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Monthly Informative Application Guidelines, with respect to *Motors & Drives* to keep you better INFORMED.

APPLICATION GUIDELINE #14

(February - Harmonics)

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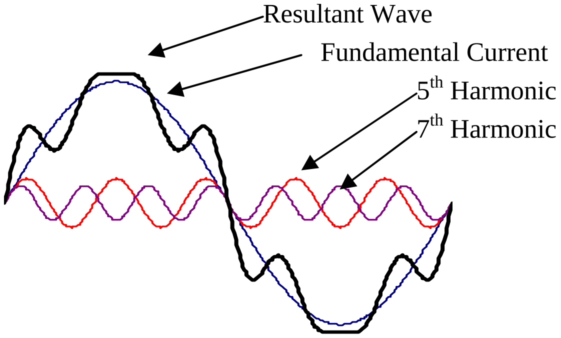
Variable Frequency Drives are becoming more and more popular in both heavy industry and even in commercial buildings as they provide both process improvements and potential for energy savings. As the quantity of drives or other non-linear loads in a facility approaches 20% of connected load (at the point of common coupling), the harmonic distortion caused by the drives can cause problems with other components such as capacitors, other drives, electronic equipment etc.

Effects of Power System Harmonics Includes:

- Excessive heating in rotating machinery
- Torque pulsation's on AC motor applications
- Mis-operation of control equipment, instrumentation, signal conditioning equipment, and computers
- Overheating of power factor correction capacitors / Blown capacitor fuses making PF correction caps ineffective
- Excessive current in neutral conductors of 3-phase 4-wire systems
- Interference with Communication Equipment
- kWh meter errors
- Overheating of transformers
- Premature tripping or failure to trip of solid-state protective relays
- Reduced power factor (increased utility rates?)
- Overloading of UPS or emergency generators
- Emergency generator instability due to voltage distortion affects on the voltage regulator

What are Harmonics: IEEE 519-1992 defines harmonics as, “A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency.”



HARMONIC ORDERS & MAGNITUDES

$$h = kn \pm 1 \quad \text{and} \quad I_h = I_1 / h$$

h = harmonic number
k = an integer
n = pulse number of circuit (6, 12, 18, 24)
I_h = estimated harmonic current magnitude
I_1 = fundamental current

For a 6 pulse rectifier (standard on PWM VFD’s)

h=5, 5th harmonic = 5 * 60 Hz = 300 Hz (I_5=1/5)
h=7, 7th harmonic = 7 * 60 Hz = 420 Hz (I_7=1/7)

IEEE 519, “Recommended Practices and Requirements for Harmonic Control in Electric Power Systems” was first published in 1981 to establish levels of voltage distortion acceptable to the distribution system. This document has been widely applied in establishing needed harmonic correction throughout the electrical power industry. The newer IEEE-519-1992 sets forth limits for both harmonic voltages on the utility transmission and distribution system and harmonic currents within the industrial distribution systems, based on the stiffness of the bus which can be measured by short circuit current which is measured at the Point of Common Coupling (PCC). Following is a table from IEEE519-1992 describing harmonic current limits, and following the table are terms which are defined for clarifying their meaning.

Table1. IEEE 519-1992 current distortion limits for general distribution systems.

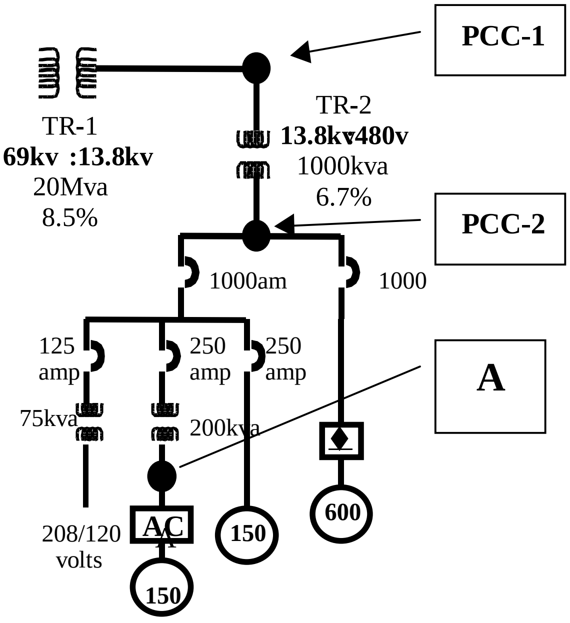
Maximum Harmonic Current Distortion in Percent of I_{load}						
I_{sc}/I_1	h<11	11≤h<17	17≤h<23	23≤h<35	35≤h	TDD(%)
20	4.0	2.0	1.5	0.6	0.3	5.0
20-50	7.0	3.5	2.5	1.0	0.5	8.0
50-100	10.0	4.5	4.0	1.5	0.7	12.0
100-1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

**TDD (Total Demand Distortion): is a measure of the total harmonic current distortion at the PCC for the total connected load.

For a harmonic analysis evaluation of your system with the help of software (Harmflow, TCI and others), answers to the following questions are needed. The software allows convenient estimation of harmonics, which allows proper decisions to be made about installing variable frequency drives.

- What is the input voltage to the ASD?
- What is the input transformer kVA rating and % impedance?
- What is your input transformer available short circuit current?
- What is the impedance ratio of all transformers (X/R) in the analysis?
- Are there AC line reactor (If yes need % impedance), phase shift transformer, DCL, etc,
- What size(s) and type(s) of ASD is going to be used?
- What is the total linear load connected to the above power system?
- Where is the Point of Common Coupling (PCC)?
- How many other drives are to be running on the same bus and what is the total capacity?

