Module
5

DC to AC Converters

Lesson
38

Other Popular PWM Techniques

After completion of this lesson, the reader shall be able to:

1. Explain the concept of sine+3rd harmonic modulated PWM inverter
2. Explain Space-Vector based PWM (SVPWM) technique
3. Estimate output voltage of the inverter using above PWM techniques
4. Compare at least five different PWM techniques for a 3-phase inverter

Lessons-36 and 37 have dealt with PWM inverters. As pointed out in these lessons, the two main advantages of PWM inverters in comparison to square-wave inverters are (i) control over output voltage magnitude (ii) reduction in magnitudes of unwanted harmonic voltages. It was also shown that PWM results in lower magnitude of output voltage of fundamental frequency. In the context of SPWM (Lesson-37) it was seen that good quality output voltage requires the modulation index (m) to be less than or equal to 1.0. For m>1 (over-modulation), the fundamental voltage magnitude increases but at the cost of decreased quality of output waveform. The maximum fundamental voltage that the SPWM inverter can output (without resorting to over-modulation) is only 78.5% of the fundamental voltage output by square-wave inverter. In this lesson some more PWM techniques have been introduced. The merits and demerits of different PWM techniques may be compared under comparable circuit conditions on the basis of factors like (i) quality of output voltage (ii) obtainable magnitude of output voltage (iii) ease of control etc. The peak obtainable output voltage from the given input dc voltage is one important figure of merit for the inverter and has been discussed in some more detail below.

38.1 How To Get More Output Voltage From The Same DC Bus Voltage?

The inverter switches need to be rated to withstand the peak magnitude of input dc link voltage, the maximum expected load current and should be able to safely dissipate the heat generated in the switch due to conduction and switching losses. Because of high frequency switching, the switches in PWM inverters have significantly more switching loss than in square wave inverters. Often the switch chosen in PWM inverters is oversized, in terms of its current rating, so that the sum total of switching loss and conduction loss remains well within the heat dissipation capability of the switch and the associated heat sink. One may talk of the VA rating of the switch, being the product of the switch voltage and current ratings. The switch cost may be roughly taken as proportional to its VA rating. The VA rating of the inverter equals the maximum VA of load power (considering only the fundamental component of output voltage and current) that the inverter may output. On account of higher fundamental output voltage and less switching loss, a square-wave inverter will produce a higher VA (for the given switch VA ratings) than a PWM inverter. The square wave inverter can use slower switches, requires simpler control circuit and thus the inverter cost comes further down. However due to better quality of output voltage (and hence current), PWM inverters may be unavoidable in many applications.

For identical magnitudes of switching frequency and switch voltage stress some particular PWM techniques may allow more output voltage than other PWM techniques (in spite of comparable quality of output voltages). Sometimes the lower achievable output voltage may mean that the inverter is not suitable for given application. For example, consider a typical case where a 3-phase 400 volts rated induction motor is to be fed from a PWM inverter for a wide range of speed control. The dc bus voltage to the inverter is, in most cases, achieved after rectifying the 3-

phase utility ac supply. Often a three-phase diode bridge rectifier followed by a large filter capacitor is used to get dc bus voltage. The magnitude of dc bus voltage, so achieved, may be considered close to the peak magnitude of supply line voltage. For 400 volts, 50 Hz, 3-phase supply system the dc bus voltage will be around 566 volts (i.e. $400\sqrt{2}$ volts). Now using a SPWM inverter with a dc link voltage of 566 volts, one can output maximum rms line voltage of 347 volts only (= 0.612 E_{dc}, as shown in Sec. 37.4 of Lesson-37). The SPWM inverter will, thus, not be able to meet the rated voltage demand of 400 volts for the motor. Instead of SPWM inverter, had one used a square wave inverter, the maximum magnitude of line voltage (fundamental component) output by the inverter would have been 441 volts (= 0.78 E_{dc}, as per Sec. 35.2, Lesson-35). Thus, on account of lower output voltage a SPWM inverter may be unsuitable in certain application. Fortunately, there are some other PWM techniques that can output good quality line voltage waveforms (similar to SPWM inverter) and can output higher voltage. In this lesson two such popular PWM techniques namely, sine+3rd harmonic modulation and space vector modulation techniques have been described. Later two more PWM techniques that were briefly touched upon in Lesson-36 have been elaborated further.

