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80KW AUXILIARY CONVERTER FOR RAILWAY APPLICATIONS

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Abstract. This paper presents a DC/DC converter utilizing the three phase dual active bridge(DAB) topology as the most convenient topology for designing a high-power-density DC/DC converters for railway applications. The three-phase DAB is analyzed concerning the current modes, output power and soft-switching region, including the effect of zero-voltage switching(ZVS) capacitors. Furthermore, a method is discussed, aiming to extend the soft-switching region, since no-load conditions in the entire operating range are required. Finally, a prototype is built with the required specifications, resulting in an efficiency of 95.6% at 80kW of output power.

Keywords: DC/DC Converter, High Power-Density, Three-Phase Dual Active Bridge, Zero Voltage Switching.

INTRODUCTION

Since the electrification of rail transportation systems, the amount of additional electrical systems has been increasing substantially. These, so called, auxiliary systems are all systems on a rail vehicle which have functions other than traction. Nowadays, a large number of auxiliary systems are present on rail vehicles. Examples are lighting, compressors, pumps, air-conditioning, and passenger information system. To provide energy to these auxiliary systems, an auxiliary power unit (APU) converts the voltage from the overhead line or a third rail into the needed supply voltages. The total auxiliary power demand is typically in the range of tens of kilowatts up to a few hundreds of kilowatts. For safety reasons, galvanic isolation between the input and output of the APU is required. In conventional APUs, the galvanic isolation is often realized with low frequency transformers, an example is shown in Figure 1(a). These transformers are bulky and result in relatively large and heavy APU. Especially for light rail vehicles, like trams and metros, this becomes a problem when the auxiliary power demand rises. Therefore, size and weight reduction of the APU is necessary to meet the auxiliary power demand within the capabilities of light rail vehicles.

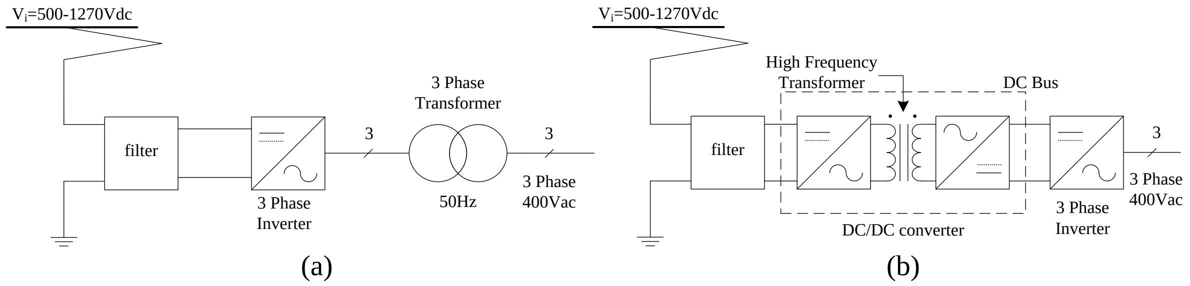


Figure 1. Simplified schematic of an auxiliary power unit: **(a)** Conventional system **(b)** with DC/DC converter using high frequency transformers.

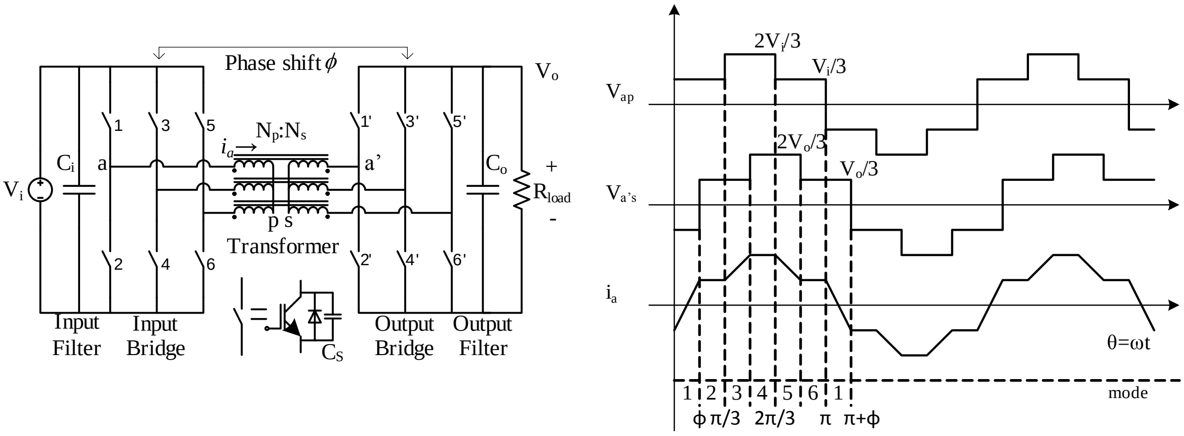
THREE PHASE DUAL ACTIVE BRIDGE CONVERTER

The field of high-power-density DC/DC converters has been addressed a lot in the last decades. From the beginning the conventional full-bridge converter topology has been the preferred choice to design a high-power DC/DC converter [1]. However, due to problems with the leakage inductance of the transformer and, consequently, reverse recovery problems of the output diodes, the maximum switching frequency is limited. To solve this problem, several solutions were presented comprising active clamps and/or auxiliary circuits [2],[3],[4]. These methods enable higher switching frequencies at the expense of additional active components and higher device stress with auxiliary circuits. The additional components impede the increase in power density and increase complexity while the efficiency is often no better than with conventional switching techniques.

