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Design of LCL Bidirectional DC-DC Converters for Electric Vehicle Applications

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ABSTRACT

This paper deals with a new resonant dual active bridge (DAB) topology in which tuned inductor-capacitor-inductor (LCL) network is used. The main features of proposed topologies to achieve a bidirectional power at a high efficiency over a wide range of power, DC supply voltage and to extend soft-switching range. Also continuous power is achieved. The advantage of this topology is the availability of energy storage port, multi winding transformer in a single core and centralized control. This proposed DAB topology reduces the magnitude of bridge current, lower both conduction and switching losses. Thereby efficiency is increased. The reactive power is minimized and the eddy current losses in the transformer winding are also reduced in the proposed converter.

Keywords: dc-dc converters, dual active bridge (DAB), resonant converter, modulation.

INTRODUCTION

Nowadays global concerns regarding future fossil fuel shortage have spurred effort to reduce the dependent on coal, oil and gas to generate electricity. Therefore, electricity is increasingly generated from wind, solar, or tidal energy sources. The Dual active bridge (DAB) converter is a high efficiency buck and boost, bidirectional dc-dc converter isolated by a high frequency transformer. There are many types of bidirectional dc-dc converters among which DAB converter are often preferred in vehicle-to-grid (V2G) system. Because it has a small component count, offers isolation, allows for high power operation and also it can be controlled to operate in buck or boost modes.

In this paper a new resonant DAB (Dual Active Bridge) topology with tuned inductor-capacitor-inductor (LCL) network is utilized. This resonant network minimizes the reactive power requirement of the converter and continuous power is achieved. The proposed tuned LCL network includes the leakage inductance of isolation transformer to reduced copper loss and magnitude of bridge current. A simple control scheme is employed. The system consists of

1. Three full bridge converter.
2. LCL network.
3. Multi winding transformer.
4. A battery

Block diagram of proposed topology: The block diagram of the proposed DAB converter is shown below

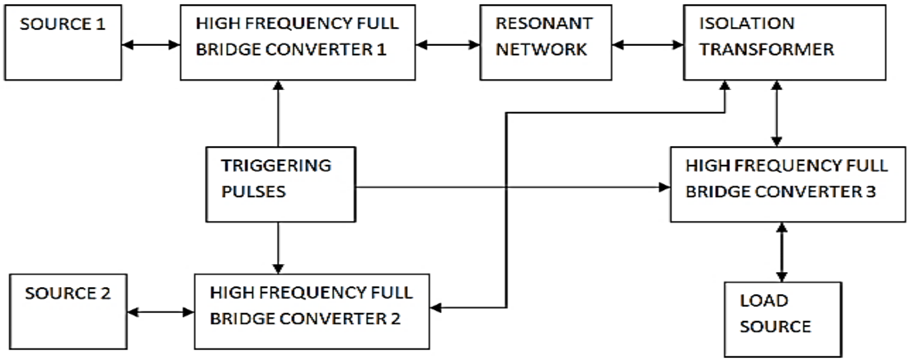

Figure.1. Block diagram of proposed DAB resonant converter

It has three full-bridge converters interconnected by an isolation transformer and a tuned $L_1C_1L_2$ network. The primary winding is spilt into two. Bridge converter 1 of the proposed resonant DAB is operated at a fixed frequency, f_s and similarly bridge 2 and bridge 3 is operated at the same frequency as bridge 1. Transformer turns ratio is n : 1. Because of the presence of tuned $L_1C_1L_2$ network the proposed system does not exhibit multiple operating modes like conventional system. There are 3 modes of operation. In mode 1 bridge 1 supplies power to the load and at the time the bridge 2 will be charging. In mode 2 bridge 2 supplies power to the load and at the time the bridge 1 will be charging. In mode 3 bridge 3 is supplies power and at the time the bridge 1, 2 will be charging.

MATERIALS AND METHODS

The components used in this system are as follows

Table.1.Components used

Components	Type	Voltage
Microcontroller	AT89C51	5
Oscillator	Crystal	5
Voltage regulator	7805	5
Buffer	741S244A	5
Gate driver	IR2110	12

Table.2. Design of resonant converter

Fundamental Frequency	$L_1C_1=L_2C_1=1/(w_s)^2=1/(2\pi f_s)^2$
ZVS range	R=nVdc2/vdc1
Total Harmonic Distortion (THD)	$\mathrm{THD} = \sqrt{1-\left(\frac{\mathrm{if}}{\mathrm{iRMS}}\right)2}$

