International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 4 (2015) pp. 11393-11404

http://www.ripublication.com

MIMO DC-DC Converter Fed Diode Clamped Multilevel Inverter: Design, Simulation and Analysis

C.Suganya[#], S.AugustiLindiya[#]and K.Vijayarekha[#]
[#]Department of Electrical and Electronics Engineering,Sastra University
Thanjavur,Tamilnadu-613 401,India
suganyac4@gmail.com

Abstract

In this paper aMultiple Input Multiple Output(MIMO) topology capable of interfacing hybridized energy source with diode clamped multilevel inverter is designed, simulated and analyzed. The MIMO converter can accommodate multiple input sources and output load and has single inductor which is cost effective. By using single stage,two input two output DC-DC boost converter,regulated voltage in series is produced. Multiple output loads have different level of voltages, so voltage regulation across the output port is done using compensators. To design a controller for the converter system small signal modeling is done for each mode of operation and its performance is analyzed and verified using SISOTOOL(GUI). This series regulated output voltage is fed to diode clamped multilevel inverter to get a sinusoidal AC output voltage. Balancing of capacitor voltage and the use of multiple energy sources for Diode Clamped Multilevel Inverter (DCMI) is possible using MIMO DC-DC boost converter system.

Keywords:MIMO (Multi Input Multi Output) DC-DC boost converter, multilevel inverter,voltage regulation, small signal modeling, SISOTOOL.

Introduction

Use of renewable energy sources has been increasing day by day due to the limited supply of conventional energy sources. It also has numerous advantages such as sustainability, low environmental impacts and less maintenance. However, renewable energy sources have the problem of intermittent that is they are not available continuously eg. Solar and wind energy [1]. In order to overcome this problem different energy sources can be combined together through a multi input system such that the optimal utilization of each energy source can be made possible [2]-[4].

Multi input multi output DC-DC boost converter system is capable of combining multiple energy sources and provide multiple output voltages [5]. For an N number of output voltages the number of inductors required is also Nbut this type of converter system use only one inductor and a less number of switches are used [6]. Hence this leads to decrease in cost, size and switching loss. The most important application of this converter is that it can boost lower input voltages and regulate lower output voltages.

Inverters are needed to connect the converter system to the power grid.The main aim of industries is to have less production cost with high efficiency[7]-[9]. There are many types of inverter among them multilevel inverters are mostly required for industries because of its medium and high power operation with reduced harmonic distortion [10]. As the number of levels increases, the output waveform produced will have more steps so that a fine staircase waveform closer to sine waveform is obtained. Among the various multilevel inverter types, diode clamped multilevel inverter is the most widely used multilevel inverters since it has high efficiency for the fundamental switching frequency [11].It also has lower number of capacitors which leads to low cost, weight and volume. Use of diode clamped multilevel inverter has the following [12] disadvantages,

1. Balancing of capacitor voltage.
2. Use of multiple energy sources.

MIMO DC-DC boost converter can solve this problem and simplify the control strategy [14],[15]. The overall block diagram for diode clamped multilevel inverter fed from MIMO DC-DC boost converter is shown in Figure 1. MIMO converter accepts multiple energy sources simultaneously and gives multiple outputs. This paper presents a dual input dual output converter system. In order to maintain a constant output voltage a controller is used. This series regulated voltage obtained across the capacitor is fed to diode clamped multilevel inverter to get a sinusoidal AC output voltage and then can be connected to the load.

