A Novel L^2c network Using Dual Active Bridge (DAB) Topology

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Abstract- *Distributed power systems employ the Grid connected Inductor capacitor inductor filtered invertors and this is should be preserved properly. Recently, many strategies have been used to damp the resonance, but the relationships between different damping strategies have not been thoroughly investigated. In comparison to conservative DAB topologies, the planned topology significantly diminishes the bridge currents, dropping both conduction and switching losses and the VA rating associated with the bridges. In this paper the improved performance of the tuned L2C DAB topology is discussed with necessary mathematical expressions and examples.*

Keywords- Dual active bridge (DAB) converter, dc–dc converters, modulation, resonant converter

I. INTRODUCTION

As Science has made progress and civilization has become innovative, human-being's control over nature has been more and more ultimate. Human-being has connected the forces of nature into his service. Heavier, gigantic, and more complicated tasks are accomplished by the use of motive power or energy. Electricity is not an supplementary source of power. It is a modern means of making available already existing sources. But in recent days the power shortage leading to the possibility of significant dynamic mismatches between electricity supply and demand levels. However, it has been proposed that the grade of mismatching can be reduced through integrating the batteries of Electric Vehicles (EVs), which are not being used at any given time, into nation wide electric grid. This would provide a means for dynamic grid stabilization, but requires a bidirectional power interface between the grid and EVs to allow Vehicle-To-Grid (V2G) energy transmissions to take place. Among the many types of bidirectional dc–dc converters that could be used in a V2G system, the DAB converter is a preferred option, as it has a small component count, offers isolation, and allows for high power operation. In addition, it has the ability to accommodate a wide range of voltage levels, as it may be skillful to operate in buck or boost modes. However, a conventional DAB converter using single phase-shift (SPS) controller draws a large reactive current component at low operating power levels, which increases the converter conduction losses. This current component also necessitates the use of a larger dc-link capacitor. Therefore, various techniques have been used to lower the reactive current levels. In pulse width modulation (PWM) of the higher voltage bridge was used with SPS to extend the zero-voltage-switching (ZVS) range to increase the converter low-load efficiency, through a reduction in the reactive current. Triangular and trapezoidal modulation schemes were investigated in an effort to reduce the current and, therefore, the conduction losses. Primarily, this resulted in a reduction in the switching losses by achieving zero current switching in some of the switches .The reactive power was reduced by using equal PWM on each bridge, as well as a phase shift between the bridges. Similar control techniques to that in were used except that the PWM was actively controlled by an algorithm. Bridge losses were minimized in the former, while ZVS was extended to the full operating range in the latter. However, the converter efficiencies in both cases were still limited for large differences in the voltage conversion ratio, particularly under low power operating conditions. Rather than minimizing bridge losses, the focus in was the minimization of either the reactive power, or the rms, or peak current values, according to a selectable algorithm. For this system, dual phase-shift control comprising equal PWM of each bridge was used, as well as a phase shift between the bridges. While each of the algorithms in was effective in improving the converter's performance over that of SPS, the resulting efficiency was less than 90% at full power, and notably less at low power. In an effort to reduce the rms currents and increase the ZVS range, independent PWM control of each bridge, as well as a phase shift between the bridges,was employed in .A composite modulation scheme was proposed, whereby the control algorithm transitioned from dual PWM, at low phase-shift values, through to single PWM which varied linearly to a maximum for a phase-shift value of $\pi/2$ at full power. This provided significant improvements in low-load efficiency without a loss in the full-power capacity. For a dc conversion ratio of 2:1, the efficiency varied from 77% at a 3% load through to approximately 90% at full load. However, this converter required a more complicated control system than SPS.

Furthermore, a number of resonant type DAB converter topologies, consisting of series resonant networks, have been proposed. These topologies exhibit an extended soft-switching range and lower eddy current losses in the transformer windings, due to improved current waveforms . However, regardless of the control and resonant schemes employed, all existing DAB converter topologies inherently draw a large reactive current component at full power and, therefore, incur large conduction losses.

