# Understanding the Relationship between Current Total Harmonic Distortion (iTHD) and Total Demand Distortion (TDD) in IEEE Std 519-2014

**Overview:**

Among those trying to apply the harmonic limits of IEEE Std 519-2014, there seems to be some confusion on the difference between Total Harmonic Distortion (THD) and Total Demand Distortion (TDD). This paper is written to provide clarity and direction on how to apply the Standard's current distortion limits as they were intended for an existing site operating for at least one year. There is also some comment on how to apply the standard during the design phase of a new or retrofit project, but for further discussion on that, please refer to an earlier published paper entitled, 'A Practical and Effective Way of Applying IEEE Std 519-2014 Harmonic Limits'.

Let's begin with the ultimate stated goal of IEEE Std 519-2014 found in the Introduction section, Page viii:

> *The limits in this recommended practice represent a shared responsibility for harmonic control between system owners or operators and users. Users produce harmonic currents that flow through the owner's or operator's system, which lead to voltage harmonics in the voltages supplied to other users. The amount of harmonic voltage distortion supplied to other users is a function of the aggregate effects of the harmonic current producing loads of all users and the impedance characteristics of the supply system.*
>
> *Harmonic voltage distortion limits are provided to reduce the potential negative effects on user and system equipment. Maintaining harmonic voltages below these levels necessitates that*

- *All users limit their harmonic current emissions to reasonable values determined in an equitable manner based on the inherent ownership stake each user has in the supply system and*
- *Each system owner or operator takes action to decrease voltage distortion levels by modifying the supply system impedance characteristics as necessary.*

So, the ultimate goal is to control voltage distortion by limiting current harmonics injected into the Source/System Impedance. The relevant Voltage Distortion Limits are covered in Table 1, Section 5.1 – Recommended voltage harmonic limits, Page 6.

TABLE I
VOLTAGE DISTORTION LIMITS IN IEEE STD 519-2014

| Bus voltage $V$ at PCC | Individual harmonic (%) | Total harmonic distortion THD (%) |
|---|---|---|
| $V \leq 1.0$ kV | 5.0 | 8.0 |
| 1 kV $< V \leq$ 69 kV | 3.0 | 5.0 |
| 69 kV $< V \leq$ 161 kV | 1.5 | 2.5 |
| 161 kV $< V$ | 1.0 | 1.5 |

To achieve these voltage distortion targets, the maximum current harmonic injection allowed at a predetermined location within the circuit, a Point of Common Coupling (PCC), is defined within the Standard Section 3, Page 4:

> *Point of Common Coupling (PCC): Point on a public power supply system, electrically nearest to a particular load, at which other loads are, or could be, connected. The PCC is a point located upstream of the considered installation.*

Highlighted within the Standard are some common locations to be considered for the PCC but the actual choice is left up to the End User,


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Consulting Engineer or Utility. Typically, the evaluation is at the Primary Metering location where the voltage distortion, being created by the site's current harmonic injection into the source impedance, can be controlled to limit the effect on the consumer and other Users connected to the system. It is highlighted that applying the limits to individual loads is not recommended. But it is important to note that applying the current limits at all of the larger individual loads will almost certainly result in the limits being met at any upstream PCC.

**Definitions of THD and TDD**:

A definition is included within the Standard for Total Harmonic Distortion (THD) which can be applied to either voltage distortion or current distortion. Also included is a definition for Total Demand Distortion (TDD) which only has application with respect to current distortion. The definitions per Section 3 are as follows:

> *Total Harmonic Distortion (THD): The ratio of the root mean square of the harmonic current, considering harmonic components up to the 50th order and specifically excluding interharmonics, expressed as a percentage of the fundamental. Harmonic components of order greater than 50 may be included when necessary.*

> *Total Demand Distortion (TDD): The ratio of the root mean square of the harmonic current, considering harmonic components up to the 50th order and specifically excluding interharmonics, expressed as a percentage of the maximum demand current. Harmonic components of order greater than 50 may be included when necessary.*

Since THD can be applied to both current and voltage distortion, for clarity, voltage distortion will be referred to as vTHD and current distortion as iTHD. For consistency, we will also use iTDD for Total Demand Distortion. Also it's worth noting that, although harmonic components up to the $50^{th}$ order are defined in the definitions, they also allow for harmonic components above the $50^{th}$ to be included when necessary. This is to recognize that active solutions, such as Active Front End Drives and parallel Active Harmonic Filters will inject higher order harmonics above the $50^{th}$ (3 kHz for 60 Hz systems) which can often lead to power quality problems. For more discussion on this, please refer to the previously published paper IEEE PCIC-2018-43 entitled 'Active Harmonic Mitigation – What the Manufacturers Don't Tell You'.

As can be seen, the definitions for current distortion are similar except for one important aspect. iTHD is expressed as a percentage of fundamental while iTDD is a percentage of maximum demand current. This may seem subtle but the difference is actually very important when the definition for maximum demand current is considered.

> *Maximum Demand Current ($I_L$): The current value at the PCC taken as the sum of the currents corresponding to the maximum demand during each of the 12 previous months divided by 12.*

This value can only be determined if there is a record of the previous 12 months of operation. When evaluation is being done for a new installation or redesign, it is impossible to definitively determine compliance with IEEE Std 519-214 current distortion limits since the maximum demand history will not be available. Please refer to the earlier referenced paper when evaluating a new or redesign application.

