FREQUENCY CONTROLLED AC MOTOR DRIVE

1.0 Features of Standard AC Motors

The squirrel cage induction motor is the electrical motor motor type most widely used in industry. This leading position results mainly from certain excellent features of the squirrel cage motor such as:

- Uncomplicated, rugged construction. For the user this means low initial cost and high reliability.
- Good efficiency coupled with low maintenance costs resulting in low overall operating costs.

Squirrel cage motors are asynchronous induction machines whose speed depends upon applied frequency, pole pair number, and load torque. At a constant supply voltage and frequency, if the effect of temperature variations is disregarded, the motor torque will depend upon slip - Shown in Figure as An.

At a positive slip, the squirrel cage machine will act as a motor - at a negative slip, as a generator. To reverse the machine's direction of rotation, the phase sequence to the motor must be changed.

Assuming similar conditions, the phase current drawn by a squirrel cage motor will depend only on the slip. A motor running at synchronous speed will only draw minimum current. As shown in Figure 1, as the slip is increased in either direction from zero, the current begins to increase rapidly.

The peak torque of standard squirrel cage motors is two to three times the permissible continuous torque, i e. the motor's rated torque. As shown in Figure 1, the positive and negative peak torques are respectively produced at slips of ±Δ n_h, determined by the electrical characteristics of the motor.

For efficient operation, the slip of a squirrel cage motor must be kept small, i.e. within a narrow range of -Δh…+Δ n_h. Because of this, speed control of squirrel cage motors can best be implemented by means of infinitely variable (stepless) frequency control. The nominal slip in most cases is 3% of the synchronous speed, and depends mainly on the motor size.

1.1 Motor Speed - In order to use the polyphase AC motor as an adjustable speed device, it is necessary to control and adjust the frequency of the 3 ϕ power applied to its terminals. The operating speed of the AC motor is determined by the following relationship:

$$\text{SHAFT SPEED}_{(\text{RPM})} = \frac{120 \times \text{Supply Frequency}}{2 \times \text{Pole Pair Number}} - \text{Slip}_{(\text{RPM})}$$

where Frequency is described in cycles per second (Hz), and Speed and Slip are expressed in RPM.

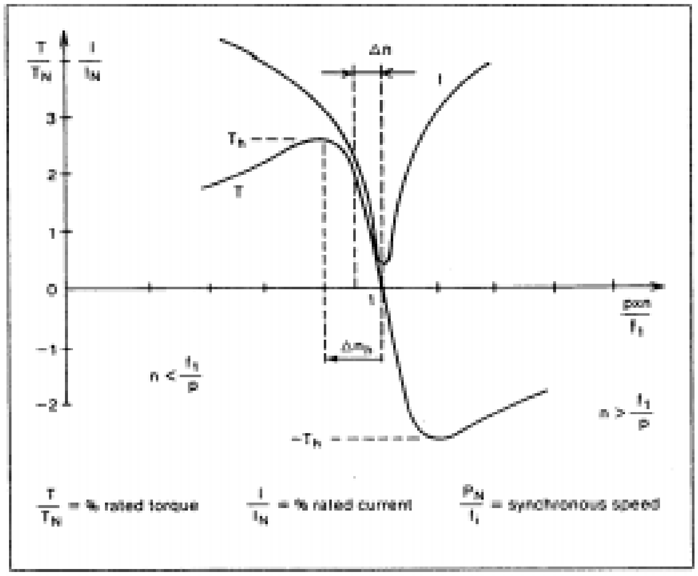


Figure 1 -Typical Squirrel Cage Motor Torque T and Current I at Constant Supply Voltage and Frequency

When a synchronous or synchronous reluctance motor is used, slip in the above equation is zero, while the motor's shaft speed is said to be synchronous, and completely controlled by applied power frequency.

Operation of an induction (NEMA Type B) machine, however, will result in a slip whose degree is a function of motor design, and a lower than synchronous operation shaft speed.

1.2 Frequency Controlled Squirrel Cage Motors

In frequency converter drives, squirrel cage motors are usually run within the range between the peak torques. The single-phase equivalent circuit of the motor, shown in Figure 2, can be used to obtain equations for the torque T, the peak torque T_h and the slip Δn_n corresponding to the peak torque. The equations are based on the assumption that the magnitude of the phase current I_1, does not affect the voltage Ui

$$T = 3p\left(\frac{U_i}{\omega_1}\right)^2 \cdot \frac{R'_2}{\omega_2} \cdot \frac{1}{\left(R'_2/\omega_2\right)^2 + \left(L'_{2\sigma}\right)^2}$$

$$T_h = 3p\left(\frac{U_i}{\omega_1}\right)^2 \cdot \frac{1}{2L'_{2\sigma}}$$

$$\Delta n_h = \frac{R'_2}{L'_{2\sigma}} \cdot \frac{1}{2\pi p}$$

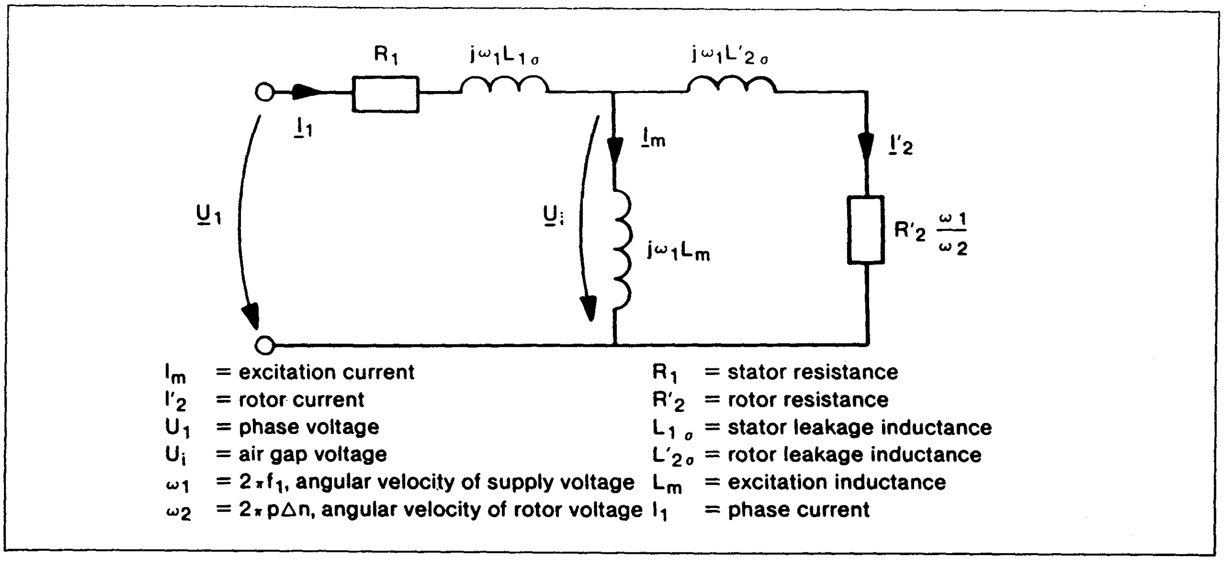


Figure 2 – Single-Phase Equivalent Circuit for Squirrel Cage Motor

1.3 Motor Torque - AC motor torque capability is proportional to magnetic flux density in the motor's air gap. In order to maintain constant torque capability at the output shaft of an AC motor used as an adjustable speed device, the flux density in the air gap must be maintained constant over the operating frequency range. Since the motor presents a highly inductive load to the power supply, its impedance increases directly with applied frequency. It is necessary, therefore, to increase the applied voltage in direct proportion to the increase in frequency or increase in speed. Therefore the ratio of volts to frequency must be kept constant, as shown in the relationship below:

Volts / Frequency = CONSTANT

This ratio is often referred to as Volts-Per-Hertz (V/Hz) and is controlled by the converter.
At low supply frequencies the stator resistance R_1 shown in Figure 2 "consumes" a significant percentage of the supply voltage, and the air gap voltage U_j easily becomes lower than desired. As shown in Figure 3, the effect of the R_1 resistance can be compensated by raising the supply voltage above the linear U_1f_1 curve at low frequencies. The compensation required, known as IR compensation, will be smaller the larger the motor is.

