3 .1 Voltage Source Inverters

3.1.1 The Two-level VSI

The two-level VSC is widely used in variable-speed drives and variable-speed wind turbine applications. The main advantages of the two-level VSC include its simplicity, proven technology and the possibility of building redundancy into the string of series-connected switching devices, usually insulated gate bipolar transistors (IGBTs). The two-level VSC allows the IGBTs to be connected in series, depending on the voltage rating of the device available and the supply voltage required. The basic principle of a single-phase, two-level VSC is shown in Figure 3.1, where it can be seen that the output waveform has two levels, $+V_{DC}$ and $-V_{DC}$. Therefore, each switch string must be rated for the full direct voltage, V_{DC}. Due to the large capacitance of the DC side of the converter, the DC voltage, V_{DC}, is more or less constant and thus the converter is known as a voltage source converter.

Three single-phase, two-level voltage source converters can be connected to the same capacitor to form a three-phase converter. This converter power circuit arrangement is often called the six-pulse converter configuration (Figure 3.2). In this circuit, the switches in one leg are switched alternatively with a small dead time to avoid both conducting simultaneously. Therefore, one switching function is enough to control both switches in a leg.

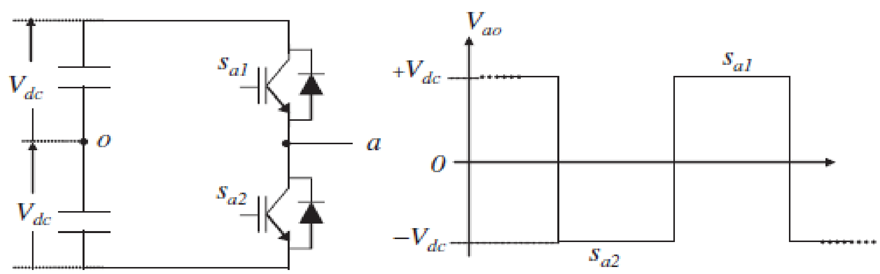

Figure 3.1 Fundamental principles of a single-phase, two-level converter

There are a number of different switching strategies for VSIs. These include square-wave operation, carrier-based pulse-width modulation (CB-PWM) techniques such as switching frequency optimal PWM (SFO-PWM), sinusoidal regular sampled PWM (RS-PWM), non-regular sampled PWM (NRS-PWM), selective harmonic elimination PWM (SHEM), space vector PWM (SV-PWM) and hysteresis switching techniques.

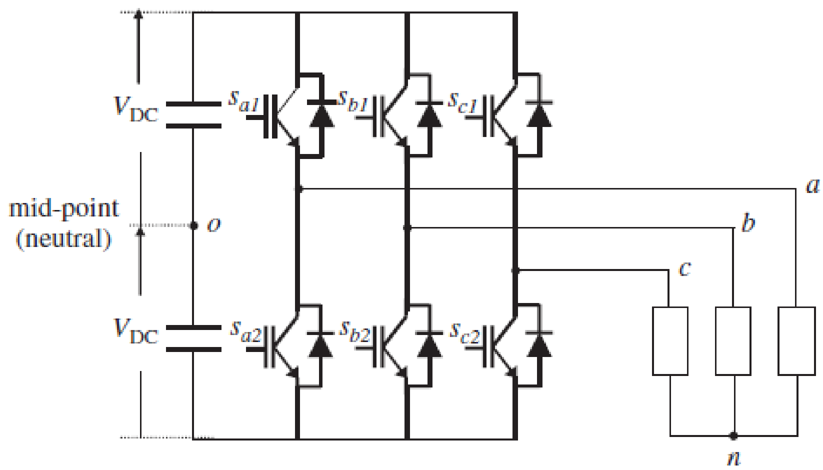

Figure 3.2 Three-phase, two-level voltage source converter.

3.1.2 Square-wave Operation

In this technique (Figure 3.3), each switch conducts for almost 180°. No two switches in the same leg conduct simultaneously. Six patterns exist for one output cycle and the rate of sequencing these patterns specifies the bridge output frequency. The six conducting switching patterns during six distinct intervals [marked as (1) to (6) in Figure 3.3] are $S_{c1}S_{b2}S_{a1}$, $Sb2Sa1Sc2$, $S_{a1}S_{c2}S_{b1}$, $S_{c2}S_{b1}S_{a2}$, $S_{b1}S_{a2}S_{c1}$ and $S_{a2}S_{c1}S_{b2}$. With fundamental frequency switching, the switching losses are low (since switching losses are proportional to the switching frequency), but the harmonic content of the output waveforms is relatively high. The output voltage contains harmonics of the order ($6k \pm 1$), where k is an integer.

