

Harmonic Sources from Industrial Loads I

Modern industrial facilities are characterized by the widespread application of nonlinear loads. These loads can make up a significant portion of the total facility loads and inject harmonic currents into the power system, causing harmonic distortion in the voltage.

This harmonic problem is compounded by the fact that these nonlinear loads have a relatively low power factor. Industrial facilities often utilize capacitor banks to improve the power factor to avoid penalty charges. The application of power factor correction capacitors can

potentially magnify harmonic currents from the nonlinear loads, giving rise to resonance conditions within the facility.

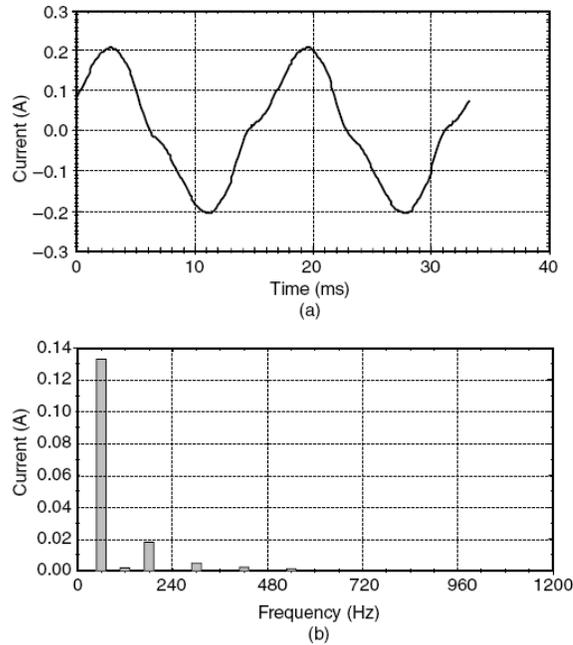


Figure 4.9 Fluorescent lamp with (a) magnetic ballast current waveform and (b) its harmonic spectrum.

The highest voltage distortion level usually occurs at the facility's low-voltage bus where the capacitors are applied. Resonance conditions cause motor and transformer overheating, and misoperation of sensitive electronic equipment.

Nonlinear industrial loads can generally be grouped into three categories:

1. Three-phase power converters,
2. Arcing devices, and

Fig 4.10 Fluorescent lamp with (a) electronic ballast current waveform and (b) its harmonic spectrum.

This is a typical current source type of adjustable-speed drive. The harmonic spectrum given in Fig. 4.11 would also be typical of a dc motor drive input current. Voltage source inverter drives (such as PWM-type drives) can have much higher distortion levels as shown in Fig. 4.12.