Within the constant flux range each torque value always corresponds to the same phase current, regardless of the frequency. In the equivalent circuit the reactive current I_m and the rotor current I_2 remain constant. In addition, the rotor current has, regardless of the supply frequency, always the same phase displacement in regard to the air gap voltage, (Figure 2).

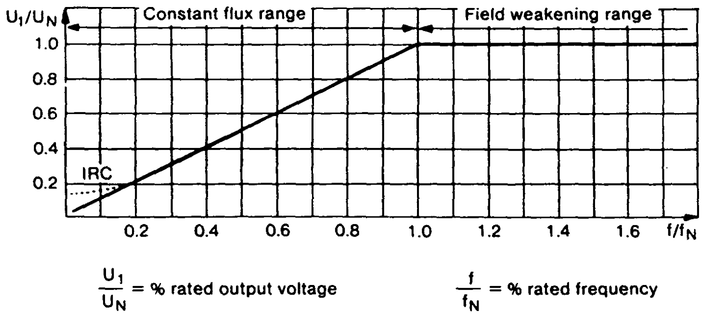


FIGURE 3 - Supply Voltage Control with an Example of IR Compensation.

1.4 Field Weakening Range - As shown in Figure 3, above the rated speed the supply voltage is maintained at the rated value. The air gap flux accordingly decreases in inverse proportion to the frequency. The peak torque decreases in inverse proportion to the square of the frequency, while the corresponding slip remains nearly constant.

Due to the lowered torque current, the slip corresponding to a given load is larger in the field weakening range than in the constant flux range.

Within the field weakening range the excitation current I_m decreases in inverse proportion to the frequency. Because of this, the phase current of an unloaded motor clearly decreases with the fre quency. On a loaded motor the power factor of the rotor current (Figure-2), tends to increase the rotor current 12. The reduction of the excitation current and the increase in the rotor current roughly cancel each other out. Within the field weakening range, therefore, a motor supplied at a constant current will produce approximately constant horsepower.

At a frequency characteristic to each individual motor (approximately $1.4f_{N}...1.6f_{N}$), the peak torque has decreased so low that the available slip has to be limited. The limit will be determined by the danger of pull-out, not by the magnitude of the current. The motor cannot continue to produce a constant output.

1.5 Output Torque -A squirrel cage motor can best be started by increasing the frequency while constantly maintaining the slip below the peak slip. This permits a starting torque equal to the rated torque without using an oversized drive. This type of starting requires a minimum output frequency of 0.5 to 2 Hz, depending on the size of the motor, and full IR compensation.

Where IR compensation is not used and the machine can only be fed with a current no higher than the rated current, the starting torque produced by a standard motor will usually be 45 to 55% of the rated torque. In this case, the motor size or the temperature have no significant effect on the starting torque achieved.

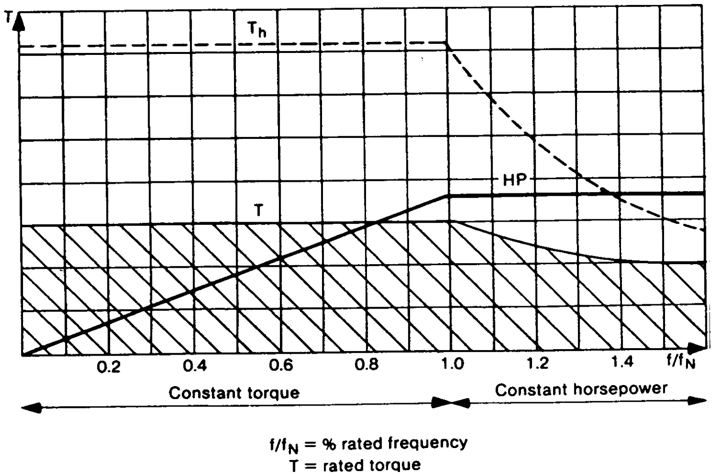


Figure 4 - Motor Torque T and HP at Constant Current

As shown in Figure 4, within the constant flux range the maximum torque is usually limited by the AC drive. An oversized AC drive will permit the motor-to deliver a maximum torque above the rated torque.

When the rated current of the adjustable frequency drive is slightly higher than the rated current of the motor, the torque produced will be approximately as indicated below:

$$T = (I_{T}/ I_{NM})\ x T_N$$

where I_T = current produced by the frequency converter
INM = rated current of the motor
TN= rated torque of the motor

If the torque is considerably higher than the rated motor torque- available, consult the Allen-Bradley Sales Office to determine the required current and drive size.

If a large overcurrent is fed into the motor, the motor inductances will be reduced due to the saturation of the magnetic circuits. The decreased inductances often limits the capacity of the converter to supply fundamental current. On the other hand, the inductances in a smaller motor are larger than those in a motor of the same size as the converter.

In all cases the peak torque of the motor is the top limit for the torque produced. Due to the danger of pullout, a certain margin has to be reversed. As a rule of thumb,2/3 x T_h can be taken as the top operating limit for the torque depending on the motor.

The magnitude of the peak torque T_h is indexed in motor catalogs. NOTE: The long-term load on a motor is restricted by the thermal load capacity of the motor.

