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Research Paper

SIMULATION & DEVELOPMENT OF INVERTER FED THREE PHASE INDUCTION MOTOR USING V/F CONTROL STRATEGY

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ABSTRACT

Amongst all electrical motors, induction motors are the most widely used motors due to their reliability, low cost and robustness. Out of the several methods of speed control of an induction motor, constant V/f speed control method is most widely used due to its simplicity. In this method, the V/f ratio is kept constant which in turn maintains the magnetizing flux constant so that the maximum torque remains unchanged. Thus, the motor is completely utilized in this method. This paper presents the simulation and implementation of three Phase inverter fed induction motor drive by using 89c52 microcontroller. The proposed drive system for three Phase inverter is simulated using MATLAB/Simulink software. For simulation, the gating pulses of inverter are generated. The hardware implementation of three phase inverter is also done and proved that the experimental results are same as that of simulation results.

I. INTRODUCTION

Amongst many methods, V/f control (scalar control) is mostly employed for Speed Control of 3 phase Induction motor. Scalar Control (V/f) of an Induction Motor In this technique, the field orientation of the motor is not used. Instead, the frequency and the voltage are the main control variables and are applied to the stator windings. The status of the rotor is ignored, meaning that no speed or position signal is fed back. The drive is therefore regarded as an open-loop drive [1]. This type of drive is suitable for applications such as pumps and fans, which do not require high levels of accuracy or precision In short it is described as frequency controlled induction motor drive:

This method involves changing synchronous speed by changing frequency of a.c. supply to induction motor to cause speed variation, as the true speed of the motor is very close to synchronous speed. This project is based on a voltage source inverter using this method of speed control. As we can see in the speed-torque characteristics in fig1, the induction motor draws the rated current and delivers the rated torque at the base

speed. When the load is increased (over-rated load), while running at base speed, the speed drops and the slip increases. The motor can take up to 2.5 times the rated torque with around 20% drop in the speed. Any further increase of load on the shaft can stall the motor.

The torque developed by the motor is directly proportional to the magnetic field produced by the stator. So, the voltage applied to the stator is directly proportional to the product of stator flux and angular velocity. This makes the flux produced by the stator proportional to the ratio of applied voltage and frequency of supply. By varying the frequency, the speed of the motor can be varied. Therefore, by varying the voltage and frequency by the same ratio, flux and hence, the torque can be kept constant throughout the speed range. Speed- torque characteristic states at the base speed, the voltage and frequency reach the rated values.

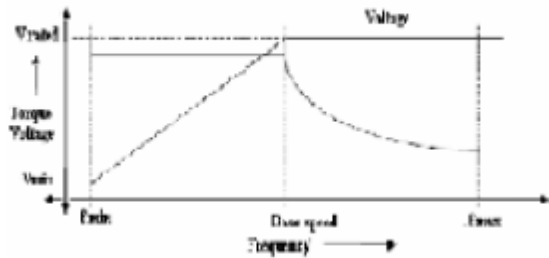


Fig.1.1 Speed Torque Characteristics With v/f Control

2. MODELLING AND SIMULATION OF INDUCTION MOTOR

A dynamic model of the machine subjected to control must be known in order to understand and design vector controlled drives. Due to the fact that every good control has to face any possible change of the plant, it could be said that the dynamic model of the machine could be just a good approximation of the real plant. Nevertheless, the model should incorporate all the important dynamic effects occurring during both steady state and transient operations. Furthermore, it should be valid for any changes in the inverter's supply such as voltages and currents.

Such a model can be obtained by means of either the space vector phasor theory or two axes theory of electrical machines. Despite the compactness and the simplicity of the space phasor theory, both methods are actually close and both methods will be explained.

For simplicity, the induction motor considered will have the following assumptions:

- ✓ Symmetrical two-pole, three phase windings.
- ✓ The slotting effects are neglected.
- ✓ The permeability of the iron parts is infinite.
- ✓ The flux density is radial in the air gap.
- ✓ Iron losses are neglected.
- ✓ The stator and the rotor windings are simplified as a single, multi-turn full pitch coil situated on the two sides of the air gap.

2.1. – Dynamic d-q Model.

The dynamic performance of an ac machine is somewhat complex because the three-phase rotor windings move with respect to the three-phase stator windings as shown in figure 3.1(a).