38.2 Sine + 3rd Harmonic PWM Technique

The idea of Sine+3rd harmonic modulation technique is based on the fact that the 3-phase inverter-bridge feeding a 3-phase ac load does not provide a path for zero-sequence component of load current. As shown in Lessons-35 & 36, only three output points are brought out from a three-phase inverter-bridge. These output points are connected to the three supply terminals of the load. Such an arrangement does not cause any confusion for the delta connected load but for a star connected load the neutral point remains floating. However for a balanced, three-phase, star-connected load this should not be a drawback as the fundamental component in the load phase voltage is identical to the fundamental component of inverter's pole voltage. In fact, the floating neutral point has the advantage that no zero sequence current (which includes dc, third and integer multiples of third harmonics) will be able to flow through the load and hence even if the pole voltage is distorted by, say, 3rd and integral multiples of third harmonics the load side phase and line voltages will not be affected by these distortions. The Sine+3rd harmonic PWM technique is a modification over the SPWM technique discussed in Lesson-37 wherein deliberately some amount of third harmonic voltage is introduced in the pole voltage waveform. Accordingly a suitable amount of third harmonic signal is added to the sinusoidal modulating signal of fundamental frequency. Now, the resultant waveform (modified modulating signal) is compared with the high frequency triangular carrier waveform. The comparator output is used for controlling the inverter switches exactly as in SPWM inverter. Thus, as brought out in Sec.37.2 of Lesson-37, the low frequency component of the pole voltage will be a replica of the modified modulating signal provided (i) The instantaneous magnitude of the modified modulating signal is always less than or equal to the peak magnitude of the carrier signal and (ii) the carrier frequency is significantly higher than the frequency of modulating signal. Accordingly, the pole voltage of Sine+3rd harmonic PWM inverter has same composition of fundamental and third harmonic as in the modified modulating signal. However, as per the earlier discussion, the third harmonic component of pole-voltage will not appear in the load phase and line voltages. The advantage of adding small amount of third harmonic in the modulating waveform is that it brings down the peak magnitude of the resultant modulating waveform. The modified modulating waveform appears more flat topped than its fundamental component. Thus if the fundamental sinusoidal modulating wave had a peak magnitude equal to the peak magnitude of the triangular carrier wave (corresponding to modulation index 'm' = 1.0),

the addition of small percentage of 3rd harmonic to the fundamental wave causes the peak magnitude of the combined signal to become lower than triangle wave's peak magnitude.
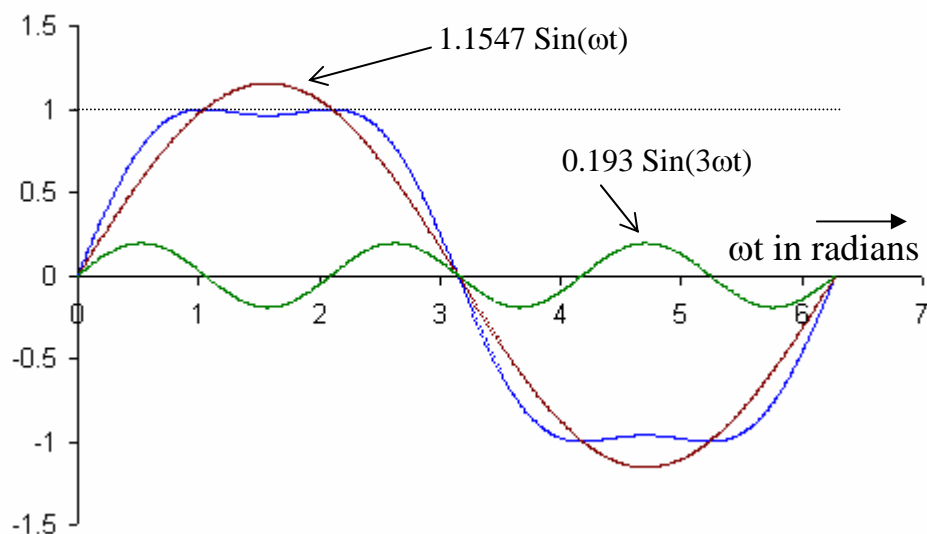
Fig. 38.1: The modulating signal for Sine+3rd harmonic modulation