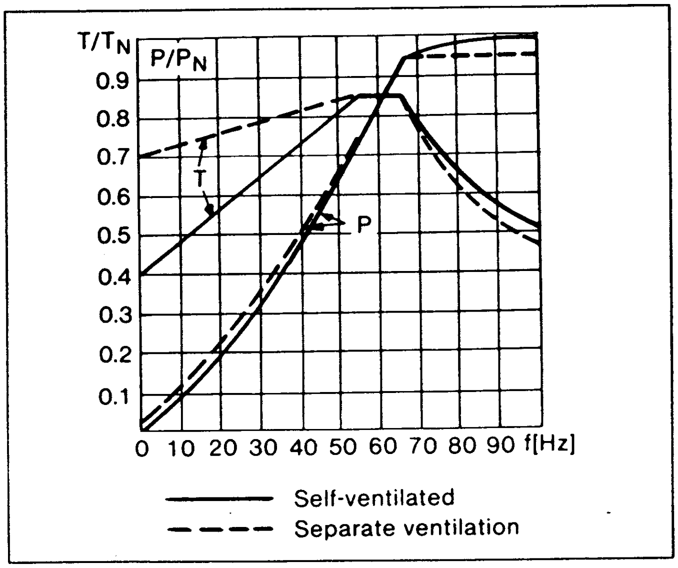


Figure 5 – Typical Motor Torque Curve

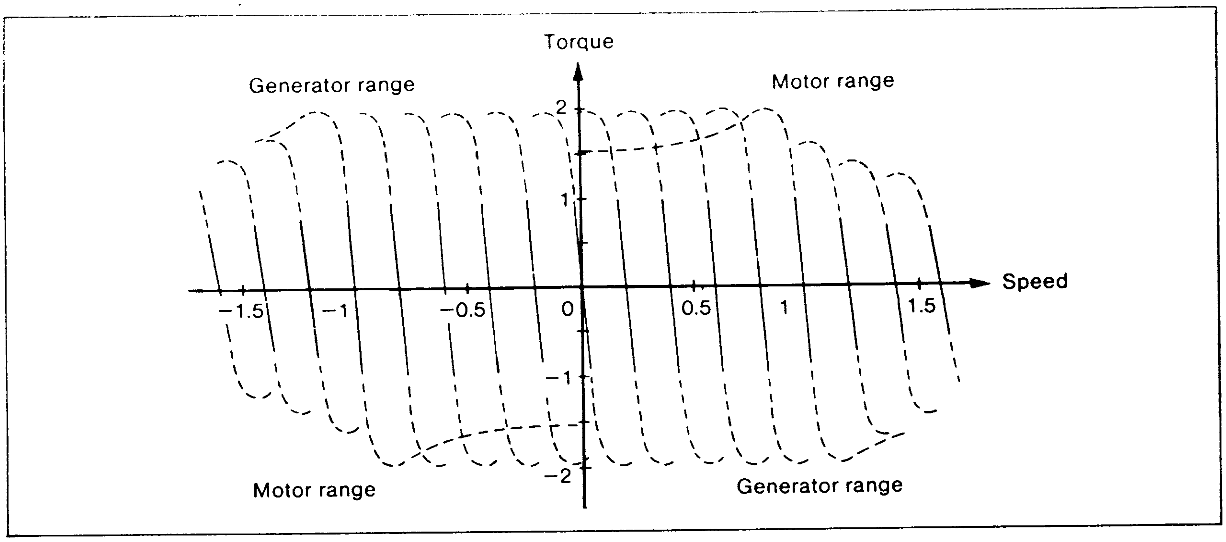


Figure 6 – Torque vs. Frequency Curves of a Squirrel Cage AC Motor

1.6 Motor Loading Capacity- Figure 5 shows both the torque and the power which is delivered by a typical adjustable frequency controlled motor in continuous use. The torque curve starts at 40% of the motor's rated torque and rises to approximately 85% at 55Hz. This is related to the fact that the motor is self-ventilated and therefore does not get fully cooled at low speeds. To improve cooling, the motor can be equipped with a separate cooling fan. Load capacity now follows the broken line shown in Figure 5. The separate fan greatly improves load capacity at low speed. Conversely, the self-ventilated motor is capable of greater load capacity at speeds above 65Hz. From this, it is evident that power is related to the actual speed and the cooling system of the motor.

As shown in Figure 6 a frequency controlled squirrel cage motor drive can, (unless the cooling fan prevents it), operate in all four quadrants above and below minimum frequency, i.e. 0.5 Hz.

A smooth shift into generator operation is accomplished, as it is not necessary to reverse the direction of the excitation current or of any other current - The shift is achieved by providing a negative slip. This means that the supply frequency is reduced to a value lower than would be required by the actual speed. The direction of rotation is usually reversed by electronic means within the drive.

In the continuous state the torque supplied by the motor depends upon the slip. In transition states, e.g. when the applied input frequency suddenly increases while the speed remains constant, the torque will, within a time constant depending on the motor, assume the value corresponding to the new slip. The time constant will increase for each larger motor output rating.

1.7 Speed Accuracy - In most cases the speed of a squirrel cage motor is controlled without a tachometer, i.e. the motor is run open loop. The speed accuracy is adequate since the torque curve of a squirrel cage motor is steep. As shown previously in Figure 1, even large changes in the torque do not result in large changes in slip.

The actual speed is lower than the synchronous speed fi/p of the frequency converter control. The difference between the synchronous speed and the actual speed is slip. Slip depends on such factors as motor size, design, load, and operating temperature. The speed error An, corresponding to a given load torque can be obtained from the actual torque curve of the motor.

When the load torque T is relatively small compared to the peak torque, the rated slip Δ_{nN} and the rated torque TN can be used to approximate the slip as follows:

$$\Delta n = \Delta n_N \times \frac{T}{T_N} \qquad \text{for } f \leq f_N$$

$$\Delta n = \Delta n_N \times \frac{T}{T_N} \times \left(\frac{f}{f_N}\right)^2 \qquad \text{for } f \geq f_N$$

where Δ_{nN} is the difference between the synchronous and rated speeds of a motor supplied at the rated frequency f_N, and f is the input frequency.

As shown previously in Figure2, the motor's rotor resistance R_2 at the rated operating temperature is approximately one and a half times that of the resistance of a cold motor. Because of this, the slip of a cold motor is approximately 60% of the slip of a motor at the rated temperature.

Where a better speed accuracy (>3% of rated speed) is desired, a tachometer for speed measurement and closed loop control has to be used. The speed accuracy will mainly be determined by the feedback transducer or tachometer employed.

2.0 General Principles of Frequency Converters

2.1 Frequency Converter Alternatives - Frequency controlled squirrel cage motor drives employ converters equipped with an intermediate circuit. Such a converter consists of four parts as shown in Figure 7.

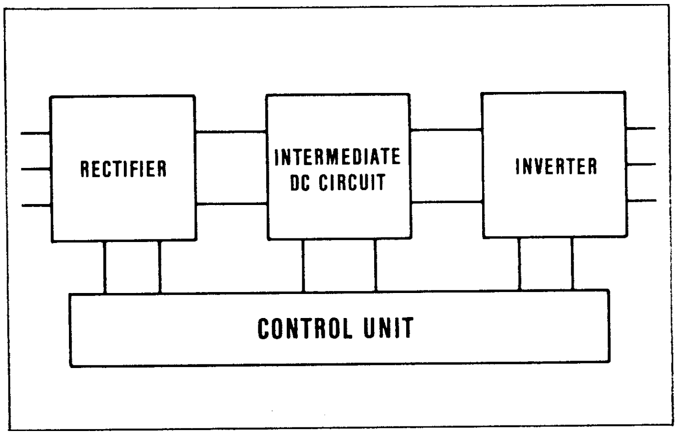


Figure 7 - Block Diagram of Frequency Converter

The first part on the supply side is a rectifier. In the intermediate circuit the pulsating DC voltage produced by the rectifier is filtered in an LC low-pass filter or converted into a DC current in a choke. The last part is converter which uses the DC current or voltage from the intermediate circuit to produce an AC current or voltage having the desired frequency. The control unit oversees the operation of the frequency converter.

