Monitoring Power Quality Risk in Heat Pump Led Buildings

Why Permanent Monitoring Is Becoming Essential

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Purpose and Scope

This Power Quality Monitoring note has been prepared by Technik & Site Authorisation Services (SAS) to provide high-level technical guidance on the power quality implications associated with the deployment of inverter-driven heat pump systems in commercial buildings. It outlines observed power quality phenomena, associated risks to low-voltage electrical infrastructure, and considerations for monitoring and governance. The document is intended to support engineering judgement, asset-risk management, and informed decision-making; it does not replace site specific design, assessment, or statutory compliance activities.

The intended audience is senior engineering consultants, commercial building landlords, and engineering directors and managers responsible for asset integrity, operational resilience, and regulatory compliance.

1. Executive Summary and Background

The accelerating replacement of gas boilers with heat pumps in commercial buildings represents a significant and growing electrical power quality (PQ) risk. While this technology is central to asset decarbonisation, its widespread adoption introduces non-linear electrical loads that can materially affect voltage quality and overall system stability.

Modern commercial heat pumps predominantly employ inverter-driven compressors and variable speed drives (VSDs). These technologies draw non-linear current from the electrical supply, introducing harmonic distortion and causing dynamic variations in electrical load. When deployed at scale — particularly in electrically heated buildings, mixed-use developments, or sites supplied by relatively weak upstream electrical networks — these effects accumulate and can materially degrade power quality at the Point of Common Coupling (PCC).

The resulting degradation in power quality presents a range of risks to low-voltage (LV) electrical infrastructure. Elevated harmonic content and voltage instability increase root mean square (RMS) current flow and associated thermal and electromagnetic stresses within conductors, busbar systems, transformers, and protective devices. This can lead to failed operation of protection devices, operational disruption, accelerated asset degradation and increased fire risk. Traditional design assumptions and short-term measurement approaches are increasingly insufficient to identify and manage these risks in highly electrified buildings.

This advisory note explains the mechanisms by which inverter-driven heat pumps impact power quality, outlines the consequential risks to LV electrical infrastructure, and sets out why continuous fixed power quality monitoring is now a necessary component of prudent engineering practice and asset-risk management.

While standards such as EN 50160 and IEEE 519 do not explicitly reference heat pumps, they impose limits on voltage characteristics and harmonic distortion. Increasing electrification therefore creates challenges with compliance, reliability, and asset protection that cannot be adequately addressed through design assumptions alone.

2. Results of the Problem: Electrical Power Quality Impacts

Operational experience consistently demonstrates increased harmonic distortion, voltage sags during compressor starts, and elevated flicker levels. These effects are magnified when multiple heat pump units or other non-linear loads operate concurrently.

In addition to conventional harmonic distortion, inverter-driven systems are increasingly associated with supraharmonics emissions in the 2–20 kHz frequency range. While these effects fall outside traditional harmonic indices, they have been linked to audible noise, neutral voltage disturbance, nuisance tripping, and interference with power line communication systems.

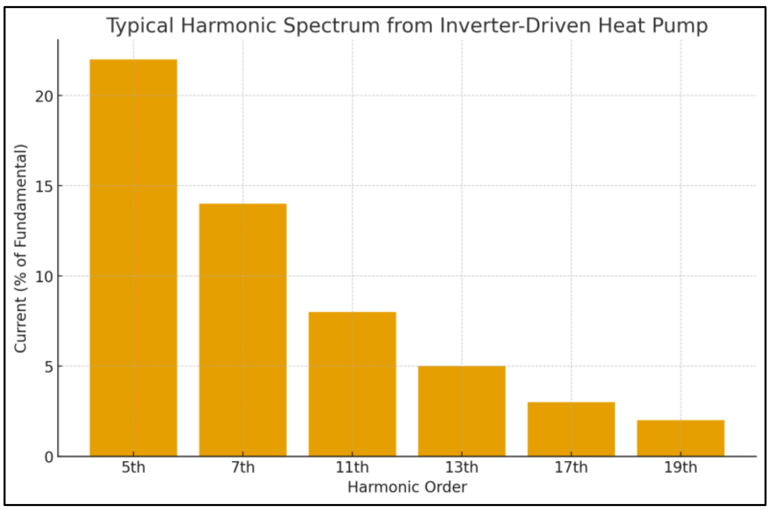

Figure 1 – Example Voltage Sag Event Associated with Compressor Load Transition

3. Consequences for LV Electrical Infrastructure

The cumulative effects of harmonics and voltage instability introduce progressive risks to LV infrastructure, including overheating of busbars and tap offs, transformer thermal stress, protective device mis-operation, and increased fire risk through accelerated insulation degradation.

Switching Transients and High-Frequency Disturbances

Fast switching within inverter driven heat pump rectifiers can introduce high frequency transients beyond the harmonic spectrum. These events may contribute to insulation stress, mis-operation of sensitive electronic equipment, and intermittent or difficult to diagnose power quality issues. Such effects are highly frequency dependent and may not be captured by conventional harmonic measurement alone.

Overheating of Busbars, Cables, and Tap-Off Boxes

Harmonics significantly increase RMS current and voltage to determent of Real Power (Useful Power) of the installation. Aggregated non-linear loads cause excess resistive heating in busbar trunking systems, neutral conductors, and tap off units. Thermal cycling degrades insulation, loosens mechanical joints, and significantly reduces equipment service life.