In other words, a fundamental frequency signal having peak magnitude slightly higher than the peak magnitude of the carrier signal, if mixed with suitable amount of 3rd harmonic may result in a modified signal of peak magnitude not exceeding that of the carrier signal. Thus the peak of the modulating signal remains lower than the peak of triangular carrier signal and still the fundamental component of output voltage has a magnitude higher than what a SPWM can output with m = 1.0. As described earlier the load sees only the fundamental component of pole voltage (and not the third harmonic) and thus the achievable load (output) voltage magnitude is higher than that of SPWM inverter. It is to be noted that higher output voltage is achieved without compromising on the quality of the output waveform. Fig. 38.1 illustrates this logic, wherein [1.1547 Sin(ωt) +0.193 Sin(3ωt)] is the modulating waveform with a resultant peak magnitude of just 1.0. A higher amount of third harmonic will cause the magnitude limit to be exceeded. Thus the fundamental voltage output by the inverter employing Sine+3rd harmonic modulation technique can be higher by nearly 15.47% than a simple SPWM inverter. Now let the practical example of 400 volt rated induction motor drive considered in Sec. 38.1 be reconsidered but with an inverter employing sine +3rd harmonic modulation. The maximum output voltage can now go to 347*1.1547 volts = 400 volts and the peak voltage requirement of the drive will be met.

38.3 Space Vector PWM (SV-PWM) Technique

The space vector modulation technique is somewhat similar to the Sine+3rd harmonic PWM technique but the method of implementation is different. Before going into details of this technique, it would be useful to explore the concept of voltage space-vector, in analogy with the concept of flux space-vector as used in three-phase ac machine. The stator windings of a three-phase ac machine (with cylindrical rotor), when fed with a three-phase balanced current produce a resultant flux space-vector that rotates at synchronous speed in the space. The flux vector due to an individual phase winding is oriented along the axis of that particular winding and its magnitude alternates as the current through it is alternating. The magnitude of the resultant flux due to all three windings is, however, fixed at 1.5 times the peak magnitude due to individual

phase windings. The resultant flux is commonly known as the synchronously rotating flux vector.

Now, in analogy with the fluxes, if a three phase balanced voltage is applied to the windings of a three-phase machine, a rotating voltage space vector may be talked of. The resultant voltage space-vector will be rotating uniformly at the synchronous speed and will have a magnitude equal to 1.5 times the peak magnitude of the phase voltage. Fig. 38.2 (a) shows a set of three-phase balanced sinusoidal voltages. Let these voltages be applied to the windings of a three-phase ac machine as shown in Fig. 38.2(b). Now, during each time period of the phase voltages six discrete time instants can be identified, as done in Fig. 38.2(a), when one of the phase voltages have maximum positive or negative instantaneous magnitude. The resultants of the three space-voltages at these instants have been named V_1 to V_6. The spatial positions of these resultant voltage space-vectors have been shown in Fig. 38.2(b). At these six discrete instants, these vectors are aligned along the phase axes having maximum instantaneous voltage. As shown in Fig. 38.2(a) the magnitude of these voltage vectors is 1.5 times the peak magnitude of individual phase voltage.
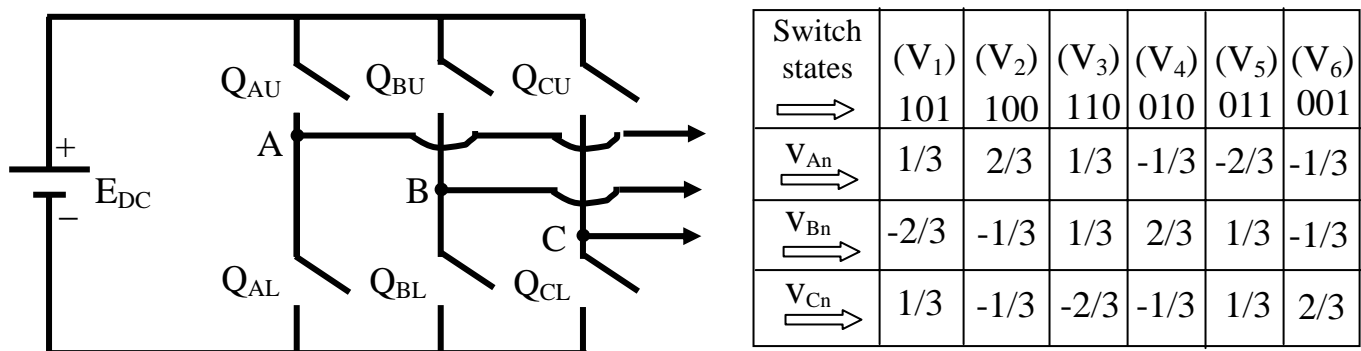
The instantaneous voltage output from a 3-phase inverter, discussed in earlier lessons, cannot be made to match the three sinusoidal phase voltages of Fig. 38.2(a) at all time instants. This is so because the inverter outputs are obtained from rectangular pole voltages and contain, apart from the fundamental, harmonic voltages too. However, the instantaneous magnitudes of the inverter outputs and the sinusoidal voltages can be made to match at the six discrete instants (talked above) of the output cycle. At these six discrete instants one of the phase voltages is at its positive or negative peak magnitude and the other two have half of the peak magnitude. The polarity of the peak phase-voltage is opposite to that of the other two phase-voltages. A similar pattern is seen in the instantaneous phase voltages output by a 3-phase inverter and is explained below.

