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Dynamic Analysis of Three phase Z-source Boost-Buck Rectifier

Kancheti Karunakar* and D.M.Vilathgamuwa**
*Ecospec Global Technology,Singapore. Email: kanchetik@yahoo.com
**Nanyang Technological University, School of Electrical and Electronic Engineering,Nanyang Ave,Singapore 639798.
Email: emahinda@ntu.edu.sg

Abstract—**Boost-type PWM voltage source rectifiers have gained popularity because they allow the output voltage to be controlled over a wider range. However newly proposed Z-source boost-buck rectifier would allow buck capability with minimal number of switches. This paper deals with dynamic analysis of the Z-source rectifier. The analysis is carried out to determine the transient response and non minimum phase effects. Further discussions are made on how to reduce the non minimum phase effect and increase the system performance. The analysis is supported with simulation results.**

Index Terms: Z-source rectifiers, Boost-Buck converters

I. INTRODUCTION

Traditional Power electronic converters like Voltage Source Converters and Current Source Converters have certain limitations. The main limitation is that, they can perform either buck or boost operations. Because of the increasing applications of power converters in energy systems, it is necessary to implement a single stage converter that can reliably perform both buck boost operations. Traditionally this can be achieved by double stage converters (AC/DC→DC/DC) but ultimately leading to less efficiency and complex control. Therefore it is necessary to implement a single stage converter that can perform both buck and boost capabilities. Z-source rectifier is a choice of such a converter which has both boost buck capabilities and better EMI performance [1]. This is achieved by an impedance network and extra switch sw7 as shown in Fig 1.1.

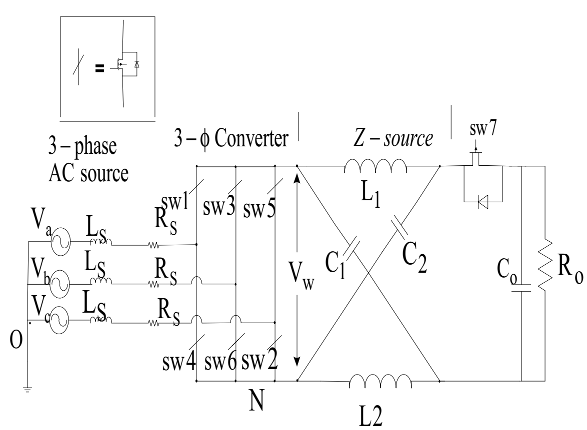

Figure 1.1. Three Phase Z source rectifier

The three phase Z –source rectifier has one extra switching state i.e. shoot through state. It has totally nine permissible switching states (six Active vectors as shown and three zero vectors including shoot through).The extra state(shoot-through) [1] can be treated as short circuiting of both the upper and lower switches of any one phase leg, two phase legs or all three phase legs. During shoot through state the switch SW7 must be kept open. This shoot through zero state provides unique feature of buck-boost operation.

Equivalent circuits of the z source rectifier when the bridge is in any one of eight non shoot through states and shoot through zero state are shown in fig 1.2. The switch SW7 must be synchronized with gating signals.

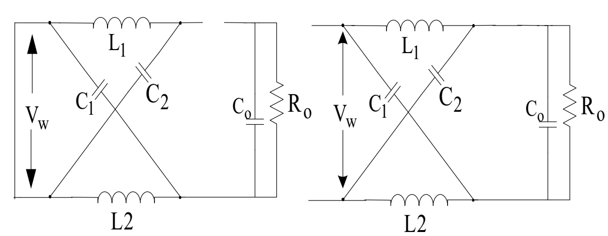

Figure 1.2. Equivalent circuits during shoot-through and non shoot-through states

Any pulse width modulation technique can be applied for the Z source rectifier. The three phase Z –source rectifier has one extra switching state i.e. shoot through state. It has totally nine permissible switching states i.e six active vectors, three zero vectors including shoot through. The extra state (shoot-through) [1] can be treated as short circuiting of both the upper and lower switches of any one phase leg, two phase legs or all three phase legs. The desired buck capability is achieved by inserting shoot-through which is limited by available modulation index. During shoot through state the switch SW7 must be kept open. This shoot through zero state provides unique feature of buck-boost operation. The switch SW7 must be synchronized with gating signals.

The converter can be analyzed from equivalent circuits [1] during shoot-through and non shoot-through states, and can be modelled [1] as shown in (2.1). Where i_a, i_b, i_c, V_c, V_{co}, I_L are phase a current, phase b current, phase c current, Z-source network capacitor voltage, dc-link capacitor voltage and Z-source inductor current.

