Inversion

Single phase quasi square wave inverter.

Inverters create a DC supply from an AC one. They do this by switching the output terminals alternately between the high side and the low side of the DC bus. A full bridge single phase inverter has a 4 switches arranged as shown in Figure 1. Two diagonally opposite switches are turned on together supplying an output voltage to the load. Later on, the other two switches are turned on instead reversing the voltage across the load. The output frequency can be varied by doing this more quickly or more slowly. The output voltage can be controlled and shaped by varying the duty cycles of the output switches.

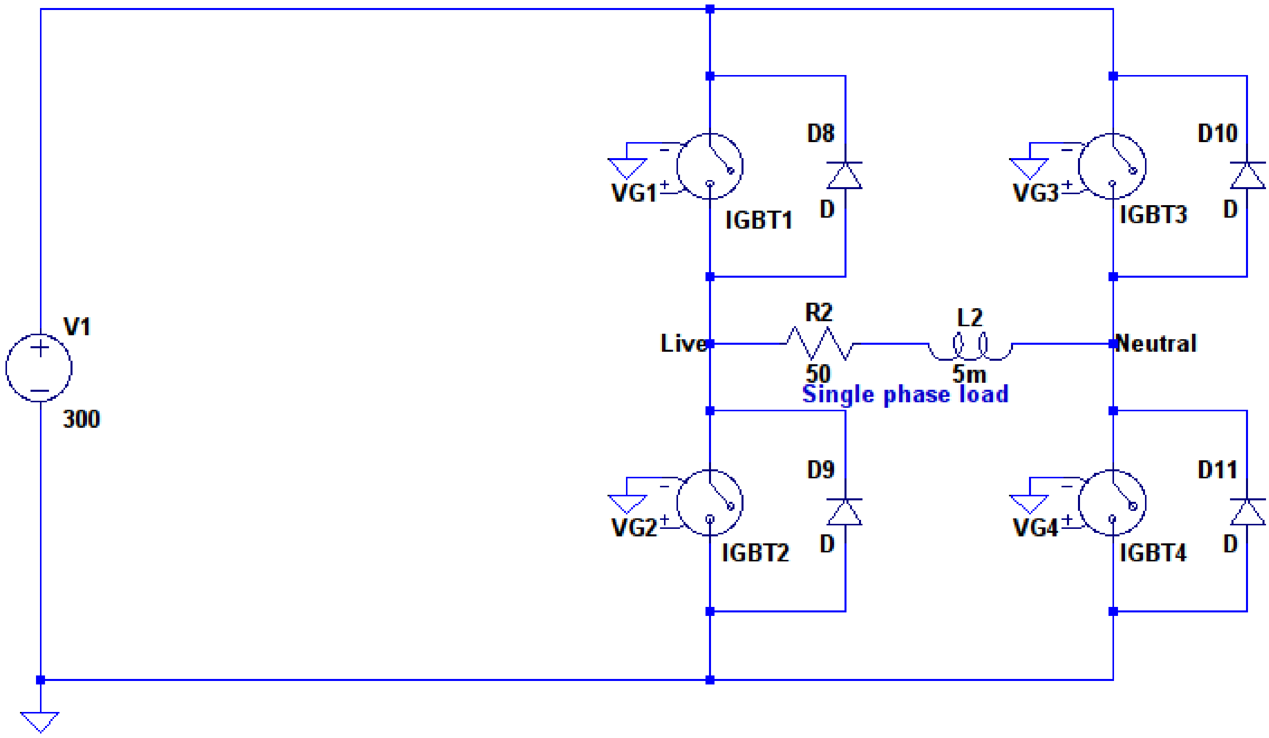

Figure 1. Idealized single phase inverter.

Figure 2 shows the voltage across the load when the inverter is switched in ***quasi square wave*** mode. It also shows the resultant current flow. As can be seen, neither the current nor the voltage are sinusoidal – what are the implications of this? Furthermore, there is a voltage spike on the output voltage near the end of each half cycle. What causes this?