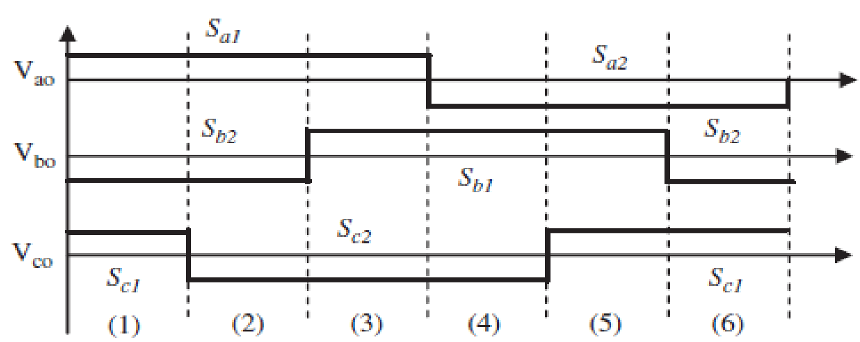

Figure 3.3 Three-phase output for fundamental frequency modulation.

3.1.3 Carrier-based PWM (CB-PWM)

This is the classical PWM where a reference signal, V_{ref}, which varies sinusoidally, is compared with a fixed-frequency triangular carrier waveform, V_{tri}, to create a switching pattern.

If the single-phase two-level circuit of Figure 3.1 is considered with the waveforms shown in Figure 3.4, then $Sa1$ is ON when $V_{ref} > V_{tri}$. S_{a2} is ON when $V_{ref} < V_{tri}$. In general:

$$S_{a1} = \begin{cases} 1 & V_{ref} > V_{tri} \\ 0 & V_{ref} < V_{tri} \end{cases} \quad (3.1)$$

$$S_{a2} = \begin{cases} 1 & V_{ref} < V_{tri} \\ 0 & V_{ref} > V_{tri} \end{cases} \quad (3.2)$$

Where '1' denotes the switch state ON and '0' denotes the switch state OFF.

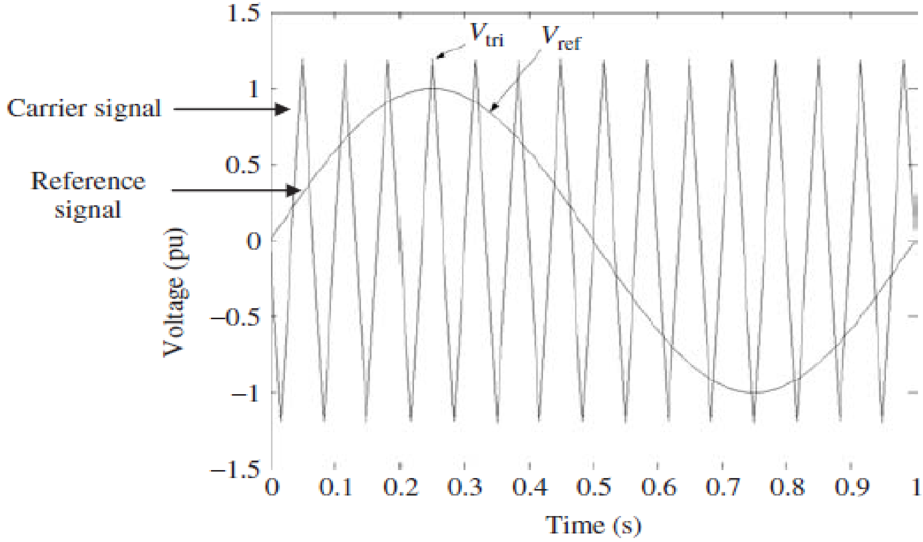

Figure 3.4 Reference voltages, V_{ref}, and the carrier waveform, V_{tri}

The amplitude modulation ratio, m_a, is defined as the ratio of the reference signal to the carrier signal.

$$m_a = \frac{\hat{V}_{ref}}{\hat{V}_{tri}} \quad (3.3)$$

Where the 'hat', '^ ', represents peak values

The frequency modulation ratio, m_f, is defined as the ratio of the carrier frequency, f_{tri}, to the reference signal frequency, f_{ref}:

$$m_f = \frac{f_{tri}}{f_{ref}} \quad (3.4)$$

It can be estimated from the waveforms in Figure 3.4 that *m*a = 0.8 and *m*f = 15.

