Three-phase Z-source PWM rectifier based on DC voltage fuzzy control

Xiao Dong Qiu*, Young Gook Jung**, Young Cheol Lim*
Chonnam National University*, Daebul University**

직류전압 퍼지 제어 기반의 3상 Z-소스 PWM 정류기

수효동*, 정영국**, 임영철*
전남대학교*, 대불대학교**

ABSTRACT

This paper describes a fuzzy PI control method to control the output voltage of three phase Z source PWM rectifier. The proposed fuzzy PI controller is a single input fuzzy with its fuzzification, inferences and de fuzzification processes. The proposed method adjusts the Kp and Ki in real time in order to find the most suitable Kp and Ki for PI controller and to simplify the controller design. The PI portion of DC voltage controller is controlled by fuzzy method. The simulation is performed with PSIM and MATLAB/SIMULINK and is verified the validity of the proposed approach.

1. INTRODUCTION

A novel PWM rectifier named as Z source PWM rectifier [1] makes the shoot through state possible which avoids the possibility of ruin by EMI noises. And the shoot though state allows the Z source rectifier to buck and boost its output voltage. Over the past few decades, a large number of inverters have been regulated using proportional integral(PI) controllers[2,3]. The design procedures for these controllers are well defined and are widely accepted by the control community. Generally, in order to design a proper PI controller, a precise mathematical model of the actual system to be controlled is required.

In this paper, the DC voltage of three phase z source PWM rectifier using simplified fuzzy PI controller is proposed. It shows that the proposed system has the compensation ability for the DC voltage variations. In the practical applications, it is able to provide a safety environment for adjustable speed system in commercial and industrial facilities.

2. THE PROPOSED METHOD

2.1 Three-phase Z-source PWM rectifier

Fig. 1 shows the three phase z source rectifier. Z network is coupled between the load and the rectifier circuit. The Z network is implemented using split inductors (L_1 and L_2) and capacitors(C_1 and C_2) connected in X shape. This z network allows the z source rectifier to buck or boost its output voltage. The three phase z source rectifier has nine permissible switching states (six active vectors, two zero vectors and one extra zero vector). When both the upper and lower devices of any one phase leg, any two phase legs, or all three phase legs are shortened through, the z source rectifier has one extra zero state. How to produce the PWM extra zero state has been described in the reference[4].

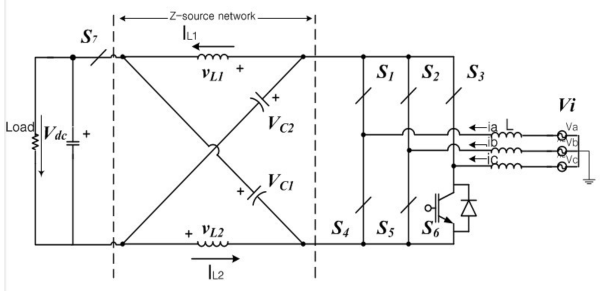

Fig.1. Three phase Z source PWM rectifier

From the symmetry and equivalent circuits, we have

$$V_{C1} = V_{C2} = V_C \quad , \quad V_{L1} = V_{L2} = V_L \tag{1}$$

where the inductors L_1 and L_2 and capacitors C_1 and C_2 have the same inductance(L) and same capacitance(C) respectively.

When the rectifier bridge is given in the shoot through zero state(T_0), during a switching cycle T, v_i is the input voltage of z network, we have

$$v_i = 0 \quad V_L = -V_C \tag{2}$$

When the rectifier bridge is given in the non shoot through zero state(T_1), one have

$$V_L = V_C - V_{dc}, v_i = V_C + V_L = 2V_C - V_{dc} \tag{3}$$

where T= T_0+T1

From the inductor volt second balance, the average voltage of the inductors over one switching period(T) should be zero in steady state, we have

$$V_L = \overline{v_L} = [T_0(-V_C) + T_1(V_C - V_{dc})]/T = 0 \tag{4}$$

or

$$\frac{V_C}{V_{dc}} = \frac{T_1}{T_1 - T_0} = \frac{1-D_0}{1-2D_0} \tag{5}$$

where D0= T0/T denote the shoot through duty cycle.

The average DC link voltage across the load can be found as follows

$$V_i = \overline{v_i} = [T_0 \times 0 + T_1(2V_C - V_{dc})]/T$$
$$= \frac{T_1}{T_1 - T_0} V_{dc} = V_C \tag{6}$$

According to equation(3),(5) and (6), we can get

$$V_{dc} = (1-2D_0)\overline{v_i} = B\overline{v_i} \tag{7}$$

where B is the buck factor.