Frequency converters can be classified into two main types on the basis of the construction of the intermediate circuit. If the intermediate circuit consists of a choke alone, the converter is said to have a DC current intermediate circuit as shown in Figure 8a. A frequency converter of this type functions as a current source that supplies the motor with a current such that the desired voltage is present on the poles of the motor. The amplitude of the current is determined by a rectifier. Frequency converters equipped with DC current intermediate circuits are generally used in single-motor drives.

Due to the operation principle of the converter, a frequency converter of this type cannot be used in the field weakening range.

Furthermore, the power rating of a motor connected to the converter has to be within a narrow output range determined by the converter as the motor forms an essential part of the commutating circuits of the converter.

Frequency converters having an LC low-pass filter in the intermediate circuit are said to have a DC voltage intermediate circuit. In frequency converters of this type the amplitude of the output voltage is adjusted either by controlling the intermediate circuit voltage (shown in Figures 8b and c), or by altering the output voltage waveform (Figure 8d). The latter method is called Pulse Width Modulation - PWM. Frequency converters equipped with DC voltage intermediate circuits are suitable for use in both single and multiple motor drives.

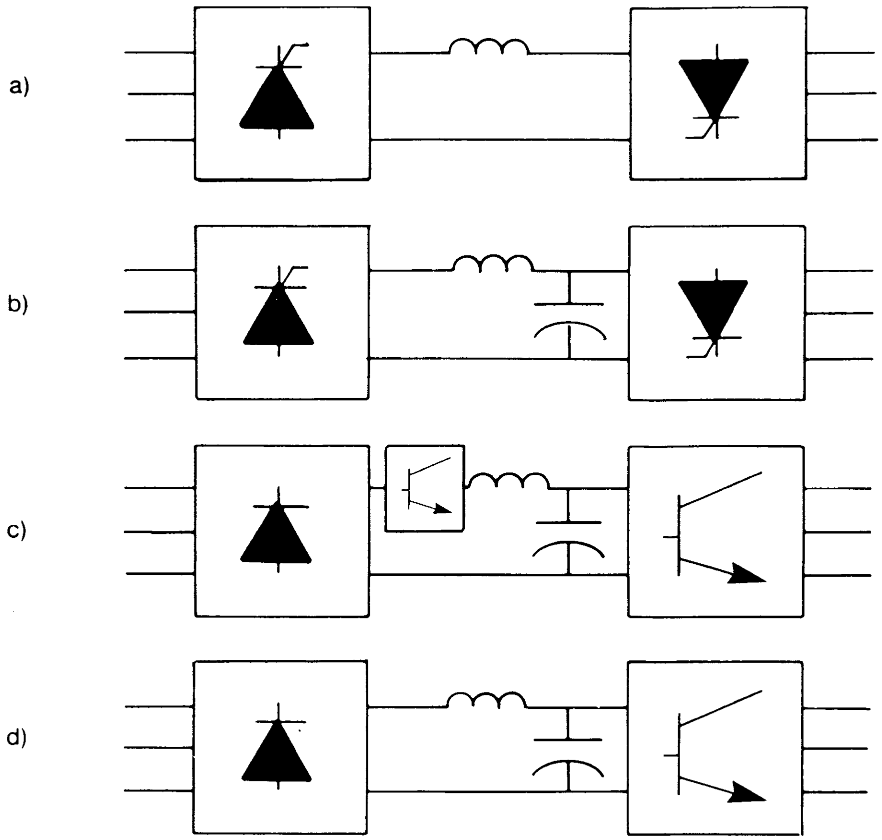
The PWM frequency converter is the most generally applicable of the alternative designs shown. It differs from the types equipped with DC voltage intermediate circuits in such areas as speed control and effects on the voltage supply lines to the converter.

Another method of control used is VVI - Variable Voltage Input. In VVI frequency converters equipped with intermediate circuit DC voltage control, the voltage is controlled by adjusting the intermediate circuit voltage. This results in poor speed control as a large capacitor in the intermediate circuit has to be charged or discharged to change the voltage. The PWM frequency converter has a large speed range, as voltage control is implemented by means of a converter.

Due to the diode bridge, the power drawn for the voltage supply lines by the PWM frequency converter consists almost entirely of active power, i.e. f_p is approximately .99. Other frequency converter types' except converters having a chopper in the intermediate circuit, consume reactive power because of their controlled rectifiers.

2.2 PWM Converter Principles - In PWM frequency converters the intermediate circuit produces a fixed voltage. The task of the converter is to use this DC voltage to produce a symmetrical, 3 ϕ voltage whose magnitude and frequency can be controlled. The operation of the converter can be illustrated by the switch model shown in Figure 9. In practice, semiconductor switches are used.

The switches R, S, and T are controlled as appropriate to produce a 3 ϕ voltage on the poles of the



a) DC current intermediate circuit
b) Controlled DC voltage
c) Controlled DC voltage — Chopper controlled
d) PWM frequency converter

Figure 8 – Alternative Frequency Converter Designs

motor. As the converter operates, each switch is in either of the positions shown, and switching is assumed to take place without delay.

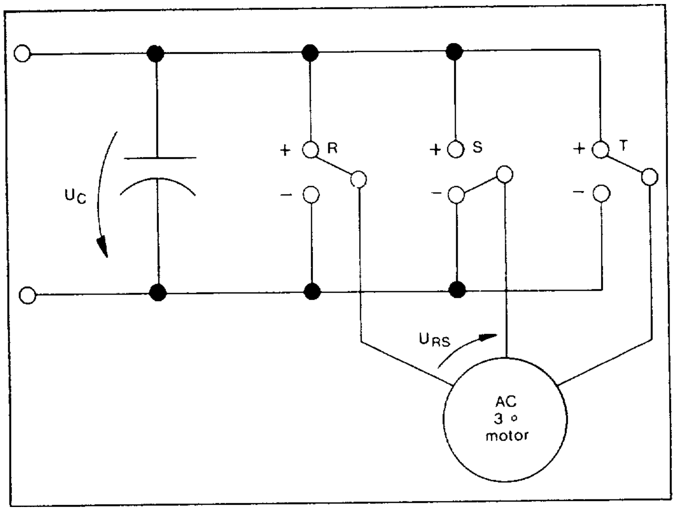
The simplest voltage waveform is obtained by keeping the switches up in the "+" position for half a cycle, and down in the "-" position for half a cycle. In addition, the switch positions must have a phase displacement of 1200 from one another. The switch positions and the phase voltage URS are shown in Figure 10.

This pulse pattern is suitable for supplying a constant voltage to a squirrel cage motor. The waveform yields an RMS value of 0.,78 U_c for the voltage at the basic frequency. PWM frequency converters have this waveform in the field weakening range, i.e. 6-step.

The frequency and the voltage can be controlled by using more voltage pulses per half-cycle in the main voltage. The RMS value of the basic frequency voltage is adjusted by varying the widths of individual pulses in the main voltage. Figure 11 shows the waveform for (5) pulses per half-cycle.

