Interharmonics

According to the Fourier theory, a periodic waveform can be expressed as a sum of pure sine waves of different amplitudes where the frequency of each sinusoid is an integer multiple of the fundamental frequency of the periodic waveform. A frequency that is an integer multiple of the fundamental frequency is called a harmonic frequency, i.e., $f_h = h f_0$ where f_0 and h are the fundamental frequency and an integer number, respectively.

On the other hand, the sum of two or more pure sine waves with different amplitudes where the frequency of each sinusoid is not an integer multiple of the fundamental frequency does not necessarily result in a periodic waveform. This noninteger multiple of the fundamental frequency is commonly known as an *interharmonic frequency,* i.e., $f_{ih} = h_{if0}$ where *hi* is a noninteger number larger than unity. Thus in practical terms, interharmonics frequencies are frequencies between two adjacent harmonic frequencies.

One primary source of interharmonics is the widespread use of electronic power converter loads capable of producing current distortion over a whole range of frequencies, i.e., characteristic and noncharacteristic frequencies. Examples of these loads are adjustable-speed

drives in industrial applications and PWM inverters in UPS applications, active filters, and custom power conditioning equipment.

As illustrated in Fig.4.15, the front end of an adjustable-speed drive is typically a diode rectifier that converts an incoming ac voltage to a dc voltage. An inverter then converts the dc voltage to variable ac voltage with variable frequency. The inverter can produce interharmonics in the current especially when the inverter employs an asynchronous switching scheme. An asynchronous switching scheme is when the ratio of the switching frequency of the power electronic switches is an integer multiple of the fundamental frequency of the inverter voltage output. If the harmonic current passes through the dc link and propagates into the supply system, interharmonic-related problems may arise.

Another significant source of interharmonic distortion commonly comes from rapidly changing load current such as in induction furnaces and cycloconverters. The rapid fluctuation of load current causes sideband frequencies to appear around the fundamental or harmonic frequencies. The generation of interharmonics is best illustrated using an induction furnace example.

Induction furnaces have been widely used to heat ferrous and nonferrous stocks in the forging and extruding industry. Modern induction furnaces use electronic power converters to supply a variable frequency to the furnace induction coil as shown in Fig. 4.34.The frequency at the melting coil varies to match the type of material being melted and the amount of the material in the furnace. The furnace coil and capacitor form a resonant circuit, and the dc-to-ac inverter drives the circuit to keep it in resonance. The inductance of the coil varies depending on the type, temperature, and amount of material as the furnace completes one cycle to another such as from a melt to pour cycle. This situation results in a varying operating frequency for the furnace. The typical range of frequencies for induction furnaces is 150 to 1200 Hz.

An induction furnace has a 12-pulse current source design with reactors on the dc link to smooth the current into the inverter as shown in Fig. 4.34. Typical characteristic harmonics in the ac-side line currents are 11th, 13th, 23rd, 25th… with some noncharacteristic harmonics such as the 5th and 7th also possibly present. However, there are also currents at noninteger frequencies due

to the interaction with the inverter output frequency as the furnace goes from one cycle to another. The switching of the inverter reflects the frequency of the furnace circuit to the ac-side power through small perturbations of the dc link current. This interaction results in interharmonic frequencies at the ac side and bears no relation to the power supply frequency. The interharmonics appear in pairs at the following frequencies:

$$2f_\text{o} \ \square \ f_s, 4 f_\text{o} \ \square \ f_s$$
$$,........$$

---------- (4.25)

Where *fo* and *fs* are the furnace operating frequency and the fundamental of the ac main frequency, respectively. Thus, if the furnace operates at 160 Hz, the first interharmonic currents will appear at 260 and 380 Hz. The second pair of lesser magnitude will appear at 580 and 700 Hz. A typical spectrum of induction furnace current is shown in Fig. 4.35.

In this particular example, the fifth harmonic was noncharacteristic but was found in significant amounts in nearly all practical power systems. The interharmonic frequencies move slowly, from several seconds to several minutes, through a wide frequency range as the furnace completes its melt and pour cycle. The wide range of the resulting interharmonics can potentially excite resonances in the power supply system.

Cycloconverters, adjustable-speed drives, induction motors with wound rotor using sub synchronous converter cascades, and arcing devices also produce interharmonics in a similar fashion.