The PWM switching pattern and the Fourier spectrum of this output waveform are shown in Figure 3.5. If *m*a is increased beyond unity (*m*a >1.0), then the fundamental voltage does not vary linearly. This condition is termed over-modulation.

As *m*a is increased beyond 3.24, the output waveform degenerates into a square waveform (Figure 3.6).

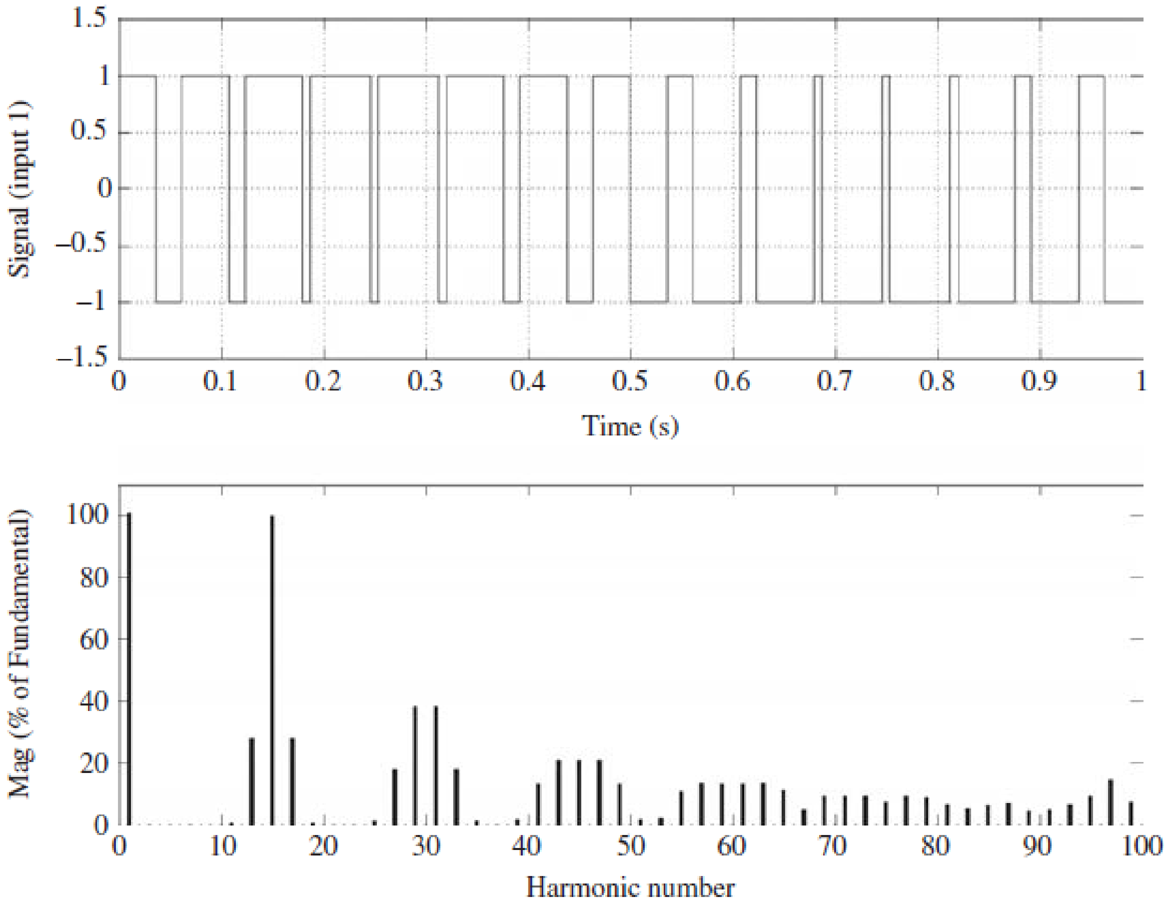

Figure 3.4 Output PWM waveform of a single-phase, two-level VSC and harmonic spectrum.