Therefore, the dual active bridge (DAB) topology introduced in [1] is an attractive alternative to the problems with the classical full-bridge topology. In comparison with the conventional full bridge topology, the output inductor is transferred to the ac-side and is in series with the leakage inductor. Consequently, the energy in the leakage inductor is transferred to the load without causing reverse recovery losses in the output diodes. This allows higher switching frequencies and, therefore, an increase in power density. Furthermore, the use of an active output bridge also increases the power density of the transformer [1]. When the desired inductance can be incorporated in the transformer, again the power density can be increased. The described properties of the DAB topology enables very high power-densities up to 11.13 kW/L [5].

A three-phase DAB, shown in Figure 2, has some advantages in comparison with the single-phase DAB [1]. The three-phase DAB has lower turn-off currents in the switches and lower rms currents per phase. Also the VA ratings for the input and output filters are significantly lower and can even go to zero due to the three-phase characteristics. Compared to the single-phase DAB, the three-phase DAB has much more sinusoidal currents through the transformer windings, resulting in less high-frequency losses in the transformers [6]. A complete comparison between single-phase and three-phase topologies is given in [1] and [7].

The three-phase DAB topology is chosen for designing the described auxiliary converter. In the next chapter the limited soft-switching region and a method to stay in this region is discussed.



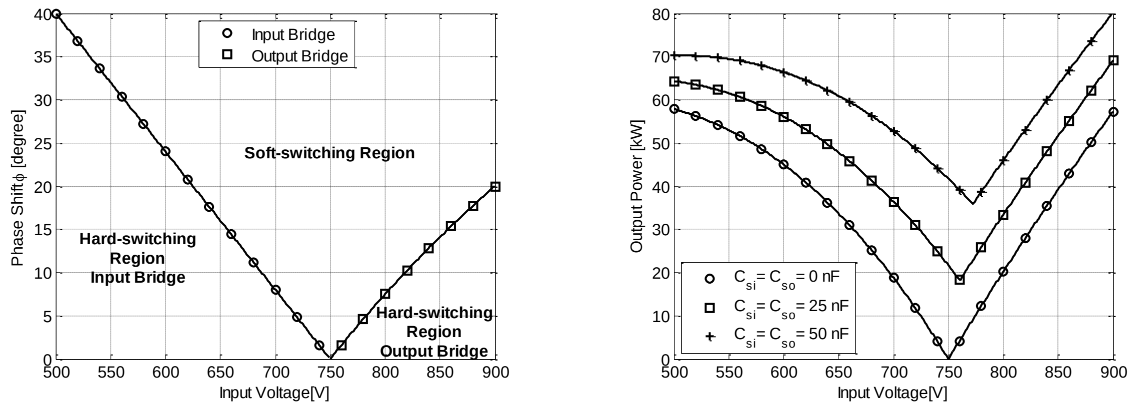
(a) (b)

Figure 2. Three-phase dual active bridge: **(a)** Topology; **(b)** Idealized waveforms.

SOFT-SWITCHING REGION

Minimizing the switching losses is the key to achieve high switching frequencies. The turn-on losses are of main interest because excessive losses in the switch and anti-parallel diode can arise when the anti-parallel diodes experience the reverse recovery process. The soft-switching region can be defined, being depicted in Figure 3(a).

ZVS capacitors, or snubber capacitors, are used to reduce turn-off losses. These are connected in parallel to the switches and supplement the output capacitance, as can be seen in Figure 2(a). This changes the soft-switching constraint for the input and output bridge, as can be seen in Figure 3(b).



(a) (b)

Figure 3. Soft-switching region: **(a)** Phase shift for soft-switching; **(b)** Output power for soft-switching with different ZVS capacitors. With V_o'=750V, L=20μH and $f_{sw} = 20$kHz .

Burst Mode

A solution to operate outside the soft-switching region is a burst mode which supplies the average output power through pulses of higher output powers, effectively operate within the soft-switching region. This straightforward switching strategy requires no extra components and only introduces a small voltage ripple on the output voltage.

CONCLUSION

The three-phase DAB topology was selected for an APU because of the preferred properties concerning buck-boost operation, low device stress, small filters, high transformer utilization and low switching losses. Subsequently, the soft-switching region is analyzed, including the effect of ZVS capacitors. Furthermore, a method is presented to extend the soft-switching region. Experimental results show a measured efficiency of 95.6% at maximum output power at nominal conditions. Also, The use of ZVS capacitors shows about 40 percent reduction in the total loss, enabling an output power above nominal and still preserve a good efficiency. The prototype is tested thoroughly in the entire operating range, including operation in the burst mode during an input voltage of 500V and 900V. The burst mode shows to be useful to extend the operating range in a soft-switching manner. Operation during burst mode shows slightly lower efficiencies compared to continuous operation.

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