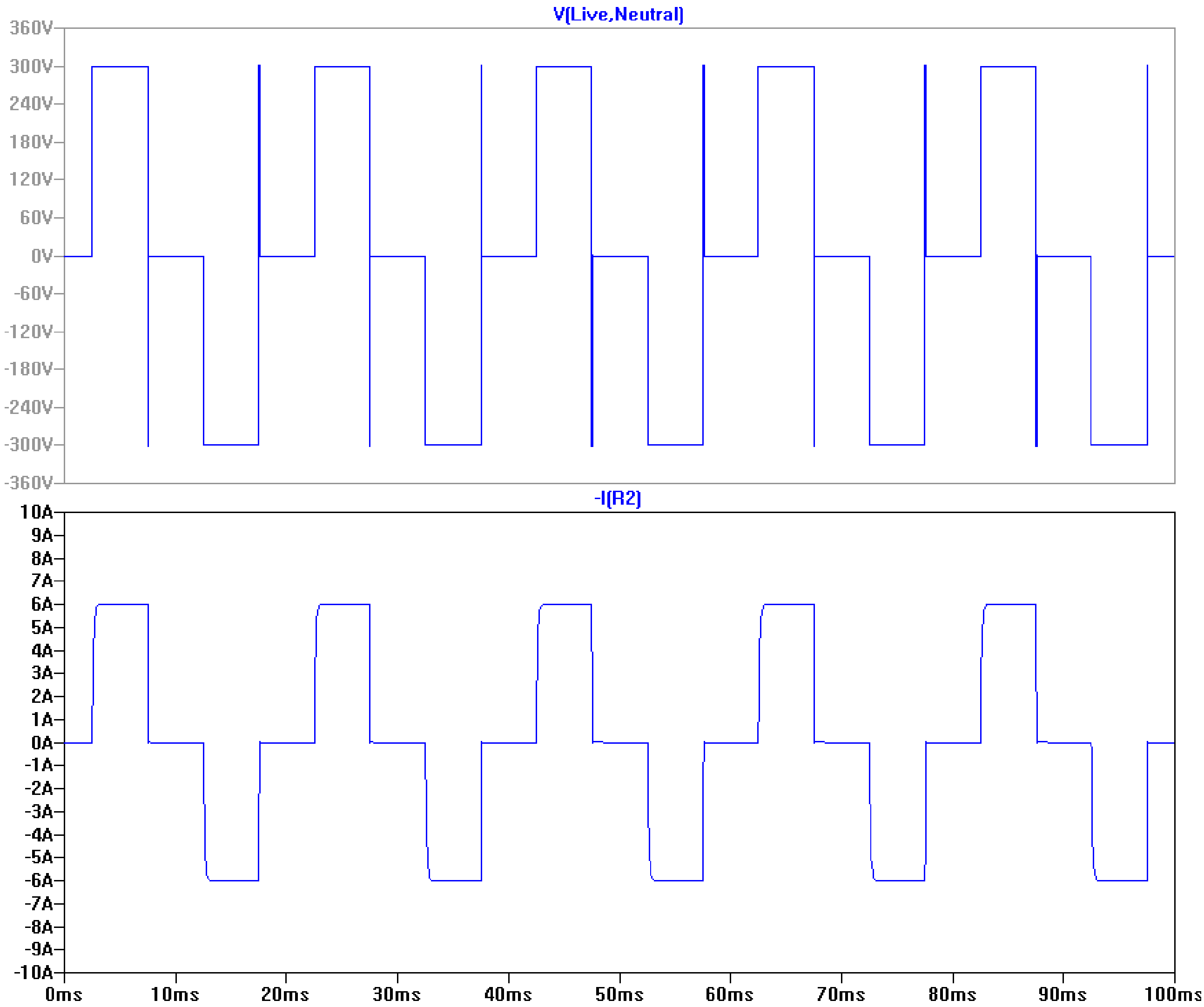

Figure 2. Load voltage and current waveforms for a quasi-square wave single phase inverter

The spectrum of a quasi-square wave inverter output (resistive load). Is shown in Figure 3 below. Note the relatively large third, fifth and seventh harmonics. The magnitude of each of the harmonics is inversely proportional to the harmonic number.