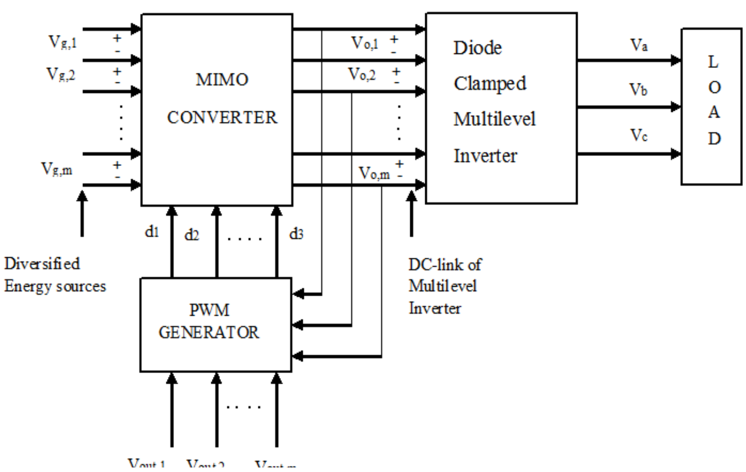

Figure 1: Block diagram for the proposed system

Converter Configuration

Circuit diagram for two input two output DC-DC boost converter is shown in Figure 2. It consist of two input sources V_{in1} and V_{in2} with the condition $V_{in1} < V_{in2}$ such that the operation can be simplified. It hasthree switches (S_1, S_2 and S_3), three diodes (D_0, D_1 and D_2) and two capacitors(C_1 and C_2).

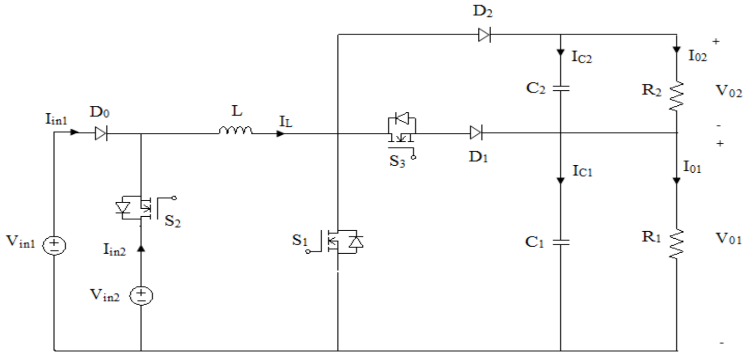

Figure 2: Twoinput two output DC-DC boost converter

Pulses for the switches and voltage and current waveforms across the inductor is shown in Figure 3. According to the switching pattern there are four different modes of operation which are explained in Table 1.

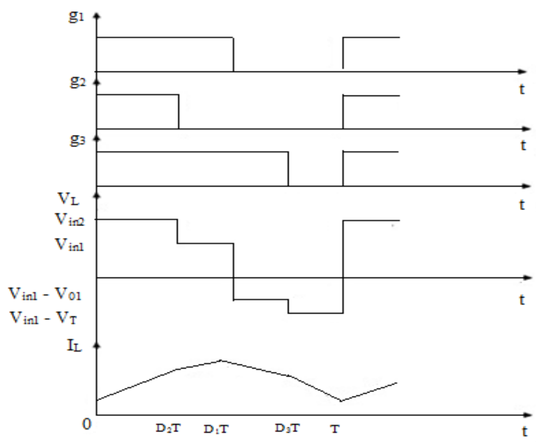

Figure 3: Steady state waveforms of the proposed converter

Table 1: Switching states of dual input dual output DC-DC boost converter

Switching state	**Interval**	**S_1**	**S_2**	**S_3**	**C_1**	**C_2**	**I_L**
1	$0 < t < D_2T$	ON	ON	OFF	Discharges	Discharges	Increases
2	$D_2T < t < D_1T$	ON	OFF	OFF	Discharges	Discharges	Increases
3	$D_1T < t < D_3T$	OFF	OFF	ON	Charges	Discharges	Decreases
4	$D_3T < t < T$	OFF	OFF	OFF	Charges	Discharges	Decreases

Use of control technique for the proposedconverter is to produce regulated voltage across the DC link capacitor which automatically avoids the capacitor voltage unbalancing of diode clamped multilevel inverter. Therefore, by using two input two output converter system the control strategy for diode clamped multilevel inverter is simplified and use of multiple energy sources is possible.Figure 4 shows the circuit diagram for DCMI.

