# Harmonic Limit Compliance Evaluations Using IEEE 519-1992

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**Abstract**: The end-use application of harmonic simulation studies usually involves an assessment of limit compliance. This chapter of the tutorial is devoted to various limit evaluations using the procedures in IEEE 519-1992 and the proposed IEEE 519A, the "application guide" for 519. The procedures are demonstrated based on a sample system with typical nonlinear load characteristics. It is assumed that the reader is familiar with the harmonic study method details presented in the previous sections of this tutorial.

## 10.1 INTRODUCTION

There are two distinct thought processes that can be applied to limit the amount of harmonics that are present in power systems. The first, favored by the International Electrotechnical Commission (IEC), is a series of limits that is appropriate for application *at the terminals* of any particular nonlinear load. The second, favored by the IEEE and the basis for IEEE 519-1992 [1], is a series of limits that is appropriate for application at a single more central point of supply to multiple nonlinear loads.

The philosophy of the IEC limits is based on the presumption that limiting harmonic production from every piece of equipment will effectively limit any combined effects. While conceptually effective, the assumptions made in developing the actual limits are quite different from those in IEEE 519-1992 and it has been shown that the IEEE limits are somewhat more restrictive due the use of both voltage and current harmonic limits.

The IEEE limits for voltage and current harmonics shown in Tables 10.1-10.4 are dependent on several variables and concepts defined as follows:

PCC: Point of common coupling. This point is defined as the point in the utility service to a particular customer where another customer could be connected.

$I_{SC}$: Available short circuit current.

$I_L$: 15 or 30 minute (average) maximum demand current.

TDD: Total demand distortion. TDD is identical to THD except $I_L$ (as defined previously) is used instead of the fundamental current component.

Note also that there are a number of appropriate footnotes that govern the application of the limit values given. The reader is strongly encouraged to consult the Standard for this additional information.

Table 10.1. Current Distortion Limits (in % of $I_L$) for General Distribution Systems (120-69,000 V) [1]

| $I_{SC}/I_L$ | <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 |

Table 10.2. Current Distortion Limits (in % of $I_L$) for General Subtransmission Systems (69,001-161,000 V) [1]

| $I_{SC}/I_L$ | <11 | 11≤h<17 | 17≤h<23 | 23≤h<35 | 35≥h | TDD |
|---|---|---|---|---|---|---|
| <20 | 2.0 | 1.0 | 0.75 | 0.3 | 0.15 | 2.5 |
| 20-50 | 3.5 | 1.75 | 1.25 | 0.5 | 0.25 | 4.0 |
| 50-100 | 5.0 | 2.25 | 2.0 | 0.75 | 0.35 | 6.0 |
| 100-1000 | 6.0 | 2.75 | 2.5 | 1.0 | 0.5 | 7.5 |
| >1000 | 7.5 | 3.5 | 3.0 | 1.25 | 0.7 | 10.0 |

Table 10.3. Current Distortion Limits (in % of $I_L$) for General Transmission Systems (>161,000 V) [1]

| $I_{SC}/I_L$ | <11 | 11≤h<17 | 17≤h<23 | 23≤h<35 | 35≥h | TDD |
|---|---|---|---|---|---|---|
| <50 | 2.0 | 1.0 | 0.75 | 0.3 | 0.15 | 2.5 |
| ≥50 | 3.0 | 1.5 | 1.15 | 0.45 | 0.22 | 3.75 |

Table 10.4. Voltage Distortion Limits (in % of $V_1$) [1]

| PCC Voltage | Individual Harmonic Magnitude (%) | $THD_V$ (%) |
|---|---|---|
| ≤69 kV | 3.0 | 5.0 |
| 69-161 kV | 1.5 | 2.5 |
| ≥161 kV | 1.0 | 1.5 |

The thought processes behind these tables are that 1) the customer should be responsible for limiting harmonic currents in accordance with Tables 10.1-10.3 and 2) the utility should be responsible for limiting harmonic voltages in accordance with Table 10.4. The numerical values in the voltage and current tables are not independent however. The values in Table 10.4 can be derived from those in Tables 10.1-10.3 by assuming that the $I_{SC}/I_L$ ratio specifies an equivalent inductive reactance.

Before beginning the case study examples demonstrating the use of these tables, it must be stressed that the values are intended as *guides* and may require modification to fit the particulars of a given situation. In practice, there are a number of "gray" areas where discretion is required and concessions from both the utility and the customer may be necessary.

## 10.2 GENERAL PROCEDURE FOR APPLYING HARMONIC LIMITS

The following series of steps outlines a general procedure for applying harmonic limits:

Step 1: Choose the point of common coupling,

Step 2: Characterize the harmonic-producing loads,

Step 3: Assess power factor correction needs,

Step 4: Calculate expected harmonics at the PCC,

Step 5: Design and implement solutions (if needed), and

Step 6: Verify performance with measurements.