Fig. 38.3 shows a three-phase voltage source inverter whose output terminals are fed to the three terminal of a three-phase ac machine (in fact to any three-phase balanced load). From the knowledge of 3-phase voltage source inverters, it may be obvious that the two switches of each inverter pole conduct in a complementary manner. Thus the six switches of the three poles will have a total of eight different switching combinations. Out of these eight combinations, two combination wherein all the upper switches or all the lower switches of each pole are simultaneously ON result in zero output voltage from the inverter. These two combinations are referred as **null states** of the inverter. The remaining six switching combinations, wherein either two of the high side (upper) switches and one of the low side (lower) switch conduct, or vice-versa, are **active states**. During the six active states the phase voltages output by the inverter to a balanced 3-phase linear load are as detailed in Sec.35.1 of Lesson 35. Accordingly instantaneous magnitude of two of the phase voltages are $1/3^{rd}$ E_{dc} and the third phase voltage is $2/3^{rd}$ E_{dc} (where E_{dc} is the dc link voltage). The voltage polarities of the two phases getting $1/3^{rd}$ E_{dc} are identical and opposite to the third phase having $2/3^{rd}$ E_{dc}. Fig. 38.3 also shows, in a tabular form, the instantaneous magnitudes of the three load-phase voltages (normalized by the dc link voltage magnitude) during the six active states of the inverter. The switching states of the inverter have been indicated by a 3-bit switching word. The 1st (MSB) bit for leg 'A', 2nd bit for leg 'B' and 3rd bit for leg 'C'. When a particular bit is 1, the high (upper) side switch of that leg is ON and when the bit is 0, the low side switch is ON. Thus a switching word 101 indicates that high side switches of legs 'A' and 'C' and low side switch of leg 'B' conduct. The resulting voltage pattern is identical to the voltage pattern of space voltage vector V_1 of Fig. 38.2 provided $2/3^{rd}$

E_{dc} equals the peak magnitude of phase voltage in Fig. 38.2. The table given in Fig. 38.3 shows how six active states of the inverter produce space voltage vectors V_1 to V_6 that can be identified on one to one basis with the six voltage vectors of Fig. 38.2. There are some important differences between the resultant space voltage vectors due to the sinusoidal phase voltages of Fig. 38.2 and the space voltage vectors formed by the inverter output voltages. These are described in the next section.
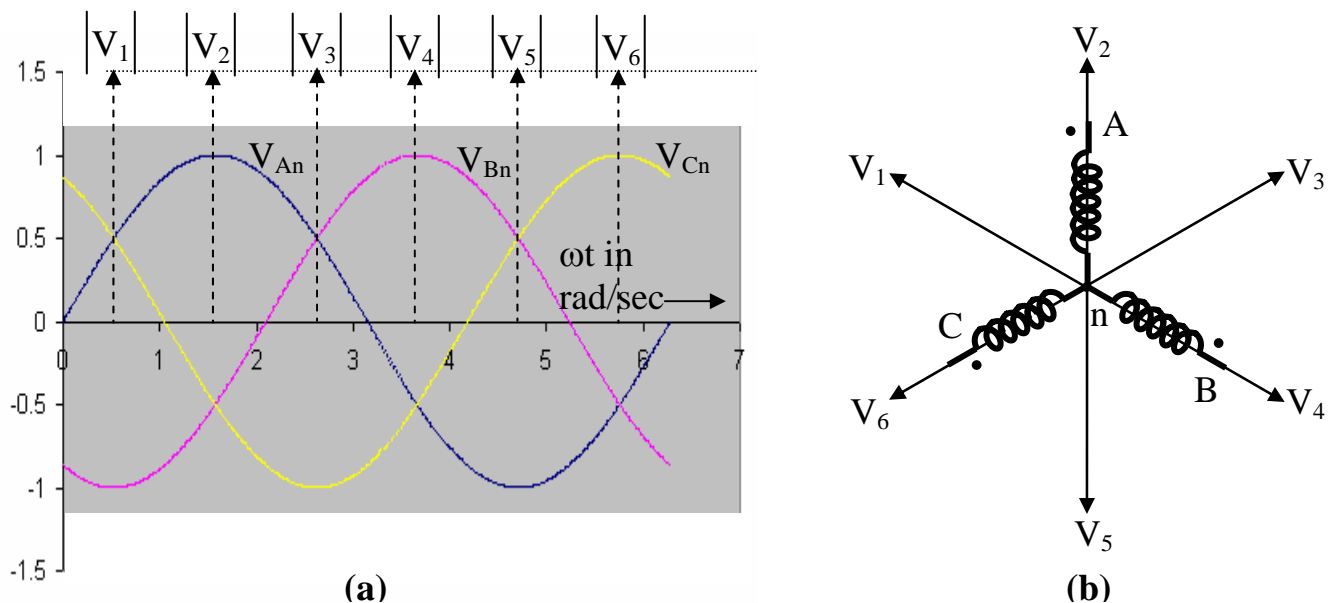
Fig. 38.2: The concept of voltage space-vectors: **(a) 3-phase balanced voltages**
(b) The voltage space-vectors

