

APPENDIX "A"

HARMONICS

A1. Nature of Harmonics

Harmonics are integral multiples of the fundamental frequency. For example, for 60 Hz power systems, the second harmonic would be 2·60 or 120 Hz and the third harmonic would be 3·60 or 180 Hz.

Harmonics are caused by devices that change the shape of the normal sine wave of voltage or current in synchronism with the 60 Hz supply. In general those include three-phase devices in which the three phase coils are not exactly symmetrical, and single and three-phase loads in which the load impedance changes during the voltage wave produce a distorted current wave such as the magnetizing current in a coil with an iron core. It can be shown that a distorted wave can be made up of a fundamental and harmonics of various frequencies and magnitudes.

Inductive reactance varies directly as the frequency so that the current in an inductive circuit is reduced in proportion to the frequency for a given harmonic voltage. Conversely, capacitive reactance varies inversely as the frequency so that the current in a capacitive circuit is increased in proportion to the frequency for a given harmonic voltage. If the inductive reactance and the capacitive reactance in a series circuit are the same, they will cancel each other, and a given harmonic voltage will cause a large current to flow limited only by the resistance of the circuit. This condition is called resonance, and is more likely to occur at the higher harmonic frequencies.

A2. Characteristics of Harmonics

The harmonic content and magnitude existing in any power system is largely unpredictable and effects will vary widely in different parts of the same system because of the different effects of different frequencies. Since the distorted wave is in the supply system, harmonic effects may occur at any point on the system where the distorted wave exists; this is not limited to the immediate vicinity of the harmonic-producing device. Where power is converted to direct current or some other frequency, harmonics will exist in any distorted alternating component of the converted power.

Harmonics may be transferred from one circuit or system to another by direct connection or by inductive or capacitive coupling. Since 60 Hz harmonics are in the low-frequency audio range, the transfer of these frequencies into communication, signaling, and control circuits employing frequencies in the same range may cause objectionable interference. In addition, harmonic currents circulating within a power circuit reduce the capacity of the current-carrying equipment and increase losses without providing any useful work.

A3. Harmonic-Producing Equipment

(1) Arc Equipment.

Arc furnaces and arc welders have a changing load characteristic during each half-cycle that demands harmonic currents from the supply system. Normally these do not cause

very much trouble unless the supply conductors are in close proximity to communication and control circuits or there are large capacitor banks on the system.

(2) Gaseous Discharge Lamps.

Fluorescent and mercury lamps produce small arcs and, in combination with the ballast, produce harmonics, particularly the third. Experience shows that the third-harmonic current may be as high as 30% of the fundamental in the phase conductors and up to 90% in the neutral where the third harmonics from each phase add directly, since they are displaced one third of a cycle. This is why the NEC [9] requires a full neutral for circuits supplying this type of load.

(3) Rectifiers.

Half-wave rectifiers, which suppress alternate half-cycles of current, generate both even and odd-numbered harmonics. Full-wave rectifiers tend to eliminate the even-numbered harmonics and usually diminish the magnitude of the odd-numbered harmonics.

The major producer of harmonics is the controlled rectifier, which chops the ac wave, particularly near the peak of the cycle. Since the wave shapes of both the input and the output depend upon the control setting to start rectification, both the shape of the input and output waves and, hence, the frequency and magnitude of the harmonics will vary with the setting of the control. Large rectifiers, which are frequently supplied from six and twelve-phase transformer connections to produce smoother direct current, will produce different harmonics than those supplied from a three-phase system.

Phase-controlled rectifiers used to provide variable-speed drives for dc motors, or used as frequency changers to provide variable-speed drives for ac motors, are major sources of harmonics.

(4) Rotating Machinery.

Normally the three phase coils of both motors and generators are sufficiently symmetrical that any harmonic voltages generated from lack of symmetry are too small to cause any interference. The nonlinear characteristics of the stator iron can produce appreciable harmonics, especially at high-flux densities.

(5) Induction Heaters.

Induction heaters use 60 Hz or higher frequency power to induce circulating currents in metals to heat the metal. Harmonics are generated by the interaction of the magnetic fields caused by the current in the induction heating coil and the circulating currents in the metal being heated. Large induction heating furnaces may create objectionable harmonics.

(6) Capacitors.

Capacitors do not generate harmonics. However, the reduced reactance of the capacitor to the higher frequencies magnifies the harmonic current in the circuit containing the capacitors. In cases of resonance, this magnification may be very large. High harmonic currents may overheat the capacitors. In addition, the high currents may induce interference with communication, signal, and control circuits.

Special capacitors prescribed by equipment manufacturers are required to perform satisfactorily under actual operating conditions. Thus the manufacturer must be furnished the harmonic voltage content of the power supply to determine the correct type to be used.

A4. Reduction of Harmonic Effects

Where harmonic interference exists, the regular measures of increasing the separation between the power and communication conductors and the use of shielded communication conductors should be considered. Where capacitor banks magnify the harmonic current, the capacitors should be changed to suitable types or removed. Where resonant conditions exist, the capacitor bank should be changed in size to shift the resonant point to another frequency. Where harmonics pass from a power system to a communications, signal, or control circuit through a direct connection such as a power supply, filters may be required to suppress or short-circuit the harmonic frequencies.

During preliminary meetings with the supplying utility, the anticipated harmonic analysis of the power supply should be determined. This information, coupled with that provided by the manufacturer of any equipment to be installed that may generate a voltage distortion (along with appropriate safety factors), can be used to govern the specifications or the application of other equipment that may be exposed to the harmonic voltage condition.

SOLUTIONS FOR HARMONICS PROBLEMS

According to the proposed IEEE 519 Standard, limits are set for harmonic current and voltages as follows:

Voltage Limits

Primary Distribution 5% THD
 At Load 8% THD

Maximum Harmonic Current Distortion in % of Fundamental
 Harmonic Order (odd only)

I_{SC}/I_L	<11	11-15	17-21	23-33	>33	THD
<20	4.0	2.0	1.5	0.6	0.3	5.0
20-50	7.0	3.5	2.5	1.0	0.5	8.0
50-100	10.0	4.5	4.0	1.5	0.7	12.0
100-1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

I_{SC} =Maximum short circuit current at the point of common coupling (PCC).

I_L = Maximum load current (fundamental frequency) at PCC.

Even harmonics are limited to 25% of values in the table.