Questions and Answers for Applying IEEE 519-1992

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Many of you that know me are probably wondering how I have gone so long writing this column without a single article on harmonics issues. Well, I'm finally doing one. The only danger is that once I get started, we may never get back to other more important power quality concerns. Since it's the first article that I've done on harmonics, I have to focus on the application of IEEE 519 – *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.*

The current version of IEEE 519 was introduced in 1992. Since that time, many utilities have adopted the standard as the basis for evaluating harmonic interaction concerns between customers and the power system. It has also influenced harmonic standards that are being developed throughout the world. Despite being widely applied, there are still many questions that continue to come up regarding interpretation and application of the standard. We are currently completing an application guide that should help with a lot of these questions. In the meantime, I will try to address some of the most common questions in this article.

One of the things that I like about IEEE 519 is that it is one of the first standards in the power quality area to define responsibilities on both sides of the meter in order to achieve *compatibility* between the power system and customer loads. The utility is responsible for the quality of the *voltage* being supplied and the customers are responsible for the *current* distortion in their load currents. If all of the customers meet the current distortion requirements, the utility should be able to maintain a power system design that will assure the quality of the voltage.

Let's get to the questions.

Where is the point of common coupling for most facilities?

The harmonic limits in IEEE 519-1992 were meant to be applied at the point of common coupling (PCC) between the utility system and multiple customers. In other words, the PCC is the location where another customer can be served from the system. The standard allows for the same procedure to be applied by the customer at other locations within a facility but different current limit values could apply in these cases. The definition used in the IEEE P519A application guide uner development is that the PCC is the location on the system where another customer can be served.

The PCC can be located at either the primary or the secondary of a supply transformer depending on whether or not multiple customers are supplied from the transformer. Figure 1 illustrates the two possibilities. Note that when the high side of a supply transformer is the PCC, current measurements for verification can still be performed at the transformer low side. Low side measurements can be used (at a metering location, for instance) and the results referred to the transformer high side by the turns ratio of the transformer, keeping in mind the effect of the transformer connection on the zero sequence harmonic components. For instance, a delta-wye transformer will not allow zero sequence components to flow from the secondary to the primary system (they will be trapped in the primary delta winding). Therefore, zero sequence components (e.g. balanced triplen harmonic components) measured on the secondary side would not be included in the evaluation for a PCC on the primary side. If the utility owns the stepdown transformer, the harmonic currents can be evaluated at the transformer secondary but the short circuit ratio (SCR) should be calculated at the primary side PCC.

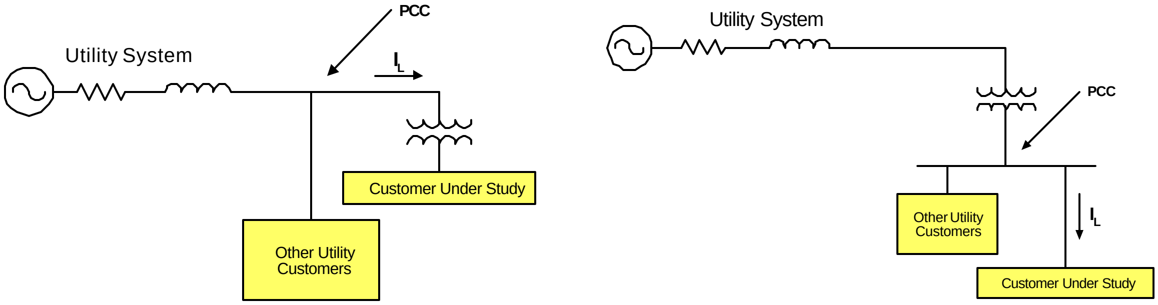

Figure 1. Selection of the PCC where other customers can be supplied.

What load current and system short circuit current should be used to calculate the short circuit ratio (SCR)?

