UNDERSTANDING CURRENT & VOLTAGE HARMONICS

Current and voltage harmonics are often used interchangeably. At most places, only harmonics is quoted and whether the values pertain to current or voltage is not mentioned. The differentiation can be done on the basis of their origin.

Understanding Total Harmonic Distortion

The current and voltage harmonics in a system are often expressed as Total Harmonic Distortion (THD). The total harmonic distortion, or THD, of a quantity is a measurement of the harmonic distortion present and is the ratio of all harmonic components to the fundamental component. It is given by the formula as under:

$$THD_Y = \frac{\sqrt{\sum_{h=2}^{\infty} Y_h^2}}{Y_1}$$

Where, Y_1 is the rms value of fundamental
Y_h is the rms value of hth harmonic

Hence, current THD is the ratio of the root-mean-square value of the harmonic currents to the fundamental current.

$$I_{THD} = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1}$$

Where do Current & Voltage Harmonics Originate?

Harmonics always originate as current harmonics and voltage harmonics are the results of current harmonics. Current harmonics originate because of the presence of non-linear loads like variable speed drives, inverters, UPS, television sets, PCs, semiconductors circuits, welding sets, arc furnaces in the system. They act as harmonic current sources. The resulting current waveform can be quite complex depending on the type of load and its interaction with other components of the system.
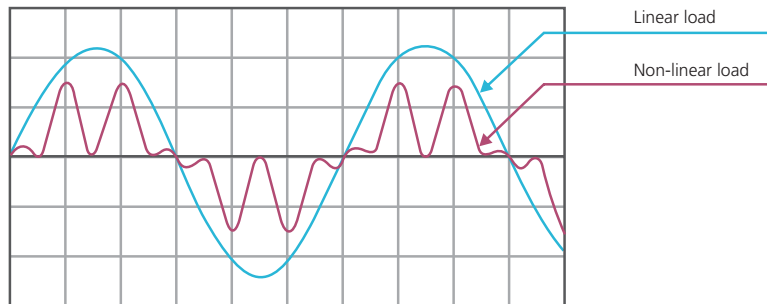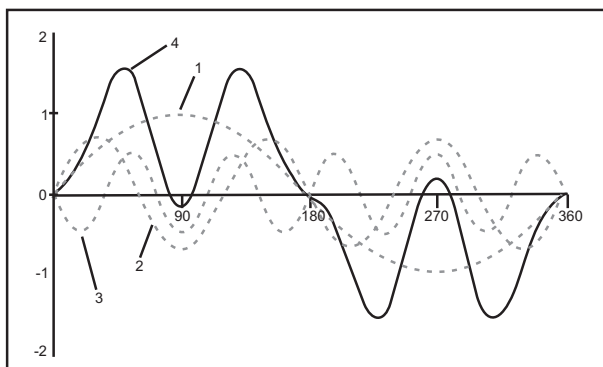

Linear load

Non-linear load

Fig 1: Linear & Non-Linear Loads

The distorted current waveforms can be represented as the sum of current waveform of fundamental frequency and of its multiples (harmonics):

$$f(t) = \sum_{h=1}^{\infty} (C_h \, Sin(h\omega_0 t + \varphi h))$$

Where,

c_h - Magnitude of nth order harmonics
φ_h - Phase angle of nth order harmonics

Fig 2: Current waveform as sum of fundamental frequency component and its multiples

Voltage harmonics do not originate directly from non-linear loads. The current harmonics (distorted waveform) flow through system impedance (source and line impedances) and cause harmonic voltage drop across the impedances. This will distort the supply voltage waveform. Thus voltage harmonics are generated. Long cable runs, high impedance transformers, etc. contribute to higher source impedance and hence, higher voltage harmonics.