A significant part of the power loss in a PWIVI converter consists of switching losses proportional to the number of switching per second. A suitable number of switching per second or pulse number (number of pulses per half cycle at the operating motor frequency) to maintain low harmonic currents and low torque pulsation in the motor vary with the power devices used. Power transistors can handle switching frequencies greater than 1 kHz while silicon controlled rectifiers prefer switching frequencies of less than 1 kHz. Switching frequencies above 300 Hz are reasonable for pulse width control of AC motors. Increasing the numbers of pulses at low operating motor frequencies is one method of reducing current pulsations when the motor is operating below 200 rpm. Pulse width modulation switching frequencies of 400 to 1200 Hz provide smooth operation over the full speed range of an AC motor.

The way in which the switch position control signals are produced is called modulation. All side effects caused by pulse type voltage on a squirrel cage motor depend on the shape of the voltage curve, i.e. on the modulation. A good overall result will be obtained when the modulation method is properly chosen.



In the simplest form, each half wave of the main voltage consists of pulses of equal widths. Such a voltage waveform is quite adequate at frequencies above 10 Hz. The relatively high 5th and 7th harmonic components, due to the shape of the voltage curve, cause the torque components to fluctuate at a frequency six times the motor's supply frequency.

At frequencies below 10 Hz and with lower overall moments of inertia of the drive, the motor's speed will also fluctuate at this frequency. At lower frequencies it is accordingly advisable to use a modulation method known as sine modulation (Figure 12).

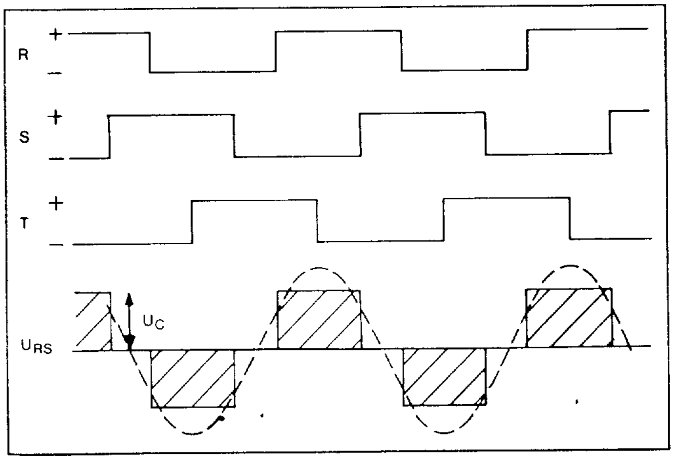


Figure 10 – Switch Positions and Main Voltage U_{RS} for a Pulse Number of (1)

In sine modulation the pulse widths of each main voltage half wave increase sinusoidally from the edges of the half wave towards the center, with significant reduction of the 5th and 7th harmonics in particular. The same also applies to the motor torque pulsation at six times the input frequency. A smooth speed is thus achieved at lower frequencies.

Concerning additional heating resulting from non-sinusoidal voltages and currents, there is no significant difference between these two voltage waveforms, i.e. modulation types.

2.3 Converter Implementation - The converter switches are power semiconductors including power transistors, GTO thyristors, or high-speed thyristors.

The industrial application range of power transistors and GTO thyristors is at present limited to power ratings of up to approximately 1000 kVA. The most generally applicable power components are the high speed thyristors. They can be used to construct converters in the megawatt range of power.

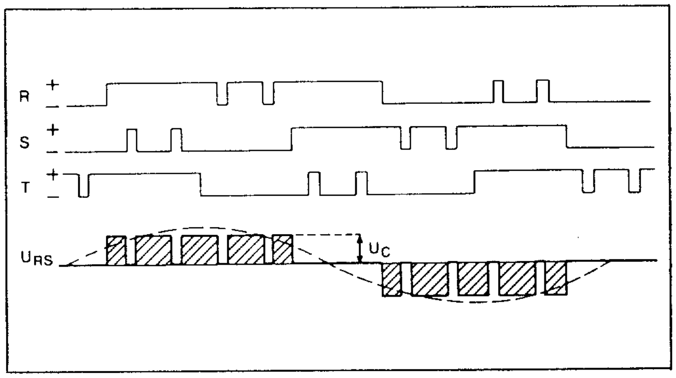


Figure 11 – Switch Positions and Main Voltage U_{RS} for a Pulse Number of (5)

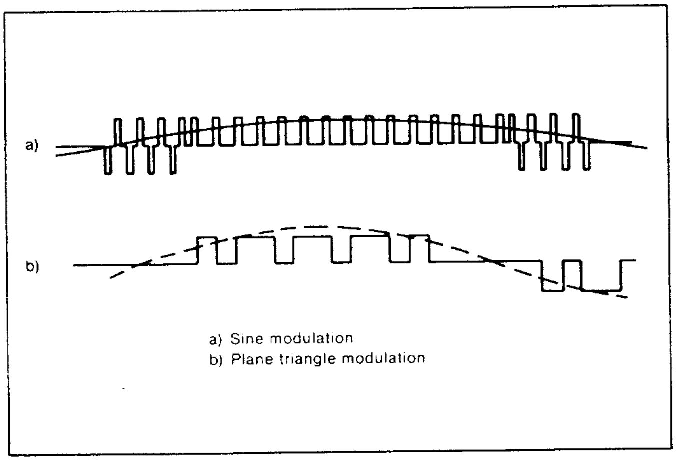


Figure 12 – Pulse Waveforms

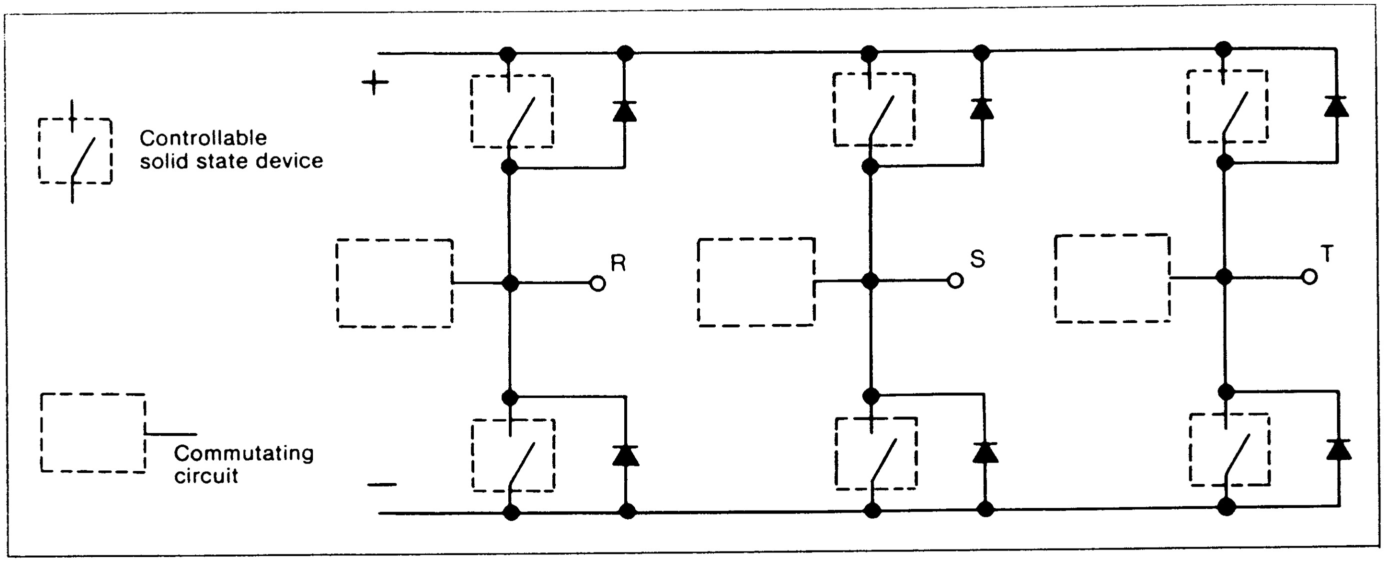


Figure 13 – PMW Converter Employing Power Semiconductors

The sequence of events used to change over a switch employing power semiconductors is called commutation. When thyristors are employed, commutation requires auxiliary circuits known as commutation circuits, which supply the current pulse needed to turn off the thyristors.

