



Harmonic Analysis Basics

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Basics of Harmonic Analysis

Introduction

In this course we will discuss the underlying concepts of harmonic analysis in relation to industrial and commercial power systems. Also included will be the reasons we require this analysis, the recognition of problems that may arise in the process, methods of correcting and preventing these issues, the data required to perform this analysis, and the benefits of technology in performing a harmonic analysis study.

The main source of power system harmonics has traditionally been the static power converter, used as a rectifier in many industrial processes. The static power converter is now used, however, in a number of different applications. These include adjustable speed drives, frequency changers for induction heating, switched-mode supplies, and many more. Increasingly, semiconductor devices are being used as static switches, to adjust the amount of voltage being applied to a load. Some applications for this include light dimmers, electronic ballasts for discharge lamps, soft starters for motors, and static var compensators. Any device with a nonlinear voltage current like an arc furnace or saturable electromagnetic device can also be included.

Nonlinear loads represent a growing portion of the total load of a commercial or industrial power system. This means harmonic studies are an important part of any system design and operation. Fortunately, the software available to assist us with harmonic analysis has grown also.

If we model power system impedances as a function of frequency, we can determine the effect of harmonic contributions produced by nonlinear loads on voltage and current in a power system. The majority of harmonic analysis software will offer the ability to do as follows:

- Calculate harmonic bus voltages and branch current flows produced by harmonic sources in a network

- See resonances in an existing or planned system
- Calculate the effects of harmonics on voltage or current waveform distortion, telephone interference etc. through performance indices. This can also aid in choosing or finding capacitors and passive filters to produce optimal system performance.

We will discuss the details of applicable standards and system modelling, particularly in industrial and commercial systems running at low or medium voltages. The basics are applicable also to higher voltage systems and other system applications. In this course, we will not cover active filters as part of a design, but some references will be made to their use and application.

From the beginning we may say that harmonic filter design is linked closely to power-factor (PF) requirements in a system, based on utility tariffs. Both must therefore be considered together. Many studies on PF compensation have previously been made without considering possible resonances or harmonic absorption by capacitors.

Background

By definition, any device or load that doesn't draw a sinusoidal current when excited by a sinusoidal voltage of the same frequency is a nonlinear load. Most commonly these are switching devices like solid-state converters which force conduction of currents for particular periods. They can also include saturable impedance devices like transformers with nonlinear voltage vs. impedance characteristics. Nonlinear loads are also considered sources of harmonic currents, in which harmonic frequencies are classed as integer multiples of the system frequency. Arc furnaces, cycloconverters, and other specific nonlinear loads can have non-integer harmonic frequencies as well as the integer harmonics expected in the system.

By definition, harmonics are a part of every fundamental current cycle. When calculating them, they are considered part of the steady-state solution. But harmonics can vary from cycle to cycle, as exceptions will always occur. These are classed as time-varying harmonics. These are not dealt with in this chapter, nor quasisteady-state or transient solutions (as in magnetization inrush current of a transformer).

In industrial application studies, the nonlinear load or harmonic source is classed as an ideal current source without a Norton's impedance (i.e. assume infinite Norton impedance), providing a constant current, regardless of the system impedance seen by the source. This is generally a reasonable assumption and tends to yield acceptable results. A Norton equivalent current source can still be used when a nonlinear device acts as a voltage source, such as with pulse-width-modulated or PWM inverters, as most computer software works on the current injection method.

Networks are solved for current and voltage individually at each frequency, as a system is subjected to current injections at multiple frequencies. Then, the total voltage or current can be found through a root-mean-square or arithmetic sum via the principle of superposition.

Different types of nonlinear loads will generate different harmonic frequencies. Most will produce odd harmonics, with small, even harmonics, but loads like arc furnaces produce the entire spectrum: odd, even, and non-integer, also known as interharmonics. In general, the harmonic amplitude will decrease as the harmonic order or frequency increases.

Depending on harmonic voltage drops in various series elements of the network, distortion of the voltage waveform is produced due to the effects of harmonic current propagation through the network (including the power source). Voltage distortion at a bus depends on the equivalent source impedance – smaller impedance means better quality voltage. Note that nonlinear loads or harmonic sources are not power sources, but the cause of active and reactive losses of power in a system.

The purpose of harmonic study

Nonlinear loads represent a growing propagation in commercial buildings and industrial plants, in the range of thirty to fifty percent of the total load. This means we need to examine the effects of harmonics within a system and the impact they have on a utility and neighbouring loads, to prevent any complaints, equipment damage, or loss in production.

The list below represents a number of situations in which a harmonic study may be necessary, including recommendations for mitigation of harmonic effects.

- a) IEEE Std. 519-1992 compliance, defining the current distortion limits that should be met in the utility at the point of common coupling or PCC. As a basis for the system design, limits of voltage distortion are also defined. These are intended to provide a good sine wave voltage in the utility, but users are expected to use them as a basis for the design of a system. If current distortion limits are met, voltage distortion limits should also, allowing for unusual and exceptional circumstances.
- b) Harmonic related problems in the past, including failure of power-factor compensation capacitors; overheating of transformers, motors, cables, and other such equipment; and misoperation of protective relays and control devices.
- c) Expansion in which significant nonlinear loads are added, or a significant capacitance is added to a plant.
- d) Designing a new power system or facility in which the power factor compensation, load-flow, and harmonic analyses need to be studied in one integrated unit, in order to determine reactive power demands, harmonic performance limits, and how to meet these requirements.

If system problems appear to be caused by harmonics, it becomes important to determine resonant frequencies at points which are causing problems. Parallel system resonance can also occur around the lower harmonic orders (3, 5...) with banks of power-factor correction capacitors. This can be critical if a harmonic current injection at that frequency excites the resonance.

Frequently you will find systems where taking harmonic measurements as a tool for diagnostics rather than performing detailed analysis studies will be a much more practical task. Measurements can also be used to verify system models before performing a detailed harmonic analysis study. Arc furnace installations are a situation in which this is especially desirable. Careful consideration must be given to procedures and test equipment to make sure harmonic measurements will produce reliable results. These may produce the cause of a problem, meaning a simpler study or even the elimination of the need for a study.

General theory

Harmonic sources

Harmonic sources are all considered nonlinear loads, as when a sinusoidal voltage is applied, they draw non-sinusoidal currents. This may be caused by the inherent characteristics of the load as in arc furnaces, or due to a switching circuit like a 6-pulse converter, which forces conduction for particular periods. There may be many such harmonic sources throughout an industrial or commercial power system.

Harmonic studies require that the performer has knowledge of harmonic currents produced by the involved nonlinear loads. An analytical engineer has three main choices.

- Measuring harmonics produced at each source
- Calculating harmonics produced via a mathematic analysis in applicable situations, e.g. converters or static var compensators



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