This PWM switching strategy provides good results in terms of harmonic distortion, possibly eliminating the requirement for passive harmonic filtering but the switching losses are increased over square-wave modulation.

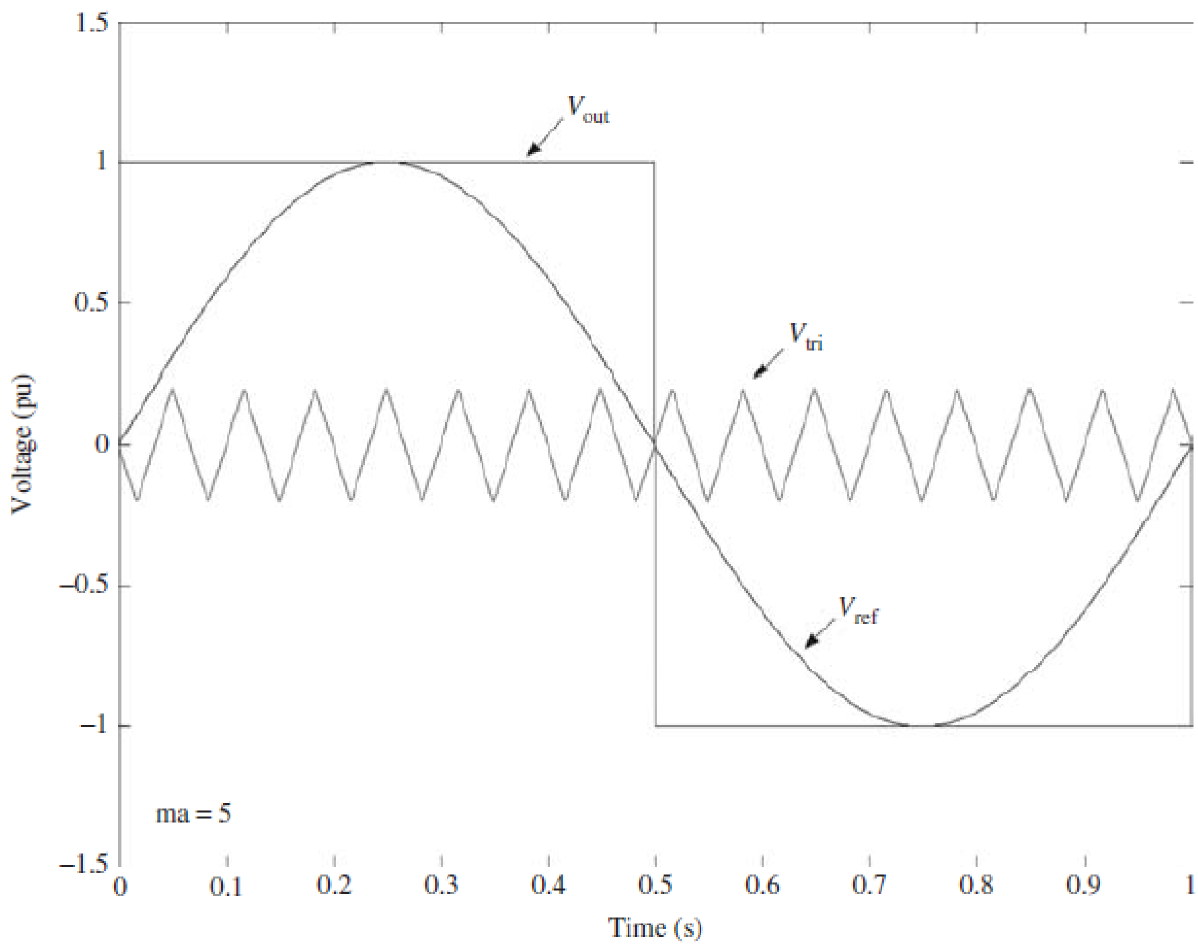

Figure 3.5 Over-modulation shown for a single-phase, two-level VSC.

3.1.4 Switching Frequency Optimal PWM (SFO-PWM)

Higher utilization of the DC link can be achieved by using reference waveforms other than pure sinusoidal waveforms.