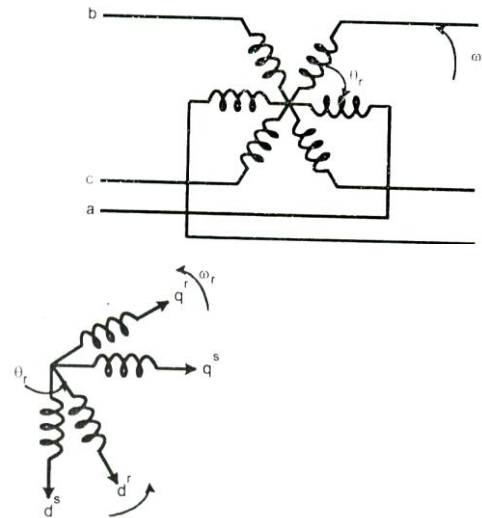


Fig. 3.1. (a) Coupling effect in three-phase
b). Equivalent two-phase machine

Stator and rotor windings

Basically, it can be looked on as a transformer with a moving secondary, where the coupling coefficients between the stator and rotor phases change continuously with the change of rotor position θ_r . The machine can be described by differential equations with time-varying mutual inductances, but such a model tends to be very complex. Note that a three-phase machine can be represented by an two-phase machine as shown in 3.1(b), where d_s - q_s correspond to stator direct and quadrature axes, and d_r - q_r correspond to rotor direct and quadrature axes.

3 PULSE WIDTH MODULATIONS

3.1 What is PWM?

Pulse Width Modulation (PWM) is the most effective means to achieve constant voltage battery charging by switching the solar system controller's power devices. When in PWM regulation, the current from the solar array tapers according to the battery's condition and recharging needs. Consider a waveform such as this: it is a voltage switching between 0v and 12v. It is fairly obvious that, since the voltage is at 12v for exactly as long as it is at 0v, then a 'suitable device' connected to its output will see the average voltage and think it is being fed 6v - exactly half of 12v. So by varying the width of the positive pulse - we can vary the 'average' voltage.

Similarly, if the switches keep the voltage at 12 for 3 times as long as at 0v, the average will be 3/4 of 12v - or 9v, as shown below and if the output

pulse of 12v lasts only 25% of the overall time, then the average is

By varying - or 'modulating' - the time that the output is at 12v (i.e. the width of the positive pulse) we can alter the average voltage. So we are doing 'pulse width modulation'. I said earlier that the output had to feed 'a suitable device'. A radio would not work from this: the radio would see 12v then 0v, and would probably not work properly. However a device such as a motor will respond to the average, so PWM is a natural for motor control.

Pulse Width modulator

So, how do we generate a PWM waveform? It's actually very easy, there are circuits available in the TEC site. First you generate a triangle waveform as shown in the diagram below. You compare this with a d.c voltage, which you adjust to control the ratio of on to off time that you require. When the triangle is above the 'demand' voltage, the output goes high. When the triangle is below the demand voltage, the

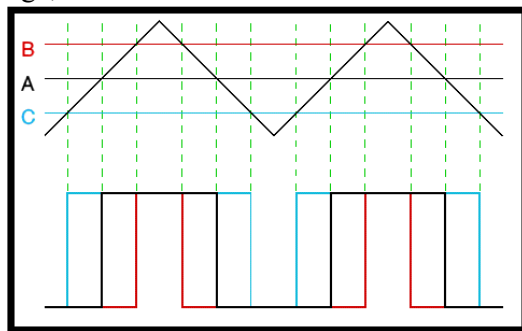


Fig 4.1 Pulse width modulation

When the demand speed it in the middle (A) you get a 50:50 output, as in black. Half the time the output is high and half the time it is low. Fortunately, there is an IC (Integrated circuit) called a comparator: these come usually 4 sections in a single package. One can be used as the oscillator to produce the triangular waveform and another to do the comparing, so a complete oscillator and modulator can be done with half an IC and maybe 7 other bits.

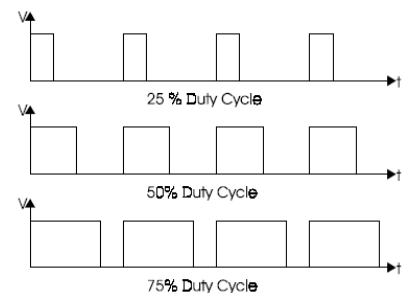
The triangle waveform, which has approximately equal rise and fall slopes, is one of the commonest used, but you can use a saw tooth (where the voltage falls quickly and rises slowly). You could use other waveforms and the exact linearity (how good the rise and fall are) is not too important.

Traditional solenoid driver electronics rely on linear control, which is the application of a

constant voltage across a resistance to produce an output current that is directly proportional to the voltage. Feedback can be used to achieve an output that matches exactly the control signal. However, this scheme dissipates a lot of power as heat, and it is therefore very inefficient.

A more efficient technique employs **pulse width modulation** (PWM) to produce the constant current through the coil. A PWM signal is not constant. Rather, the signal is on for part of its period, and off for the rest. The **duty cycle**, D, refers to the percentage of the period for which the signal is on. The duty cycle can be anywhere from 0, the signal is always off, to 1, where the signal is constantly on. A 50% D results in a perfect square wave.