The DC output voltage of the traditional V source PWM rectifier can be expressed as

$$V_{dc} = \frac{2V_i}{Mcos\psi} \qquad where, \psi = \arctan\frac{wL}{r} \qquad (8)$$

M is the modulation index, L is the input inductor, r is the equivalent input resistance, V_i is the peak phase AC input voltage.

According to equation(7) and (8), we have

$$V_{dc} = \frac{B}{M}\frac{2V_i}{\cos\psi} = B_B\frac{2V_i}{\cos\psi} \qquad (9)$$

where, B_B is the buck boost factor.

2.2 Fuzzy PI Control scheme

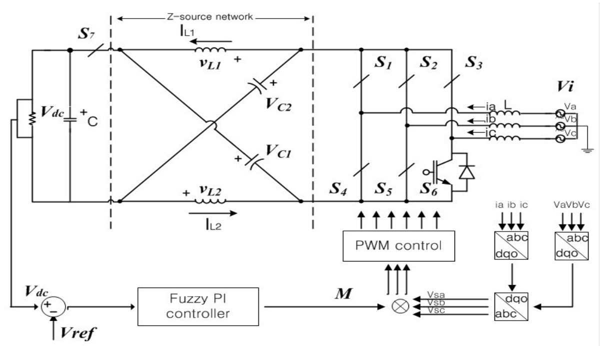

Fig.2. Control block diagram of the proposed system

From the given formulas, we can know that the modulation index is determined by the shoot through duty cycle in a half working period of three phase z source rectifier. The SIMCOUPLE module gets input port from PSIM to MATLAB as one sensor. After transmission and operation in MATLAB, the duty cycle D_0 will be give back to the only one output port, and return to the PSIM.

3. SIMULATION AND DISCUSSION

The simulation parameters are as follows:

- Input voltage: 380V
- Input inductance and resistance: 1mH and 0.5Ω
- Z network: L1=L2=2mH C1=C2=1000μF
- Output capacitor: C=1000μF
- Output load: 20Ω
- Switching frequency: 10kHz

Fig 3 shows the simulation results for the AC input voltages and currents of the three phase z source rectifier. It can be seen from figure that almost unity power factor and nearly sinusoidal AC current operation is achieved.

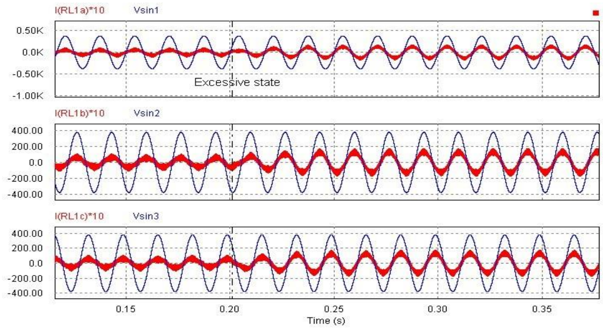

Fig. 3. The waveforms of the AC input voltages and currents

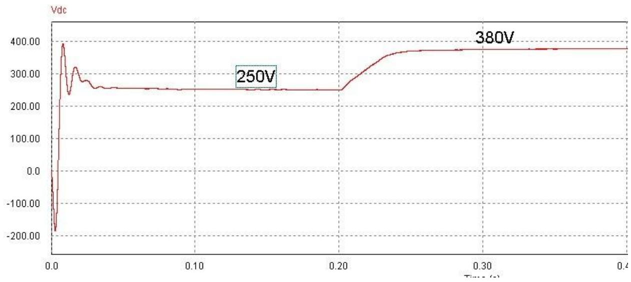

Fig. 4.. The DC output voltage

Fig. 4 shows the DC output voltage with the fuzzy PI controller. According to equation(9), we can get the following calculations.

1)When M is 0.6, D0 is 0.4, we have

$$V_{dc} = \frac{(1-2D_0)}{M}\frac{2V_i}{\cos\psi} = \frac{1-2\times0.4}{0.6}\frac{2\times380}{0.99} = 253\,V$$

2) When M is 0.6, D0 is 0.35, we have

$$V_{dc} = \frac{(1-2D_0)}{M}\frac{2V_i}{\cos\psi} = \frac{1-2\times0.35}{0.6}\frac{2\times380}{0.99} = 380\,V$$

4. CONCLUSIONS

The goal of this paper is to control the DC output voltage of the three phase Z source PWM rectifier by fuzzy PI controller. From the results, the three phase Z source rectifier can buck or boost input voltage by using a shoot through state. It was shown that the proposed controller produced a comparable performance as its conventional fuzzy PI controller, but with a much reduced computation time. The voltage control stability of the z source PWM rectifier system can be improved by the fuzzy PI controller.

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