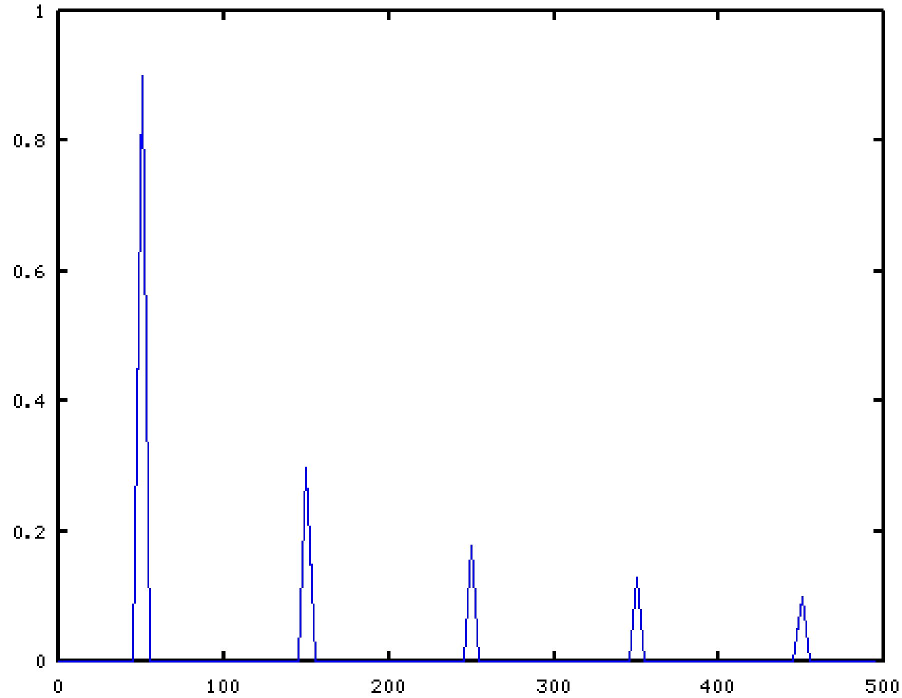

Figure 3. Quasi-square wave harmonic content.

Why are large low frequency harmonics such a problem? They are hard to filter as they are very close (in frequency) to the fundamental (which you don't want to filter). Also, their low frequency means that larger inductors and capacitors will be required to remove them. Output harmonics can lead to problems. Figure 4 below shows the relationship between the fundamental, the third and the fifth harmonics in a three phase system. The thirds are all in-phase (zero-sequence). The order of the fifths is opposite that of the fundamentals (negative sequence). Zero-sequence harmonics can lead to high neutral currents and/or a high neutral voltage. Negative sequence harmonics lead to loss of torque in rotating machinery. More generally, only the fundamental components actually contribute to power delivery so all other harmonics give rise to more losses (worse *power factor*)

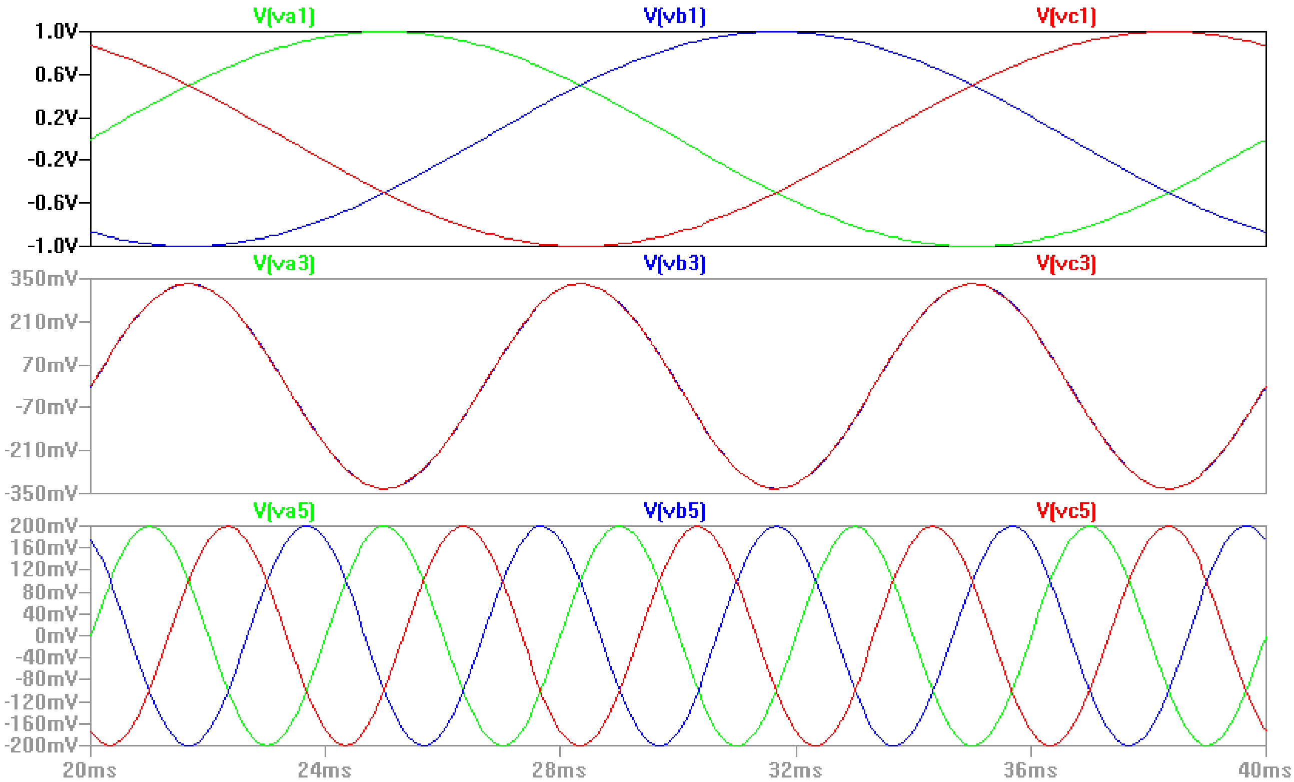

Figure 4. The first three harmonics in a three phase system

Sinusoidal Pulse Width Modulation.