The SCR is calculated as the ratio between the short circuit current at the PCC and the customer's maximum load current (average maximum demand load current, I_L). The SCR is used as a measure of the customer size in relation to the system capacity. The smaller the customer, the less likely it will be that the customer can cause harmonic voltage distortion problems on the overall power system. For this reason, smaller customers can have somewhat higher levels of harmonic current expressed as a percentage of their total load current. This assumes that there will be some amount of diversity or cancellation as harmonic currents from these customers are combined on the power system.

IEEE 519 gives a procedure for calculating $I_{L.}$ You take the maximum demand current from billing records for 12 months and average these values. Obviously, this is not possible if you are evaluating IEEE 519 compliance for a new customer or for a customer where the facility is being expanded or changed. In these cases, the maximum load current must be estimated. Sometimes, you may just want to use a rated current, such as the transformer rating. The important thing is to have a consistent method for choosing this current and to get agreement between the utility and the customer as to what value will be used.

The short circuit current for the calculation should be the minimum short circuit current for normal conditions at the PCC. Note that this is different than the short circuit current that would normally be used for protection studies where the maximum short circuit current is most important. The minimum short circuit current results in the most voltage distortion for a given amount of harmonic current injection.

What is Total Demand Distortion (TDD)?

TDD is a new term introduced in IEEE 519. It is a very important concept. Here's the formula:

$$TDD = \frac{\sqrt{\sum_{h=2}^{50} I_h^2}}{I_L} \times 100\%$$

where:

I_h = magnitude of individual harmonic components (rms amps)
h = harmonic order
I_L = maximum demand load current (rms amps) defined above

Look familiar? It's the same formula used to calculate the total harmonic distortion (THD) except that the denominator is the maximum demand load current (a constant), rather than the fundamental value of the load current for a particular measurement (a value that will change with each measurement).

The limits for harmonic currents are all expressed in % of the maximum demand load current, $I_{L.}$ This allows harmonic currents to be evaluated over a wide variety of load conditions with a constant base value. If we used the fundamental component of the current as the base, the distortion values at light load might look very high but would not have a significant impact on the power system. The method of expressing everything in % of I_L allows evaluation of the actual amps of harmonic current being injected onto the power system.

How long should harmonics be measured to evaluate compliance with IEEE 519 guidelines?

Remember that harmonics are continuous. Harmonic distortion levels are changing all the time, just like the overall load and the rms voltage magnitude. You cannot evaluate harmonics with a single snapshot of the voltage and the current any more than you can evaluate voltage regulation with this approach. IEC guidelines for evaluating harmonics recommend measurements over a minimum one week period in order to characterize the daily and weekly variations in the load levels. The important thing is to get enough samples so that you characterize the overall statistical nature of the harmonic levels (Figure 2).

Once you have determined the statistical characteristics of the harmonic distortion levels, what value should you use to compare with the IEEE 519 limits? IEEE 519 states that the limits specified can be exceeded for up to one hour per day (4.2% of the time). IEC guidelines use the 95% probability point (level that is exceeded 5% of the time) for many evaluations. At least remember that it's ok to exceed the limits for short periods since most of the impacts of harmonics are time related (e.g. overheating of motors and transformers).