This paper, therefore, proposes a novel DAB topology, which utilizes a resonant network to minimize the reactive power requirement of the converter over the entire load range. The proposed converter employs a tuned inductor–capacitor–inductor (LCL) network, which includes the leakage inductance of the isolation transformer, to significantly reduce the magnitude of bridge currents and, therefore, the switch and copper losses. A simple control scheme is employed, where each bridge is driven with equal PWM while maintaining the phase shift between the bridges fixed at 90 ◦ or −90 ◦, to regulate the direction and magnitude of power flow. Theoretical analyses as well as simulated results are presented in comparison with experimental evidence of a 2.5-kW prototype system, demonstrating the ability of the proposed topology to transfer bidirectional power at a high efficiency over a wide range of power and dc supply voltages.

II. PROPOSED TOPOLOGY

A schematic of the proposed resonant DAB converter is shown in Fig. 1, in which S1 − S8 represent semiconductor switches. For simplicity, the active load on the secondary side is represented by a voltage source, VDC2. In practice, this voltage source, which is connected to the output of the secondary converter, can be a battery pack used for storing or retrieving energy.

Furthermore, in a practical system, L2 may be incorporated with the leakage inductance of the transformer rather than employing a discrete inductor. The primary side full-bridge converter, Bridge 1, of the proposed resonant DAB, is operated at a fixed frequency, fs , and converts dc supply voltage VDC1to a three-level pulse-width-modulated ac voltage source v1 .

Similarly, Bridge 2 is operated at the same frequency as the primary and converts its dc supply voltage VDC2 to a Pulse Width Modulated ac voltage source vB2 . These two ac voltage sources are connected together through an isolation transformer and an L1C1L2 network, which is tuned to fs. Traditional resonant DAB converters employ quasi-resonant networks, comprising inductors and capacitors to reduce switching losses by improving the soft-switching range. These converters exhibit multiple operating or resonant modes within a switching cycle, and typically complex modulation schemes

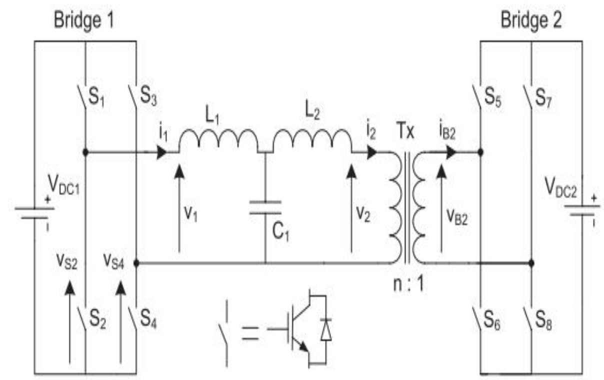

Fig. 1. Proposed resonant DAB converter.

are employed to control the switches in order to achieve soft switching [19]–[22]. However, as a result of the tuned (resonant) L1C1L2 network employed, the proposed system does not exhibit multiple operating modes as both the resonant and switching frequencies are identical and can be controlled using a simple PWM scheme. In the proposed system, the direction and magnitude of power flow is regulated by controlling the pulse width of voltages v1 and vB2 , while keeping the phase shift between them constant . This is achieved by operating switches S1 and S2 of Bridge 1 in antiphase at the switching frequency fs with a duty cycle of 50% to generate voltage vS2 ,as indicated in Fig. 2. Switches S3 and S4 are operated in the same way, except that vS4 lags vS2 by a displacement of α1degrees. The resulting voltage v1 , driving the network, is equal to the difference between vS2 and vS4. Thus, α1 modulates the pulse width (i.e., duty cycle) of the ac voltage v1 in the range of 0–50% as α1 changes from 0 ◦ to 180 ◦. Bridge 2 is controlled in a similar way, using a phase displacement of α2 , to produce a pulse-width-modulated ac voltage vB2 which is offset fromv1 by a phase shift φ. The tuned (resonant) L1C1L2 network presents a high impedance to harmonics generated by the converters, and therefore, the currents *i*1 and *iB*2 are approximately sinusoidal as shown by dotted lines in Fig. 2. Under tuned conditions, the magnitudes of the bridge currents *i*1 and *iB*2 are proportional to *vB*2 and *v*1 , respectively. In addition, *i*1 will beleading *vB*2 by 90 ◦, whereas *iB*2 will be lagging *v*1 by 90 ◦, thus causing the bridge currents to align with the voltages when *φ* is±90 ◦. As such, the power flow of the proposed resonant DAB can be regulated by controlling $\alpha 1$ and $\alpha 2$, while maintaining φ fixed at ±90 ◦ to minimize the VA rating of the bridges.