A three-phase PWM converter is usually implemented as a bridge circuit such as shown in Figure 13.

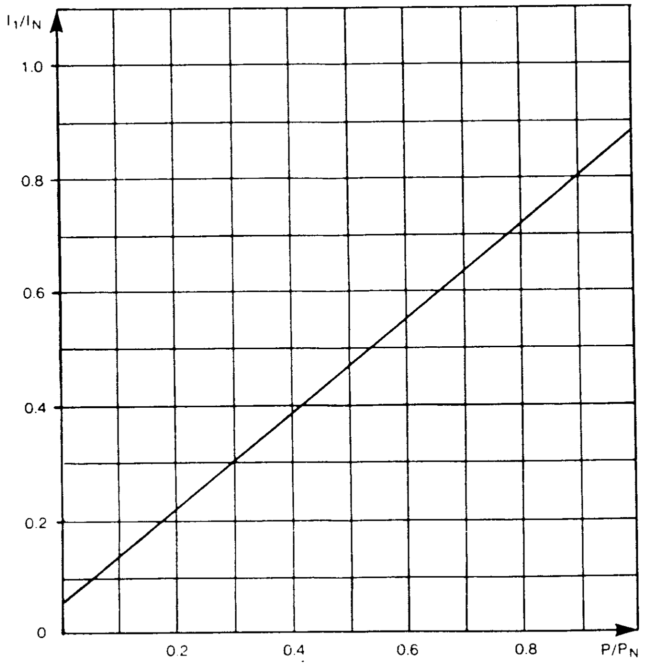
The diodes (so called free-wheeling diodes) are required for handling inductive load. The diodes also pass a part of the commutation pulse supplied from the commutation circuit.

A number of commutation circuits have been developed employing thyristors and free-wheeling diodes. One of the most efficient of these various modifications is the McMurray circuit.

A commutation circuit can be constructed with components common for all phases or with a separate commutation circuit for each phase. The circuit shown in Figure 13 is of the latter type.

The different commutation circuits also differ in their operation in that some converters turn off all main thyristors for charging over a switch.

In most frequency converters the commutation pulse is only applied to the switch of the next phase to be inverted.



I_1 = fundamental component of supply current
I_N = rated current of squirrel cage motor

Figure 14 – Approximate Dependence of Fundamental Component of Supply Current on Power Load of Motor

3.0 General Characteristics of PWM Frequency Converters

3.1 Supply Current- In PWM frequency converters the DC voltage supplied from the intermediate circuit remains constant. Connection to the power supply is normally made with a diode bridge. Because of the fixed intermediate voltage, the RMS value of the fundamental component of the supply current is directly proportional to the active power drawn by the motor, as shown in Figure 14.

With a constant load torque the active power decreases in direct proportion to the speed as the speed decreases. The current drawn from the supply by the frequency converter also decreases, although the phase current of the motor remains at a constant value.

A DC drive draws a higher supply current than the PWM frequency converter because in DC drives:

a) The rectifier voltage is lower than the diode bridge voltage even at rated speed.

b) As the speed decreases and the torque remains constant, the output and rectifier voltage decreases in direct porportion to the speed, and the supply current remains constant. In PWM frequency converters the voltage remains constant and the current decreases.

As shown in Figure 15, DC drive curves also apply to frequency converters with thyristor bridge rectifiers.

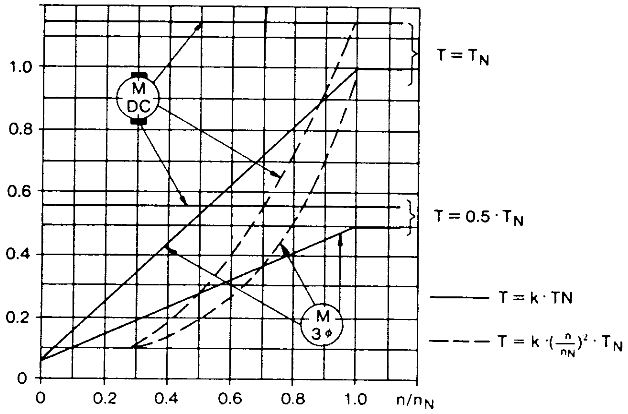


Figure 15 – Drawn by a PMW frequency converter for respective load torques equal to the rated torque, half the rated torque, and zero.

At constant load at both rated as well as half load, a DC drive draws from its power supply lines a constant current throughout the entire speed range, whereas the PWM converter drive has an input current which decreases with decreasing speed. From the rated speed upwards, the power supply line current of a PWM converter is constant but still smaller than that for a DC drive of the same size.

The broken curves in Figure 15 indicate loads with a torque proportional to the speed squared, e.g. pumps and fans. For comparison, the supply current of a DC drive capable of equal performance is also shown.

There is a significant difference in the current taken from the power supply lines by the type of drive as well. For example, at 70% of speed the PWM converter draws only 2/3 of the current drawn by the DC drive. There are, of course, several advantages with a low power supply line current. For example, the total current drawn by a number of variable speed drives together is considerably lower with PWM converter drives than with DC drives of the same size.

3.2 Harmonic Components of Supply Current -Seen from the supply side network, the diode bridge is a non-linear device. The non-linearity results in harmonic distortion of the supply current of the frequency converter.