A solenoid is a length of wire wound in a coil. Because of this configuration, the solenoid has, in addition to its resistance, R, a certain **inductance**, L. When a voltage, V, is applied across an inductive element, the current, I, produced in that element does not jump up to its constant value, but gradually rises to its maximum over a period of time called the **rise time**



ig 4.2 Duty cycle of PWM

Conversely, I does not disappear instantaneously, even if V is removed abruptly, but decreases back to zero in the same amount of time as the rise time.

Therefore, when a low frequency PWM voltage is applied across a solenoid, the current through it will be increasing and decreasing as V turns on and off. If D is shorter than the rise time, I will never achieve its maximum value, and will be discontinuous since it will go back to zero during V's off period (Figure 3). * In contrast, if D is larger than the rise time, I will never fall back to zero, so it will be continuous, and have a DC average value. The current will not be constant, however, but will have a ripple (Figure 4).

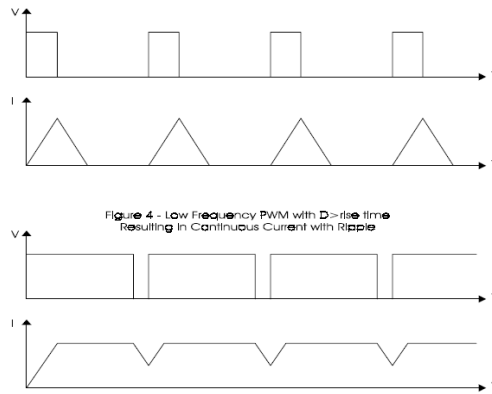


Fig 4.3 Low Frequency PWM with $D > \text{rise time}$ resulting in continuous current with ripple

At high frequencies, V turns on and off very quickly, regardless of D , such that the current does not have time to decrease very far before the voltage is turned back on. The resulting current through the solenoid is therefore considered to be constant. By adjusting the D , the amount of output current can be controlled. With a small D , the current will not have much time to rise before the high frequency PWM voltage takes effect and the current stays constant. With a large D , the current will be able to rise higher before it becomes constant. (Figure 5)

Dither

Static friction, stiction, and hysteresis can cause the control of a hydraulic valve to be erratic and unpredictable. Stiction can prevent the valve spool from moving with small input changes, and hysteresis can cause the shift to be different for the same input signal. In order to counteract the effects of stiction and hysteresis, small vibrations about the desired position are created in the spool. This constantly breaks the static friction ensuring that it will move even with small input changes, and the effects of hysteresis are averaged out.

Dither is a small ripple in the solenoid current that causes the desired vibration and thereby increases the linearity of the valve. The amplitude and frequency of the dither must be carefully chosen. The amplitude must be large enough and the frequency slow enough that the spool will respond, yet they must also be small and fast enough not to result in a pulsating output.

The optimum dither must be chosen such that the problems of stiction and hysteresis are overcome without new problems being created. Dither in the output current is a byproduct of low

frequency PWM, as seen above. However, the frequency and amplitude of the dither will be a function of the duty cycle, which is also used to set the output current level. This means that low frequency dither is not independent of current magnitude. The advantage of using high frequency PWM is that dither can be generated separately, and then superimposed on top of the output current.

3.2 Why the PWM frequency is important:

The PWM is a large amplitude digital signal that swings from one voltage extreme to the other. And, this wide voltage swing takes a lot of filtering to smooth out. When the PWM frequency is close to the frequency of the waveform that you are generating, then any PWM filter will also smooth out your generated waveform and drastically reduce its amplitude. So, a good rule of thumb is to keep the PWM frequency much higher than the frequency of any waveform you generate.

Finally, filtering pulses is not just about the pulse frequency but about the duty cycle and how much energy is in the pulse. The same filter will do better on a low or high duty cycle pulse compared to a 50% duty cycle pulse. Because the wider pulse has more time to integrate to a stable filter voltage and the smaller pulse has less time to disturb it the inspiration was a request to control the speed of a large positive displacement fuel pump. The pump was sized to allow full power of a boosted engine in excess of 600 Hp.

3.3 Motor Speed Control (Power Control)

Typically when most of us think about controlling the speed of a DC motor we think of varying the voltage to the motor. This is normally done with a variable resistor and provides a limited useful range of operation. The operational range is limited for most applications primarily because torque drops off faster than the voltage drops.

Most DC motors cannot effectively operate with a very low voltage. This method also causes overheating of the coils and eventual failure of the motor if operated too slowly. Of course, DC motors have had speed controllers based on varying voltage for years, but the range of low speed operation had to stay above the failure zone described above.