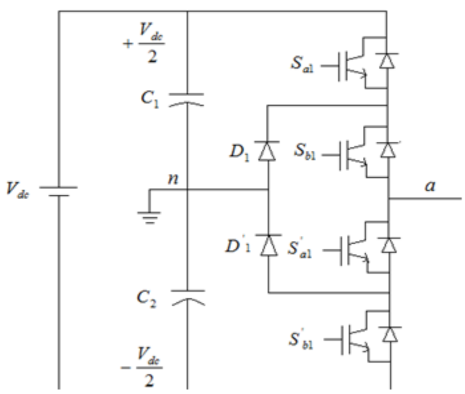

Figure 4: Three level diode clamped multilevel inverter

Dynamic Modeling of TheConverter

According to the small signal modeling method the input voltages, duty ratios and the state variableshave its DC values and perturbations. Thus, based on state space averaging method applied to the equations obtained from four different modes of operation,equation (1) is obtained.

$$L\frac{d\hat{i}_L}{dt} = (V_{in2} - V_{in1})\,\hat{d}_2(t) + D_2\hat{v}_{in2}(t) + (1 - D_2)\,\hat{v}_{in1}(t) - (1- D_1)\,\hat{v}_{01}(t) + (D_3 - 1)\,\hat{v}_{02}(t) + V_{01}\hat{d}_1(t) + V_{02}\hat{d}_3(t)$$

$$C1\frac{d\hat{v}_{01}(t)}{dt} = -I_L\hat{d}_1(t) + (1- D_1)\,\hat{i}_L(t) - \frac{\hat{v}_{01}(t)}{R_1} \qquad (1)$$

$$C_2 \frac{d\hat{v}_{02}(t)}{dt} = -I_L \hat{d}_3(t) + (1-D_3)\hat{i}_L(t) - \frac{\hat{v}_{02}(t)}{R_2}$$

Switching period for S_1, S_2 and S_3 are found from equation (3) which is the steady state equation.

$$\begin{bmatrix} V_{01} & V_{in2}-V_{in1} & V_{02} \\ R_1 I_b & V_{01} & 0 \\ 0 & V_{02} & R_2 I_b \end{bmatrix} \begin{bmatrix} D_1 \\ D_2 \\ D_3 \end{bmatrix} = \begin{bmatrix} V_{02}+V_{01}-V_{in1} \\ R_1 I_b \\ R_2 I_b \end{bmatrix} \quad (2)$$

The state space model of the proposed converter is given in the equation (3) and (4).

$$\begin{bmatrix} \dot{\hat{i}}_L \\ \dot{\hat{v}}_{01} \\ \dot{\hat{v}}_{02} \end{bmatrix} = \begin{bmatrix} 0 & \frac{(D_1-1)}{L} & \frac{(D_3-1)}{L} \\ \frac{(1-D_1)}{C_1} & \frac{-1}{R_1C_1} & 0 \\ \frac{(1-D_3)}{C_2} & 0 & \frac{-1}{R_2C_2} \end{bmatrix} \begin{bmatrix} \hat{i}_L \\ \hat{v}_{01} \\ \hat{v}_{02} \end{bmatrix} + \begin{bmatrix} \frac{V_{02}}{L} & \frac{V_{01}}{L} & \frac{(V_{in2}-V_{in1})}{L} \\ 0 & \frac{-I_L}{C_1} & 0 \\ \frac{-I_L}{C_2} & 0 & 0 \end{bmatrix} \begin{bmatrix} \hat{d}_3 \\ \hat{d}_1 \\ \hat{d}_2 \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} \hat{v}_{01} \\ \hat{v}_T \\ \hat{I}_{in2} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 1 & 1 \\ D_3 & 0 & 0 \end{bmatrix} \begin{bmatrix} \hat{i}_L \\ \hat{v}_{01} \\ \hat{v}_{02} \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & I_L & 0 \end{bmatrix} \begin{bmatrix} \hat{d}_3 \\ \hat{d}_1 \\ \hat{d}_2 \end{bmatrix} \quad (4)$$