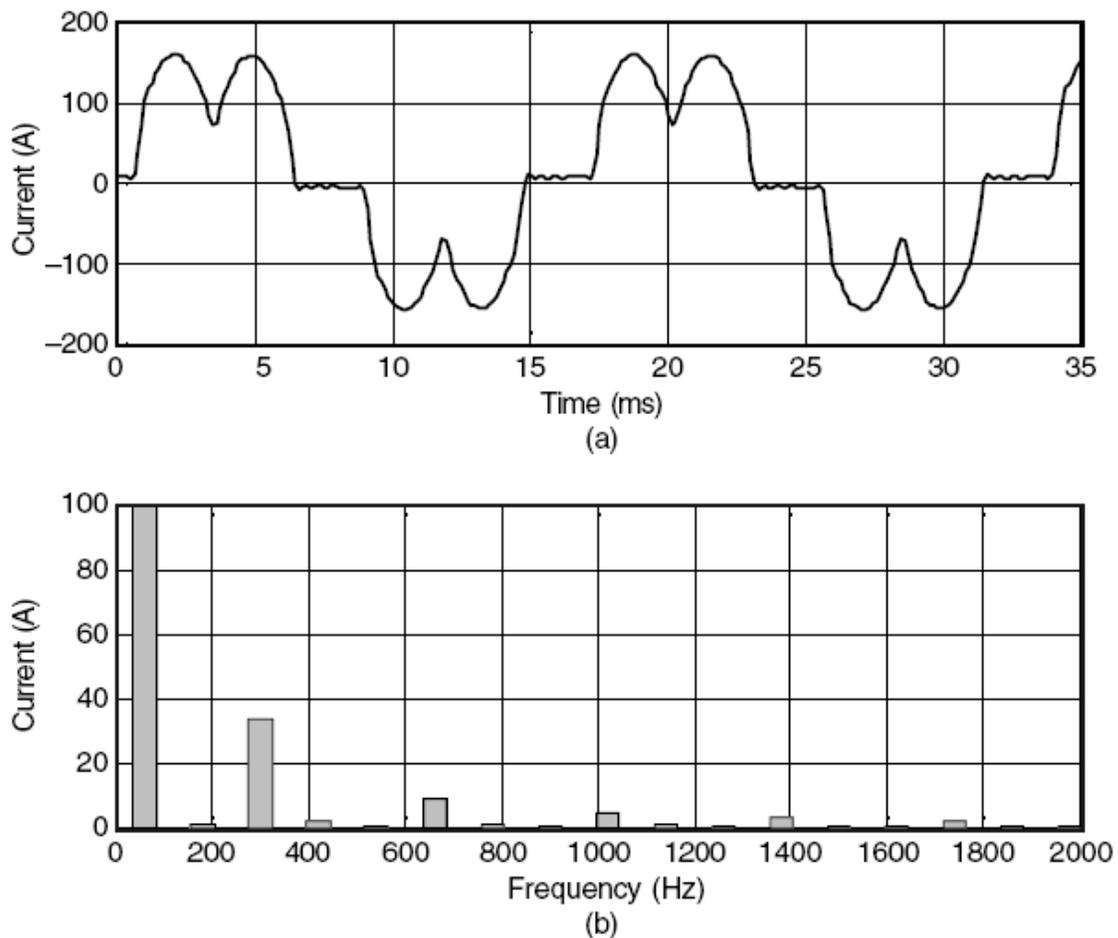


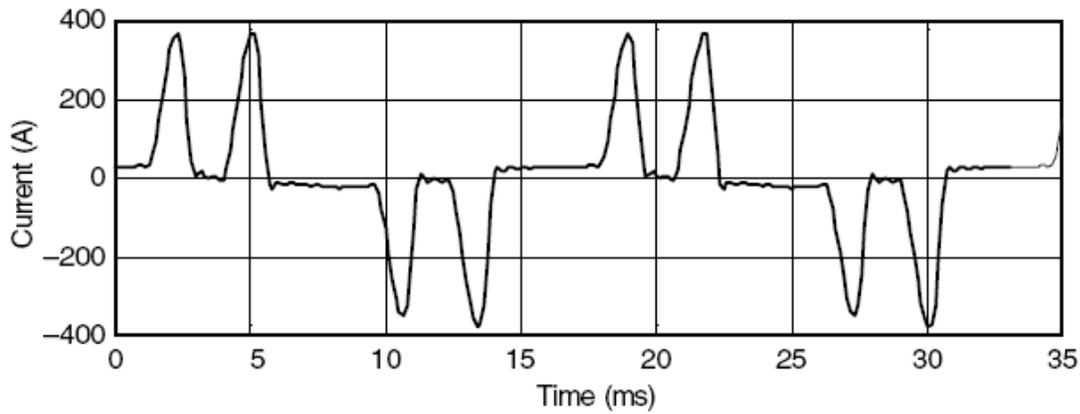
Fig. 4.11. Current and harmonic spectrum for CSI-type ASD.

The input to the PWM drive is generally designed like a three-phase version of the switch-mode power supply in computers. The rectifier feeds directly from the ac bus to a large capacitor on the dc bus. With little intentional inductance, the capacitor is charged in very short pulses, creating the distinctive "rabbit ear" ac-side current waveform with very high distortion.

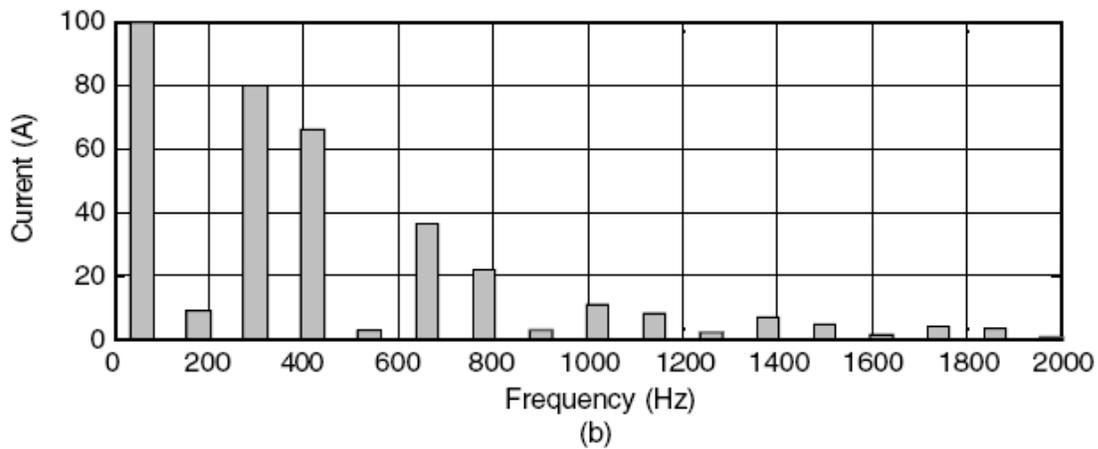
Whereas the switch-mode power supplies are generally for very small loads, PWM drives are now being applied for loads up to 500 horsepower (hp).