Switch states ⟹	(V_1) 101	(V_2) 100	(V_3) 110	(V_4) 010	(V_5) 011	(V_6) 001
V_{An} ⟹	1/3	2/3	1/3	-1/3	-2/3	-1/3
V_{Bn} ⟹	-2/3	-1/3	1/3	2/3	1/3	-1/3
V_{Cn} ⟹	1/3	-1/3	-2/3	-1/3	1/3	2/3

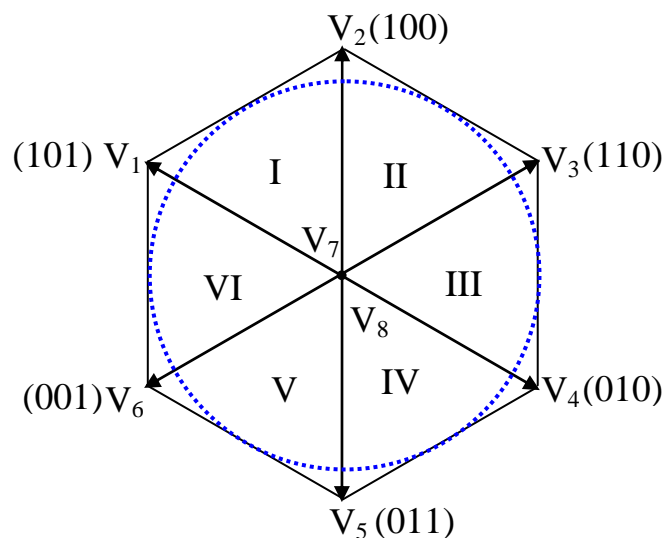**Fig. 38.3: Space vectors output by a 3-phase voltage source inverter**

38.3.1 Smoothly Rotating Space Voltage Vector From Inverter

The continuously varying sinusoidal waveforms, as shown in Fig. 38.2, result in a space voltage vector of fixed magnitude rotating at fixed (synchronous) speed in the space. If the inverter could have produced ideal sinusoidal 3-phase voltages, the resultant space voltage vector would have also moved smoothly in space with constant magnitude and constant angular speed. However by now the reader would know that the practical power electronic inverter could never produce the perfectly ideal sinusoidal voltages. In fact when the inverter switches from one active state to another, the space voltage vector changes its direction abruptly, the abrupt change in direction

being in multiples of 60 electrical degrees. If at a time only one bit of the inverter switching word changes (i.e., only one leg of the inverter changes the switching state) the abrupt change in space vector direction is by 60 electrical degrees.

Knowing that the inverter cannot produce ideal sinusoidal voltage waveforms, a good PWM inverter aims to remove low frequency harmonic components from the output voltage at the cost of increasing high frequency distortion. The high frequency ripple in the output voltage can easily be filtered by a small external filter or by the load inductance itself. In terms of voltage space vectors the above trade-off between low and high frequency ripples means that the resultant voltage vector will have two components; (i) a slowly moving voltage vector of constant magnitude and constant speed superimposed with (ii) a high frequency ripple component whose direction and magnitude changes abruptly.