Sinusoidal PWM helps to reduce the magnitude of low frequency harmonics. The process works as follows (can be done in analogue/digital hardware or software). A high frequency triangle or sawtooth waveform is compared with a low frequency sine wave. The triangle waveform is commonly referred to as the *carrier wave*; the low frequency sine wave is called the *modulating wave*. See Figure 5.

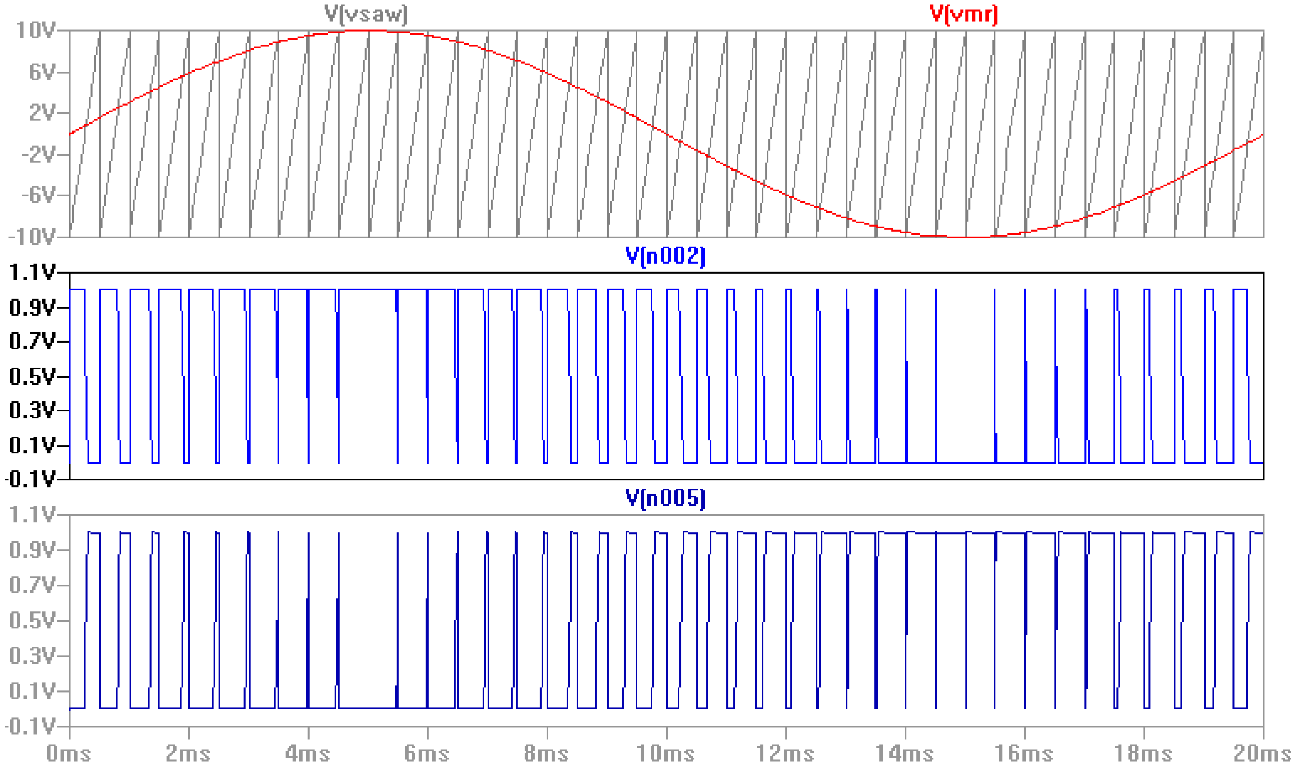

Figure 5. Sinusoidal PWM

When the modulating wave is greater than the carrier wave, one diagonal pair of IGBT's in the (single phase) inverter is turned on. When it is less, the other pair are turned on. The resultant inverter output voltage and current waveforms are shown in Figure 6. Note how the current is much more sinusoidal than before.

