Solid-State Induction Motor Drives

The method of choice today for induction motor speed control is the solid-state variable-frequency induction motor drive. A typical drive of this sort is shown in the figure given below. The drive is very flexible: its input power can be either single-phase or three-phase, either 50 or 60 Hz, and anywhere from 208 to 230 V. The output from this drive is a three-phase set of voltages whose frequency can be varied from 0 up to 120 Hz and whose voltage can be varied from 0 V up to the rated voltage of the motor.

Figure x: A typical solid-state variable-frequency induction motor drive

The output voltage and frequency control are achieved by using the pulsewidth modulation (PWM) techniques. Both output frequency and output voltage can be controlled independently by pulse-width modulation. Figure 1 illustrates the manner in which the PWM drive can control the output frequency while maintaining a constant rms voltage level, while Figure 2 illustrates the manner in which the PWM drive can control the rms voltage level while maintaining a constant frequency.

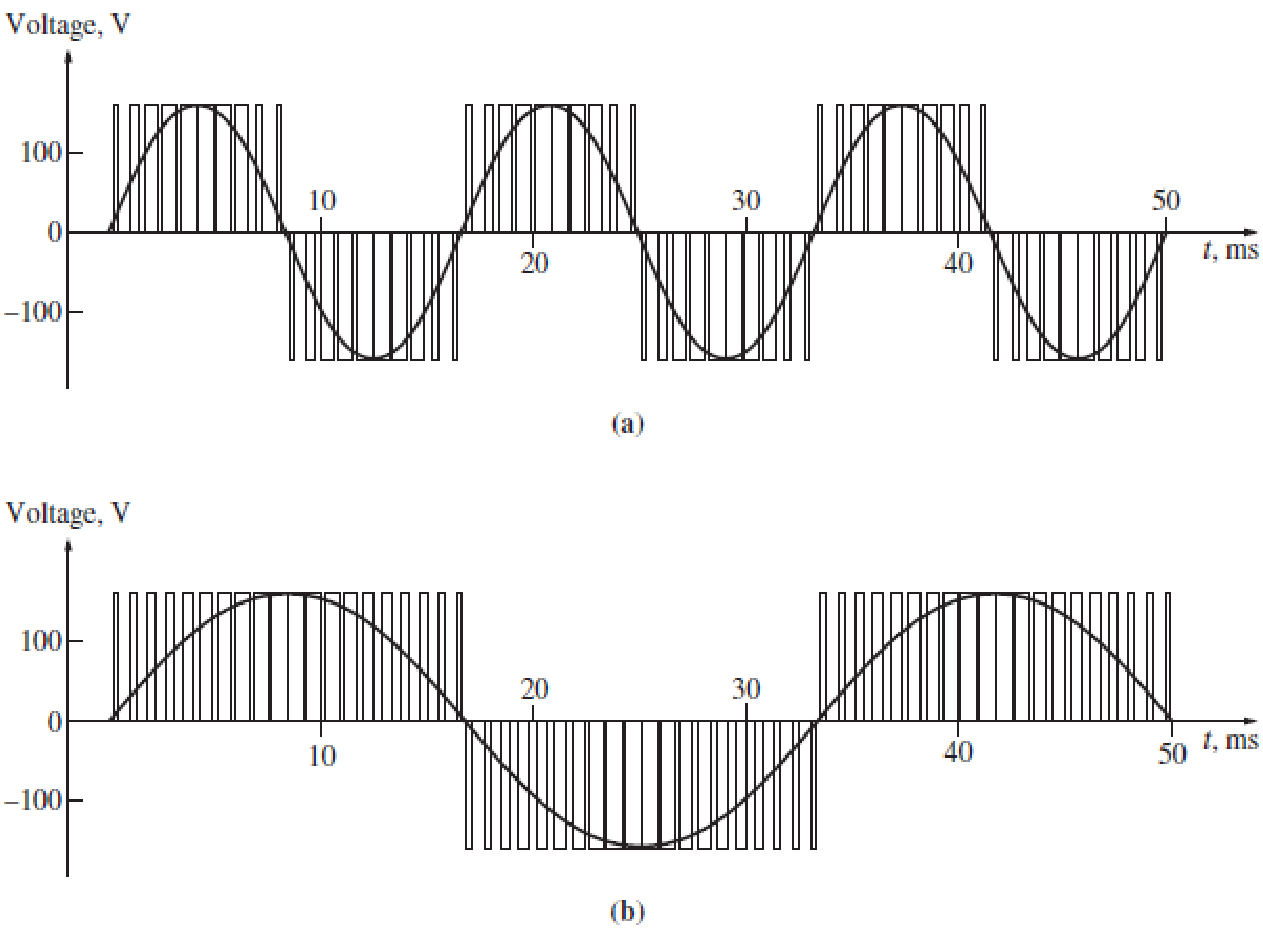


Figure 1: Variable-frequency control with a PWM waveform: (a) 60-Hz, 120-V PWM waveform; (b) 30-Hz, 120-V PWM waveform.