As the case study examples will show, it is not necessarily required that a complete and detailed harmonic study be conducted. The concept of "automatic acceptance" is sufficient for the majority of smaller utility customers and can often serve to eliminate the need for a comprehensive simulation. The "automatic acceptance" procedure requires completion of only the first three steps while a complete simulation often covers the first five steps. While not a simulation issue, result verification via measured data is always recommended especially if equipment additions were required to correct a limit violation.

## 10.3 AUTOMATIC ACCEPTANCE

As previously described, there are many cases involving smaller customers where a complete harmonic study is not required. It is possible to evaluate limit compliance issues at the PCC without detailed studies provided that the short-circuit kVA is much greater than a weighted sum total of the nonlinear load kVA supplied from the PCC. The following series of four steps outlines the procedure for "automatic" verification of limit compliance:

Step 1: Determine $S_{SC}$ (short-circuit kVA) at the PCC.

Step 2: Determine the size and type of nonlinear load served.

Step 3: Evaluate $S_{DW} = \sum_i S_{D_i} * W_i$, where $S_{Di}$ is (kVA) demand of the $i^{th}$ nonlinear load.

Step 4: Accept automatically (limits will be met) if

$$\frac{S_{DW}}{S_{SC}} * 100\% < 0.1\% .$$

The weighting factors $W_i$ are given in Table 10.5 for various common nonlinear loads. In general, the weight is larger for nonlinear loads that produce a more distorted ac current.

Table 10.5. Weighting Factors for Automatic Acceptance Procedures

| Type of Load | $W_i$ |
|---|---|
| Single Phase SMPS | 2.5 |
| Semiconverter | 2.5 |
| 6 pulse converter, no choke | 2.0 |
| 6 pulse converter, >3% choke | 1.0 |
| 6 pulse converter, large series L | 0.8 |
| 12 pulse converter | 0.5 |

## 10.4 COMPREHENSIVE LIMIT COMPLIANCE EVALUATIONS

The previous chapters of this tutorial have considered the modeling and analysis requirements for a harmonic study in detail. In general, the analyst is free to choose their own analysis procedure, but the following capabilities are essential for limit compliance evaluations:

1. Modeling of network components such as overhead lines, cables, transformers, etc. (The analyst has some flexibility in selecting the level of detail needed; sensitivity studies should be considered to determine which degrees of detail can be avoided in any particular study.)
2. Modeling of various nonlinear loads including pre-defined models and the capability for user-defined models based on measured or typical data. (It is left to the analyst to determine what degree of sophistication is required, especially if time-domain simulation techniques are to be used.)

3. Modeling of power factor correction capacitors should be “built in” to any software being considered. (The representation of the equivalent capacitance is the most important requirement; other details are somewhat insignificant for limit compliance evaluations.)
4. Modeling of utility system equivalents should be straightforward. (In an advanced study, the analyst should consider the capability to represent the frequency dependence of network equivalents.)

Fortunately, there are a great number of computer packages available that easily meet (and exceed) these requirements. A key point is that the level of accuracy available in the program should match 1) the level of accuracy available in the data and 2) the level of accuracy required in the results. It is up to the analyst to make this determination for each compliance issue to be investigated.

The end result of the detailed harmonic analysis must be the voltages and currents at the PCC. (Note that similar values at other system locations may be of interest in a given study but they are not relevant to limit compliance evaluation.) Given these values, the system strength (as indicated by the available short-circuit at the PCC), and the average maximum demand current at the PCC, a simple comparison to the limit values given in Tables 10.1-10.4 is all that is required.

## 10.5 CASE STUDIES

The following case studies demonstrate limit compliance based on both the automatic acceptance criteria and the detailed harmonic analysis procedures described previously. Figure 10.1 shows the single-line diagram of the example system. As is typical, only positive sequence data is used in these studies due to the assumed balanced nature of the system. The short circuit MVA, $S_{SC}$, and the average maximum demand, $S_{AVG,MAX}$, at the PCC are total (three-phase) values.

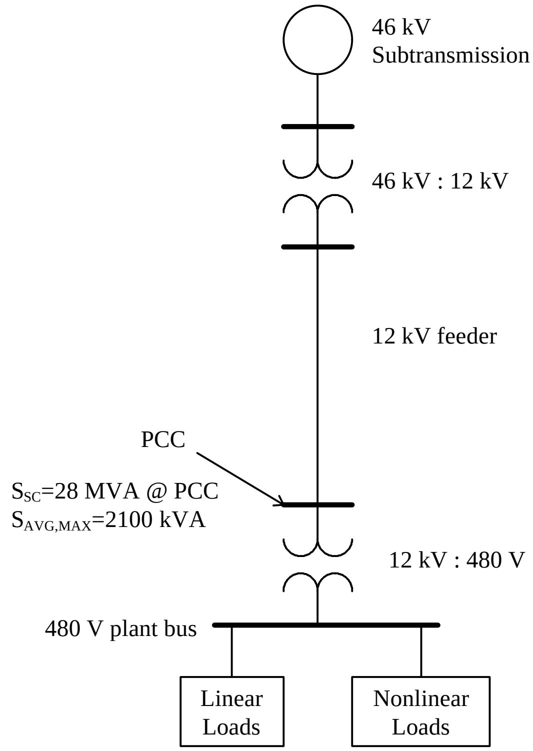


Figure 10.1. Example System for Limit Compliance Case Studies

The nonlinear loads are known to be 50 kVA of small PWM motor drives (no choke) and 100 kVA of small PWM drives (with 3% inductive choke). The harmonic current spectra for these two loads are shown in Table 10.6. Note that it is important to use the provided harmonic current phase angles to account for possible harmonic current cancellation at the PCC.