3.1.4.1 Trapezoidal Modulating Function

The reference signal is a trapezoidal function (Figure 3.6), which increases the ratio of the fundamental component of the maximum phase voltage to the DC supply voltage. This then reduces the ratings required for the converter elements and decreases the turn-on losses of the converter elements. However, the lower-order harmonic content of the output waveform is increased.

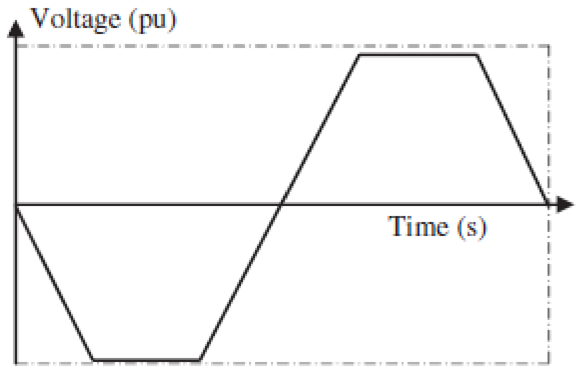

Figure 3.6 Trapezoidal modulating function.

3.1.4.2 Third Harmonic Modulating Function

As shown in Figure 3.7 a third harmonic may be added to the reference sinusoidal waveform to increase the output fundamental frequency voltage and to allow an increase in m_a.

3.1.4.2.1 Regular and Non-regular Sampled PWM (RS-PWM and NRS-PWM)

In the RS-PWM, the reference signal is sampled at equidistant time instants (Ts). Figure 3.8 shows an example where two samples per carrier cycle are generated. The pulse width of the RS-PWM signal is modulated based on the magnitude of the samples $h1$ and $h2$. Several variations of the RS-PWM modulation technique can be found in the literature namely, 'single-edge', 'symmetrically double-edge' or 'asymmetrically double-edge' modulation.

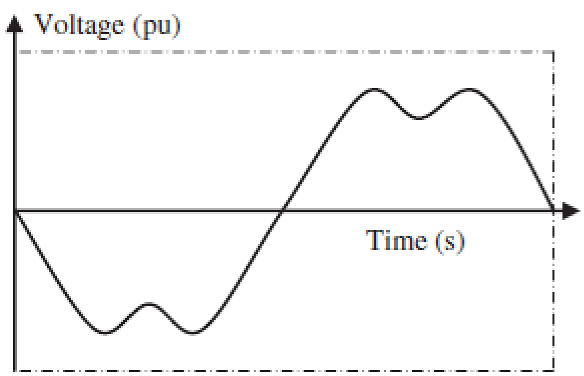

Figure 3.7 Harmonic modulating function.

In the 'non-regular sampling' or 'natural sampling' technique, the modulation time instants are not equidistant but are dependent on the modulation process.

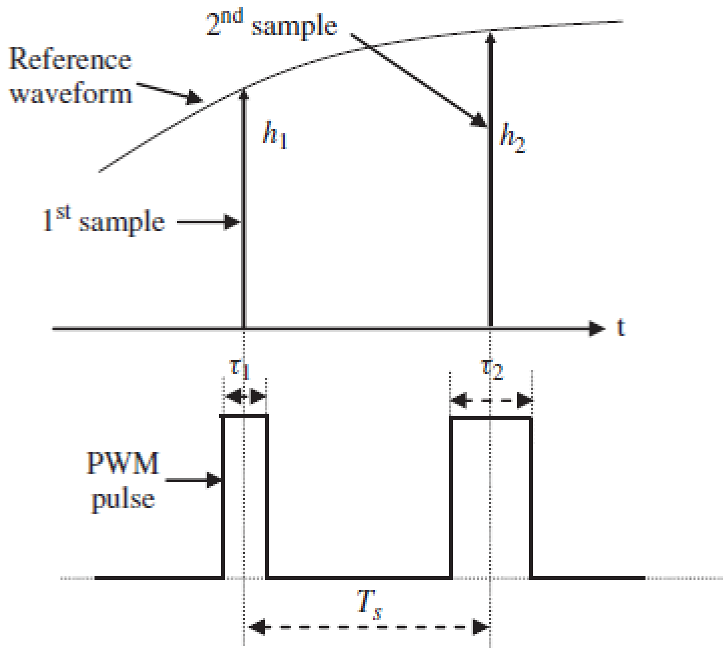

Figure 3.8 Regular sampling