Single Stage Dual Active Bridge AC-DC Converter with Active Power Decoupling

Davide Gottardo, Liliana De Lillo, Lee Empringham, Alessandro Costabeber, Linglin Chen

PEMC Research Group

Department of Electrical and Electronic Engineering

University of Nottingham

Email: davide.gottardo@nottingham.ac.uk

Abstract—The paper introduces a new a isolated DC-AC DAB converter topology, capable of active power decoupling on the AC side of the transformer, made up of two full bridges with no additional active component. The differential voltage modulated by the DC-side full bridge is used to control the voltage applied to the primary winding of a high-frequency transformer, while the common mode voltage generated by the AC-side full bridge is applied to the secondary windings.

The choice of applying the common mode voltage ripple of the AC-side full bridge to the transformer, allows to have the required ripple voltage to transfer the power, while keeping the differential voltage ripple, that is applied to the AC output, at its minimum value, making possible the use of a small AC filter inductor.

A control strategy is proposed and validated by simulation.

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Index Terms—Active power decoupling, single-phase system, dual active bridge, DAB, AC-DC DAB.

I. INTRODUCTION

When galvanic isolation is required, the dual active bridge (DAB) topology is widely used, because of its high efficiency and power density [1], [2]. For this reason, many AC-DC converters that require galvanic insulation are made by two stages: an isolated DC-DC DAB stage followed by a VSI or CSI DC-AC inverter [3]. In case of unidirectional power transfer from DC to AC, such as in PV generation, the AC side bridge can be a simple diode rectifier, otherwise, a full bridge is used.

In case of single phase AC systems, one or more power decoupling elements have to be included in the converter, in order to deal with the ripple power components [4], [5]. This power decoupling action can be provided on the AC side of the isolation transformer, or on the DC side. If the power decoupling action is performed on the AC side, the power exchanged through the transformer is equal to the power exchanged through the DC port of the converter, which is constant, while if power decoupling is performed on the DC side, it is equal to the power exchanged through the AC port, that oscillates between zero and double DC power at twice grid frequency. For this reason, AC-side power decoupling is usually better in terms of efficiency of the transformer and its driving circuit.

In order to increase the efficiency and/or reduce the number of active devices, single stage AC-DC DAB are used [6]–[9]. However, in the topologies considered in [8], [9], the ripple current coming from the transformer is present on the AC modulated output of the converter, and has to be filtered out by adequate passive filters, while in [6], [7] a reverse blocking capable H bridge is required, with a total of 8 active switches on the AC side, the same number required in a two stage converter. In [7] active power decoupling is achieved on the DC side, while in [8], [9] power decoupling is not provided.

The proposed topology is a single stage AC-DC dual active bridge, that provides active power decoupling on the AC side of the converter. The topology has a total of 4 active switches on the AC side, and the ripple current flowing through the transformer does not appear on the AC modulated output.
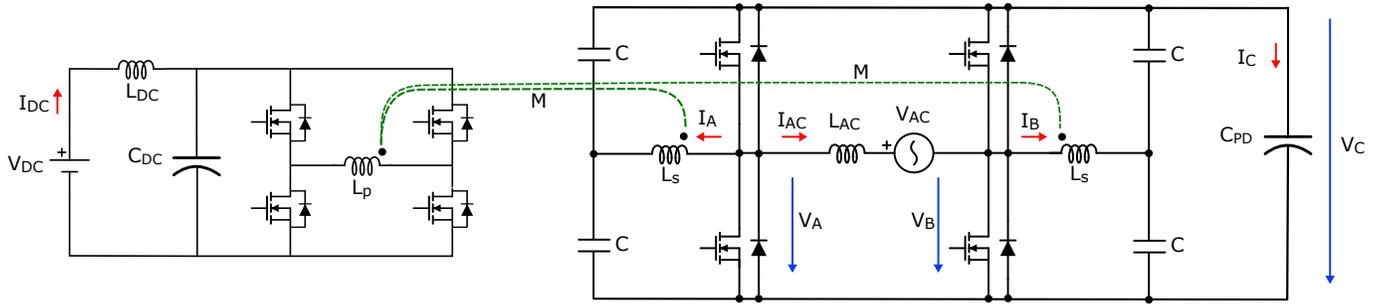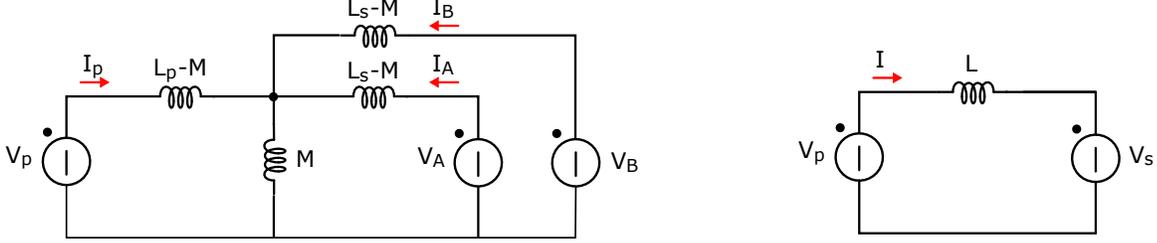
Fig. 1: Proposed topology

