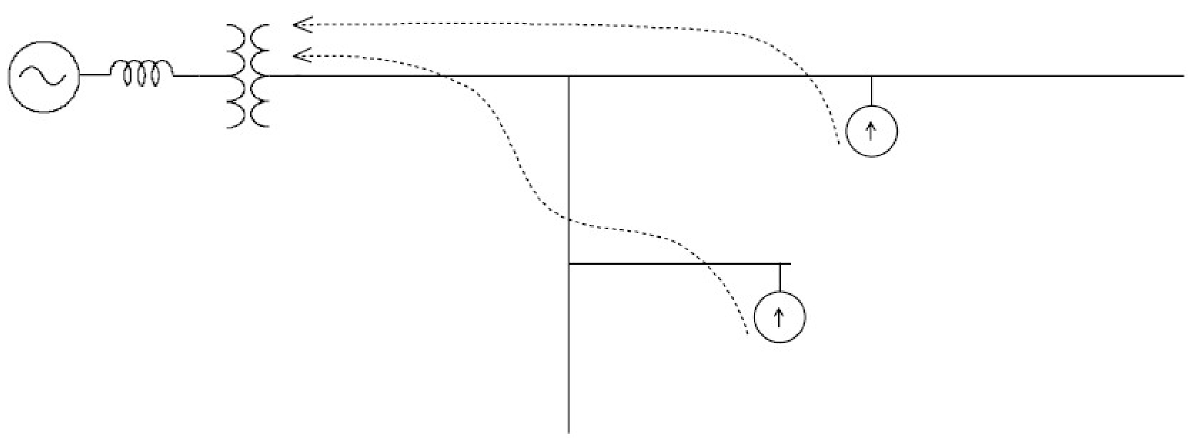
Locating Harmonic Sources

On radial utility distribution feeders and industrial plant power systems, the main tendency is for the harmonic currents to flow from the harmonic-producing load to the power system source. This is illustrated in Fig.4.20. The impedance of the power system is normally the lowest impedance seen by the harmonic currents. Thus, the bulk of the current flows into the source.

This general tendency of harmonic current flows can be used to locate sources of harmonics. Using a power quality monitor capable of reporting the harmonic content of the current, simply measure the harmonic currents in each branch starting at the beginning of the



circuit and trace the harmonics to the source.

Fig. 4.20. General flow of harmonic currents in a radial power system.

Power factor correction capacitors can alter this flow pattern for at least one of the harmonics. For example, adding a capacitor to the previous circuit as shown in Fig. 4.21 may draw a large amount of harmonic current into that portion of the circuit. In such a situation, following the path of the harmonic current will lead to a capacitor bank instead of the actual harmonic source. Thus, it is generally necessary to temporarily disconnect all capacitors to reliably locate the sources of harmonics.

It is usually straightforward to differentiate harmonic currents due to actual sources from harmonic currents that are strictly due to resonance involving a capacitor bank. A resonance current typically has only one dominant harmonic riding on top of the fundamental sine wave.

They all produce more than one single harmonic frequency. Waveforms of these harmonic sources have somewhat arbitrary wave shapes depending on the distorting phenomena, but they contain several harmonics in significant quantities. A single, large, significant harmonic nearly always signifies resonance.

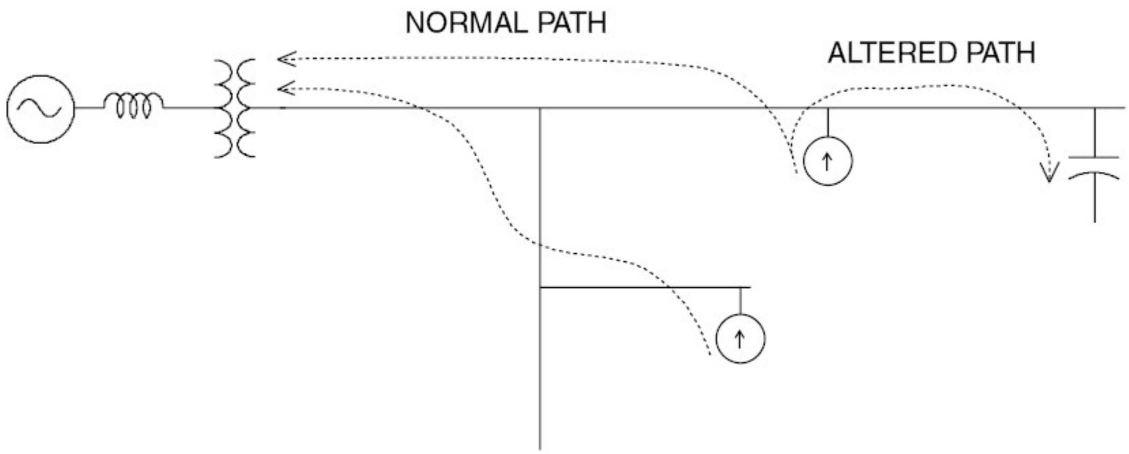


Figure 4.21 Power factor capacitors can alter the direction of flow of one of the harmonic components of the current.

Another method to locate harmonic sources is by correlating the time variations of the voltage distortion with specific customer and load characteristics. Patterns from the harmonic distortion measurements can be compared to particular types of loads, such as arc furnaces, mill drives, and mass transits which appear intermittently. Correlating the time from the measurements and the actual operation time can identify the harmonic source.