The space-vector PWM technique aims to realize this slowly rotating voltage space vector (corresponding to fundamental component of output voltage) from the six active state voltage vectors and two null state vectors. The active state voltage vectors have a magnitude = E_{dc} and they point along fixed directions whereas null state vectors have zero magnitude. Fig. 38.4 shows the voltage space-vector plane formed by the active state and null state voltage vectors. The null state voltage vectors V_7 and V_8 are each represented by a dot at the origin of the voltage space plane. The switching word for V_7 is 000, meaning all lower side switches are ON and for V_8 is 111, corresponding to all upper side switches ON. The active-state voltage space vectors point along directions shown previously in Fig. 38.2(b). A regular hexagon is formed after joining the tips of the six active voltage vectors. The space-plane of Fig. 38.4 can be divided in six identical zones (I to VI). The output voltage vector from the inverter (barring high frequency disturbances) should be rotating with fixed magnitude and speed in the voltage plane. Now it is possible to orient the resultant voltage space-vector along any direction in the space plane using the six active vectors of the inverter. Suppose one needs to realize a space voltage vector along a direction that lies exactly in the center of sector-I of the space-plane shown in Fig.38.4. For this the inverter may be continuously switched (at high frequency) between V_1 and V_2 active states, with identical dwell time along these two states. The resultant vector so realized will occupy the mean angular position of V_1 and V2 and the magnitude of the resultant vector can be found to be 0.866 times the magnitude of V_1 or V_2 (being the vector sum of 0.5 V_1 and 0.5 V_2). Further, the magnitude of the resultant voltage vector can be controlled by injecting suitable durations of null state.

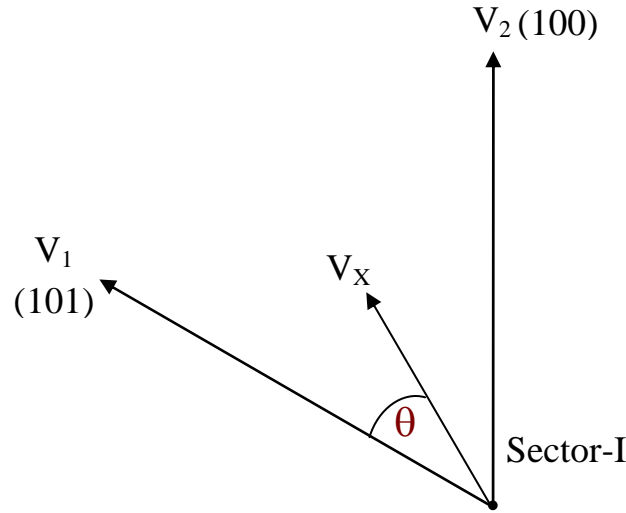**Fig. 38.4: The voltage space-vectors output by a 3-phase inverter**

In general both magnitude and direction control of the resultant voltage vector can be achieved by properly controlling the dwell times of two adjacent active voltage vectors and null voltage vectors. The two active state vectors chosen are the ones that define the boundary of the space-plane sector in which the desired resultant vector lies. The following illustrative example may be helpful.

Example:

Let us assume that a resultant vector 'V_X' of magnitude $\alpha(E_{dc})$, lying in sector-I and making an angle 'θ' from active vector V_1 is to be realized (Fig. 38.5). Let us further assume that T_S is the sampling time for which the desired vector V_X may be assumed to be stationary in space along the described direction. Now as per the above discussion the desired vector is to be realized using active vectors V_1, V_2 and null vectors V_7, V_8. Let the respective dwell time along these vectors be t_1, t_2, t_7 and t_8 such that

$$t_1 + t_2 + t_7 + t_8 = T_S \qquad \text{---} (38.1)$$

Fig. 38.5: The voltage space-vectors output by a 3-phase inverter

Now the resultant space vector V_X is the vector sum of $\dfrac{t_1}{T_S}(V_1)$ and $\dfrac{t_2}{T_S}(V_2)$, where V_1 and V_2 are space vectors, each having magnitude E_{dc}. Thus, according to vector algebra,

$$\alpha = \frac{t_1}{T_S}\text{Cos}\theta + \frac{t_2}{T_S}\text{Cos}\left(\frac{\pi}{3} - \theta\right) \qquad \text{----------------------------} (38.2)$$

and $\qquad \dfrac{t_1}{T_S}\text{Sin}\theta = \dfrac{t_2}{T_S}\text{Sin}\left(\frac{\pi}{3} - \theta\right) \qquad \text{----------------------------} (38.3)$

From Eqns. (38.2) and (38.3), one can determine the fraction of sampling time during which the inverter is along active states V_1 and V_2.