The transfer functions are obtained as,

$$g_{11} = \frac{\hat{v}_{01}(s)}{d_3(s)}$$

$$= \frac{\left(\frac{V_{02}(1-D_1)}{LC_1}\right)S + \left(\frac{(1-D_1)V_{02}}{LR_2C_1C_2} - \frac{(1-D_1)(D_3-1)I_L}{LC_1C_2}\right)}{S^3 + \left(\frac{R_1C_1+R_2C_2}{R_1R_2C_1C_2}\right)S^2 + \left(\frac{L+(1-D_1)^2R_1R_2C_2+(D_3-1)^2R_1R_2C_1}{LR_1R_2C_1C_2}\right)S + \left(\frac{R_1(1-D_1)^2+(D_3-1)^2R_2}{LR_1R_2C_1C_2}\right)} \quad (5)$$

$$g_{22} = \frac{\hat{v}_T(s)}{d_2(s)}$$

$$= \frac{\left(\frac{V_{in2}-V_{in1}}{L}\right)\left(\frac{(1-D_1)}{C_1} - \frac{D_3-1}{C_2}\right)S + \left(\frac{(1-D_1)}{R_2C_1C_2} - \frac{(D_3-1)}{R_1C_1C_2}\right)\left(\frac{V_{in2}-V_{in1}}{L}\right)}{S^3 + \left(\frac{R_1C_1+R_2C_2}{R_1R_2C_1C_2}\right)S^2 + \left(\frac{L+(1-D_1)^2R_1R_2C_2+(D_3-1)^2R_1R_2C_1}{LR_1R_2C_1C_2}\right)S + \left(\frac{R_1(1-D_1)^2+(D_3-1)^2R_2}{LR_1R_2C_1C_2}\right)} \quad (6)$$

$$g_{33} = \frac{\hat{I}_{in2}(s)}{d_1(s)}$$

$$= \frac{\left(\frac{V_{01}D_2}{L}\right)S^2 + \left(\frac{D_2V_{01}}{L}\left(\frac{1}{R_1C_1}+\frac{1}{R_2C_2}\right)+\frac{I_L(1-D_1)D_2}{LC_1}\right)S + \left(\frac{D_2V_{01}}{LR_1R_2C_1C_2}+\frac{I_L(1-D_1)D_2}{LR_2C_1C_2}\right)}{S^3 + \left(\frac{R_1C_1+R_2C_2}{R_1R_2C_1C_2}\right)S^2 + \left(\frac{L+(1-D_1)^2R_1R_2C_2+(D_3-1)^2R_1R_2C_1}{LR_1R_2C_1C_2}\right)S + \left(\frac{R_1(1-D_1)^2+(D_3-1)^2R_2}{LR_1R_2C_1C_2}\right)} \quad (7)$$

Thus from the transfer functions (5), (6) and (7)it is obviously seen that the output voltages V_{01} and V_T are controlled by controlling the duty cycles d_3 and d_2 respectively. The specifications which are designed and used in the model are given in Table 2.

Table 2: Specifications of two input two output DC-DC boost converter

Parameters	**Values**
Input voltage 1 (V_{in1})	24V
Input voltage 2 (V_{in2})	36V
Inductor (L)	28mH
Capacitor (C_1 and C_2)	1000µF and 2200µF
Resistor (R_1 and R_2)	35Ω and 35Ω
Switching Frequency (f_{sw})	10kHZ
Output Voltage (V_{01})	80V
Output Voltage (V_{02})	40V

The values specified in Table 2 are substituted in the transfer functions g_{11}, g_{22} and is obtained as,

$$g_{11} = \frac{\hat{v}_{01}(s)}{d_3(s)} = \frac{396428.57S + 10262059.37}{S^3 + 41.558S^2 + 3950.60S + 52179.96} \quad (8)$$

$$g_{22} = \frac{\hat{v}_T(s)}{d_2(s)} = \frac{157791.68S + 2504636.54}{S^3 + 41.558S^2 + 3950.60S + 52179.96} \quad (9)$$

Control Strategy

The need for control system design of MIMO DC-DC boost converter system is to maintain the constant output voltage. Compensators are one of the best controllers. Using compensators stability of the system can be increased and the steady state error can be eliminated. Lead, Lag, Lead/Lag are the types of compensators. These are designed in the form of transfer functions using SISO tool in MATLAB Simulink.Using the transfer functions g_{11} and g_{22} obtained from small signal modeling method, for switches S_2 and S_3 compensators can be designed.Bode plot obtained before applying compensator for g_{11} is shown in Figure 5a. The phase margin of the system obtained is low so to increase the phase margin a lead compensator is designed using frequency response and is given in equation (10).

$$G_{11}(s) = 1000\frac{(S+1)}{(S+21200)} \tag{10}$$

Bode plot obtained after applying compensator for g_{11} is shown in Figure 5b. Thus the phase margin of the system and system stability is improved.