(a) Primary equivalent circuit

(b) $Vs = (V_A + V_B)/2$, $L = Lp - M + (Ls - M)/2$

Fig. 2: High frequency equivalent circuit

II. PROPOSED TOPOLOGY

The proposed topology, shown in figure 1, is constituted by two H bridges, a high frequency transformer with one primary and two equal secondary windings, a power decoupling capacitor C_{PD}, an AC filter inductor L_{AC}, and four DC blocking capacitors C. Those capacitors are sized in order to block the flow of DC or low-frequency currents across the transformer windings, while behaving like a closed circuit for the ripple components at switching frequency. Since those capacitors are subjected to high current ripple, low ESR is required.

The differential voltage modulated by the AC-side H bridge is used to control the AC current, while the modulated outputs of its two legs are connected to one end of each of the transformer secondary windings, closing the circuit through the DC blocking capacitors. This has the equivalent effect of applying the common mode voltage ripple of the AC side H bridge to a single secondary winding of the high voltage transformer. The DC blocking capacitors also contribute to lower the ripple current flowing through C_{PD}, thus reducing its I^2t stress.

TABLE I: Circuit parameters

Name	Value	Unit	Name	Value	Unit
V_G	230	V_{RMS}	V_{DC}	500	V
C_{PD}	55	μF	C	0.1	μF
L_{AC}	0.5	mH	M	600	μH
Lp	666	μH	Ls	666	μH
L_{DC}	10	μH	C_{DC}	10	μF

The DC-side H bridge is used to drive the primary side of the transformer, in order to transfer the required power. Power decoupling is performed by capacitor C_{PD} on the AC-side, so that the power transferred by the transformer is continuous across the entire AC period. Since the voltage ripple applied on C_{PD} can be high, a small capacitance is required, enabling the use of reliable film capacitors.

The AC-side half bridge legs are modulated in phase, with a steady-state duty cycle equal to $0.5 \pm \frac{V_{AC}}{2V_C}$, so that the differential voltage is equal to V_{AC}.

III. CONTROL STRUCTURE

The control system is formed by three control loops: the AC current controller, the DC power controller and the power decoupling capacitor DC
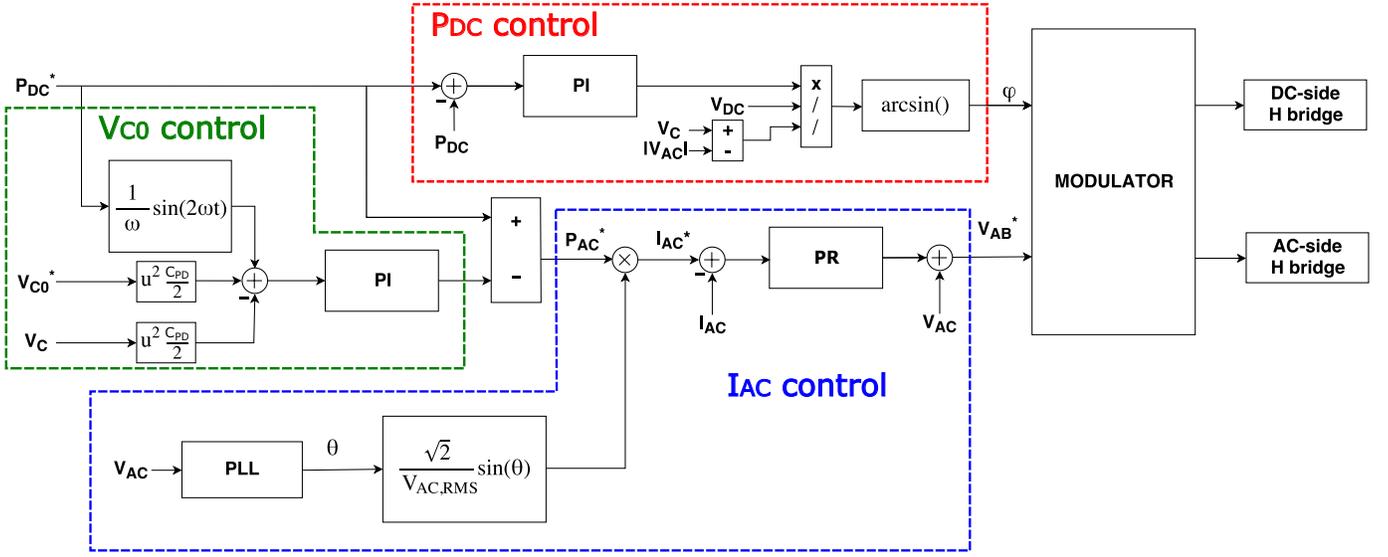
Fig. 3: Control structure