In addition to the current component at the fundamental frequency, the supply current contains harmonic components at frequencies f_n:

$$f_n = n \times f_o = (6k \pm 1) \times f_o$$

where f_n = frequency of the nth harmonic component
n = ordinal number of the harmonic
f_o = frequency of the supply current
k = 1,2,3

In the ideal case the magnitudes I_n of the harmonic components are:

$$I_n = I_1/n$$

where I_n = nth harmonic component
I_1 = magnitude of the basic current

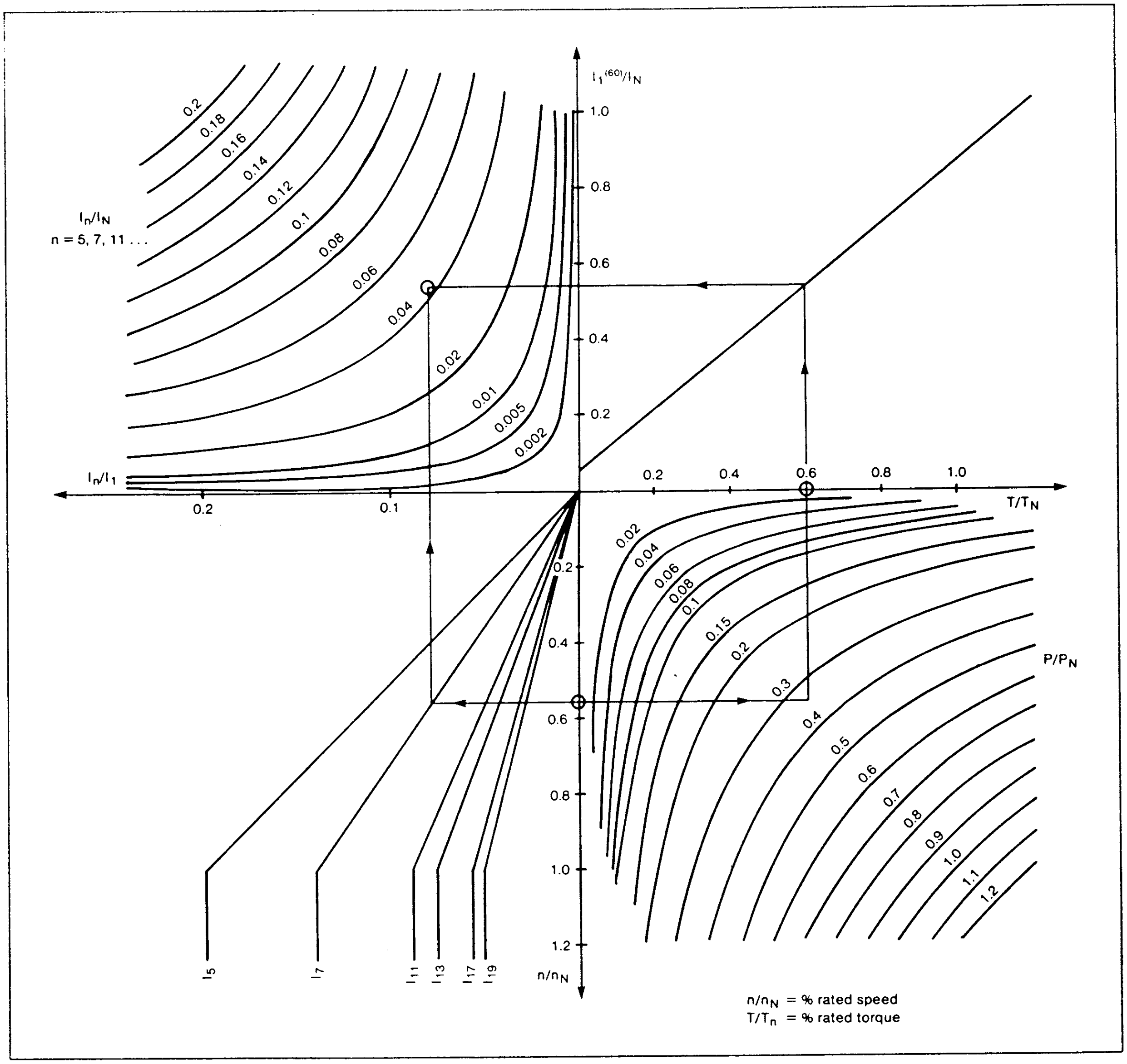


Figure 16 – Nomogram for estimating the magnitude of the harmonic current in the supply current in relation to the rated current of the motor for a known speed and torque or output.

The harmonic currents are thus directly proportional to the fundamental current. The nomogram shown in Figure 16 can be used to obtain (in the ideal case) the magnitudes of the harmonic current components of a PWM frequency converter for different speeds and torques.

The harmonic components are their highest at the rated speed and the maximum torque. At a constant load torque, as the speed is reduced, the harmonic currents decrease because the fundamental current decreases.

As an example: The torque is 60% of the rated torque and the speed 55% of the rated speed. For 60 Hz operation, what is the amplitude of the 7th (i.e. 60 x 7 or 420 Hz) harmonic current?

It can be seen in the lower right-hand quadrant that the output is 33% of the rated current. Draw lines parallel to the axes up to the straight lines, then draw lines to the upper left-hand quadrant. The intersection point shows that the magnitude of the 7th harmonic is less than 5% of the motor's rated current.

As was mentioned earlier, the supply current of a PWM frequency converter drops in proportion to the speed. Because the harmonics are proportional to the fundamental current of the supply line, the content, of harmonics drops with decreasing motor speed.

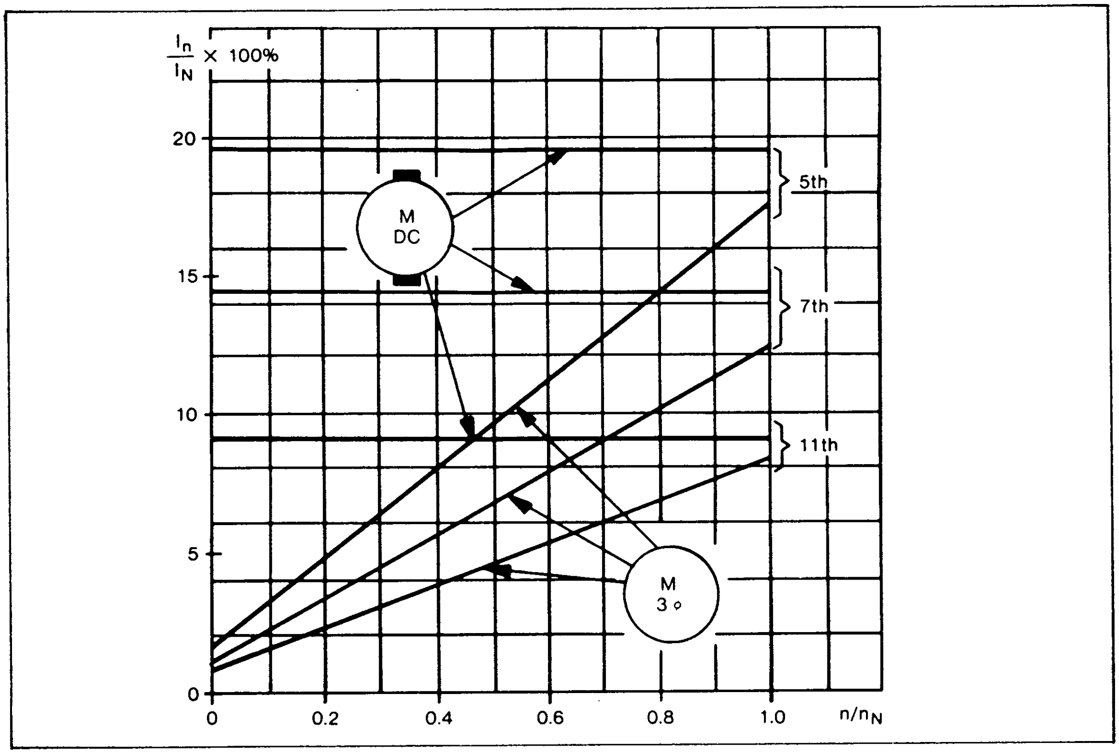


Figure 17 – Harmonics

As an example, as shown in Figure 17, the 7th harmonic at 1/2 speed is only 50% of that caused by a DC drive at the same speed.