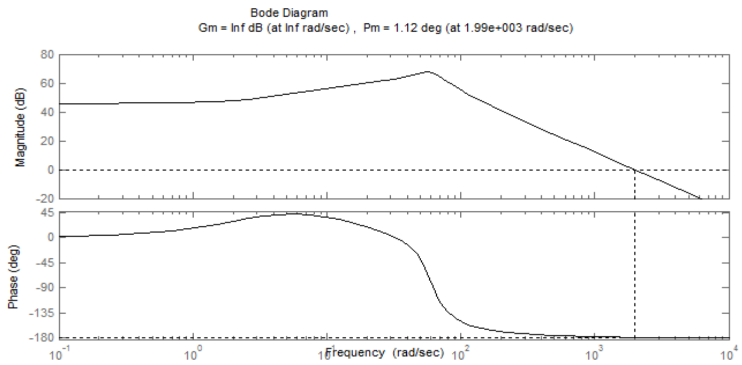

Figure5a: Bode plot of g_{11} obtained before applying compensator

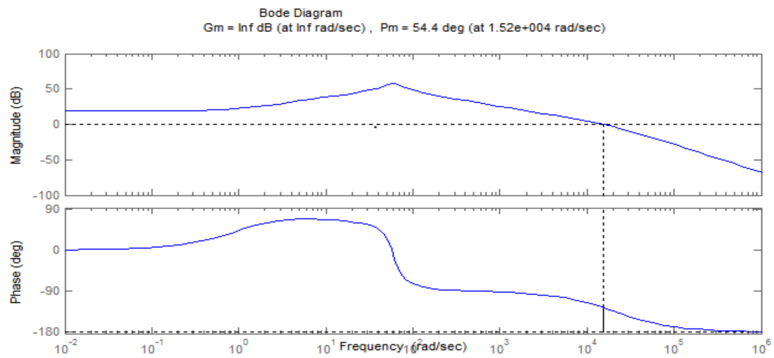

Figure5b: Bode plot of g_{11} obtained after applying compensator

Bode plot obtained for g_{22} before applying compensator is shown in Figure 6a.This figure shows that the phase margin of the system obtained is low so to increase the phase margin a lead compensator is designed using frequency response and is given in equation (11).

$$G_{22}(s) = 9\frac{(S+15)}{(S+1000)} \tag{11}$$

Bode plot obtained after applying compensator for g_{22} is shown in Figure 6b. Thus the phase margin of the system and system stability is improved.