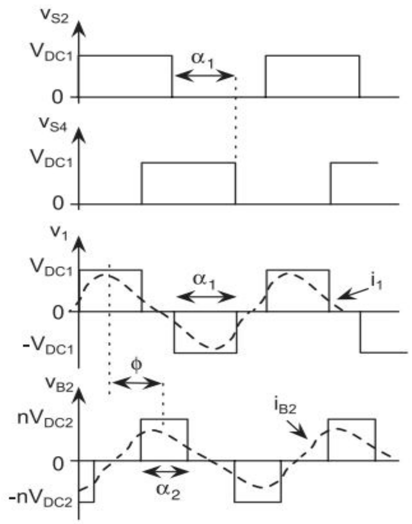

Fig. 2. Typical voltage and current waveforms of the two bridges.

III. MATHEMATICAL ANALYSIS

Circuit Operation at the Fundamental Frequency As evident from Fig. 2, voltages $v1$ and $vB2$ are in the form of pulse-width-modulated square waves and, therefore, comprise sinusoids of diminishing amplitudes at odd multiples of fs. However, if the L1C1L2 is tuned to fs as given by Then, the tuned network presents a high impedance to harmonics generated by the converters. Consequently, the effects of these harmonics on the operation will be insignificant. Therefore, to gain an insight into the operation of the converter, the circuit is initially analyzed at the fundamental switching frequency fs , at which most of the power transfer takes place. Generally, the impedance due to the magnetizing inductance of transformer Tx is large relative to other circuit impedances. Hence, it can be ignored, allowing the resonant DAB to be represented by the equivalent circuit model shown in Fig. 3. If the network, comprising L1,C1 , and L2 , is tuned to the switching frequency fs , as defined by (1), it can be shown that the voltage across capacitor C1 is equal to the vector sum of v1 and v2 . Thereby, the voltage across L1 is v2 and that across L2 is v1 , so that i1 is proportional to v2 , and i2 is proportional to v1 . Thus, each end of the LCL network behaves as a current source with an amplitude dependent on the voltage on the opposite side.Further, as shown in the phasor diagram of Fig. 4(a), it can be shown that I1 leads V2 by 90 ◦ and V1 leads I2 by 90 ◦, where V1,I1,V2 , and I2 represent the phasors of v1,i1,v2 , and i2 , respectively. For the case shown, in which V1 leads V2 by φ, power is transferred in the forward direction from v1 to v2 .

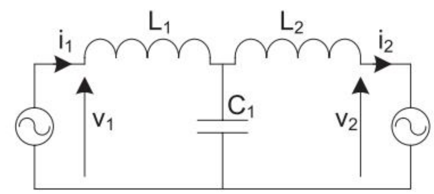

Fig. 3. Model of the proposed DAB.

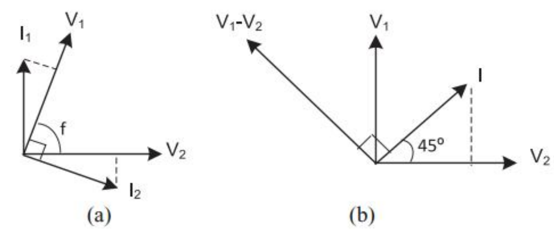

Fig. 4. Phasors at the switching frequency. (a) Resonant DAB. (b) Conventional DAB.

Furthermore, maximum forward power transfer occurs when φis 90 ◦, in which case phasors I2 and V2 , and I1 and V1 align. In a similar way, when φ is −90 ◦ and V1 lags V2 , maximum reverse power flow occurs and the voltage and current pairs are in inverse phase. It is because of the quadrature nature of these phase relationships that the resonant converter has full load bridge currents that are significantly smaller than those of a conventional DAB converter, for which the bridge voltage and current phasors do not align, as shown in Fig. 4(b). To maintain the resonant DAB converter currents, and therefore the losses to a minimum, it is operated with a fixed φ of either 90 ◦ or −90 ◦, for forward and reverse power transfer, respectively. PWM ofthe bridge voltages through α1 and α2 is used to control the magnitude of the power flow.