This sends a steady frequency of pulses into the motor windings. When full power is needed one

pulse ends just as the next pulse begins, 100% modulation. At lower power settings the pulses are of shorter duration. When the pulse is On as long as it is Off, the motor is operating at 50% modulation. Several advantages of PWM are efficiency, wider operational range and longer lived motors. All of these advantages result from keeping the voltage at full scale resulting in current being limited to a safe limit for the windings.

PWM allows a very linear response in motor torque even down to low PWM% without causing damage to the motor. Most motor manufacturers recommend PWM control rather than the older voltage control method. PWM controllers can be operated at a wide range of frequencies. In theory very high frequencies (greater than 20 kHz) will be less efficient than lower frequencies (as low as 100 Hz) because of switching losses.

3.3 PWM Controller Features:

This controller offers a basic “Hi Speed” and “Low Speed” setting and has the option to use a “Progressive” increase between Low and Hi speed. Low Speed is set with a trim pot inside the controller box. Normally when installing the controller, this speed will be set depending on the minimum speed/load needed for the motor. Normally the controller keeps the motor at this Lo Speed except when Progressive is used and when Hi Speed is commanded (see below). Low Speed can vary anywhere from 0% PWM to 100%.

Progressive control is commanded by a 0-5 volt input signal. This starts to increase PWM% from the low speed setting as the 0-5 volt signal climbs. This signal can be generated from a throttle position sensor, a Mass Air Flow sensor, a Manifold Absolute Pressure sensor or any other way the user wants to create a 0-5 volt signal. This function could be set to increase fuel pump power as turbo boost starts to climb (MAP sensor). Or, if controlling a water injection pump, Low Speed could be set at zero PWM% and as the TPS signal climbs it could increase PWM%, effectively increasing water flow to the engine as engine load increases. This controller could even be used as a secondary injector driver (several injectors could be driven in a batch mode, hi impedance only), with Progressive control

(0-100%) you could control their output for fuel or water with the 0-5 volt signal.

Progressive control adds enormous flexibility to the use of this controller. Hi Speed is that same as hard wiring the motor to a steady 12 volt DC source. The controller is providing 100% PWM, steady 12 volt DC power. Hi Speed is selected three different ways on this controller: 1) Hi Speed is automatically selected for about one second when power goes on. This gives the motor full torque at the start. If needed this time can be increased (the value of C1 would need to be increased). 2) High Speed can also be selected by applying 12 volts to the High Speed signal wire. This gives Hi Speed regardless of the Progressive signal.

When the Progressive signal gets to approximately 4.5 volts, the circuit achieves 100% PWM – Hi Speed.

How does this technology help ?:

The benefits noted above are technology driven. The more important question is how the PWM technology jumping from a 1970's technology into the new millennium offers:

- **Longer battery life:**

- reducing the costs of the solar system
- reducing battery disposal problems

- **More battery reserve capacity:**

- increasing the reliability of the solar system
- reducing load disconnects
- opportunity to reduce battery size to lower the system cost

- **Greater user satisfaction:**

- get more power when you need it for less money!!

5. SINGLE-PHASE VOLTAGE SOURCE CONVERTER

Single-phase voltage source converter can be found as half-bridge and full-bridge topologies. Although the power range they cover is the low one, they are widely used in power supplies, single-phase UPSs, and currently to form elaborate high-power static power topologies, such as for instance, the multicell configurations that are reviewed. The main features of both approaches are reviewed and presented in the following.

5.1 Half-Bridge VSI:

The power topology of a half-bridge VSI, where two large capacitors are required to provide a

neutral point N, such that each capacitor maintains a constant voltage $= \frac{v_i}{2}$. Because the current harmonics injected by the operation of the inverter are low-order harmonics, a set of large capacitors (C_+ and C_-) is required. It is clear that both switches S_+ and S_- cannot be on simultaneously because short circuit across the dc link voltage source v_i would be produced. There are two defined (states 1 and 2) and one undefined (state 3) switch state as shown in Table 14.1. In order to avoid the short circuit across the dc bus and the undefined ac output voltage condition, the modulating technique should always ensure that at any instant either

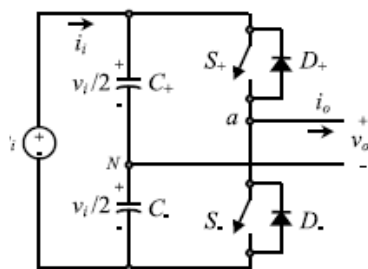


Fig 5.1 Single phase half bridge VSI

shows the ideal waveforms associated with the half-bridge inverter shown in Fig. 14.2. The states for the switches S_+ and S_- are defined by the modulating technique, which in this case is a carrier-based PWM.