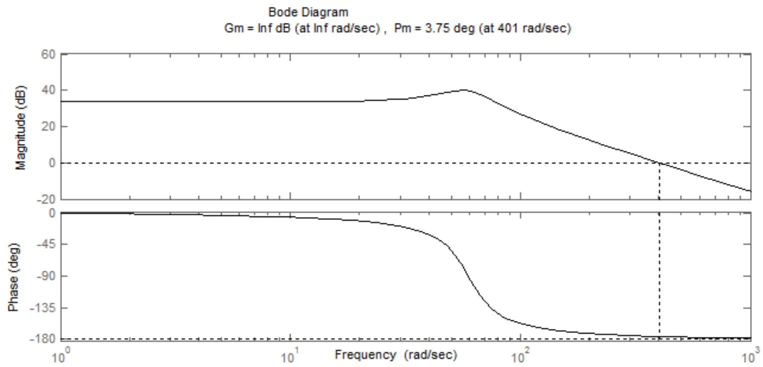

Figure6a: Bode plot of g_{22} obtained before applying compensator

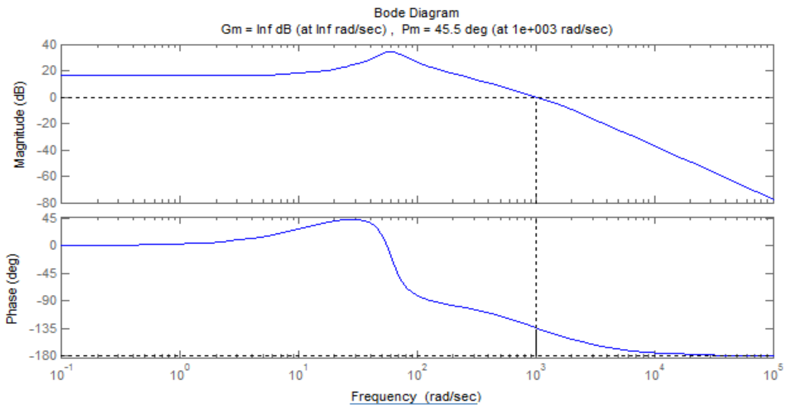

Figure6b: Bode plot of g_{22}obtained after applying compensator

Simulation Results

The performance of the proposed converter has been verified using MATLAB Simulink software. The converter system has two input voltage sources V_{in1} and V_{in2} of 24V and 36V respectively connected through various switches and an inductor. The converter system produces regulated output voltages in series andis fed to the inverter. Simulation results across the inductor of the converter is measured and obtained as shown in Figure 7.

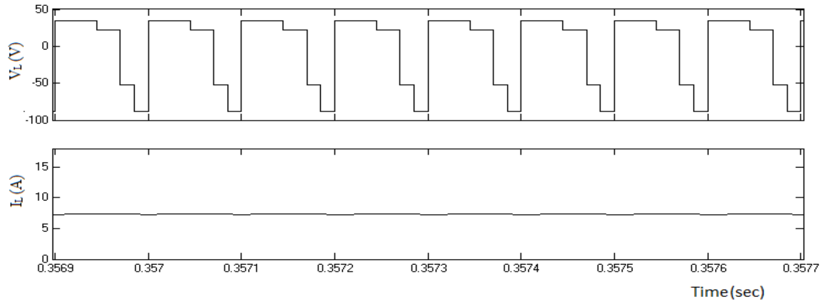

Figure 7: Simulation results across the inductor of the converter

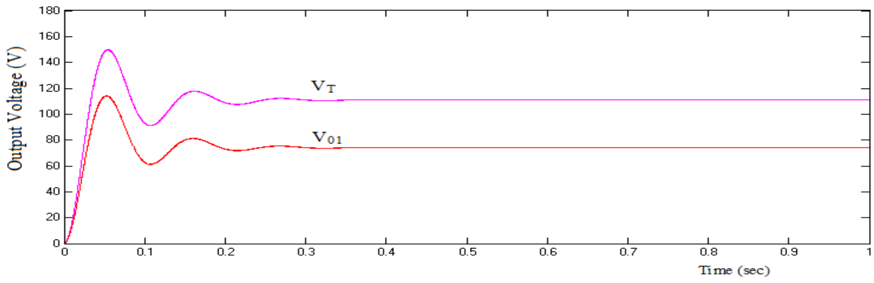

Figure8: Output voltage waveform of the converter under open loop condition

The output voltages measured across the converter is shown in Figure 8. Since it is boost converter the total output voltage required to obtain is 120V that is 80V and 40V across the loads R_1 and R_2 respectively but only 76V and 34V is obtained. So to produce a series regulated output voltage controllers are used. The simulation results of closed loop control fortwo input two output DC-DC boost converter is shown in Figure 9.

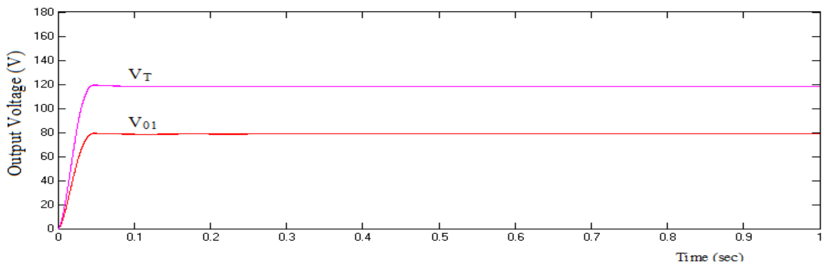

Figure9: Output voltage waveforms of theconverter under closed loop condition

In order to verify the performance of controller disturbances are given to load current. Figure 10 shows that under closed loop condition even though disturbances are given the output voltage is maintained constant, but it takes 0.1 Sec to settle.