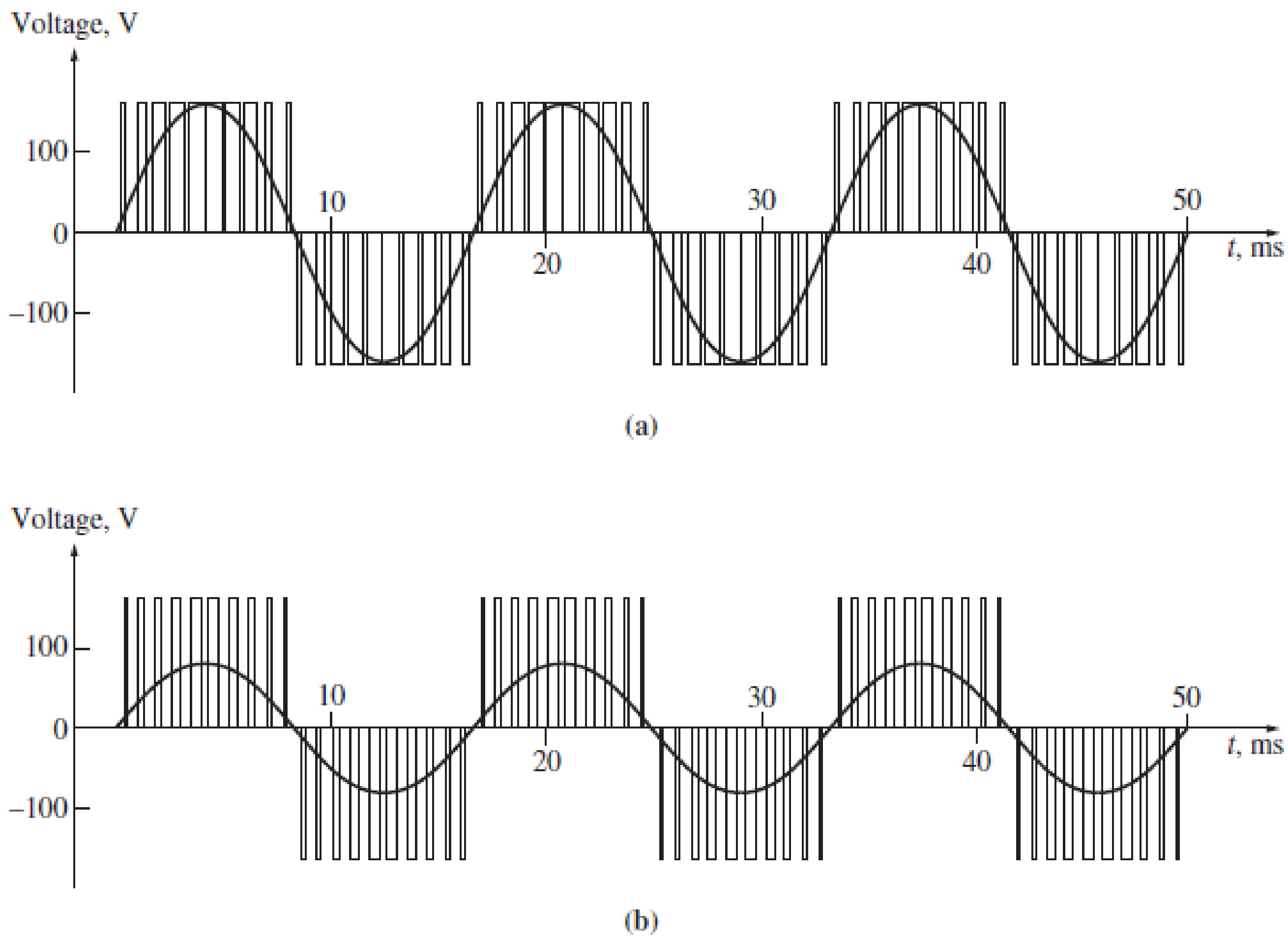


Figure 2: Variable voltage control with a PWM waveform: (a) 60-Hz, 120-V PWM waveform; (b) 60-Hz, 60-V PWM waveform.

It is often desirable to vary the output frequency and output rms voltage together in a linear fashion. Figure 3 shows typical output voltage waveforms from one phase of the drive for the situation in which frequency and voltage are varied simultaneously in a linear fashion.

Fig.3(a) shows the output voltage adjusted for a frequency of 60 Hz and an rms voltage of 120 V. Fig.3(b) shows the output adjusted for a frequency of 30 Hz and an rms voltage of 60 V, and Fig.(c) shows the output adjusted for a frequency of 20 Hz and an rms voltage of 40 V. Notice that the peak voltage out of the drive remains the same in all three cases; the rms voltage level is controlled by the fraction of time the voltage is switched on, and the frequency is controlled by the rate at which the polarity of the pulses switches from positive to negative and back again.

The typical induction motor drive shown in Fig.x has many built-in features which contribute to its adjustability and ease of use. Here is a summary of some of these features.