The Carrier-Based Pulse width Modulation (PWM) Technique: As mentioned earlier, it is desired that the ac output voltage $V_a N$ follow a given waveform (e.g., sinusoidal) on a continuous basis by properly switching the power valves. The carrier-based PWM technique fulfils such a requirement as it defines the on and off states of the switches of one leg of a VSI by comparing a modulating signal v_c (desired ac output voltage) and a triangular waveform v_D (carrier signal). In practice, when $v_c > v_D$ the switch S_+ is on and the switch is off; similarly, when $v_c < v_D$ the switch S_+ is off and the switch S_- is on. A special case is when the modulating signal v_c is a sinusoidal at frequency f_c and amplitude $\hat{v}_c$, and the triangular signal v_D is at frequency f_D and amplitude $\hat{v}_D$. This is the sinusoidal PWM (SPWM) scheme. In this case, the modulation index m_a is defined as

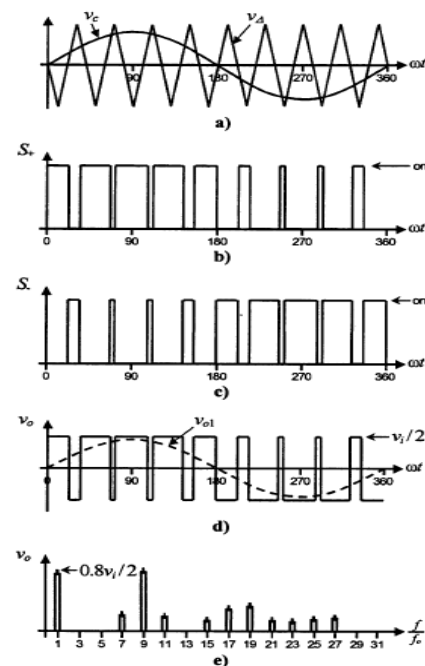
$$m_a = \frac{\hat{v}_c}{\hat{v}_A}$$

and the normalized carrier frequency m_f (also known as the frequency-modulation ratio) is

$$m_f = \frac{f_A}{f_c}$$

v_{aN} is basically a sinusoidal waveform plus harmonics, which features: (a) the amplitude of the fundamental component of the ac output voltage $\hat{v}_{o1}$ satisfying the following expression:

$$\hat{v}_{o1} = \hat{v}_{aN1} = \frac{v_i}{2} m_a$$



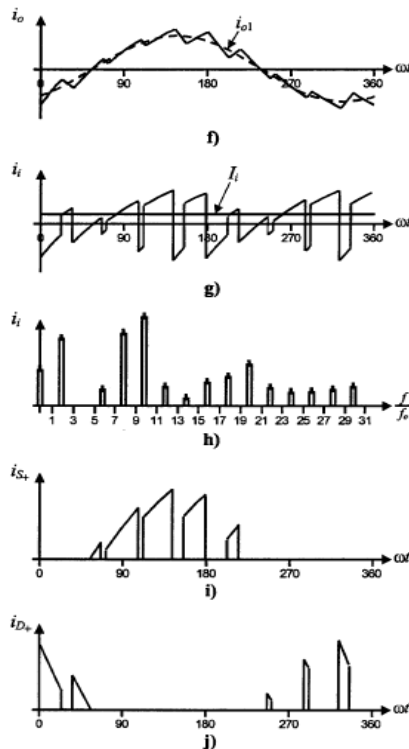


Fig 5.2 The amplitude of the fundamental & normalised component of the ac output voltage will be discussed later); (b) for odd values of the normalized carrier frequency m_f the harmonics in the ac output voltage appear at normalized frequencies h centered around m_f and its multiples, specifically,

$$h = lm_f \pm k \quad l = 1, 2, 3, \dots$$

Where $k = 2; 4; 6; \dots$ for $l = 1; 3; 5; \dots$; and $k = 1; 3; 5; \dots$ for $l = 2; 4; 6; \dots$; (c) the amplitude of the ac output voltage harmonics is a function of the modulation index m_a and is independent of the normalized carrier frequency m_f for $f > 9$; (d) the harmonics in the dc link current (due to the modulation) appear at normalized frequencies p centered around the normalized carrier frequency m_f and its multiples, specifically,

$$p = lm_f \pm k \pm 1 \quad l = 1, 2, \dots$$

where $k = 2; 4; 6; \dots$ for $l = 1; 3; 5; \dots$; and $k = 1; 3; 5; \dots$ for $l = 2; 4; 6; \dots$. Additional important issues are: (a) for small values of m_f ($m_f < 21$), the carrier signal v_D and the modulating signal v_c should be synchronized to each other (m_f integer), which is required to hold the previous features; if this is not the case, sub harmonics will be present in the ac output voltage; (b) for large values of m_f ($m_f >$