4.5.2 DC Drives

Rectification is the only step required for dc drives. Therefore, they have the advantage of relatively simple control systems. Compared with ac drive systems, the dc drive offers a wider speed range and higher starting torque. However, purchase and maintenance costs for dc motors are high, while the cost of power electronic devices has been dropping year after year. Thus, economic considerations limit use of the dc drive to applications that require the speed and



(a)



(b)

torque characteristics of the dc motor.

Fig 4.12 Current and harmonic spectrum for PWM-type ASD.

Most dc drives use the six-pulse rectifier shown in Fig.4.13 Large drives may employ a 12-pulse rectifier. This reduces thyristor current duties and reduces some of the larger ac current harmonics. The two largest harmonic currents for the six-pulse drive are the fifth and seventh. They are also the most troublesome in terms of system response. A 12-pulse rectifier in this application can be expected to eliminate about 90 percent of the fifth and seventh harmonics, depending on system imbalances. The disadvantages of the 12-pulse drive are that there is more cost in electronics and another transformer is generally required.

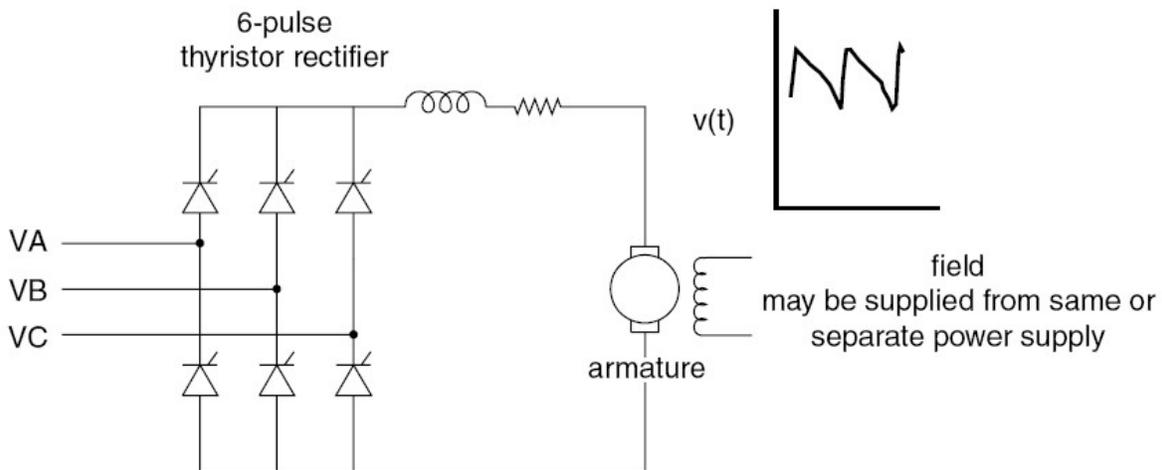


Fig. 4.13 Six-pulse dc ASD.

4.5.3 AC Drives

In ac drives, the rectifier output is inverted to produce a variable-frequency ac voltage for the motor. Inverters are classified as voltage source inverters (VSIs) or current source inverters (CSIs). A VSI requires a constant dc (i.e., low-ripple) voltage input to the inverter stage. This is achieved with a capacitor or *LC* filter in the dc link. The CSI requires a constant current input; hence, a series inductor is placed in the dc link

AC drives generally use standard squirrel cage induction motors. These motors are rugged, relatively low in cost, and require little maintenance. Synchronous motors are used where precise speed control is critical.

A popular ac drive configuration uses a VSI employing PWM techniques to synthesize an ac waveform as a train of variable-width dc pulses (see Fig. 4.14). The inverter uses either SCRs, gate turnoff (GTO) thyristors, or power transistors for this purpose. Currently, the VSI PWM drive offers the best energy efficiency for applications over a wide speed range for drives up through at least 500 hp.

Another advantage of PWM drives is that, unlike other types of drives, it is not necessary to vary rectifier output voltage to control motor speed. This allows the rectifier thyristors to be replaced with diodes, and the thyristor control circuitry to be eliminated.

Very high power drives employ SCRs and inverters. These may be 6-pulse, as shown in Fig. 4.15, or like large dc drives, 12-pulse. VSI drives (Fig. 4.15a) are limited to applications that do not require rapid changes in speed. CSI drives (Fig. 4.15b) have good acceleration/deceleration characteristics but require a motor with a leading power factor (synchronous or induction with capacitors) or added control circuitry to commutate the inverter thyristors. In either case, the CSI drive must be designed for use with a specific motor. Thyristors in current source inverters must be protected against inductive voltage spikes, which increases the cost of this type of drive