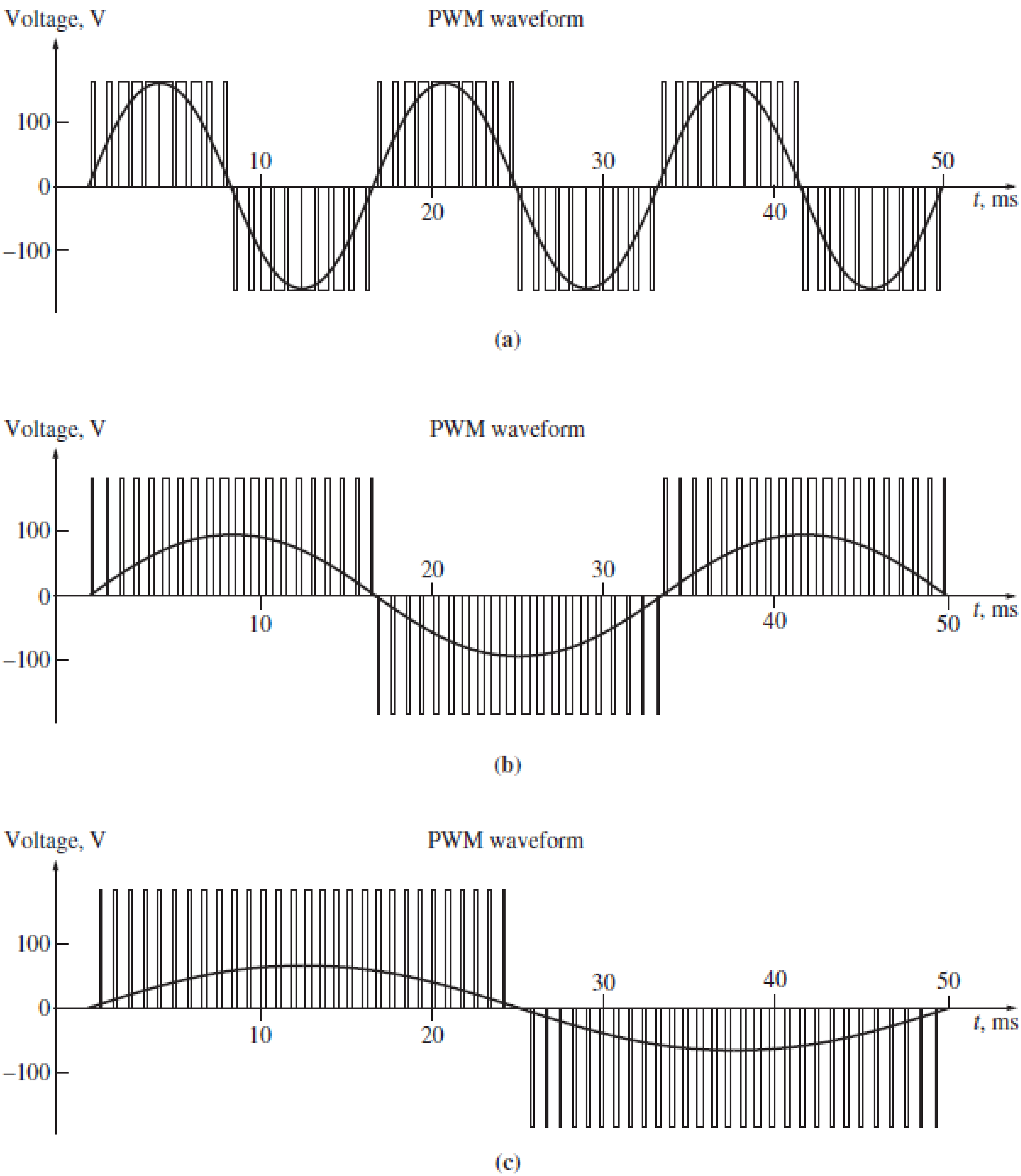


Figure 3: Simultaneous voltage and frequency control with a PWM waveform: (a) 60-Hz, 120-V PWM waveform; (b) 30-Hz, 60-V PWM waveform; (c) 20-Hz, 40-V PWM waveform.

Frequency (Speed) Adjustment:

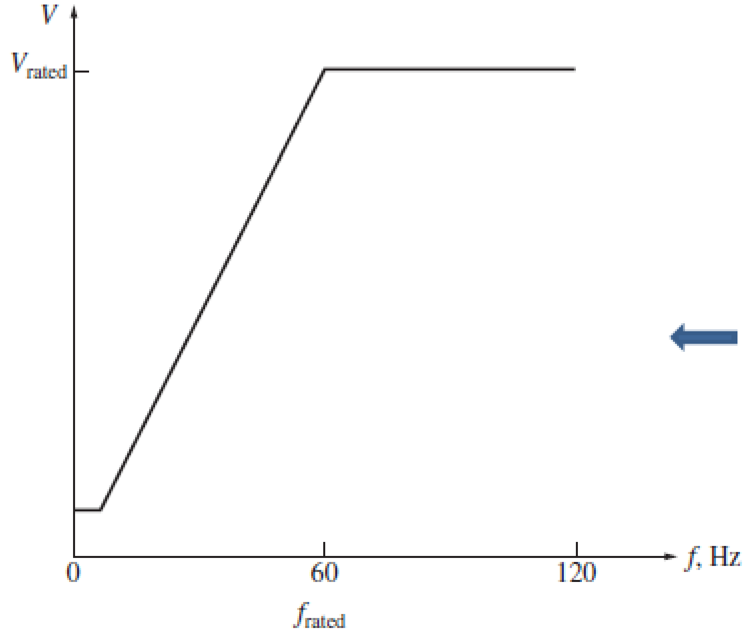
The output frequency of the drive can be controlled manually from a control mounted on the drive cabinet, or it can be controlled remotely by an external voltage or current signal. The ability to adjust the frequency of the drive in response to some external signal is very important, since it permits an external computer or process controller to control the speed of the motor in accordance with the overall needs of the plant in which it is installed.