21), the sub harmonics are negligible if an asynchronous PWM

technique is used, however, due to potential very low-order sub harmonics, its use should be avoided; finally (c) in the over modulation region ($m_a > 1$) some intersections between the carrier and the modulating signal are missed, which leads to the generation of low-order harmonics but a higher fundamental ac output voltage is obtained; unfortunately, the linearity between m_a and $\hat{v}_o$ achieved in the linear region does not hold in the over modulation region, moreover, a saturation effect can be observed

The PWM technique allows an ac output voltage to be generated that tracks a given modulating signal. A special case is the SPWM technique (the modulating signal is a sinusoidal) that provides in the linear region an ac output voltage that varies linearly as a function of the modulation index and the harmonics are at well-defined frequencies and amplitudes.

These features simplify the design of filtering components. Unfortunately, the maximum amplitude of the fundamental ac voltage is $\hat{v}_i = 2$ in this operating mode. Higher voltages are obtained by using the over modulation region ($m_a > 1$); however, low-order harmonics appear in the ac output voltage.

Square-Wave Modulating Technique:

Both switches S_1 and S_2 are on for one-half cycle of the ac output period. This is equivalent to the SPWM technique with an infinite modulation index m_a . Figure 14.5 shows the following: (a) the normalized ac output voltage harmonics are at frequencies $h = 3; 5; 7; 9; \dots$, and for a given dc link voltage; (b) the fundamental ac output voltage features an amplitude given by

$$\hat{v}_{o1} = \hat{v}_{aN1} = \frac{4}{\pi} \frac{v_i}{2},$$

and the harmonics feature an amplitude given by

$$\hat{v}_{oh} = \frac{\hat{v}_{o1}}{h}$$

5.2 Selective Harmonic Elimination:

The main objective is to obtain a sinusoidal ac output voltage waveform where the fundamental component can be adjusted arbitrarily within a range and the intrinsic harmonics selectively eliminated. This is achieved by mathematically generating the

exact instant of the turn-on and turn-off of the power valves.

The ac output voltage features odd half- and quarter wave symmetry; therefore, even harmonics are not present ($v_{o1} = 0$; $h = 2; 4; 6; \dots$). Moreover, the per-phase voltage waveform ($v_{o1} = v_{aN}$), should be chopped N times per half-cycle in order to adjust the fundamental and eliminate $N - 1$ harmonics in the ac output voltage waveform. For instance, to eliminate the third and fifth harmonics and to perform fundamental magnitude control ($N = 3$), the equations to be solved are the following:

$$\begin{aligned}\cos(1\alpha_1) - \cos(1\alpha_2) + \cos(1\alpha_3) &= (2 + \pi \hat{v}_{o1}/v_i)/4 \\ \cos(3\alpha_1) - \cos(3\alpha_2) + \cos(3\alpha_3) &= 1/2 \\ \cos(5\alpha_1) - \cos(5\alpha_2) + \cos(5\alpha_3) &= 1/2\end{aligned}$$

where the angles α_1, α_2 , and α_3 are defined as shown. The angles are found by means of iterative algorithms as no analytical solutions can be derived.

The angles α_1, α_2 , and α_3 are plotted for different values of $\hat{v}_{o1}/v_i$ in Fig. 14.7a. The general expressions to eliminate an even $N - 1$ ($N = 2; 4; 6; \dots$) number of harmonics is

$$\begin{aligned}-\sum_{k=1}^N (-1)^k \cos(\alpha_k) &= \frac{2 + \pi \hat{v}_{o1}/v_i}{4} \\ -\sum_{k=1}^N (-1)^k \cos(n\alpha_k) &= \frac{1}{2} \quad \text{for } n = 3, 5, \dots, 2N - 1\end{aligned}$$

where $\alpha_1, \alpha_2; \dots; \alpha_N$ should satisfy $\alpha_1 < \alpha_2 < \dots < \alpha_N < \pi/2$. Similarly, to eliminate an odd number of harmonics, for instance, the third, fifth and seventh, and to perform