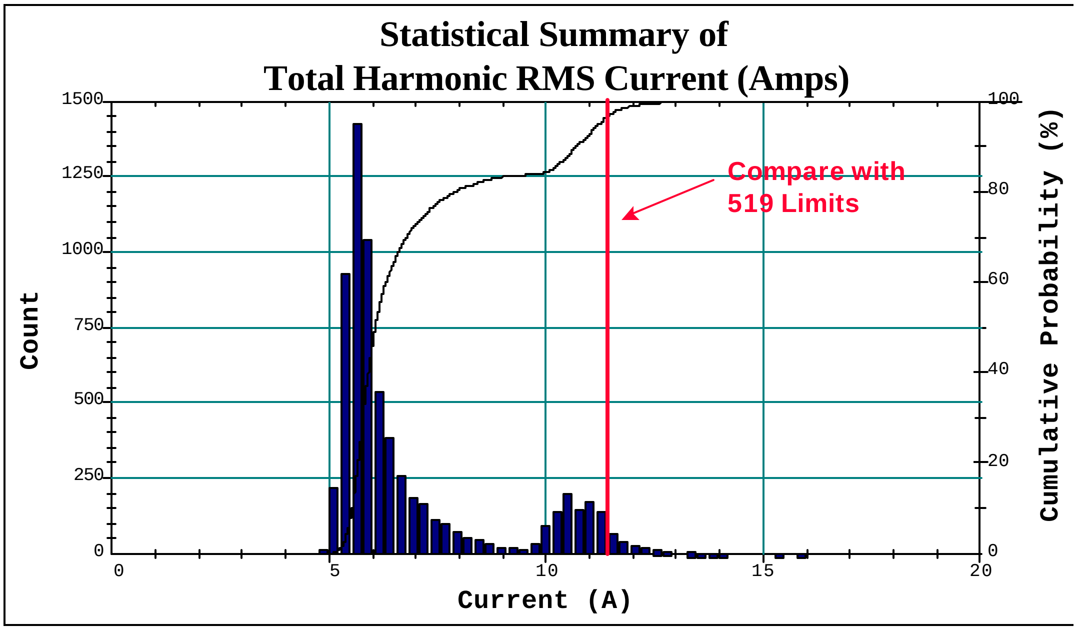

Figure 2. Representing the harmonic distortion as a statistical distribution for comparison with IEEE 519 limits.

How much nonlinear load can I have in my plant without exceeding IEEE 519 guidelines?

It is useful to look at a simple example system to help answer this question. Let's assume an industrial customer is supplied by a 1500 kVA transformer and that his average maximum demand load is 1200 kVA (see Figure 3). How much of this 1200 kVA of load could be adjustable speed motor drives without causing the plant to exceed IEEE 519 guidelines?

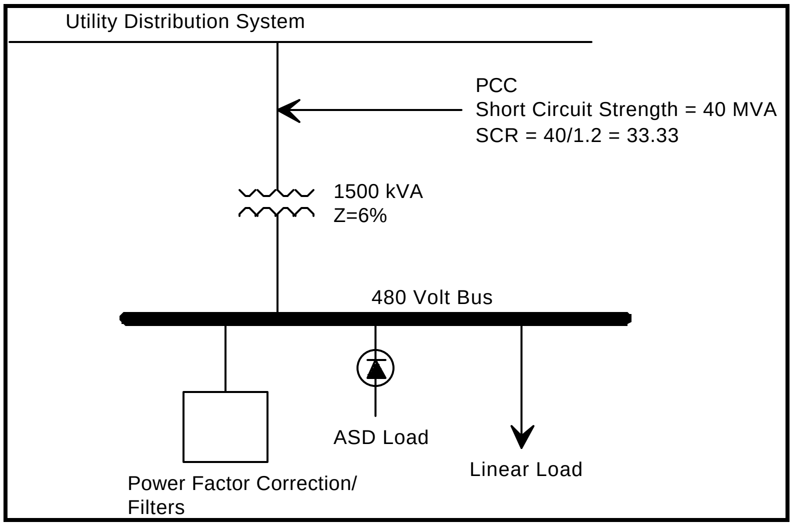

Figure 3. One line diagram for example evaluation of IEEE 519 limits.

Let's assume an adjustable speed drive current waveform that could be representative of ASD loads in the facility. The waveform in Figure 4 is typical of most modern ASDs with pulse width modulated inverters and diode bridge rectifier front ends. The waveform assumes a choke inductance is part of the design. If this waveform is characteristic of all the ASDs in the facility (not too bad an assumption for drives with diode bridge rectifier front ends), then the relationship plotted in Figure 5 can be derived. It shows that we reach the IEEE limit for the fifth harmonic current injection when the ASD load becomes about 20% of the plant load.