A Choice of Voltage and Frequency Patterns:

The types of mechanical loads which might be attached to an induction motor vary greatly. Some loads such as fans require very little torque when starting (or running at low speeds) and have torques which increase as the square of the speed. Other loads might be harder to start, requiring more than the rated full-load torque of the motor just to get the load moving. This drive provides a variety of voltage versus- frequency patterns which can be selected to match the torque from the induction motor to the torque required by its load. Three of these patterns are shown in Figures 4 through 6. Fig.4(a) shows the standard or general-purpose voltage-versus frequency pattern. This pattern changes the output voltage linearly with changes in output frequency for speeds below base speed and holds the output voltage constant for speeds above base speed. (The small constant-voltage region at very low frequencies is necessary to ensure that there will be some starting torque at the very lowest speeds.) Fig.4(b) shows the resulting induction motor torque–speed characteristics for several operating frequencies below base speed.

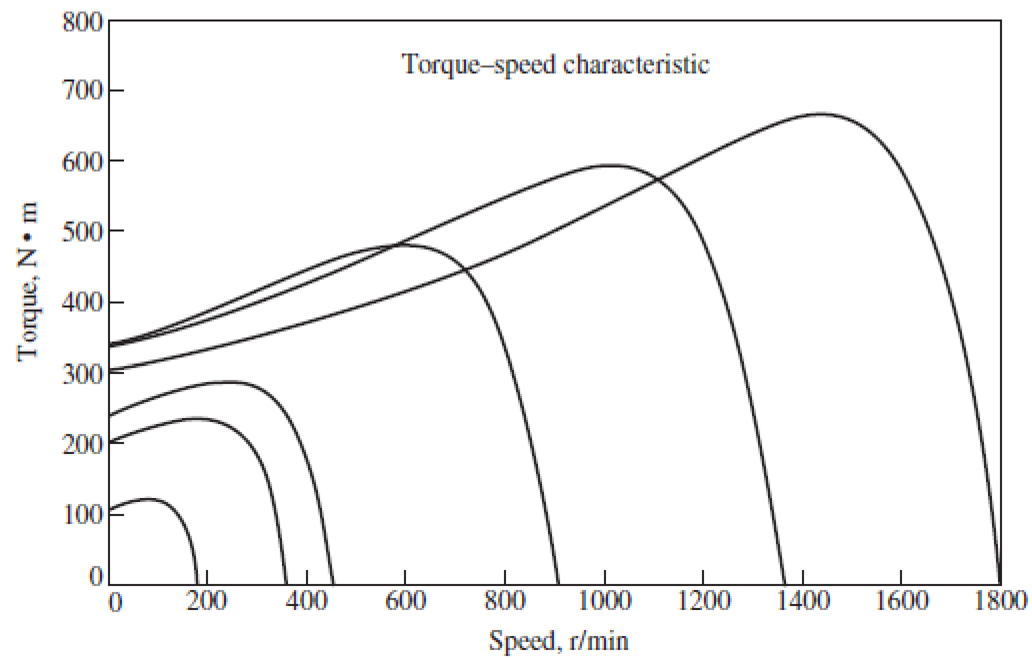
Figure 4:

(a) Possible voltage-versus-frequency patterns for the solid-state variable-frequency induction motor drive: *general-purpose pattern. This pattern consists of a linear voltage–frequency curve below rated* frequency and a constant voltage above rated frequency.