Fundamental magnitude control ($N = 3$), the equations to be solved are:

$$\begin{aligned}\cos(1\alpha_1) - \cos(1\alpha_2) + \cos(1\alpha_3) - \cos(1\alpha_4) &= (2 - \pi \hat{v}_{o1}/v_i)/4 \\ \cos(3\alpha_1) - \cos(3\alpha_2) + \cos(3\alpha_3) - \cos(3\alpha_4) &= 1/2 \\ \cos(5\alpha_1) - \cos(5\alpha_2) + \cos(5\alpha_3) - \cos(5\alpha_4) &= 1/2 \\ \cos(7\alpha_1) - \cos(7\alpha_2) + \cos(7\alpha_3) - \cos(7\alpha_4) &= 1/2\end{aligned}$$

where the angles $\alpha_1; \alpha_2; \alpha_3$, and α_4 are defined as shown in Fig. 14.6b. The angles $\alpha_1; \alpha_2; \alpha_3$ and α_4 are plotted for different values of $\hat{v}_{o1}/v_i$. The general expressions to eliminate an odd $N - 1$ ($N = 3; 5; 7; \dots$) number of harmonics are given by

$$\begin{aligned}-\sum_{k=1}^N (-1)^k \cos(n\alpha_k) &= \frac{2 - \pi \hat{v}_{o1}/v_i}{4} \\ -\sum_{k=1}^N (-1)^k \cos(n\alpha_k) &= \frac{1}{2} \quad \text{for } n = 3, 5, \dots, 2N - 1\end{aligned}$$

where $\alpha_1, \alpha_2, \dots, \alpha_N$ should satisfy $\alpha_1 < \alpha_2 < \dots < \alpha_N < \pi/2$.

5.3 Full-Bridge VSI:

The power topology of a full-bridge VSI. This inverter is similar to the half-bridge inverter; however, a second leg provides the neutral point to the load. As expected, both switches S_{1+} and S_{1-} (or S_{2+} and S_{2-}) cannot be on simultaneously because a short circuit across the dc link voltage source v_i would be produced. There are four defined and one undefined

The undefined condition should be avoided so as to be always capable of defining the ac output voltage. In order to avoid the short circuit across the dc bus and the undefined ac output voltage condition, the modulating technique should ensure that either the top or the bottom switch of each leg is on at any instant. It can be observed that the ac output voltage can take values up to the dc link value v_i , which is twice that obtained with half-bridge VSI topologies. Several modulating techniques have been developed that are applicable to full-bridge VSIs. Among them are the PWM (bipolar and unipolar) techniques.

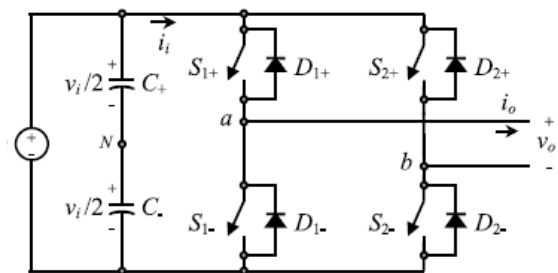


Fig 5.3 Full bridge converter

5.4 Bipolar PWM Technique:

States 1 and 2 (Table 14.2) are used to generate the ac output voltage in this approach. Thus, the ac output voltage waveform features only two values, which are v_i and $-v_i$. To generate the states, a carrier-based technique can be used a sine half-bridge configurations where only one sinusoidal modulating signal has been used. It should be noted that the on state in switch S_{-} in the half-bridge

corresponds to both switches S1. and S2 being in the on state in the full-bridge configuration.

Similarly, $S_{\bar{y}}$ in the on state in the half-bridge corresponds to both switches $S_{1\bar{y}}$ and $S_{2\bar{y}}$ being in the on state in the full-bridge configuration. This is called bipolar carrier-based SPWM. The ac output voltage waveform in a full-bridge VSI is basically a sinusoidal waveform that features a fundamental component of amplitude $\hat{v}_o$ that satisfies the expression

$$\hat{v}_{ol} = \hat{v}_{abl} = v_i m_a$$

In the linear region of the modulating technique ($m_a \leq 1$), which is twice that obtained in the half-bridge VSI. Identical conclusions can be drawn for the frequencies and amplitudes of the harmonics in the ac output voltage and dc link current, and for operations at smaller and larger values of odd m_f (including the over modulation region ($m_a > 1$)), than in half bridge VSIs, but considering that the maximum ac output voltage is the dc link voltage v_i . Thus, in the over modulation region the fundamental component of amplitude $\hat{v}_{o1}$ satisfies the expression

$$v_i < \hat{v}_{o1} = \hat{v}_{ab1} < \frac{4}{\pi} v_i$$

In contrast to the bipolar approach, the unipolar PWM technique uses the states 1, 2, 3, and to generate the ac output voltage. Thus, the ac output voltage waveform can instantaneously take one of three values, namely $v_i, -v_i$. The signal v_c is used to generate v_{aN1} , and $-v_c$ is used to generate v_{bN1} ;

$$v_{bN1} = -v_{aN1}.$$

On the other hand,

$$v_{o1} = v_{aN1} - v_{bN1} = 2 \cdot v_{aN1};$$

thus

$$\hat{v}_{o1} = 2 \cdot \hat{v}_{aN1} = m_a \cdot v_i.$$

This is called unipolar carrier-based PWM.