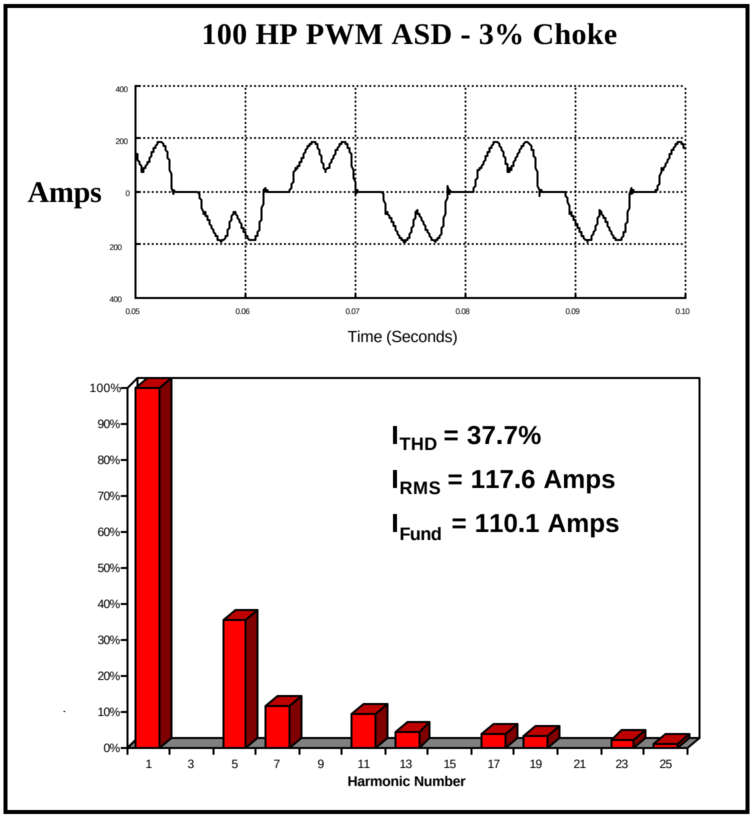

Figure 4. Adjustable speed drive current waveform assumed for the analysis.

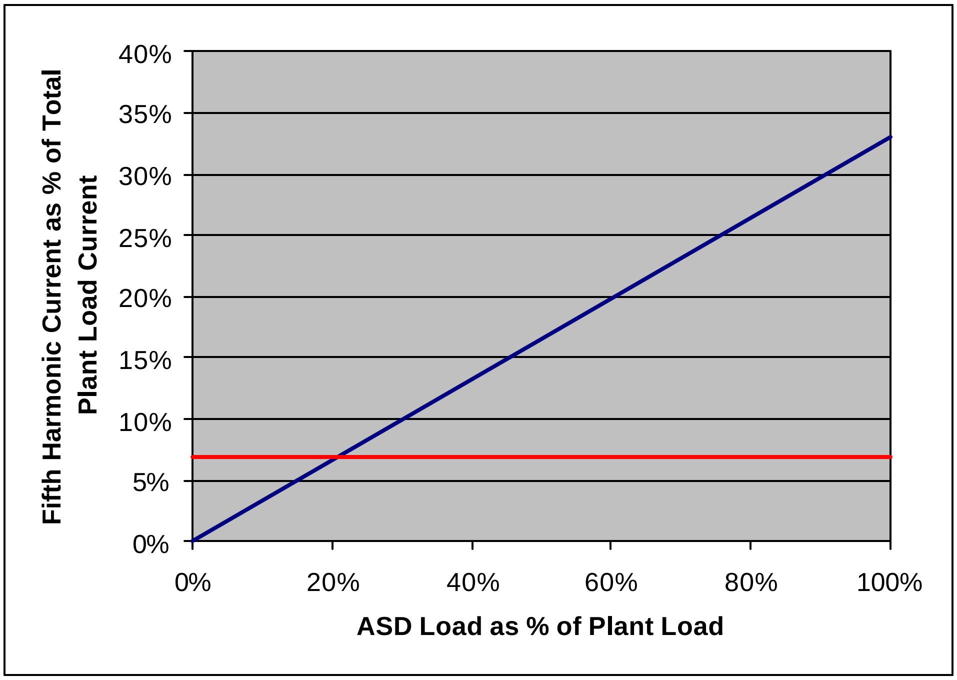

Figure 5. Fifth harmonic current distortion as a function of the ASD load in the facility.