(a)

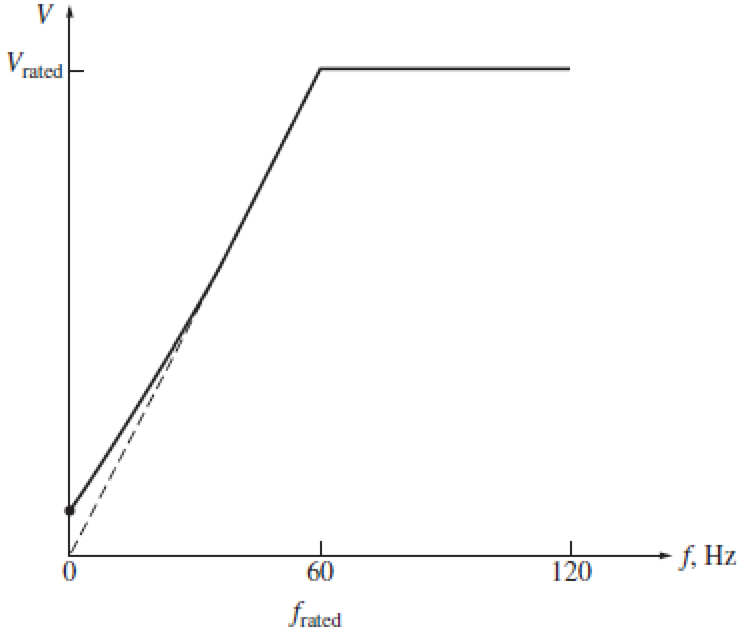
(b) The resulting torque–speed characteristic curves for speeds below rated frequency.



(b)

Fig.5(a) shows the voltage-versus-frequency pattern used for loads with high starting torques. This pattern also changes the output voltage linearly with changes in output frequency for speeds below base speed, but it has a shallower slope at frequencies below 30 Hz. For any given frequency below 30 Hz, the output voltage will be *higher than it was with the previous pattern. This higher* voltage will produce a higher torque, but at the cost of increased magnetic saturation and higher magnetization currents. The increased saturation and higher currents are often acceptable for the short periods required to start heavy loads. Fig.5(b) shows the induction motor torque–speed characteristics for several operating frequencies below base speed. Notice the increased torque available at low frequencies compared to Fig.4(b).

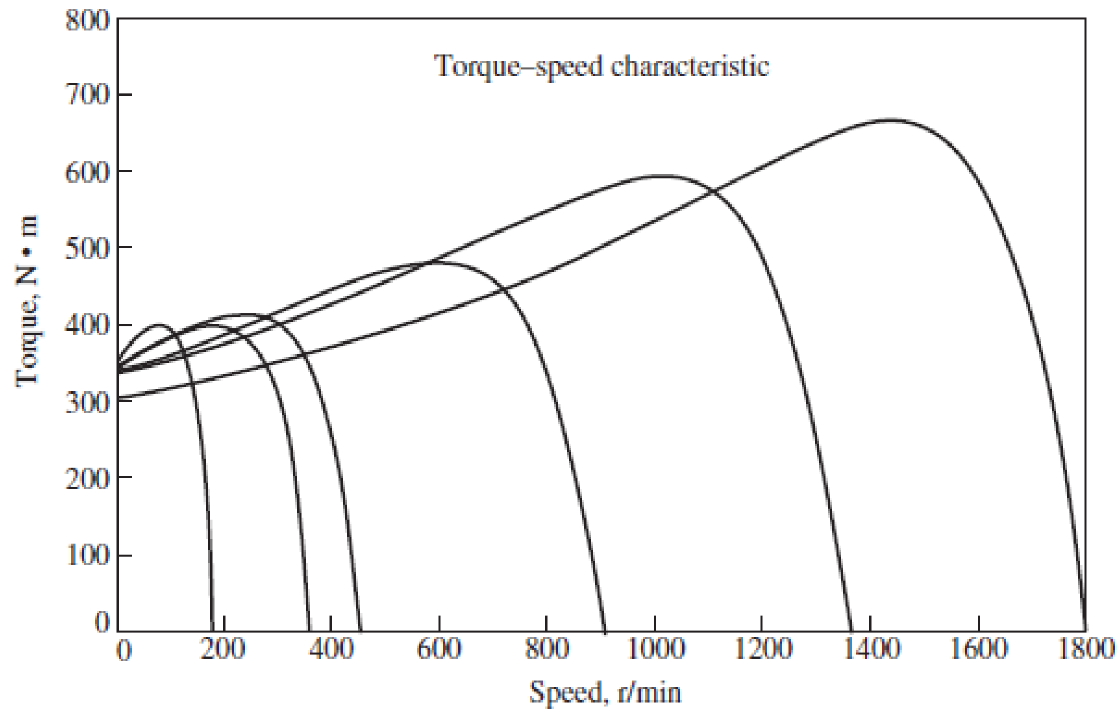
Figure 5:



