Voltage Distortion – Cause and Effect

Cause

System harmonic voltage distortion is caused by the flow of harmonic currents through system impedance, namely inductive reactance. For each frequency, at which harmonic current is flowing, there is a corresponding inductive reactance associated with system and thus a voltage drop at that frequency. The factors that affect the system inductive reactance are the generator, transformer, series line reactors or current limiting reactors, and circuit conductors.
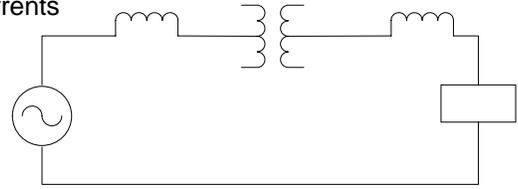
Fig. 1

When the load current consists of fundamental current and 5th harmonic current, there will be a voltage drop across the system impedance at both the fundamental and 5th harmonic frequencies. The presence of any harmonic voltage causes distortion of the system voltage. The voltage will be the least distorted nearest to its generating source and will become more distorted nearer to the load, as the harmonic current flows through larger amounts of impedance. If the load in Fig. 1 draws harmonic current, the highest level of voltage distortion will be present at the load terminals, less voltage distortion at the transformer secondary terminals and less distortion yet at the generator and its associated source impedance.

Effect on other equipment

The major problem with voltage distortion is that other loads supplied by a distorted voltage source may not operate properly or efficiently. When an electrical load is supplied with distorted voltage, then it receives harmonic voltage in addition to the fundamental frequency voltage. If a load is supplied with a harmonic voltage, then it will also draw harmonic current (for each frequency of applied voltage). Any non-linear load, drawing distorted current, will cause harmonic voltage distortion. The magnitude of voltage distortion will depend on the magnitude of harmonic currents flowing from source to load and the circuit impedances that this current flows through between the source and load.

Nema STD MG-1, part 30.1.2 explains that motor efficiency is reduced, electrical losses increased, and motor temperature is increased when the motor supply voltage is distorted. Figure 30-1 of this Nema standard provides a motor derating curve to be used when motors are operated at rated conditions and supplied with distorted voltage.

In some cases, the voltage distortion may be so severe as to cause parts on the voltage waveform to touch the zero volts axis at more points than at 0 and 180 degrees. Referred to as multiple zero crossings, this type of voltage distortion can cause mis-operation of zero cross sensitive circuits such as those used in SCR controllers and electronic timing circuits.

Fig. 2

Interestingly, this type of voltage distortion, referred to as notching, is caused during SCR commutation. During the moment that the SCR for one phase (of a three phase converter) is turning OFF, and another phase SCR is turning ON, there is a brief short circuit. At this moment, the current rises rapidly and the voltage drops rapidly resulting in a distorted voltage waveform as illustrated in Fig. 2. When the notching is severe enough, it will cause multiple zero crossings. Multiple zero crossings, in a distorted voltage waveform, have been the culprit for many failed SCR circuits.

Effect on current distortion measurements

If there are multiple sources of current and voltage distortion in a facility, applying a harmonic mitigating remedy to a single harmonic generating load, may not enable you to achieve the normal current distortion expected through the use of that particular remedy. For example, if the bus voltage is distorted due to the contribution of harmonics from many loads on the system, a single load fitted with a harmonic filter than normally achieves 5% harmonic distortion, may in fact measure higher than this. Since a distorted voltage source causes harmonic current flow into any load (linear or non-linear) the presence of harmonic voltage distortion, although due to other loads on the system, will cause additional harmonic currents to flow into the filtered load also. The proper way to adjust for this is to measure the background voltage distortion when this single load is NOT operating. Subtract this magnitude from the current distortion that is measured to determine the contribution of harmonic current distortion actually caused by the filtered load (ie: Measured THD-V = 2.4% and THD-I =7.1%; actual THD-I contribution is 7.1 – 2.4 = 4.7% THD-I).

Voltage Distortion Example (5.75% impedance transformer)

Consider a single variable frequency drive (VFD) rated 100HP, 480V, 60Hz, that is supplied by a transformer rated 500kVA and 5.75% impedance. Therefore, FLA = 124 amps and X_t = 0.026496 ohms.

Since the load rating is 20% of the transformer capacity, the effective percent impedance of the transformer relative to this load is 5.75 x 0.20 = 1.15%, and thus harmonic current distortion for this VFD at full load, will be about **67% THD-I**. The predicted harmonic spectrum is: I1 = 124A, I5 = 70A, I7 = 41A, I11 = 15A, I13 = 9A, I17 = 6A, I19 = 4.7A.

The harmonic voltage distortion is a function of harmonic current times the inductive reactance of the transformer impedance at the respective harmonic frequency. The inductive reactance of the transformer is 0.026496 times the harmonic number.

Harmonic	Freq	Amps	Ohms	Volts	Volts^2
5	300	70	0.13248	9.27	85.93
7	420	41	0.18547	7.60	57.76
11	660	15	0.29146	4.37	19.09
13	780	9	0.34448	3.10	9.61
17	1020	6	0.45043	2.70	7.29
19	1140	4.7	0.50342	2.36	5.57

Sum of voltages squared = 185.25
Square root of sum of voltages squared = 13.61 volts

Voltage distortion = 13.61 / (480/1.732) x 100% = **4.91% THD-V**

Voltage Distortion Example (3.0% impedance transformer)

If the transformer impedance was lower (3%) then the harmonic current distortion will be higher and the voltage distortion will be (For 500kVA, 480V, 3% impedance, X_t = 0.013824 ohms and effective %Z = 0.6%).
The expected harmonic current distortion is about **91% THD-I**.
The predicted current spectrum is: I1 = 124A, I5 = 90A, I7 = 63A, I11 = 20A, I13 = 12A, I17 = 8.3A, I19 = 6.6A.

Harmonic	Freq	Amps	Ohms	Volts	Volts^2
5	300	90	0.06912	6.22	38.69
7	420	63	0.09678	6.10	37.21
11	660	20	0.15206	3.04	9.24
13	780	12	0.17971	2.15	4.62
17	1020	8.3	0.23501	1.95	3.80
19	1140	6.6	0.26265	1.73	2.99

Sum of voltages squared = 96.55
Square root of sum of voltages squared = 9.826

Voltage distortion = 9.826 / (480/1.732) x 100% = **3.54% THD-V**