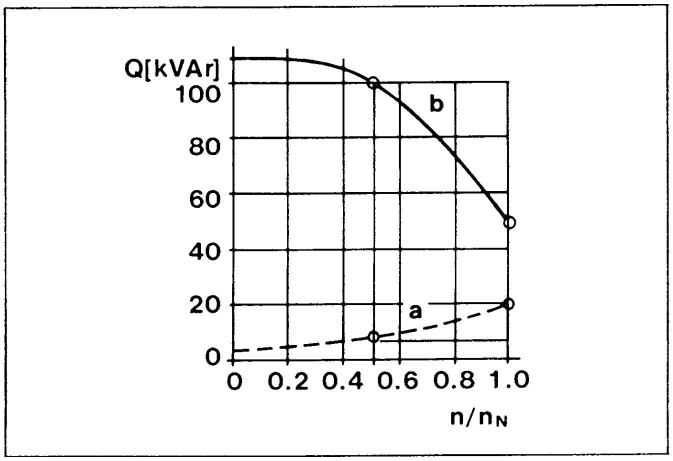
Considering the influence that harmonics in the power supply lines may have on computers, control devices, capacitor banks, etc., the advantage of the PWM converter over the DC drive or current controlled converter is evident.

3.3 Reactive Power - A device connected to the supply consumes fundamental reactive power if the fundamental current drawn lags the supply voltage. The reactive power causes a voltage drop and a loss in the supply network, resulting in costs to the user in the form of reactive power payments, increased losses, and oversized design made necessary by the reactive power.

The basic power factor of a diode bridge is in general almost (1) regardless of the load.

In PWM frequency converters the consumption of reactive power is further reduced by the fact that the supply current drawn decreases as the speed is reduced. There is a thyristor bridge in regenerating PWM frequency converters and in those PWM converters which also have intermediate circuit voltage control. However, the consumption of reactive power is relatively small, thanks to the small active power.

As shown in Figure 18, the PWM converter, which is represented by the lower, flat curve, has a diode rectifier connected to the power supply lines, and therefore draws only active power from the power supply lines, i.e. the power factor cos is almost equal to (1) and is constant throughout the whole control range. The upper curve (with the sinking characteristic) represents both a DC drive and a current controlled frequency converter. As is evident, the reactive power is very high at low speeds and sinks gradually with rising speed. But even at rated speed the reactive power is high, which causes a poor power factor.



3.4 Braking and Reversing - In PWM frequency inverters, the power can flow in either direction through the actual converter. The inverter can thus both drive and brake a motor. A diode bridge is used to connect the frequency converter to the supply. As the diode bridge can only transfer power from the supply to the intermediate circuit, the braking power must be smaller than the power loss - otherwise braking power will be stored in the intermediate circuit capacitor, and the DC voltage increases excessively.

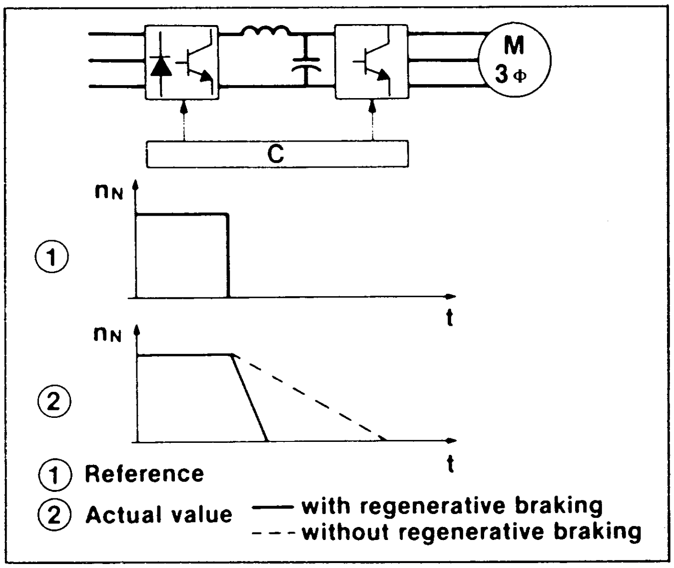


Figure 19 – Braking

If a greater braking power is required, special solutions are needed. The braking power can be either dissipated in a braking resistance connected to the intermediate circuit, or returned to the supply by means of an inverting thyristor bridge. Figure 19 compares the difference in braking types.

In order to change the direction of motor rotation, reversing can be accomplished by electronically changing the phase order of the motor.

The reversing sequence is carried out in different ways depending on the converter's optional equipment. If the converter is equipped with an integrator or a ramp device, the reversing takes place as indicated in Figure 20 by the solid line. The deceleration time is determined either by the drive's set ramp or by the motor's moment of inertia, depending on whether controlled deceleration is required or the motor is simply to freewheel to a halt. Acceleration time depends on the set acceleration time or, if the moment of inertia is very big, on the pull-out torque of the motor. If the motor must be reversed within a fixed time, calculations may show that the above mentioned system is not sufficient and regenerative braking must be applied into the supply to achieve a suitable reversing time. The braking sequence is shown in Figure 20 by the broken line.

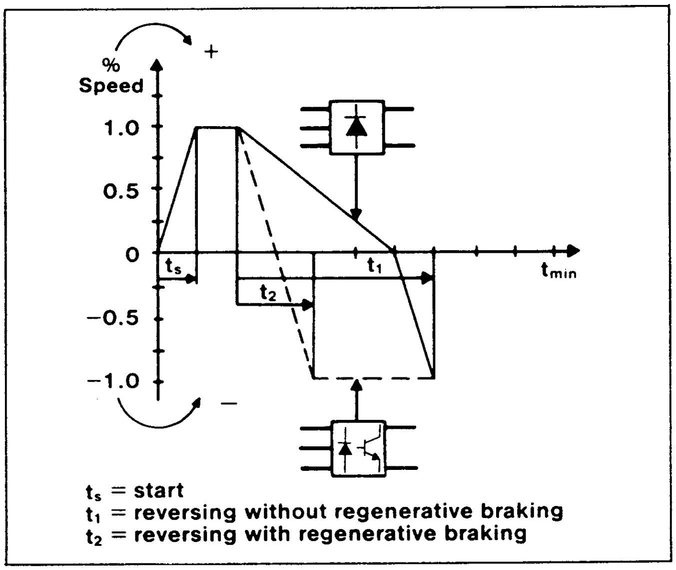


Figure 20 – Reversing

3.5 Multiple-Motor Drives - Frequency inverters equipped with DC voltage intermediate circuits, i.e. PWM frequency inverters, can be used to supply several parallel motors instead of a single motor.

All the motors will then have the same input voltage and frequency, and the speeds of the motors differ as determined by their pole pair numbers and slips. The slips of different motors depend on the load torques.

In the normal case, the motor has to be connected to the frequency inverter before the inverter is started. In multiple-motor drives however, it is occasionally necessary to start and stop motors while the frequency inverter is running. This can be achieved by choosing a sufficiently large frequency inverter - consult the Allen-Bradley Sales Office.