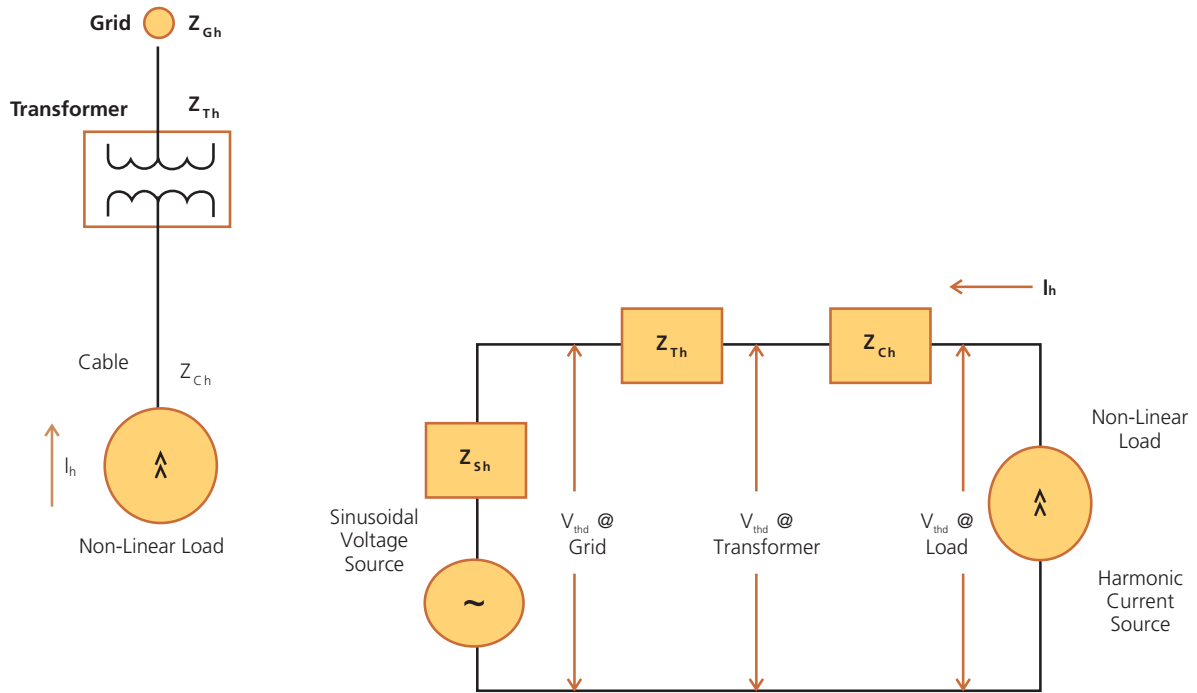A typical power system has the following impedances as indicated in the line diagram:

Fig 3: Impedance in a power system

In the above diagram,

V_h = h^{th} harmonic voltage

I_h = h^{th} harmonic current

Z_h = Impedance at h^{th} harmonic

V_{thd} = Voltage total harmonic distortion

At load, $V_h = I_h \times (Z_{Ch} + Z_{Th} + Z_{Gh})$

At transformer, $V_h = I_h \times (Z_{Th} + Z_{Gh})$

At grid, $V_h = I_h \times (Z_{gh})$

Usually, grid impedances are very low and hence, the harmonic voltage distortions are also low there. However, they may be unacceptably higher on the load side as they are subjected to full system impedance there. Hence, it becomes important where the harmonics measurements are done.

However, in case of DG sets, the source impedance is large resulting in high voltage harmonics despite small current harmonics. Thus, a clear distinction between current and voltage harmonics becomes important here.

An industry, say industry A, that has large non-linear loads will generate huge current harmonics in its system. A nearby industry, say industry B, connected to the same grid may not have non-linear loads, yet, it may be subjected to high voltage harmonics. These voltage harmonics are the result of high current harmonics of industry A and impedance of grid & transformer. Thus, industry B despite small current harmonics, has high voltage harmonics. However, if industry B goes for power factor correction, then, due to the presence of capacitors, current harmonics may also appear in the system, magnifying voltage harmonics further.

How do Current & Voltage Harmonics Affect the System?