voltage offset controller. The overall control structure is shown in figure 3.

In order to control the system, five measurements are taken:

- DC voltage and current V_{DC} and I_{DC};
- AC voltage and current V_{AC} and I_{AC};
- power decoupling capacitor voltage V_C.

A. DC power

The DC power controller regulates the DC power by acting on the outer phase shift φ.

Assuming to consider only the fundamental component of the voltages applied to the primary and the secondary of the transformer, the power transfer is estimated as:

$$P \simeq \frac{V_p V_s}{2\pi f_{SW} L} sin(\varphi) \tag{1}$$

where f_{SW} is the switching frequency, L is the leakage inductor of the transformer, φ is the phase shift between the two voltages, and V_p and V_s are the amplitudes of the fundamental components at switching frequency of the voltages applied to the primary and secondary of the transformer, as shown in figure 2b.

As V_s is the common mode voltage modulated by the AC full bridge, its amplitude and waveform change during the grid period. Approximately, the amplitude of the fundamental component of V_s is proportional to the difference between the DC-side of the full bridge, which is V_C, and the differential voltage modulated by the bridge, which is V_{AC}. In the same way, the fundamental component of V_p is proportional to V_{DC}. Thus:

$$V_s \propto V_C - |V_{AC}| \tag{2}$$
$$V_p \propto V_{DC} \tag{3}$$

Substituting in eq.1:

$$P \propto V_{DC}(V_C - |V_{AC}|)\sin(\varphi) \tag{4}$$

Inverting this equation allows to linearise the control loop that regulates the power, so that in steady state a constant power reference corresponds to a constant output of the controller.

B. Power decoupling capacitor offset voltage

The difference between the instantaneous power flowing in the AC port P_{AC} and the power coming from the DC side P is stored in the capacitor C_{PD}. Assuming an ideal converter (zero power loss, constant P and perfectly sinusoidal V_{AC} and I_{AC}), the integral of $P - P_{AC}$, that is the energy ripple on C_{PD}, is equal to [10]:

$$E_R = \frac{P}{\omega}\sin(2\omega t) \tag{5}$$

Since the mean value over the AC period of E_R is zero, it involves a ripple voltage but does not affect the DC offset voltage on the capacitor. In general, the mean value of $P - P_{AC}$ is non-zero, and that
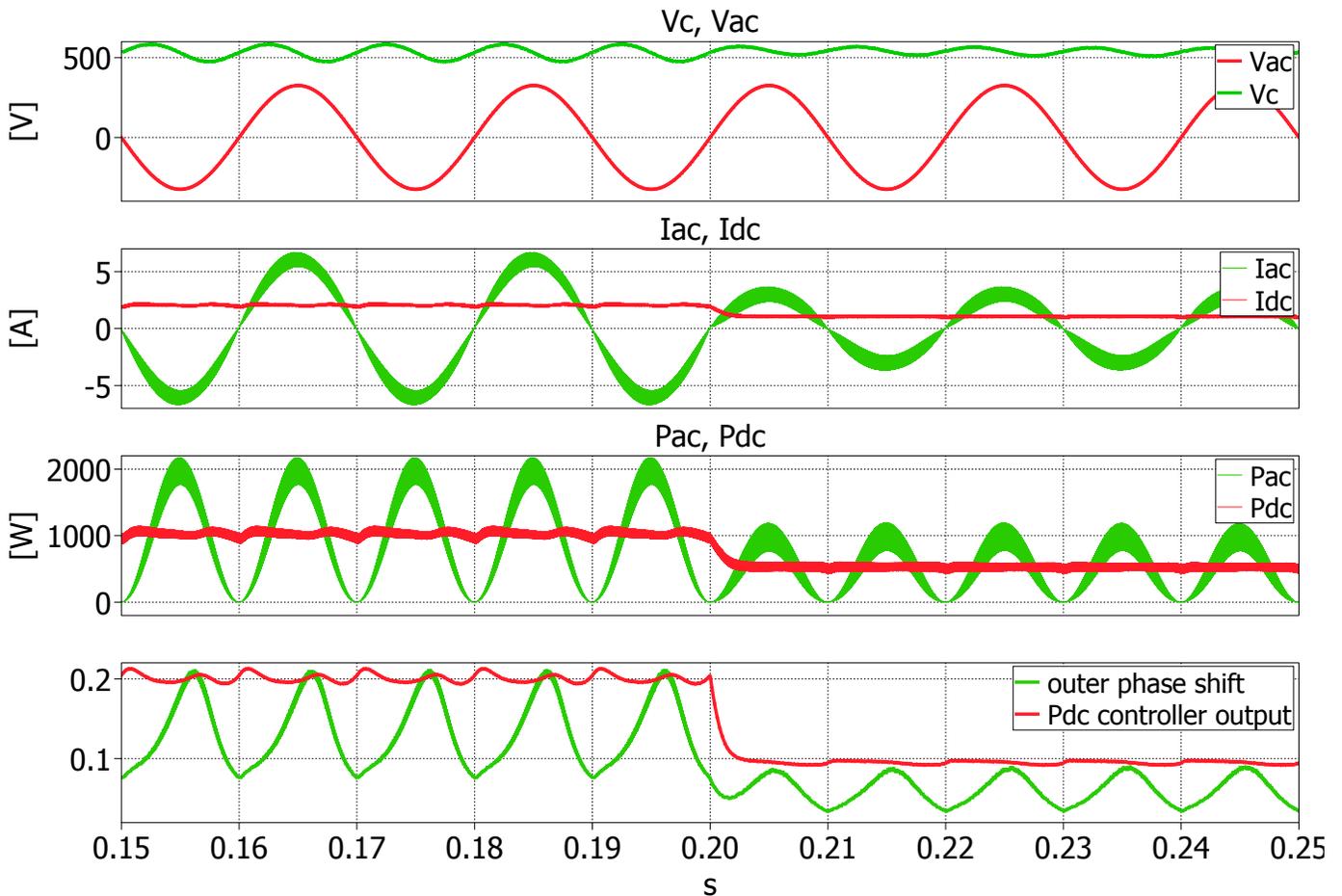
Fig. 4: Simulation results: step power transfer from 1kW to 0.5kW at t=0.2s

translates in a change of the offset energy on the capacitor, which is approximately proportional to the square of its DC voltage offset.

The capacitor offset voltage controller changes the AC power set-point in order to control the average energy stored in the power decoupling capacitor C_{PD}, while maintaining a constant DC power. In order to remove the $100Hz$ ripple, a notch filter is generally included in the controller [5]. In this case, instead, the ideal ripple energy, shown in eq.5, is calculated and cancelled out, so that the input of the controller is the mean stored energy error. In steady-state, the output of the controller is equal to the average power losses of the converter, plus a very small ripple.

C. AC current

The AC current controller takes the reference current calculated starting from the reference AC power, and outputs the desired differential voltage V_{AB} to be modulated by the AC-side full bridge. A proportional-resonant controller tuned at $50Hz$ was chosen.

Simple PI controllers were used for all the other control loops, achieving good simulation results.

IV. SIMULATIONS

In order to validate the proposed control structure, simulations were made using Simulink and the PLECS Blockset simulation tool.

The circuit parameters used are shown in table I. The chosen switching frequency f_{SW} is $100kHz$.

Figure 4 shows the behaviour of the converter during a transient from 1kW to 0.5kW.

V. CONCLUSION

The paper introduces a new topology for a isolated DC-AC DAB converter, capable of active power decoupling on the AC side of the transformer,

made up of two full bridges with no additional active component. The differential voltage modulated by the DC-side full bridge is used to control the voltage applied to the primary winding of a high-frequency transformer, while the common mode voltage generated by the AC-side full bridge is applied to the secondary windings.

The choice of applying the common mode voltage ripple of the AC-side full bridge to the transformer allows to have enough ripple voltage to transfer the power, while keeping the differential voltage ripple at its minimum value, making possible the use of a small AC filter inductor.

The simulation results confirm the correct behaviour of the converter and of the control system.

The limited number of active and the small size of the required passive components contribute to make this topology an interesting solution for application such as PV distributed generation and energy storage solutions.

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