PCC (point of common coupling) is probably the most important and most controversial term in the entire IEEE document. It is defined as the electrical connecting point or interface between the utility distribution system and the customer's(user) electrical distribution system. While simple in concept, identification of this point is sometimes misunderstood, which leads to confusion and mis-application of the specifications in the table.



This figure represents a typical small distribution system. The utility distributes power at 69kv. The utility feeds a distribution line with 13.8kv, 3ph, 60hz power through an 8.5% impedance distribution 20Mva transformer. The factory uses a 1000kva 6.7% impedance service transformer to step the 13.8kv down to 480volts, which is bused throughout the plant. <u>The columns of the IEEE table which should be used to determine harmonic limits will depend on the location of the PCC</u>. PCC-1 is the primary of the service transformer. Often when the customer owns the service transformer, the utility will meter the medium voltage (13.8kv) at this point. If the Utility meters the 480volt bus, PCC-2 is the interface. As we shall see shortly, the allowable harmonic distortion depends on the defined PCC.

There is often a tendency to apply the limits of the IEEE table to an individual load, as represented by point "A". One must remember that any distortion at this point is produced by the drive when it is operating, and will not affect the drive's functions.

Furthermore, high distortion at point A does not necessarily result in out-of-limit distortion on the distribution system. If an attempt is made to meet limits for each individual load, one discovers either that currently available technology is incapable of doing the job, or high-cost equipment is needed. If one remembers that IEEE 519-1992, is meant to apply to system harmonic distortion, rather than to individual load distortion, unnecessary expense can be avoided. The most effective way to meet harmonic distortion limits is to filter the harmonics at each individual load and measure them at the PCC.

$$\mathbf{I}_{\mathbf{SC\,(PCC\text{-}1)}} = \frac{\text{Full Load Current TR1}}{\text{Im pedanceTR1}} = \frac{\frac{20{,}000\text{kva}}{13{,}800\,\text{x}\sqrt{3}}\,\text{x}1{,}000}{0.085} = \frac{838\text{amps}}{0.085} = \underline{9{,}858\text{amps}}$$

$$\mathbf{I}_{\mathbf{L(PCC-1)}} = \text{I}_{\text{L}(480\text{v})}\ \text{x}\left(\frac{480}{13{,}800}\right) = 1000\text{amps}\ \text{x}\left(\frac{480}{13{,}800}\right) = \underline{34.8\text{amps}}$$

@PCC-1
- I_{SC}/I_L=**283**

@PCC-2 (with data from TR2)
- $I_{SC}/I_L = \frac{17{,}970\text{amps}}{1{,}000\text{amps}} = \mathbf{17.5}$

If PCC1 is the measuring point, the data from the IEEE table shows that TDD permitted for an I_{SC}/I_L=283 is 15%. The 5th and 7th harmonics are each permitted to be 12%. The values measured (10%TDD, 9%5th and 4.4% 7th) are within the permitted limits and no further action is warranted. This should be expected, since a relatively small 1000amp (830kva) load is being fed by a relatively stiff (20Mva) system transformer. If PCC2 is the measuring point, the data from the IEEE table shows that the TDD permitted for an I_{SC}/I_L=17.5 is 5%. The 5th and 7th harmonics are each permitted to be 4%. The values measured are all greater than the permitted limits and this system would need harmonic mitigation to meet the requirements of IEEE 519-1992.

Options for Harmonic mitigation includes:

- **Add drive input impedance** - Line reactors, DC link reactors or isolation transformers. This should be your first line of defense. Input impedance minimizes harmonic distortion on the power system plus helps improve reliability of the drive. It is therefore very good practice to install input reactors with a minimum 5% impedance on all drives.
- Installing **larger service transformer** (in effect "derating" the transformer) or **reduce utility/source impedance** (higher short circuit capability)
- **Passive filters** - There are third party manufacturers that make harmonic filters that can be very effective in solving harmonic related problems, such as TCI and Mirus. Toshiba Houston has had experience with both of these companies and is able to provide a drive package including the required harmonic solution. TCI's HarmonicGuard Filter is a series tuned L-C shunt filter often called a "harmonic trap filter", or Mirus Lineator UHF filter "Universal Harmonic Filter", eliminates lower order harmonics to make a 6 pulse VFD look like an 18 pulse.
- **Phase multiplication - 12,18 or 24 pulse**. The typical PWM drive with a six pulse input rectifier creates harmonics beginning with the 5th. By increasing the pulse number to twelve, the first harmonic created is the 11th. The higher the harmonic number, the lower the magnitude of the harmonic distortion. Theoretically, using an 18-pulse rectifier provides 4.22% less THD than a 12-pulse rectifier and 20.4% less THD than a 6-pulse rectifier. Similarly, a 24-pulse-rectifier provides 2% less THD than an 18 pulse. Overall 6.26 % less THD can be obtained by using a 24-pulse rectifier compared to a 12-pulse rectifier.
- **Active filters** - Cancels current harmonics directly by injecting the inverse of the nonlinear load's harmonic spectrum. Responds to the amount and type of harmonics encountered by continuously monitoring the load currents.

Each method has its own advantages and disadvantages from the perspective of cost, performance, complexity, reliability, size, etc. Moreover, in each method there are various configurations based on different effectiveness, cost, and complexity. For example, using different pulse numbers, series or parallel connection, and transformers or auto-transformers constitute different options for the multi-pulse rectifiers.