Three phase a-b-c quantities in (2.1) can be converted into a rotating synchronous frame (d-q-0) using Park transformation, and the transformed 6×6 matrix can be

$$\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \\ V_C \\ V_{co} \\ I_L \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & 0 & 0 & -\frac{2d_a}{L_s} & \frac{d_a}{L_s} & 0 \\ 0 & -\frac{R_s}{L_s} & 0 & -\frac{2d_b}{L_s} & \frac{d_b}{L_s} & 0 \\ 0 & 0 & -\frac{R_s}{L_s} & -\frac{2d_c}{L_s} & \frac{d_c}{L_s} & 0 \\ \frac{(1-d_z)d_a}{C} & \frac{(1-d_z)d_b}{C} & \frac{(1-d_z)d_c}{C} & 0 & 0 & \frac{-1(1-2d_z)}{C} \\ \frac{-(1-d_z)^2 d_a}{C_o} & \frac{-(1-d_z)^2 d_b}{C_o} & \frac{-(1-d_z)^2 d_c}{C_o} & 0 & \frac{-1}{R_o C_o} & \frac{2(1-d_z)^2}{C_o} \\ 0 & 0 & 0 & \frac{1-2d_z}{L} & \frac{-(1-d_z)}{L} & 0 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \\ V_C \\ V_{co} \\ I_L \end{bmatrix} + \begin{bmatrix} \frac{V_a}{L_s} \\ \frac{V_b}{L_s} \\ \frac{V_c}{L_s} \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

………….. (2.1)

reduced to 5×5 matrix with the assumption of a-axis and q-axis coincide each other. To linearize this model [2] a small signal disturbance for all the state variables around it's DC operating point can be applied like, $x=X+\hat{x}$. Substituting these disturbances in the transformed d-q matrix, steady state model and small signal ac model can be obtained. The small signal AC model is shown in (2.2).

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II. DYNAMIC MODEL FOR CONTROLLER DESIGN

In this section, the derived model is applied to synthesize the current and voltage control loops. From the small signal equations, however, the well separated poles between AC side and DC side ac current control and dc output voltage control bandwidth make the quasi static dynamic approximation, i.e. the upper two rows and lower three rows expressed can be dealt separately.

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$$L_s\frac{d\hat{i}_q}{dt} = -R_s\hat{i}_q - \omega_e L_s\hat{i}_d - d_q\left(2\hat{V}_c - \hat{V}_{CO}\right) - \hat{d}_q(2V_C - V_{C0}) + \hat{v}_q$$

$$L_s\frac{d\hat{i}_d}{dt} = \omega_e L_s i_q - R_s\hat{i}_d - - d_d\left(2\hat{V}_c - \hat{V}_{CO}\right) - \hat{d}_d(2V_C - V_{C0})$$

Assuming that the harmonic fluctuation in V_C and V_{co} is negligible by proper choice of elements in the Z-source network, it may be clear that the well developed AC current control for boost converters can be applied.

The general model for DC side variables can be obtained from the lower three rows of equation (2.2). Dynamic response is shown in fig 4.1 and Fig 4.2 for the operating condition Vq=80V, M=0.6, R_o =15Ω, dz=0, L_s=2.5mH, R_s=0.1Ω, L=6mH, C=220µF, and C_o=2200µF.

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$$\frac{d}{dt}\begin{bmatrix} \hat{i}_q \\ \hat{i}_d \\ \hat{V}_C \\ V_{co} \\ \hat{I}_L \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & -\omega_e & -\frac{2Dq}{L_s} & \frac{D_q}{L_s} & 0 \\ \omega_e & -\frac{R_s}{L_s} & -\frac{2D_d}{L_s} & \frac{D_d}{L_s} & 0 \\ \frac{3}{2}\frac{(1-D_z)D_q}{C} & \frac{3}{2}\frac{(1-D_z)D_d}{C} & 0 & 0 & \frac{-(1-2D_z)}{C} \\ \frac{-3}{2}\frac{(1-D_z)^2 D_q}{C_o} & \frac{-3}{2}\frac{(1-D_z)^2 D_d}{C_o} & 0 & \frac{-1}{R_o C_o} & \frac{2(1-D_z)^2}{C_o} \\ 0 & 0 & \frac{1-2D_z}{L} & \frac{-(1-D_z)}{L} & 0 \end{bmatrix} \begin{bmatrix} \hat{i}_q \\ \hat{i}_d \\ \hat{V}_C \\ \hat{V}_{co} \\ \hat{I}_L \end{bmatrix} + \begin{bmatrix} \frac{\hat{V}_q}{L_s} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 2I_L - \frac{3}{2}Dqiq - \frac{3}{2}Ddid \\ (1-D_Z)(-4I_L + 3Dqiq + 3Ddid) \\ -2V_C + V_{co} \end{bmatrix}\begin{bmatrix} \hat{D}_Z \end{bmatrix} + \begin{bmatrix} -2V_C + V_{co} & 0 \\ 0 & -2V_C + V_{co} \\ \frac{3}{2}\frac{(1-D_Z)i_q}{C} & \frac{3}{2}\frac{(1-D_Z)i_d}{C} \\ \frac{-3}{2}\frac{(1-D_Z)^2 i_q}{C_o} & \frac{-3}{2}\frac{(1-D_Z)^2 i_d}{C_o} \\ 0 & 0 \end{bmatrix}\begin{bmatrix} \hat{D}_q \\ \hat{D}_d \end{bmatrix}$$

(2.2)

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