Modulation of a four quadrant DC-DC converter

Figure 2.3 shows a four-qadrant DC-DC converter where the transistors are denoted T_1-T_4, and the freewheeling diodes D_1-D_4.

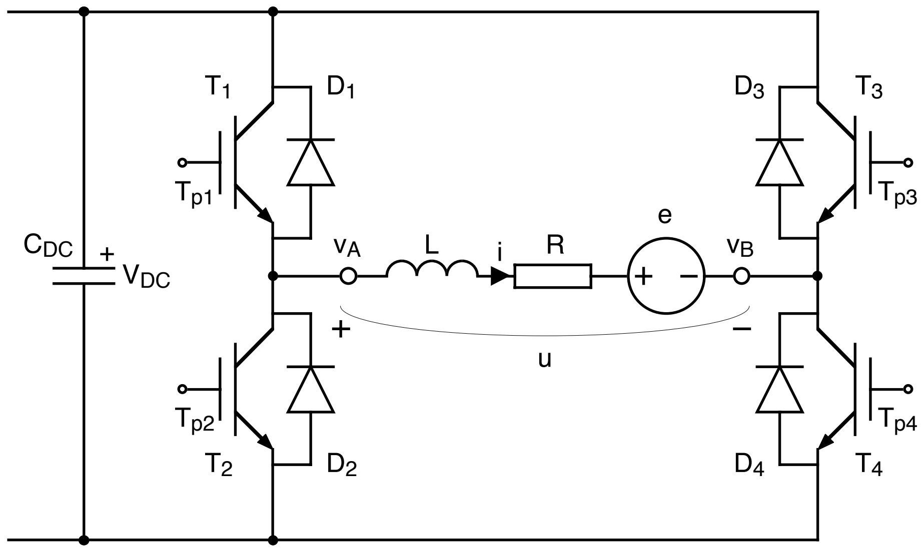

Figure 2.3: Four-quadrant DC-DC converter utilized in the study of modulation.

In the case of DC-DC conversion, the current controller inherently provides only a single voltage reference, the load voltage reference. However, for the converter in Figure 2.3, two transistor half bridges should be modulated. To solve this, the original load voltage reference is split in two phase potential references, one for each half bridge. Here, these phase potential references are denoted $v_{a,\,ref}$ and $v_{b,\,ref}$, which must be selected so that $v_{a,\,ref} - v_{b,\,ref} = v_{ref}$. These two references can be selected in any way as long as the difference between them equals the load voltage reference (in engineering units). Often, the phase potential references are chosen so that the risk of entering over-modulation is minimized. Over-modulation occurs when one or several of the phase potential references exceeds the peak of the carrier wave. A suitable choice is therefore to choose the phase potential references in such a way that two (both for the four-quadrant DC-DC converter) phase potential references reach over-modulation simultaneously for a certain load voltage reference. This means that the phase potential references should be selected according to

$$v_{a,ref} = \frac{v_{ref}}{2} \quad \text{and} \quad v_{b,ref} = -\frac{v_{ref}}{2} \tag{2.1}$$

This selection of modulator references where they are equal but with opposite sign, i.e. symmetrical with respect to the time axis, is referred to as symmetrical modulation. Over-modulation occurs when

$$v_{a,ref} = \hat{v}_{tri} \quad \Leftrightarrow \quad v_{b,ref} = -\hat{v}_{tri} \tag{2.2}$$

Since the maximum load voltgae that can be obtained is equal to V_{dc}, this corresponds to the boundary between linear modulation and over-modulation, i.e.

$$\hat{v}_{tri} = v_{a,ref} = \frac{V_{dc}}{2} \tag{2.3}$$

The triangular carrier should thus have an amplitude of $V_{dc}/2$. Usually, the current controller operates in engineering units (for example full scale of transducers often correspond to 10 V), which means that the triangular carrier must be scaled in the same way. Figure 2.4 shows typical modulator waveforms and converter output voltage and current, in the case of an ideal four-quadrant DC-DC converter.