Table.3.Design of transformer

Number of turns	$(V_1/N_1)=(V_2/N_2)=(V_3/N_3)$
Power	$\mathrm{P}=P=\frac{\varphi(\pi-\lvert\varphi\rvert)}{\pi\omega L}VK$
Core size	A_eA_c=(0.68*P_{out}*D*10^3)/(f*B_{max})cm^4 P_{out}=1.16*B_{max}*f*d*A_eA_{c*10}^-9 A_e=3.54cm^2 A_e=core effective area, cm^2 A_c=winding area, cm^2
Maximum flux density	B_{max}=(V_p*10^8)(K*f*$N_{p*}A_e$) K=4.44 (sine wave)
Number of primary windings	N_p=(V_p*10^8)/(K*f*B_{max}*A_e)
Number of secondary windings	$N_s=N_p/1.4$

Table.4. Design of battery

State of charge	SOC=(Remaining capacity / Rated capacity)
Depth of discharge	DOD=1-SOC
State of health	SOH=(Aged energy capacity / Rated energy Capacity)
Efficiency	$\eta = E_D/E_C$ E_D=total energy during discharging E_C=total energy during charging

SIMULATION RESULTS

To validate the proposed DAB converter and method, simulation based on the MATLAB/SIMULINK are implemented in this section.

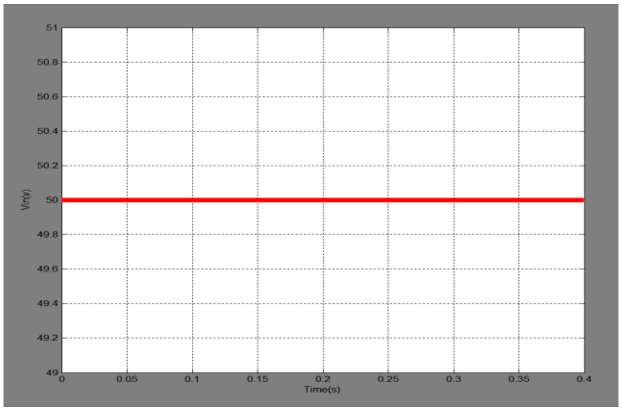

Fig.2.Input voltage [Mode 1]

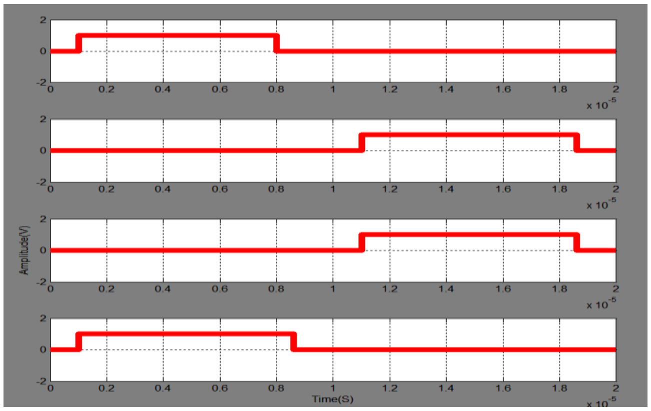

Fig.3.Triggering pulse [Mode 1]

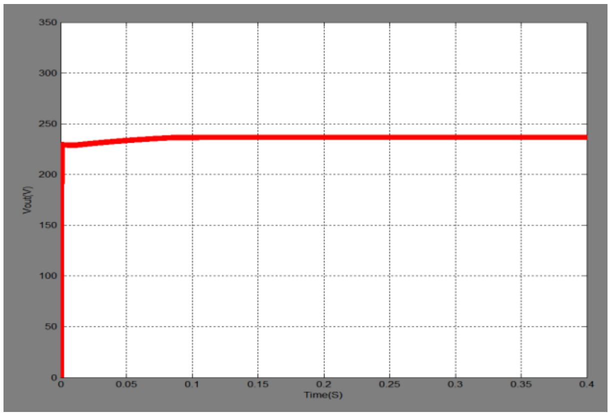

Fig.4.Output voltage [mode 1]

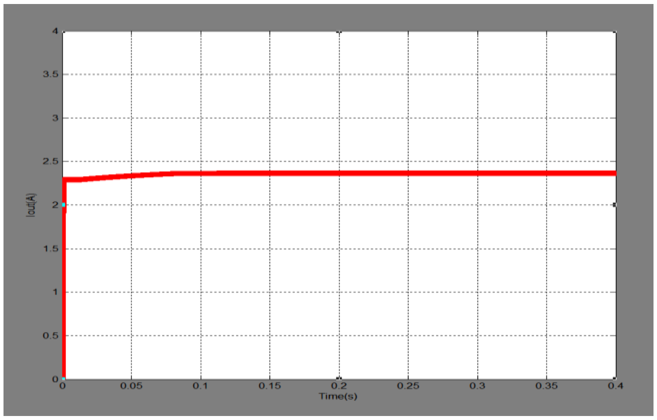

Fig.5.Output current [Mode 1]

