltage. Two basic operation mode of ZSI are illustrated in Fig.2.

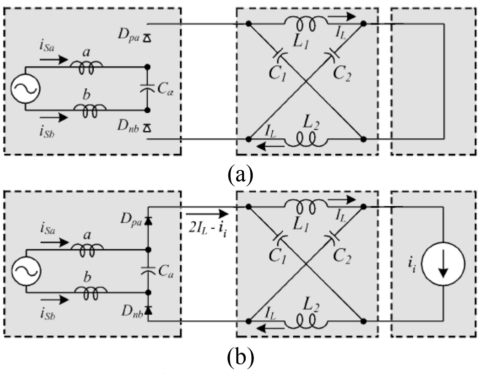


Fig.2. Equivalent circuits of ZSI. (a) shoot-through mode. (b) Non-shoot-through mode

As verified in detail in [1] the basic principal relationships for ZSI are:

$$V_{C1} = V_C = \frac{1-\frac{T_0}{T}}{1-2\frac{T_0}{T}} V_o \tag{1}$$

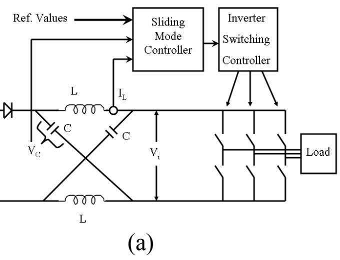
$$V_{C2} = V_C = \frac{1-\frac{T_0}{T}}{1-2\frac{T_0}{T}} V_o \tag{2}$$

$$\begin{cases} V_{in} = \dfrac{1}{1-2\frac{T_0}{T}} V_o = BV_o & While \quad non \quad shoot-through \\ V_{in} = 0 & While \quad shoot-through \end{cases} \tag{3}$$

Where V_{C1} and V_{C2} are capacitors voltage of impedance network which are the same due to circuit symmetry. B is the boost factor of ZSI. V_o and V_{in} denote input and output of impedance network dc voltage respectively.

III. SLIDING MODE CONTROLLER FOR Z-SOURCE INVERTER

Schematic diagrams of sliding mode controlled z-source inverter and the hysteresis sliding mode controller used in ZSI and inverter switching controller are shown in Fig.3.



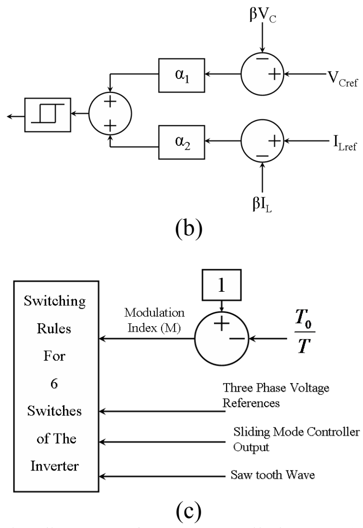


Fig.3. Schematic diagram of SM controlled ZSI. (a) z source and controller. (b) hysteresis sliding mode controller for output network impedance voltage. (c) Controller of inverter switching

In the following the procedures of designing SM controller for ZSI are described in detail. To derive the equations it is assumed ZSI working in continuous current mode (CCM).

A. *State Space Description*

The first step to the design of SM controller is describing the system (here z-source inverter) in state space equations. In this paper inductor current error and capacitor voltage error are considered as state variables (4), and it is assumed the converter operates in continuous conduction mode (CCM).

$$X = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} V_{cref} - \beta V_c \\ I_{Lref} - \beta I_L \end{bmatrix} \tag{4}$$

Where V_{cref} and I_{Lref} are capacitor voltage reference and inductor current reference respectively. β denotes the feedback network ratio.

As it is clear the input reference of the controller is output voltage reference of the impedance network (V_{iref}). Using (1) and (2) relationship between V_{cref} and V_{iref} is calculated easily and is given by (5).

$$V_{cref} = \left(1 - \frac{T_0}{T}\right) V_{iref} \tag{5}$$

Inductor current reference can be calculated in three ways. Applying input-output power balance, I_{Lref} can be estimated by (6). Applying capacitor charge balance gets (7). If the load is resistive, the value of I_{Lref} can given by (8). Consider that $k = \frac{V_{Cref}}{\beta V_o}$. The third way is by means of high-pass filter. In fact, steady state dc value of variable i_L (I_L), automatically adapt to actual ZSI operation. Only the ac components of this variable is needed for control, consequently state variable x_2 can be obtained by means of high pass filter [21].