(a)

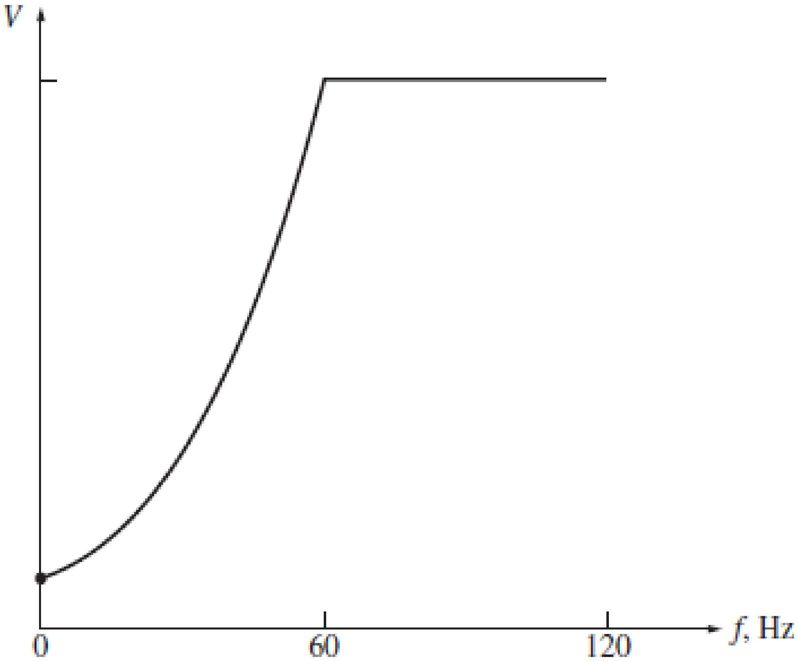
(a) Possible voltage-versus-frequency patterns for the solid-state variable-frequency induction motor drive: *high-starting-torque pattern. This is a modified voltage–frequency pattern suitable for loads* requiring high starting torques. It is the same as the linear voltage–frequency pattern except at low speeds. The voltage is disproportionately high at very low speeds, which produces extra torque at the cost of a higher magnetization current.

(b) The resulting torque–speed characteristic curves for speeds below rated frequency.



(b)

Fig.6(a) shows the voltage-versus-frequency pattern used for loads with low starting torques (called *soft-start loads). This pattern changes the output* voltage parabolically with changes in output frequency for speeds below base speed. For any given frequency below 60 Hz, the output voltage will be lower than it was with the standard pattern. This lower voltage will produce a lower torque, providing a slow, smooth start for low-torque loads. Fig.6(b) shows the induction motor torque–speed characteristics for several operating frequencies below base speed. Notice the decreased torque available at low frequencies compared to Fig.4.