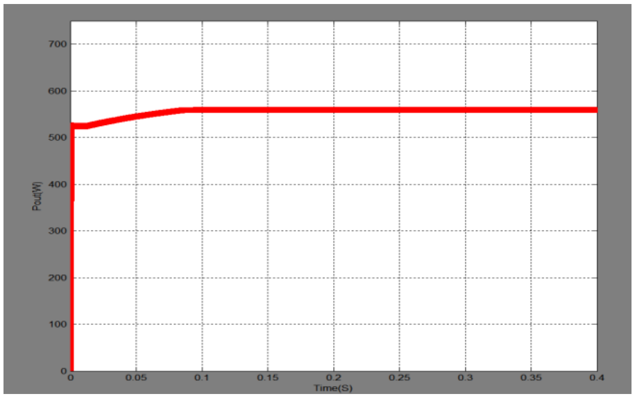

Fig.6.Output power [Mode 1]

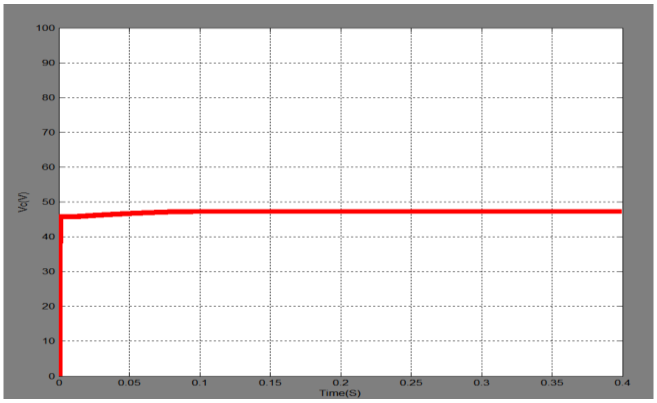

Fig.7.Charging voltage [Mode 1]

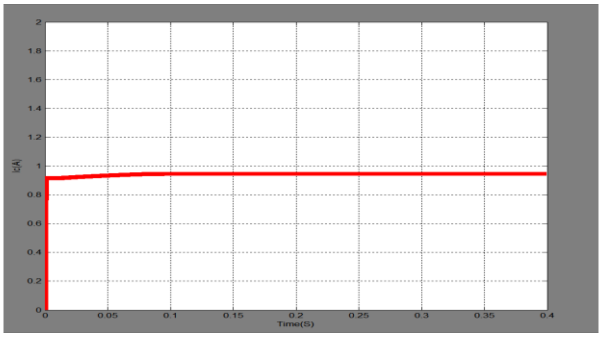

Fig.8.Charging current [mode 1]

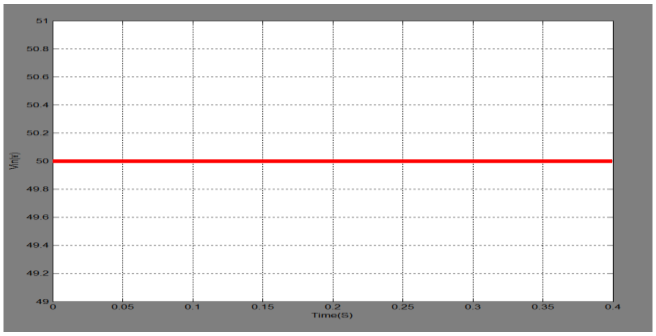

Fig.9.Input voltage [Mode 2]

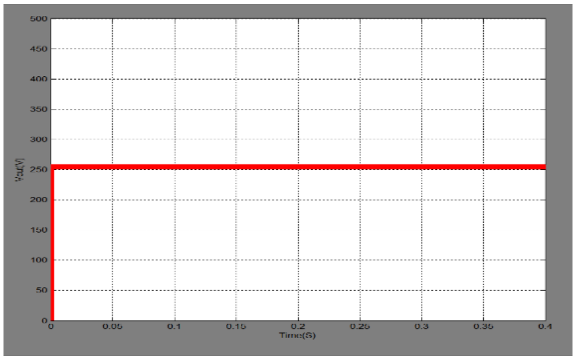

Fig.10.Output voltage [mode 2]

