Harmonics - An Introduction

Voltage as a Service (VAAS)™ is an energy-saving service solution for regulating and optimizing the voltage supplied to electrical equipment to the optimal level for efficient operation. The purpose of VAAS is to reduce energy consumption, lower electricity bills, and decrease carbon emissions by ensuring that electrical devices operate at their most efficient voltage level.

Introduction

Harmonics in electrical systems refer to distortions in the waveform of current or voltage from the ideal sinusoidal shape.

These are caused by non-linear loads such as variable frequency drives (VFDs), UPS systems, computers, and LED lighting. Harmonics introduce a range of adverse effects on electrical equipment, leading to reduced efficiency, overheating, accelerated aging, and reliability issues. In this Application Note, we examine these impacts in more detail, including how harmonics affect motors, transformers, and electronic systems.

What Are Harmonics?

In an ideal AC system, the voltage and current waveforms are **sinusoidal**. However, non-linear loads draw current in abrupt pulses, introducing higher-frequency components called **harmonics**. These harmonics are multiples of the fundamental frequency (50 or 60 Hz). For example:

- **3rd harmonic** = 3 × 50 Hz = 150 Hz
- **5th harmonic** = 5 × 50 Hz = 250 Hz

Harmonics are quantified using **Total Harmonic Distortion (THD)**, which measures the cumulative distortion in a waveform.

Impact of Harmonics on Different Equipment

Motors

Harmonics increase the electrical and mechanical stress on motors, especially in induction and synchronous motors. Key effects include:

- **Overheating**: Harmonic currents create additional losses (I^2R) in the windings, causing higher operating temperatures.
- **Torque pulsations**: Harmonic distortion leads to uneven torque, causing mechanical vibrations and potentially damaging bearings.
- **Reduced efficiency**: The presence of higher-frequency currents reduces the efficiency of the motor.
- **Shortened lifespan**: Increased thermal stress accelerates insulation degradation, reducing motor life.

Example: A 3rd harmonic causes **negative sequence currents**, which create a counter-rotating magnetic field, further stressing the motor.

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Transformers

Transformers experience significant losses and degradation due to harmonic currents:

- **Increased copper losses**: Harmonics increase the RMS value of the current, leading to higher I^2R losses in the windings.
- **Increased core losses**: Harmonics raise eddy current losses in the transformer's core, increasing heat.
- **Derating**: Transformers must often be derated when exposed to harmonic-rich loads to prevent overheating.
- **Humming noise**: Harmonic currents cause mechanical vibrations in the core, leading to audible noise.

Example: A transformer exposed to a THD of 10% may require a 15-20% derating to prevent thermal overload.

Electronic Equipment and Power Supplies

Harmonics have severe effects on sensitive electronics, especially those relying on AC-DC conversion.

- **Overloading of power supplies**: Harmonics increase peak currents, stressing capacitors and rectifiers in power supplies.
- **Poor power factor**: Harmonics result in reactive power, reducing the power factor and increasing losses in distribution systems.
- **EMI and interference**: Harmonics can cause electromagnetic interference (EMI) that disrupts communication systems and sensors.
- **Reduced reliability**: Constant exposure to harmonic distortions accelerates wear in components like electrolytic capacitors.

Example: In data centres, harmonic currents can overload uninterruptible power supplies (UPS), reducing their efficiency and reliability.

Cables and Distribution Networks

Harmonics affect cables and distribution networks by increasing losses and the risk of failures.

- **Increased I^2R losses**: Higher RMS currents due to harmonics increase resistive losses.
- **Overheating of neutral conductors**: Non-linear loads produce zero-sequence harmonics (e.g., 3rd harmonics) that accumulate in the neutral conductor, leading to overheating.
- **Insulation stress**: Harmonic distortions increase voltage peaks, stressing cable insulation and reducing its life.

Example: In buildings with large numbers of LED lights, **neutral currents can exceed phase currents**, causing potential fire risks due to overheated conductors.

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Quantitative Example: Motor with Harmonic Distortion

A motor rated for 10 kW with a supply voltage of 415 V and a THD of 12% experiences increased losses. Assume the harmonic distortion increases the motor's RMS current by 10%.

- Initial current: I = 10,000 / (SQRT(3) × 415) ≈ 13.9 A
- With harmonics: I_{new}= 1.1 × 13.9 ≈ 15.3 A

The copper losses increase by:

$$\frac{(15.3)^2}{(13.9)^2} \approx 1.21$$

This 21% increase in copper losses raises the motor's temperature, reducing its lifespan according to the Arrhenius law.

Mitigating Harmonic Effects

Several strategies help mitigate harmonic effects:

- **Passive filters**: Use of LC filters to block specific harmonic frequencies.
- **Active filters**: Dynamic filtering to cancel out harmonics in real-time.
- **Derating**: Reducing the load on transformers and motors to prevent overheating.
- **K-rated transformers**: Designed to handle harmonic loads without overheating.
- **Power factor correction**: Reduces reactive power and minimises harmonic impacts.

Conclusion

Harmonics pose significant risks to electrical equipment by increasing losses, causing overheating, reducing efficiency, and shortening equipment life. Motors, transformers, and electronic systems are particularly vulnerable, and the accumulation of harmonic currents in distribution networks can lead to severe operational problems, such as neutral conductor overloading and insulation stress. Effective harmonic mitigation techniques, such as filtering and proper equipment design, are essential to maintaining system reliability and preventing premature failures.

Therefore, controlling harmonics with the assistance of Voltage as a Service (VAAS) is critical to ensuring long equipment lifetimes.

For further information, contact us at sales@vaasco.net

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