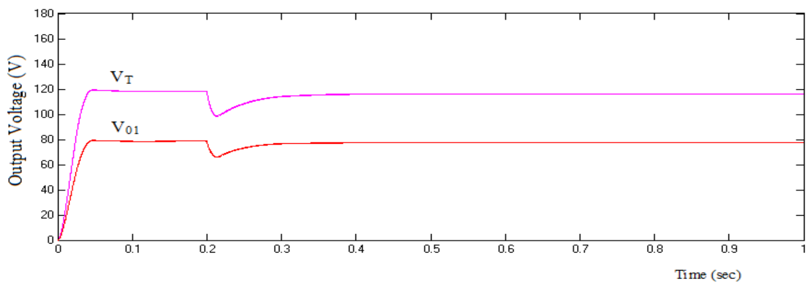

Figure 10: Output voltage waveforms of the converter under disturbances

Three phase three level multilevel inverters is designed to interface with MIMO DC-DC boost converter. Simulation results forthephaseand line voltageof diode clamped multilevel inverter fed from two input two output DC-DC boost converter is shown in Figure 11 and Figure 12respectively.

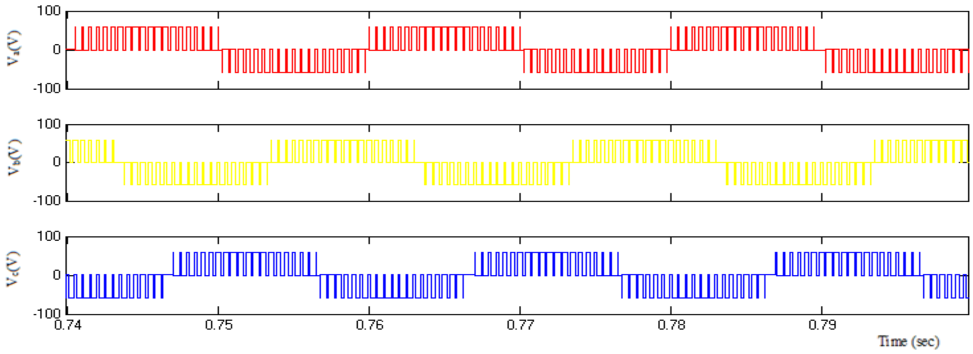

Figure 11: Phase voltage of diode clamped multilevel inverter fed from two input two output DC-DC boost converter

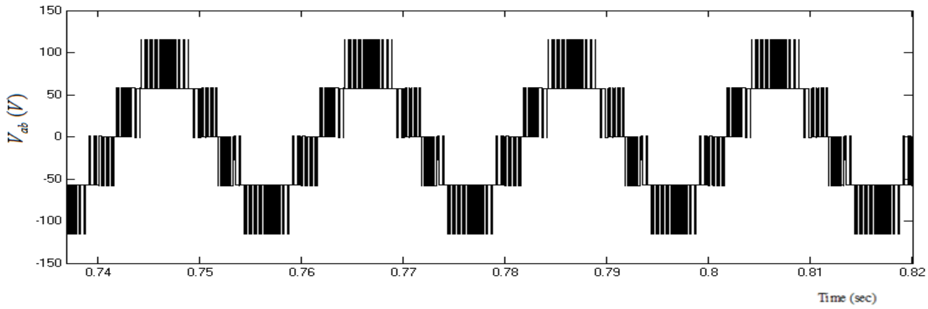

Figure 12: Line voltage (V_{ab}) of diode clamped multilevel inverter fed from two input two output DC-DC boost converter

Conclusion

This paper proposes a diode clamped multilevel inverter fed from MIMO DC-DC boost converter. Using two input two output DC-DC boost converter two different energy sources have been combined by which two different output voltages are produced. Its different modes of operation, steady state and dynamic characteristics has been studied. Controllers for the converter system using small signal modeling is designed and closed loop operation for MIMO converter has been performed. This MIMO converter is fed to diode clamped multilevel inverter with a DC link capacitor as an intermediate. Thus multiple energy sources are fed to diode clamped multilevel inverter and its capacitor voltage imbalance is reduced.