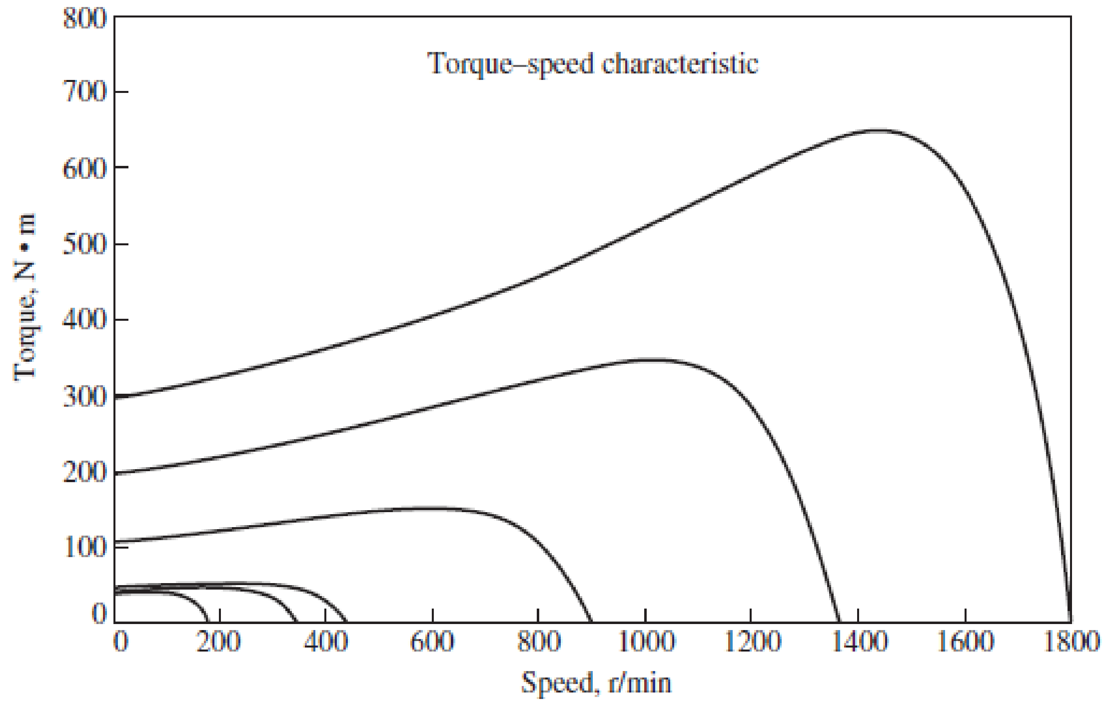


(a)

Figure 6:

(a) Possible voltage-versus-frequency patterns for the solid-state variable-frequency induction motor drive: *fan torque pattern. This is a voltage–frequency pattern suitable for use with motors driving* fans and centrifugal pumps, which have a very low starting torque.

(b) The resulting torque–speed characteristic curves for speeds below rated frequency.



(b)

Independently Adjustable Acceleration and Deceleration Ramps:

When the desired operating speed of the motor is changed, the drive controlling it will change frequency to bring the motor to the new operating speed. If the speed change is sudden (e.g., an instantaneous jump from 900 to 1200 r/min), the drive does not try to make the motor instantaneously jump from the old desired speed to the new desired speed. Instead, the rate of motor acceleration or deceleration is limited to a safe level by special circuits built into the electronics of the drive. These rates can be adjusted independently for accelerations and decelerations.

Motor Protection:

The induction motor drive has built into it a variety of features designed to protect the motor attached to the drive. The drive can detect excessive steady-state currents (an overload condition), excessive instantaneous currents, overvoltage conditions, or undervoltage conditions. In any of these cases, it will shut down the motor. Induction motor drives like the one described above are now so flexible and reliable that induction motors with these drives are displacing dc motors in many applications which require a wide range of speed variation.