Note that a higher percentage of ASD load might be acceptable in terms of the voltage distortion caused in the plant (typically, about 40% of the plant load could be ASDs without exceeding 5% voltage distortion).

The IEEE 519 limits were developed to prevent problems from the combination of all customers injecting harmonics onto the power system, not to prevent problems within a single customer facility.

A higher percentage of ASD load would be acceptable if 12 pulse drives were used or if harmonic filters were applied. If power factor correction is applied (not as filters), resonance problems could cause the limits to be exceeded for even less ASD load.

What if voltages inside my facility exceed the voltage distortion guidelines provided in IEEE 519?

The IEEE 519 voltage distortion guidelines should be applied at the PCC where multiple customers are supplied. This is usually the primary of the distribution system. If individual customers have higher voltage distortion numbers within their facilities, this is not necessarily a problem. We usually don't see equipment problems associated with voltage distortion for distortion levels less than 8%. In fact, the European guidelines for voltage distortion indicate a limit of 8%. This means that it should be acceptable in most cases (in fact it is quite common) for the voltage distortion inside facilities to exceed 5%.

Why are the limits for even harmonic components more strict than the limits for odd harmonic components?

Signficant levels of even harmonics in the voltage or the current are quite rare. You can tell there are even harmonic components present when the positive half cycle is different from the negative half cycle (waveform is not symmetrical). Even harmonics are often associated with transformer saturation (transformer inrush currents have high levels of even harmonics but this is a transient condition) which can be caused by dc currents. This association between dc currents and even harmonics resulted in a stricter limit on even harmonic components in the IEEE 519 standard. In fact, it is usually not necessary to apply this stricter limit because the impacts of even harmonic components are not any different than the impacts of odd harmonic components (at least at the levels specified as limits in IEEE 519). The presence of significant even harmonic components can make filter design to control harmonics very difficult because new resonances introduced by the filter can often magnify the even harmonic components.

Are there any guidelines for acceptable levels of interharmonic components?

This is an issue that really only comes up when we are dealing with loads like cycloconverters and arc furnaces. Interharmonics are frequency components in the voltage or current that are not integer multiples of the fundamental frequency. Unfortunately, IEEE 519 doesn't provide any guidance here. There is an IEEE task force working on developing some guidelines on control of interharmonics. It is also an active topic in IEC. However, there are no well-accepted standards for interharmonic levels at this time. One design objective that we have used for some arc furnace applications is to limit the interharmonic components to less than 25% of the coresponding integer harmonic limits specified in IEEE 519-1992.

How can we apply the IEEE 519 limits when we have power factor correction capacitors or harmonic filters?

Capacitors and filters make the application of the 519 limits difficult to evaluate because these components will absorb harmonics from the power system. In fact, customers need to be careful when applying power factor correction or filters to make sure they are designed for the harmonics they will absorb from the power system. The customer shouldn't be penalized for acting like a filter to the power system. Unfortunately, we can't tell which direction the harmonics are going when we make a measurement at a single point. There are ways to get around this by measuring over time but it is getting beyond the scope of this particular article. Why don't we just make this a two part article and I will cover it in the next issue. I've been wanting to cover the topic of active filters vs. passive filters anyway and it is part of this overall topic. I warned you that, once I got started, I wouldn't be able to get off the topic of harmonics.

Anyway, I hope this article might have addressed some of your burning questions on IEEE 519. If you have others, I'd love to hear them.