Identical conclusions can be drawn for the amplitude of the fundamental component and harmonics in the ac output voltage and dc link current, and for operations at smaller and larger values of m_f , (including the over modulation region ($m_a > 1$)), than in full-bridge VSIs modulated by the bipolar SPWM. However, because the phase voltages (v_{aN} and v_{bN}) are identical but 180° out of

phase, the output voltage ($v_o = v_{ab} = v_{aN} - v_{bN}$) will not contain even harmonics. Thus, if mf is taken even, the harmonics in the ac output voltage appear at normalized odd frequencies fh centered around twice the normalized carrier frequency mf and its multiples. Specifically,

$$h = lm_f \pm k \quad l = 2, 4, \dots$$

where $k = 1; 3; 5; \dots$ and the harmonics in the dc link current appear at normalized frequencies f_p centered around twice the normalized carrier frequency $m f$ and its multiples. Specifically,

$$p = lm_f \pm k \pm 1 \quad l = 2, 4, \dots$$

where $k = 1; 3; 5; \dots$. This feature is considered to be an advantage because it allows the use of smaller filtering components to obtain high-quality voltage and current waveforms while using the same switching frequency as in VSIs modulated by the bipolar approach.

5. SIMULATION RESULTS

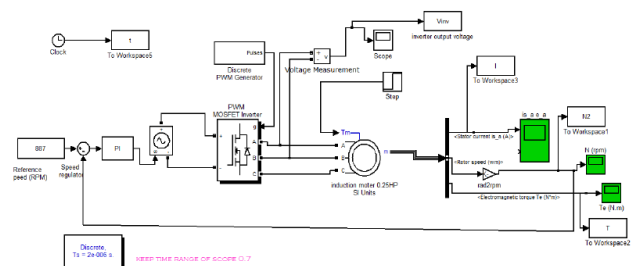


Fig 3: Simulation Block Diagram of V/f Control

Fig 6.1 Simulation block diagram of V/f control

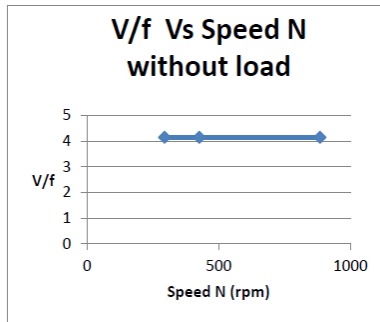


Fig 4: V/f Vs Speed without load

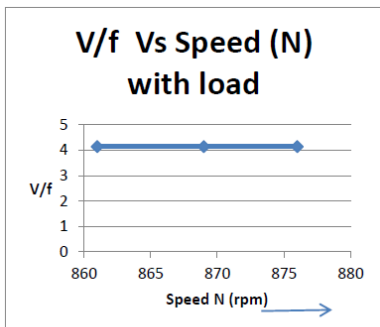


Fig 5: V/f Vs Speed with load

Fig 6.2 plot between V/f and speed with & without load

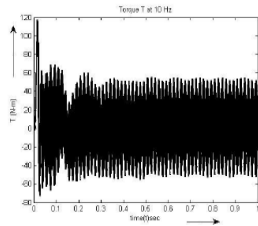


Fig 8: Output Torque Waveform at 10 Hz

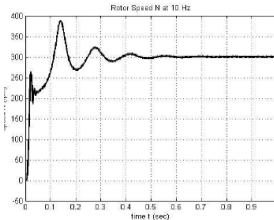


Fig 5.7: Output Speed Waveform at 10 Hz

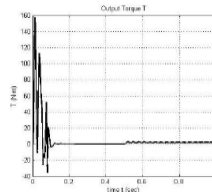


Fig 6: Output Torque Waveform at 50 Hz

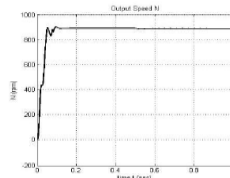


Fig 7: Output Speed Waveform at 50 Hz

Fig 6.3 Output waveforms of Torque and Speed at 10 & 50 Hz

6. CONCLUSION

The speed of three-phase induction motor is being controlled by varying supply voltage and frequency with constant (V/f) ratio. From the observation table no.1, it is clear that by maintaining constant v/f ratio, motor runs at variable speed with load & without load below rated speed. It is simple, economic & easier to design, & to implement in open loop. But the drawback of open loop is that, it doesn't correct the change in output. Also it doesn't

reach the steady state quickly. These drawbacks can be overcome by modifying an open loop into a closed loop system. It can be realized by MATLAB simulation software. The Hardware results are compared by MATLAB Simulation results & found matched with them.

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