Accordingly, $\dfrac{t_1}{T_S} = \dfrac{\alpha}{\left(Cos\theta + Sin\theta Cot\left(\frac{\pi}{3} - \theta\right)\right)} = \dfrac{\alpha Sin\left(\frac{\pi}{3} - \theta\right)}{Sin\left(\frac{\pi}{3}\right)}$ -------------------- (38.4)

and $\dfrac{t_2}{T_S} = \dfrac{\alpha}{\left(Cos\left(\frac{\pi}{3} - \theta\right) + Cot\theta Sin\left(\frac{\pi}{3} - \theta\right)\right)} = \dfrac{\alpha Sin\theta}{Sin\left(\frac{\pi}{3}\right)}$ ----------- (38.5)

The total null duration is generally equally divided between t_7 and t_8 and hence

$$t_7 = t_8 = 0.5\left(1 - \dfrac{t_1}{T_S} - \dfrac{t_2}{T_S}\right) = 0.5 - 0.5\alpha\left(\dfrac{Sin\left(\frac{\pi}{3} - \theta\right) + Sin\theta}{Sin\left(\frac{\pi}{3}\right)}\right)$$ ----------- (38.6)

Knowing the magnitude factor 'α' and the angular position 'θ' the inverter switching-pattern is determined as per the above equations. Along any fixed direction 'θ', the magnitude of the voltage space vector is controlled by controlling the null duration time. For maximum magnitude along a particular direction the null vector duration must be zero. Thus, from Eqn. (38.6) one can determine the maximum possible voltage magnitude factor 'α_{max}' along 'θ' as

$$\alpha_{max} = \dfrac{Sin\left(\frac{\pi}{3}\right)}{Sin\left(\frac{\pi}{3} - \theta\right) + Sin\theta}$$ ------------------------------- (38.7)

As θ is varied in the range $0 \leq \theta \leq \frac{\pi}{3}$, the minimum magnitude of α_{max} is encountered at $\theta = \frac{\pi}{6}$ and equals 0.866. Thus to have a rotating space voltage vector (fundamental component) of uniform magnitude over the whole voltage space-plane, the upper limit on the voltage vector magnitude will be 0.866 E_{dc}. The tip of the corresponding space voltage vector falls on the interior circle of the hexagon in Fig. 38.4. It may be recalled that the SPWM technique can output maximum (corresponding to modulation index = 1.0) voltage space vector magnitude $=1.5\dfrac{E_{dc}}{2} = 0.75E_{dc}$, where $\dfrac{E_{dc}}{2}$ is the peak magnitude of fundamental phase voltage (Lesson-37) and the factor 1.5 is due to the resultant of the three phases. Thus space-vector PWM technique can output 1.1547 (=0.866/0.75) times more voltage, exactly as in Sine+3rd harmonic modulation technique discussed in the beginning of this lesson (section 38.2).

38.3.2 Algorithm For Producing Sinusoidal Output Voltages Using SV-PWM

 As would be clear from the discussions in the above sections, the SV-PWM is concerned with the control of inverter output voltages in a unified manner. It does not control the individual phase voltages separately. The instantaneous magnitude and direction of the desired resultant voltage vector is decided as per the frequency and magnitude of inverter's fundamental output voltage. The SV-PWM is best realized with the help of a digital computing device, like microprocessor or Digital Signal Processor. The algorithm to be executed is outlined below:

(1) Get the input data like; input dc link voltage (E_{dc}), desired output frequency 'f_{OP}' (this will determine the speed of the resultant voltage vector), desired phase sequence of output voltage (will determine which way, clockwise or anticlockwise, the resultant voltage vector is moving), desired magnitude of output voltage and the desired switching frequency. It will be shown later that the switching frequency (f_{SW}) and sampling time period (T_S) are related. During each sampling time period three switching take place, where one turn-on and one turn-off is taken as one switching.

(2) Calculate magnitude factor 'α' from the knowledge of input dc link voltage and the desired output voltage (α E_{dc} = 3/2 times peak of phase voltage). Also, calculate the sampling time period T_S = 1/(3 f_{SW}).

(3) Initialize sector position = I, and angle 'θ' = 0. Assume the rotating space voltage vector to remain stalled at this position for the sampling time period 'T_S'. Calculate the time duration for active and null state vectors as per Eqns. (38.4) to (38.6). Output the inverter switching pulses as per the calculated time durations so as to realize the space vectors in the following sequence: $V_8(111)$, $V_1(101)$, $V_2(100)$, $V_7(000)$.

(4) Calculate the next position angle $\theta = 2T_S\pi f_{OP} + \theta_{old}$ for clockwise rotation in the vector space-plane of Fig. 38.4. The reader should be able to work out the changes when the rotation is anti-clock wise. Recalculate the time durations as in step (3) above but this time the switching sequence will be $V_7(000)$, $V_2(100)$, $V_1(101)$, $V_8(111)$.