References

[1]. H.Tao, A.Kotsopulous, J.L. Duarte, and M.A.M. Hendrix, "Family of multiport bidirectional DC-DC converters," Inst. Electr. Eng. proc. Elect. Power Appl., vol. 153, no. 3, pp.451-458, May 2006.

[2]. Y.C. Liu, Y.M.Chen, "A systematic approach to synthesizing Multi-Input DC-DC converters", IEEE Trans. Power Electron, vol.24, no.1, pp.116-127, Jan.2009.

[3]. H. Matsuo, W. Lin, F. Kurokawa, T. Shigemizu, and N. Watanabe, "Characteristics of the multiple-input dc-dc converter,"IEEE Trans. Ind. Electron., vol. 51, no. 3, pp. 625–631, Jun. 2004.

[4]. A. Kwasinski, "Identification of feasible topologies for multiple-input DC-DC converters," *IEEE Trans. Power Electron.*, vol. 24, no. 3, pp. 856-861, March 2009.

[5]. Hamid Behjati and Ali Davoudi, "A Multiple-Input Multiple-Output DC–DC Converter," IEEE Transactions on industry applications, vol. 49, no. 3, May/June2013.

[6]. F.Nejabatkhah, S. DAnyali, S.H.Hosseini, M. Sahahi and S.A.MozaffariNiapour, "Modelling and control of a new Three-Input DC-DC Boost converter for Hybrid PV/FC/Battery Power System" IEEE Trans. Power Electronics, vol.27, no.5,pp.2309-2325.

[7]. Reza Ahmadi and Mehdi Ferdowsi, "Double-Input Converters Based on H-Bridge Cells: Derivation, Small-Signal Modeling, and Power Sharing Analysis" in IEEE transactions on Circuits and Systems—I: regular papers, vol. 59, no. 4, April 2012.

[8]. KarteekGummi and Mehdi Ferdowni, "Double-Input DC-DC Power Electronic Converters for Electric-Drive Vehicles-Topology Exploration and Synthesis Using a Single-Pole Triple-Throw Switch" IEEE transanctios on Industrial Electronics, vol. 57, no. 2, February 2010.

[9]. S. M. Dehghan, M. Mohamadin, A. Yazdian and I. Ashrafzadeh, Dual-Input Dual-Output Z-Source Inverter" IEEE transactions on power electron, vol. 25, no. 2, pp. 360-368, February 2010.

[10]. Jih-Sheng Lai, "Multilevel Converters – A New Breed of Power Converters" in IEEE transactions on industry applicstions, vol. 32, no. 3, Ma/June 1996.

[11]. Jose Rodriguez, Steffen Bernet, Peter K. Steimer and Ignacio E. Lizama, "A Survey on Neutral-Point-Clamped Inverters," IEEE transactions on industrial electronics, vol. 57, no. 7, July 2010.

[12]. Hirofumi Akagi, and TakaakiHatada, "Voltage Balancing Control for a Three-Level Diode-Clamped Converter in a Medium-Voltage Transformerless Hybrid Active Filter," IEEEtransactions on power electronics, vol. 24, no. 3, March 2009.

[13]. G. P. Adam, S. J. Finney, A. M. Massoud, and B. W. Williams, "Capacitor Balance Issues of the Diode-Clamped Multilevel Inverter Operated in a

Quasi Two-State Mode," IEEE Transaction Ind.Electron, vol. 55, no. 8, pp. 3088-3099, August 2008.

[14]. A. Nami, F. Zare, A. Ghosh, and F.Blaabjerg, "Multi-output dc–dc converters based on diode-clamped converters configuration: Topology and control strategy," IET Power Electron., vol. 3, no. 2, pp. 197–208, 2010.

[15]. Hamid Behjati and Ali Davoudi, " A MIMO Topology with Series Outputs: An Interface between Diversified Energy Sources and Diode-lamed Multilevel Inverter," in Proc. Applied Power Electronics Conference and Exposition (APEC), 2012.