Since interharmonics can assume any values between harmonic frequencies, the interharmonic spectrum must have sufficient frequency resolution. Thus, a single-cycle waveform sample is no longer adequate to compute the interharmonic spectrum since it only provides a frequency resolution of 50 or 60 Hz. Any frequency in between harmonic frequencies is lost. The one-cycle waveform though is commonly used to compute the harmonic spectrum since there is no frequency between harmonic frequencies.

A 12- or 10-cycle waveform is then recommended for a 60- or 50-Hz power system to achieve higher frequency resolution. The resulting frequency resolution is 5 Hz. Impacts of interharmonics are similar to those of harmonics such as filter overloading, overheating, power line carrier interference, ripple, voltage fluctuation, and flicker. However, solving interharmonic problems can be more challenging, especially when interharmonic frequencies vary from time to time as do those in induction furnaces. Broadband filters are usually used to mitigate interharmonic problems.
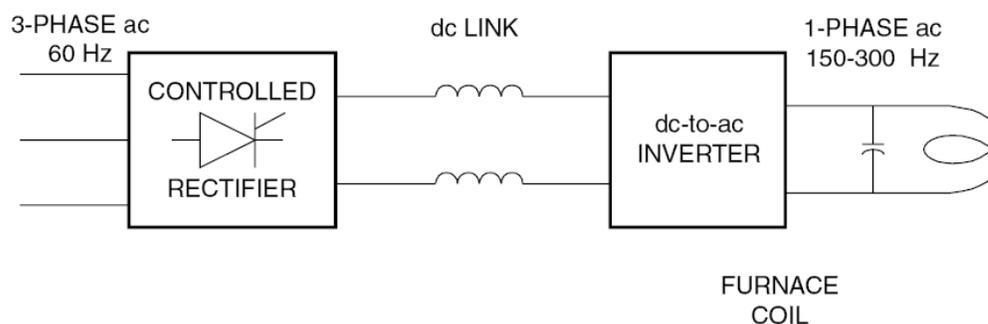
Figure 4.34 Block diagram of a modern induction furnace with a current source inverter.
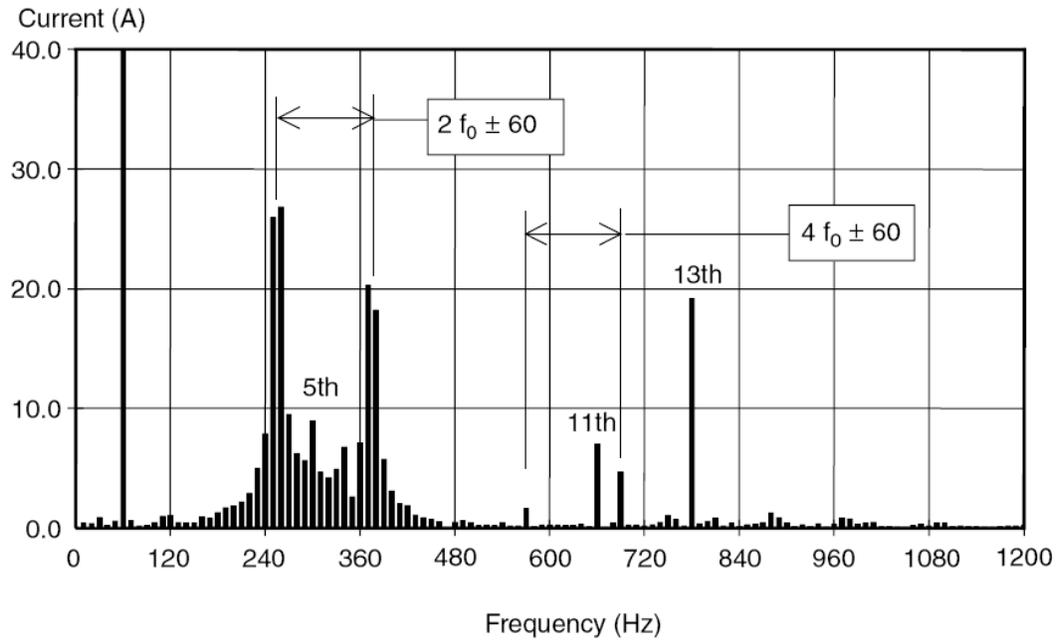
Figure 4.35 Typical spectrum of induction furnace current.