(5) Step (4) is to be repeated but every time the switching sequence alternates between the sequences given in steps 4 and 5. This helps in reducing the switching losses. The reader may note that this way there are only 3 switching per sampling period. The switching to next space vector involves change of only one bit of the switching word (i.e., only one turn-on and one turn-off). When the space vector enters sector-II (for $\theta \geq \pi/3$), the vector V_1 is replace by V_2 and V_2 is replaced by V_3. At the same time, angular position is reset to a value within $\pi/3 \geq \theta \geq 0$ by subtracting 60 degrees from the old value. Every time the voltage vector enters a new sector the angle θ is readjusted so that it varies between 0 and 60 degrees. The active state vectors are also reassigned as described above. The process continues to produce a continuously rotating voltage space vector of fixed magnitude and fixed speed.

38.4 Some Other Popular PWM Techniques

By now the readers must be familiar with sine-PWM (SPWM), sine +3rd harmonic PWM and space vector PWM (SV-PWM) techniques. In the following sections two more PWM techniques are briefly touched upon. These are (i) selective harmonic elimination technique and (ii) current controlled PWM (CCPWM) technique.

38.4.1 Selective Harmonic Elimination Technique

In Lesson-36 (sections 36.1 and 36.2) it was shown that some selected harmonics could be eliminated from the inverter output voltage by introducing notches at suitable time instants (angles) in the pole voltage waveform. To eliminate more number of unwanted harmonics from the output one needs to have more notches per output cycle. For the required magnitude of output voltage and frequency and the inverter's dc bus voltage, these notch angles need to be

calculated off-line using digital computer and later used for generating the switching sequence. The notch angle information for all three phases taken together can be converted into a matrix of switching word for the inverter. The consecutive switching word information at short and regular time interval (in time steps of, say, 10 microseconds) is stored for a full output cycle in consecutive locations of a memory device, like, EPROM. To output the proper switching signal these stored values are output sequentially by sequentially incrementing the address word of the EPROM. The time rate at which the address changes should be identical to the time rate at which the information was stored. The switching word information is then converted into gate control signals for the inverter switches. As the inverter's input and output parameters change, the switching matrix changes too. For an inverter producing variable voltage, variable frequency output the total requirement of memory size becomes large. However the cost of memory chips is coming down and hence the scheme is one of the preferred PWM schemes.

38.4.2 Current Controlled PWM (CCPWM) Technique

In this technique, reference load current (as desired by the user) signals are generated and the inverter switches are controlled so that the actual inverter phase currents match these within tolerable error limits. The scheme requires current sensors to sense actual phase currents. For a three-phase load, sensing two phase-currents suffices as the third phase current can be obtained by algebraic manipulation of the other two. The actual currents are compared with the corresponding reference currents to generate the required switching action. Most often hysteresis type bang-bang controllers are used. To increase the magnitude of current leaving the inverter pole (and entering the load terminal), the high side switch of the particular pole is turned on. Conversely the low side switch is turned on to decrease the magnitude of load current. Turning of high side switch causes input dc voltage to support the load phase current. The load phase current flows against the input dc voltage when low side switch is ON. The control actions for individual legs are generally independent of each other but the rate at which current changes in one leg may get affected by the switching state of the other legs. The control required is simple and the load current is directly controlled, hence the name CCPWM. The necessity of two numbers of fast current sensors may be seen as a drawback but current sensor costs are coming down and most inverter circuits employ current sensors, any way, for protection against over-current. Another draw back of the scheme may be associated with the hysteresis controller, if used. The switching frequency of such controllers becomes dependent on load parameters and may not remain optimum for the given load. There are, however, other control schemes for CCPWM inverter where the switching frequency can remain fixed in spite of load parameter changes.

Quiz problems

1. For a dc link voltage of 142 volts, which of the following PWM schemes can produce good quality line voltage (free from lower order harmonics) of 95 volts (rms) and 50 Hz.

   (a) Sine PWM
   (b) Sine+3rd harmonic PWM
   (c) Space vector PWM
   (d) all the above

2. The third harmonic component in the pole voltages of a 3-phase inverter, connected to a balanced 3-phase load, affects:
(a) load-phase voltage
(b) load-line voltage
(c) load-phase current
(d) none of the above

3. An inverter designed to work with fixed input dc voltage is fed with a fluctuating dc voltage. The basic controller for the following PWM scheme can still be used to output good quality current of constant magnitude:

(a) Sine
(b) (b) Sine+3rd Harmonic
(c) (c) Space Vector
(d) (d) Current Controlled PWM

4. With 283 volts dc link voltage connected to a 3-phase inverter what maximum phase voltage (rms magnitude) of good quality can be output by Sine PWM and Space Vector PWM:

(a) 50 and 75 volts
(b) 100 and 115 volts
(c) 141 and 200 volts
(d) 200 and 282 volts

Answers: 1-b & c, 2-d, 3-d, 4-b.