4.6.1 System Response Characteristics

In power systems, the response of the system is equally as important as the sources of harmonics. In fact, power systems are quite tolerant of the currents injected by harmonic-producing loads unless there is some adverse interaction with the impedance of the system. Identifying the sources is only half the job of harmonic analysis. The response of the power system at each harmonic frequency determines the true impact of the nonlinear load on harmonic voltage distortion. There are three primary variables affecting the system response characteristics, i.e., the system impedance, the presence of a capacitor bank, and the amount of resistive loads in the system.

4.6.2 System Impedance

At the fundamental frequency, power systems are primarily inductive, and the equivalent impedance is sometimes called simply the short-circuit reactance. Capacitive effects are frequently neglected on utility distribution systems and industrial power systems. One of the most frequently used quantities in the analysis of harmonics on power systems is the short-circuit impedance to the point on a network at which a capacitor is located. If not directly available, it can be computed from short-circuit study results that give either the short-circuit megavoltampere (MVA) or the short-circuit current as follows:

$$Z_{SC} = R_{SC} + jX_{SC} \approx \frac{kV^2}{MVA_{SC}} = \frac{kV \cdot 1000}{\sqrt{3} I_{SC}} \quad \text{---------------------- (4.4)}$$

Where Z_{SC} = short-circuit impedance

R_{SC} = short-circuit resistance

X_{SC} = short-circuit reactance

kV = phase-to-phase voltage, kV

MVA_{SC} = three-phase short-circuit MVA

I_{SC} = short-circuit current, A

Z_{SC} is a phasor quantity, consisting of both resistance and reactance. However, if the short-circuit data contain no phase information, one is usually constrained to assuming that the impedance is purely reactive. This is a reasonably good assumption for industrial power systems for buses close to the mains and for most utility systems.

The inductive reactance portion of the impedance changes linearly with frequency. One common error made by novices in harmonic analysis is to forget to adjust the reactance for frequency. The reactance at the h_{th} harmonic is determined from the fundamental impedance reactance $X1$ by:

$$X_h = hX_1 \qquad \text{------------(4.5)}$$

In most power systems, one can generally assume that the resistance does not change significantly when studying the effects of harmonics less than the ninth. For lines and cables, the resistance varies approximately by the square root of the frequency once skin effect becomes significant in the conductor at a higher frequency.

At utilization voltages, such as industrial power systems, the equivalent system reactance is often dominated by the service transformer impedance. A good approximation for X_{SC} may be based on the impedance of the service entrance transformer only:

$$X_{SC} \approx X_{tx} \qquad \text{------------ (4.6)}$$

Transformer impedance in ohms can be determined from the percent impedance Z_{tx} found on the nameplate by

$$X_{tx} = \left(\frac{kV^2}{MVA_{3\phi}}\right) \times Z_{tx}(\%) \qquad \text{------------ (4.7)}$$

Where MVA three phase is the kVA rating of the transformer. This assumes that the impedance is predominantly reactive. For example for a 1500-kVA, 6 percent transformer, the equivalent impedance on the 480-V side is

$$X_{tx} = \left(\frac{kV^2}{MVA_{3\phi}}\right) \times Z_{tx}(\%) = \left(\frac{0.480^2}{1.5}\right) \times 0.06 = 0.0092\,\Omega \qquad \text{---------------- (4.8)}$$

A plot of impedance versus frequency for an inductive system (no capacitors installed) would look like Fig. 4.22

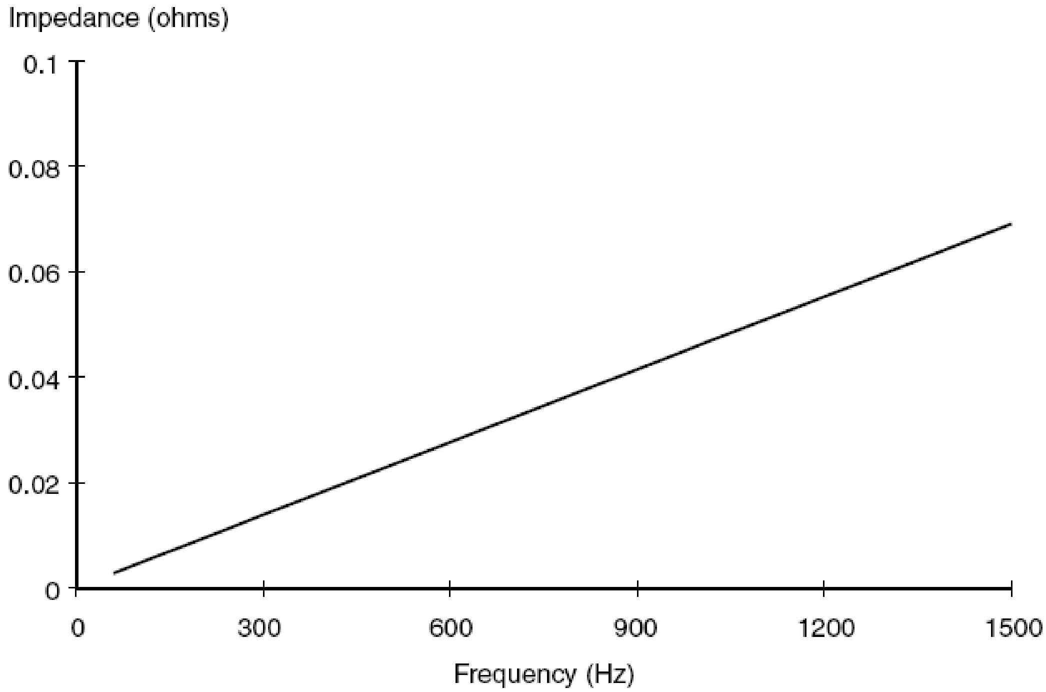


Fig. 4.22 Impedance versus frequency for inductive system.

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