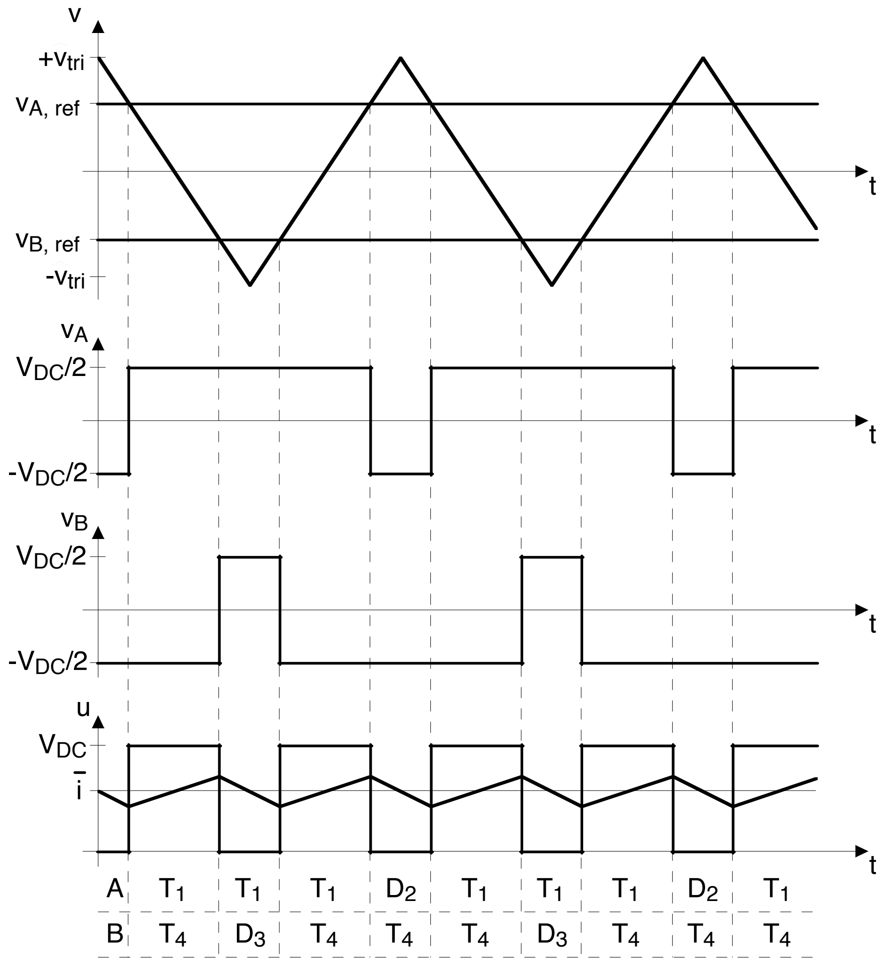

Figure 2.4: Modulation Waveforms and converter output voltage and current for an ideal four-quadrant DC-DC converter.

The output potentials of the half bridges are denoted v_a and v_b. The voltage across the load is denoted u, and is given by

$u = v_a - v_b$. The load current is denoted i. During one period of the triangular carrier, each half bridge output exhibits one positive and one negative step. The switching frequency is therefore equal to the frequency of the triangular carrier. If the period time of the triangular carrier is considerably shorter than the time constant of the load, the load current will exhibit a triangular shape as in Figure 2.4. In Figure 2.4 it is also shown which among the eight power semiconductors that are conducting in each sub-interval of the switching period. Note that the direction of the current play as important role in determining this.

As earlier stated, Figure 2.4 shows the modulator waveforms and the output voltage and current of the converter in the case of an ideal four-quadrant DC-DC converter. In reality, power semiconductor devices cannot traverse from off-state to on-state and vice versa instantly. If both transistors of a half bridge operate in the on-state simultaneously there will be a extremely high power dissipation inside both since the DC link voltage will be divided between the two conducting devices but also since the current will be very high due to the low on-state resistance of the devices. To prevent this from occurring, during switching transients, transistor turn-on is delayed but not transistor turn-off. The duration of this time delay is termed blanking time or interlock time and the circuit performing the delay (which is a part of the transistor driver) is called blanking time or interlock circuit. Figure 2.5 shows the resulting modulation waveforms together with the output voltage and current of the four-quadrant DC-DC converter. Note that the average output voltage and current becomes lower than expected due to blanking time. Therefore, converter current controllers should be equipped with an integral part.

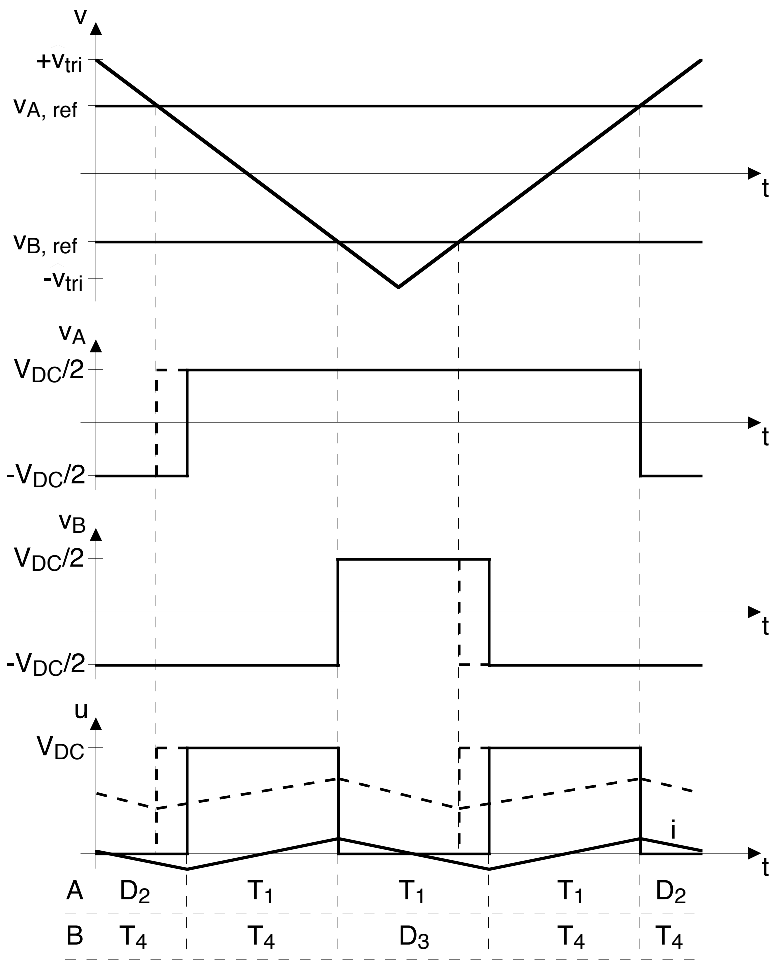

Figure 2.5: Modulation waveforms and converter output voltage and current for a four-quadrant DC-DC converter including blanking time effects. Note that the effect is strongly exaggerated.