Current harmonics increase the rms current flowing in the circuit and thereby, increase the power losses. Current harmonics affect the entire distribution all the way down to the loads. They may cause increased eddy current and hysteresis losses in motor and transformers resulting in over-heating, overloading in neutral conductors, nuisance tripping of circuit breakers, over-stressing of power factor correction capacitors, interference with communication etc. They can even lead to over-heating and saturation of reactors.

Voltage harmonics affect the entire system irrespective of the type of load. They affect sensitive equipment throughout the facility like those that work on zero-voltage crossing as they introduce voltage distortions.

Understanding IEEE 519 Guidelines

The purpose of harmonic limits in a system is to limit the harmonic injection from individual customers to the grid so that they do not cause unacceptable voltage distortion in the grid. IEEE 519 specifies the harmonic limits on Total Demand Distortion (TDD) and not Total Harmonic Distortion (THD). TDD represents the amount of harmonics with respect to the maximum load current over a considerable period of time (not the maximum demand current), whereas, THD represents the harmonics content with respect to the actual load current at the time of measurement.

It is important to note here that a small load current may have a high THD value but may not be significant threat to the system as the magnitude of harmonics is quite low. This is quite common during light load conditions.

TDD limits are based on the ratio of system's short circuit current to load current (I_{sc}/I_L). This is used to differentiate a system and its impact on voltage distortion of the entire power system. The short circuit capacity is a measure of the impedance of the system. Higher the system impedance, lower will be the short circuit capacity and vice versa.

The Guidelines IEEE 519-2014 at PCC Level are as under:

Current distortion limits for General Distribution systems (120V Through 69 kV)						
Maximum Harmonic Current Distortion in %I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{sc}/I_L	$3 \leqslant h < 11$	$11 \leqslant h < 17$	$17 \leqslant h < 23$	$23 \leqslant h < 35$	$35 \leqslant h \leqslant 50$	**TDD**
<20	4.00%	2.00%	1.50%	0.60%	0.30%	5.00%
20-50	7.00%	3.50%	2.50%	1.00%	0.50%	8.00%
50-100	10.00%	4.50%	4.00%	1.50%	0.70%	12.00%
100-1000	12.00%	5.50%	5.00%	2.00%	1.00%	15.00%
>1000	15.00%	7.00%	6.00%	2.50%	1.40%	20.00%

where
I_{sc} = maximum short-circuit current at PCC [Can be calculated as MVA/(%Z x V)]
I_L = maximum demand load current (fundamental frequency component) at PCC

Systems with higher I_{SC}/I_L have smaller impedances and thus they contribute less in the overall voltage distortion of the power system to which they are connected. Thus, the TDD limits become less stringent for systems with higher I_{SC}/I_L values. In other words, higher the rating of transformer used for the same amount of load, higher will be the allowable current distortion limits.

Voltage distortion limits		
Bus Voltage at PCC	**Individual Voltage Distortion**	**V_{THD}**
V ⩽ 1.0 kV	5.00%	8.00%
1 kV ⩽ V ⩽ 69 kV	3.00%	5.00%
69 kV ⩽ V ⩽ 161 kV	1.50%	2.50%
> 161 kV	1.00%	1.50%

The limits on voltage are set at 5% for total harmonic distortion and 3% of fundamental for any single harmonic at PCC level. Harmonics levels above this may lead to erratic functioning of equipment. In critical applications like hospitals and airports, the limits are more stringent (less than 3% V_{THD}) as erroneous operation may have severe consequences. As discussed already, the harmonic voltage will be higher downstream in the system.

Solutions for Current & Voltage Harmonics

Current Harmonics (I_{THD})	Voltage Harmonics (V_{THD})	Recommended Solutions**
High	Low (≤5%)	Detuned Harmonic Filter with (SHD / LTXL)480 V Capacitors and/or Active Harmonic Filter
High	High (>5%)	Active Harmonic Filter and 525 V (SHD / LTXL Cyl) Capacitors
Low	High (>5%)	Grid may be polluted with imported voltage harmonics. It may not be possible to reduce them at the load side. Check with utility to rectify

**These are typical solutions. However the actual solution may vary depending up on the actual harmonic content in the system.