**Converting iTHD to iTDD and Determining Compliance:**

For an existing system when a one year electrical history is available:

***iTDD = iTHD x (fundamental current at time of iTHD measurement/average demand current over the previous 12 month period)***

***or***

***iTDD = iTHD x (If/IL)***

Example:

| Month | Peak Demand Current @ PCC (Amp) |
|---|---|
| March | 1150 |
| April | 1410 |
| May | 1335 |
| June | 1240 |
| July | 1350 |
| August | 1390 |
| September | 1260 |
| October | 1314 |
| November | 1262 |
| December | 1203 |
| January | 1237 |
| February | 1087 |
| 12 mo. average | 1270 |

iTHD at time of measurement:  11.5%

Fundamental current load at time of measurement:  975A

iTDD = 11.5 x 975/1270 = 8.83%

With iTDD calculated, it can be compared against the limits as defined in Table 2 – Current distortion limits for systems rated 120V through 69kV, found in Section 5.2 Page 7.

**Table 2—Current distortion limits for systems rated 120 V through 69 kV**

| Maximum harmonic current distortion in percent of $I_L$ | | | | | | |
|---|---|---|---|---|---|---|
| Individual harmonic order (odd harmonics)[a, b] | | | | | | |
| $I_{SC}/I_L$ | $3 \le h < 11$ | $11 \le h < 17$ | $17 \le h < 23$ | $23 \le h < 35$ | $35 \le h \le 50$ | TDD |
| $< 20$[c] | 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 |

[a]Even harmonics are limited to 25% of the odd harmonic limits above.

[b]Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

[c]All power generation equipment is limited to these values of current distortion, regardless of actual $I_{sc}/I_L$.

where

$I_{sc}$ = maximum short-circuit current at PCC

$I_L$ = maximum demand load current (fundamental frequency component) at the PCC under normal load operating conditions

To determine the limit that applies, calculation of the Short Circuit Ratio (SCR) is required.  SCR is defined in the Standard as follows:

> *Short Circuit Ratio ($I_{SC}/I_L$):  At a particular location, the ratio of the available short-circuit current, in amperes, to the load current, in amperes.*

For this example, let's assume the Maximum Short Circuit current at the PCC is around 65 kA, then the Short Circuit Ratio would be 66.7 (65000/975). Per Table 2, the TDD limit would be 12%, and the corresponding calculated value of 8.86% would be comfortably within that limit.

But, if the Short Circuit current was instead 45 kA, the calculated SCR would be 46 resulting in a TDD limit of 8%.  This results in the calculated TDD of 8.86% exceeding the limit.

The rational for more stringent limits on 'weaker' systems is understandable since the higher impedance would result in higher voltage distortion levels created from the injected harmonic currents.

Often an existing site will not have access to a full year history of monthly peak current demand but confirmation of IEEE Std 519-2014 compliance may still be required.  In those circumstances, it is still not appropriate to simply take an iTHD measurement and use that to determine compliance.  Instead, it is recommended that a power quality analyzer be left connected for at least a few days to try to capture a period of heaviest demand load.  The iTHD measured at the time of that peak demand can then be used as the TDD value.   If a higher peak demand can be proven to occur under certain expected operating conditions, this can also be used to calculate the ratio of measured current to peak demand current and applied to the measured iTHD to determine iTDD.

**Voltage Distortion versus Current Distortion:**

As mentioned earlier, the stated objective of IEEE Std 519-2014 is to control the source voltage distortion since that is the critical objective to controlling the power quality subjected to other Users connected to the distribution system. That being said, the current harmonic limits included in the Standard are based on mathematical projections and calculations. This may result in situations where the required limits for voltage distortion may be met but the current harmonics are not, or vice versa. When applied at a proper PCC, both vTHD and iTDD limits should be met.

Factors that can lead to only one set of limits being met are (i) applying the current limits as iTHD instead of iTDD, (ii) using incorrect data for the Available Short Circuit and/or calculating the Short Circuit Ratio incorrectly, (iii) extremely high source impedance that produces high vTHD even with low levels of iTHD, (iv) high levels of background voltage distortion from the Source and (v) contributions of resonance due to power factor correction capacitors within the system. This last item is referenced in the Introduction Section Page viii of the Standard:

> *When reactive power compensation, in the form of power factor improvement capacitors, is used, resonant conditions can occur that may result in high levels of harmonic voltage and current distortion when the resonant condition occurs at a harmonic associated with non-linear loads.*

When reviewing any given installation and/or application, the primary goal should be to comply with the required vTHD and iTDD at an appropriate Point of Common Coupling.

**Conclusion:**

- The goal of any IEEE Std 519-2014 compliance review should be to meet the voltage distortion, vTHD, and current distortion, iTDD, limits as set forth in Table 1 and Table 2 of the Standard at an appropriate Point of Common Coupling.
- iTHD should never be used to determine compliance with current distortion limits. iTHD should only be used to calculate iTDD which then should be used to determine compliance.
- In order to fully understand the factors that will impact on the review, consideration should be given to all relevant harmonic impact sources, including the presence of Power Factor Corrective equipment or Static Var Compensation, upstream or within the subject load structure.
- Source based voltage conditions, such as background voltage distortion and load/source voltage imbalance, should be noted and understood since these factors can and will have a dramatic effect on the overall harmonic condition.
- For existing systems, a proper value must be established for a Peak Demand Current 12 month average. If this is not available, a power quality analyzer should be used to measure iTHD and load current readings over the longest period of time that is practical in order to capture the peak demand. iTHD measured at the peak load can then be used as iTDD to determine compliance. For new or retrofit installations a realistic peak demand value must be calculated based on estimated maximum load projections.


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