Table 10.6. Harmonic Current Spectra for Nonlinear Loads

| | 50 kVA Load (no choke) | | 100 kVA Load (3% choke) | |
|---|---|---|---|---|
| h | $I_h$ (%) | $\theta_h$ (°) | $I_h$ (%) | $\theta_h$ (°) |
| 1 | 100.00 | -7.40 | 100.00 | -15.50 |
| 5 | 72.46 | -219.03 | 34.81 | -268.72 |
| 7 | 51.03 | -56.20 | 10.76 | -176.84 |
| 11 | 13.75 | -285.10 | 6.30 | -149.36 |
| 13 | 5.02 | -172.22 | 3.24 | -118.55 |
| 17 | 5.27 | -113.89 | 2.48 | -53.90 |
| 19 | 3.51 | -334.00 | 1.89 | -36.00 |
| 23 | 2.21 | -288.60 | 1.16 | -332.30 |
| 25 | 2.17 | -153.11 | 1.12 | -309.20 |

*Automatic Acceptance Evaluation*

The data given in Figure 10.1 and Tables 10.5 and 10.6 can be used to make quick limit compliance evaluations. Based on the descriptions of the load, the weighting factors in Table 10.6, and the short-circuit MVA at the PCC, the following calculation demonstrates that automatic acceptance is not recommended.

$$\frac{S_{DW}}{S_{SC}} = \frac{50*2+100*1}{28{,}000}*100\% = 0.71\%$$

This result is not a true indicator that harmonic limits will be violated due to the fact that the resultant 0.71% is only slightly greater than the 0.1% required for automatic acceptance. However, the fact that the 0.71% is not low enough for automatic acceptance indicates that a detailed harmonic study should be conducted to evaluate the true nature of the harmonic voltages and currents at the PCC before a limit violation is declared. Unfortunately, there is no way to correlate (for the general case) the amount by which the 0.71% result exceeds the 0.1% criteria with whether or not a detailed study will indicate limit violations. Values slightly greater than 0.1% could lead to violations if strong system resonances are present at frequencies near those generated by the load(s) in question.

*Detailed Harmonic Study*

The data given in Figure 10.1 and Table 10.6 can be used to conduct a detailed harmonic study using any one of a number of available computer programs. Based on an equivalent impedance of 2.286+j5.151 Ω/phase seen looking from the PCC to the subtransmission system, Table 10.7 gives the harmonic current magnitudes calculated at the PCC in both amperes and in percent of the average maximum demand current (=97.22 A).

The final step in the process is the comparison of the first row in Table 10.1 (based on the ratio $I_{SC}/I_L$=13.3) and the third column of Table 10.7. This comparison is given in Table 10.8 and shows that limit compliance is not a problem for this example case study (the more accurate calculation approach should overrule the more approximate "automatic acceptance" criteria).

Table 10.7. PCC Currents for Limit Compliance Evaluation

| | Currents @ PCC | |
|---|---|---|
| h | $I_h$ (A) | $I_h$ (% of $I_L$) |
| 1 | 95.44 | 98.16 |
| 5 | 3.52 | 3.62 |
| 7 | 2.24 | 2.30 |
| 11 | 0.47 | 0.49 |
| 13 | 0.43 | 0.44 |
| 17 | 0.32 | 0.33 |
| 19 | 0.20 | 0.21 |
| 23 | 0.12 | 0.12 |
| 25 | 0.02 | 0.02 |

Table 10.8. Evaluation of Simulated Results with IEEE 519-1992 Limits

| | Currents @ PCC | |
|---|---|---|
| h | Limit (% of $I_L$) | $I_h$ (% of $I_L$) |
| 5 | 4.0 | 3.62 |
| 7 | 4.0 | 2.30 |
| 11 | 2.0 | 0.49 |
| 13 | 2.0 | 0.44 |
| 17 | 1.5 | 0.33 |
| 19 | 1.5 | 0.21 |
| 23 | 0.6 | 0.12 |
| 25 | 0.6 | 0.02 |
| TDD | 5.0 % | 4.44 % |

The reader should be cautioned that using different software packages may produce results different from those shown in Tables 10.7 and 10.8. It is, therefore, important for the analyst to have a complete understanding of both the harmonic theory and the particular techniques used and assumptions made by the software being used.

## 10.6 REFERENCES


1. IEEE Standard 519-1992, *Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*, The Institute of Electrical and Electronics Engineers, 1993.