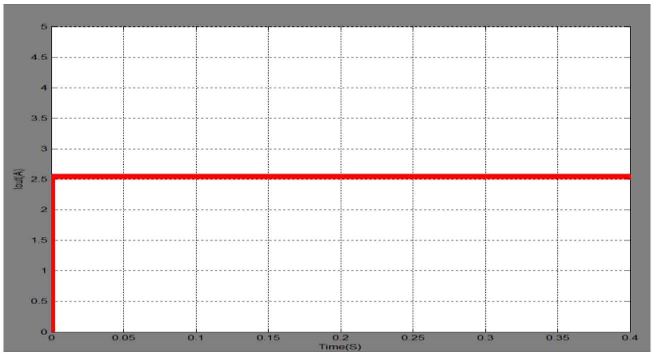

Fig.11.Output current [Mode 2]

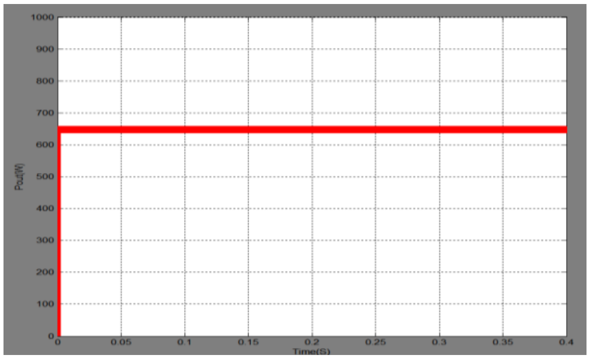

Fig.12.Output power [Mode 2]

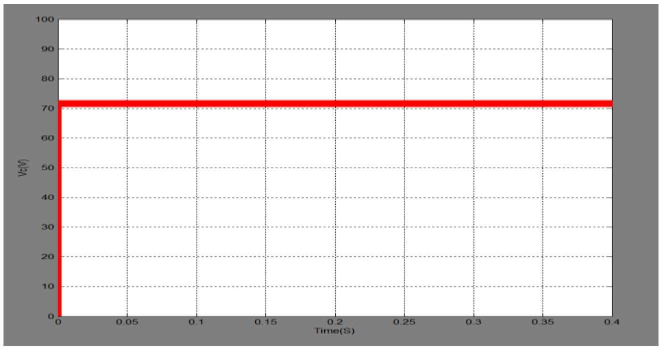

Fig.13.Charging voltage [Mode 2]

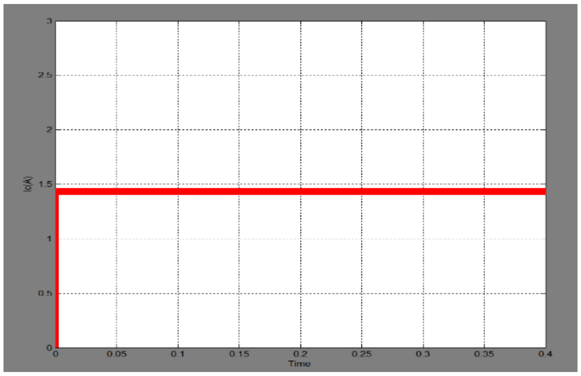

Fig.14.Charging current [Mode 2]

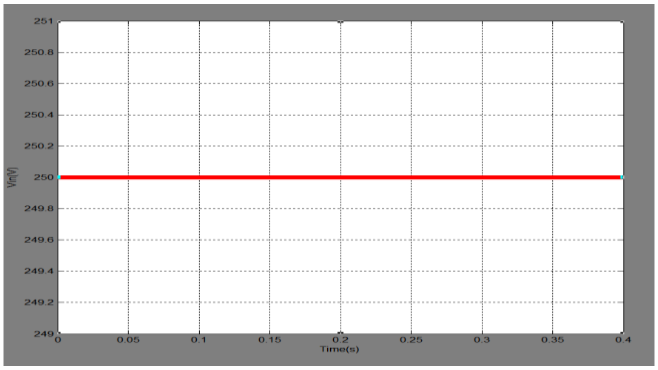

Fig.15.Input voltage [Mode 3]

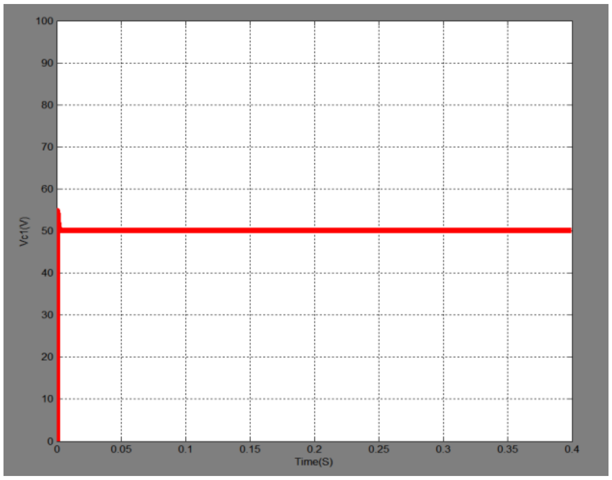

Fig.16.Charging voltage 1 [Mode 3]