Results

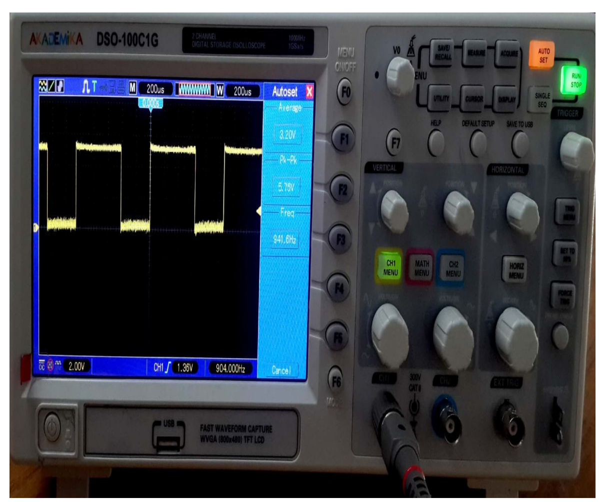

Fig 5. PWM output in DSO

A prototype 2.5-kW resonant DAB was built and tested and the results obtained from this prototype are presented below together with theoretical results to verify the viability of the proposed system and the accuracy of the mathematical model derived in Section III. The time-domain theoretical waveforms of the system operating under steady-state conditions were obtained using a MATLAB function to evaluate by summing the forced responses of the first hundred frequency components in a Fourier decomposition of v1 and v2 . The design parameters of the prototype system, which has an efficiency of 96% at rated load, are given in Table I. The bridges were controlled by an open-loop controller, using equal modulation values of α1 and α2 and a fixed φ of +90 ◦ or −90 ◦. To demonstrate the ability of the proposed DAB to transfer power inthe forward direction at near unity power factor, Bridge 2 was controlled to generate a voltage *vB*2 that is lagging 90 ◦with respect to *v*1 . Both bridges were operated with modulations of 165 ◦ and, under these conditions, approximately 2.5 kW was delivered to *V*dc2 from *V*dc1 . The bridge currents were approximately sinusoidal and in phase with their respective voltages, thus indicating near zero reactive power transfer between the bridges and the LCL resonant network.

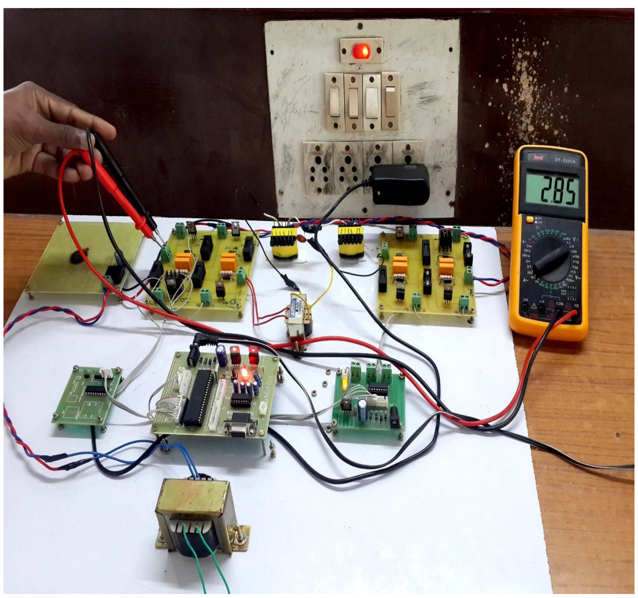

Fig 6. The L2C Network using Dual Active Bridge

A new dual DAB topology that employs an LCL resonant network has been described. A mathematical model has been presented to accurately predict the performance of the proposed topology. Experimental results of a 2.5-kW prototype DAB, operated under various conditions, have also been presented to demonstrate the improved performance of the converter. Results indicate that the proposed DAB topology has lower bridge currents and, consequently, offers higher efficiency over a wider supply voltage and load range in comparison to conventional DAB topologies.

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