Two ratios are talked about when it comes to Sinusoidal PWM (SPWM). The Amplitude Modulation Index (ma) and the Frequency Modulation index mf. These are as follows:

$$ma = \frac{Magnitude of\ Modulating\ wave}{Magnitude\ of\ Carrier\ wave}$$

$$mf = \frac{Frequency\ of\ Carrier\ wave}{Frequency\ of\ Modulating\ wave}$$

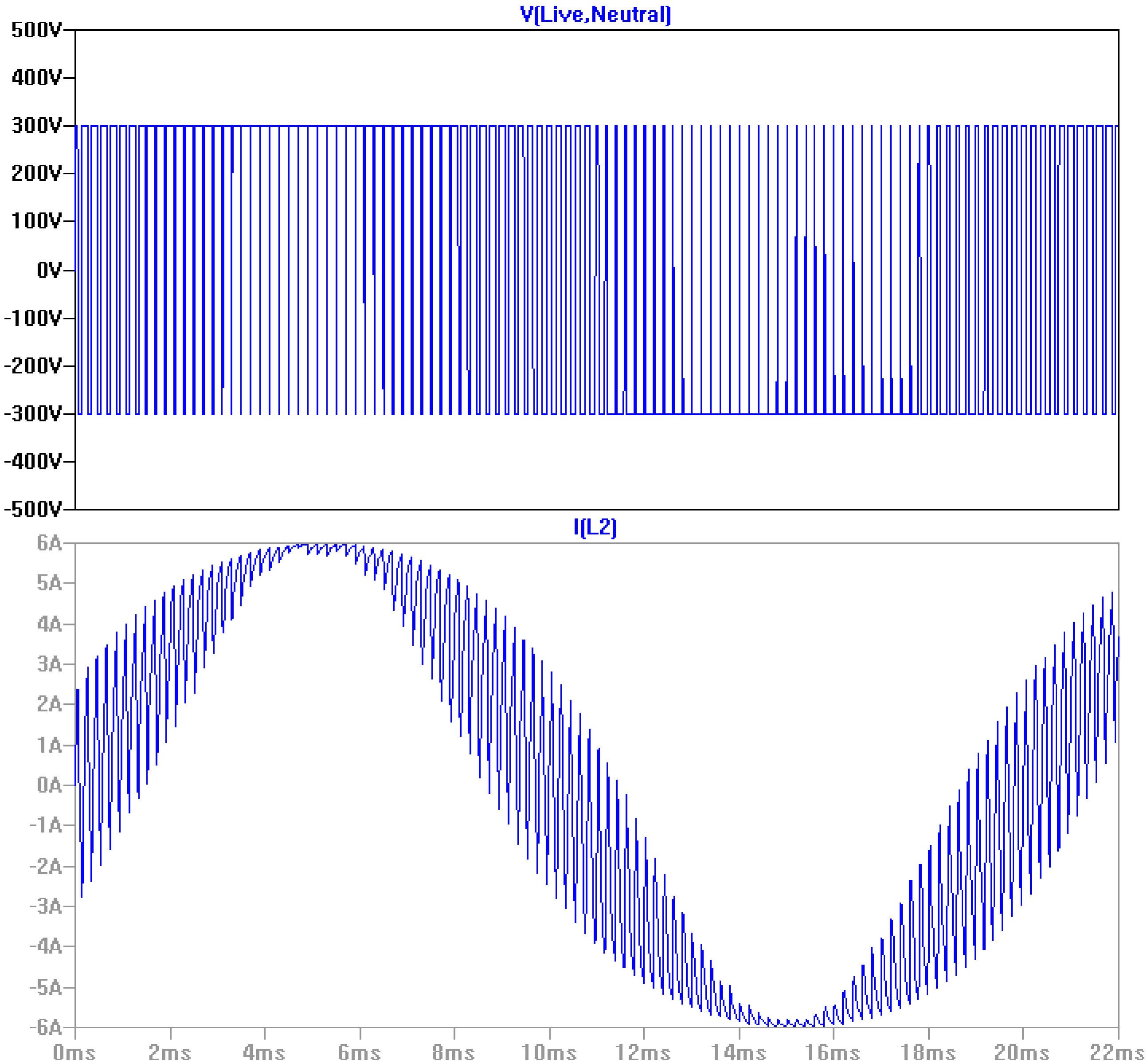

Figure 6. Sinusoidal PWM outputs for a single phase RL load.

Higher values of ***mf*** push the harmonic content further up the spectrum making it easier to filter. Higher values of ma lead to higher amplitude fundamental output voltage component (up to a point) however if the value of ***ma*** is significantly greater than 1 then the output tends to be more quasi-square square in nature leading to large low frequency harmonics again.