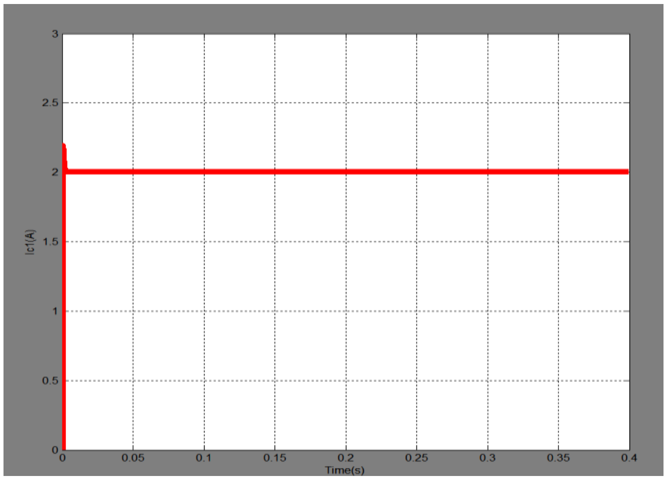

Fig.17.Charging current 1 [Mode 3]

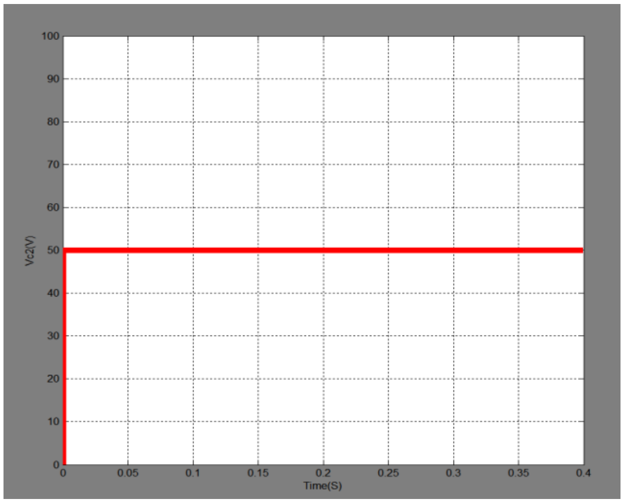

Fig.18.Charging voltage 2 [mode 3]

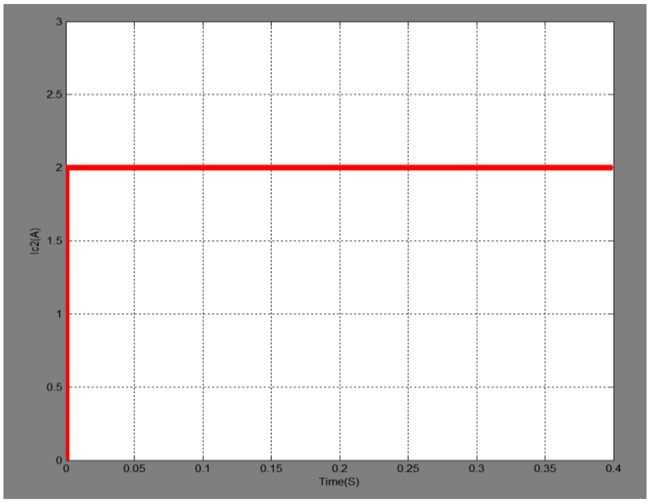

Fig.19.Charging current 2 [Mode 3]

CONCLUSION

The proposed DAB topology analyzed using MATLAB/SIMULINK demonstrate the improved performance of the converter. The proposed three-port converter with three active full bridges, two series-resonant tanks, and a three winding transformer uses a single power conversion stage with high- frequency link to control power flow between batteries, load, and a renewable source such as fuel cell. The converter has capabilities of bidirectional power flow in the battery and the load port. Use of series-resonance aids in high switching frequency operation with realizable component values when compared to existing three-port converter with resonant circuits. The converter has high efficiency due to soft-switching operation in all three bridges. The proposed system achieve Continuous power, has energy storage port, centralized control, multi winding transformer in a single core, offers higher efficiency over a wider supply voltage and load range and has lower bridge currents.

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