Transformer Overloading and Premature Heating

Harmonic currents increase RMS current flow and raise the effective AC resistance of transformer windings due to skin and proximity effects, resulting in elevated copper losses. In addition, harmonics increase eddy current and stray flux losses within the transformer core and structural components. As a result, transformers may appear operationally within kVA limits while experiencing elevated internal temperatures, accelerating insulation ageing and reducing transformer lifespan.

Quantifying Transformer Risk Through K-Factor Monitoring

The impact of harmonic loading on transformers is quantified through the K Factor, which represents the additional heating effect of harmonic currents relative to fundamental frequency loading.

Modern power quality meters continuously measure the actual K Factor of the connected load. When the measured K Factor exceeds the transformer's K Rating, the transformer must be de-rated (operated at reduced kVA capacity) to avoid overheating.

Breaker and Protective Device Malfunction

Distorted waveforms interfere with protective device sensing and discrimination. This can result in nuisance tripping, delayed operation, or failure to trip under fault conditions. RCDs and RCBOs are particularly susceptible to harmonic induced mis-operation.

Mechanical Vibration, Noise, and Structural Stress

Non sinusoidal magnetic forces induce vibration in busbars and transformer cores. Over time, this contributes to loosened connections, audible noise, and progressive mechanical degradation.

Resonance Conditions and Harmonic Amplification

Interaction between system inductance and capacitive elements such as power factor correction equipment can create resonant conditions. These can amplify specific harmonic orders, resulting in extreme THD levels, overheating, and premature failure of capacitors and associated equipment.

High Inrush Currents During Voltage Sags

Voltage sags force motors and VSDs to draw increased current to maintain torque. These elevated currents place significant magnetic and thermal stress on busbars, tap off units, and upstream protective devices.

Nuisance Tripping and Equipment Reset

Repeated sag events can cause PLCs, BMS controllers, IT equipment, and VSDs to reset or malfunction. This disrupts operations, increases wear on control components, and undermines system reliability.

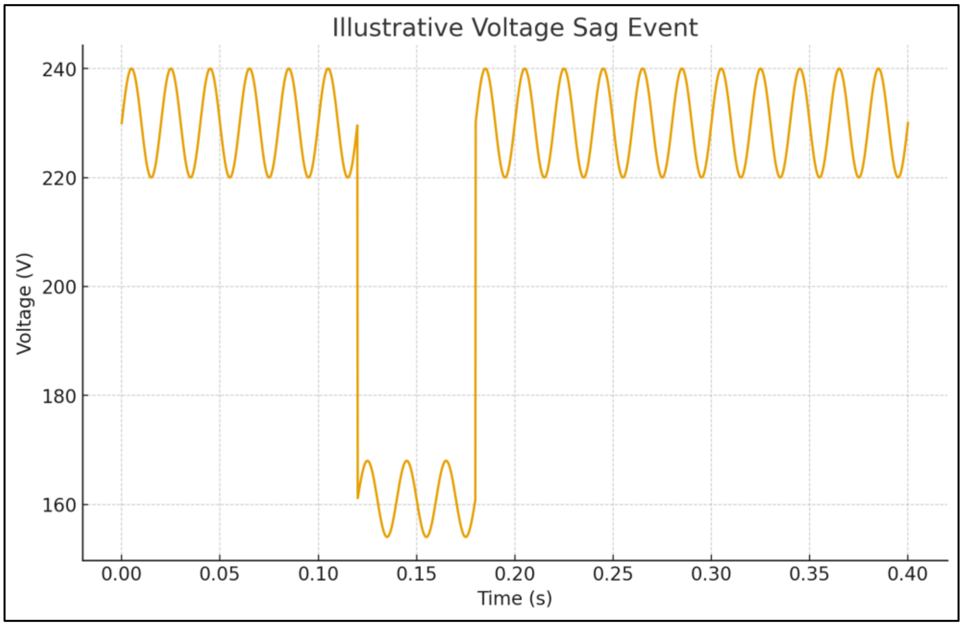

Figure 2 – Representative Harmonic Distortion Profile from Inverter-Driven HVAC Equipment

Accelerated Wear of Tap-Off Breakers

Repeated current surges and arcing associated with sag recovery cycles accelerate contact wear in tap off breakers, reducing their life expectancy and potentially compromising fault interruption capability.

Damage from Voltage Swells

Voltage swells impose insulation stress on cables, switchgear, and tap-off units. Sensitive electronic loads such as LED drivers, power supplies, and IT equipment are particularly vulnerable to overvoltage damage.

Combined Harmonic and Sag/Swell Effects

Harmonics elevate baseline operating temperatures while sag-induced high currents add transient stress. Combined effects accelerate insulation breakdown, compromise protective discrimination, and materially increase fire risk within LV distribution infrastructure.

4. Real-World Examples and Observed Outcomes

Investigations undertaken following low-voltage (LV) electrical equipment failures and operational disturbances in large commercial buildings have, in a number of cases, identified elevated harmonic distortion and repeated voltage disturbance events coincident with the operation of newly installed inverter-driven heat pump systems.

In these instances, temporary power quality monitoring has identified patterns of harmonic loading and voltage sags consistent with known behaviours of variable speed, inverter driven plant, particularly during compressor start up, load transitions, and coincident operation of multiple units.

While it is rarely possible to attribute LV asset degradation to a single causal factor, the absence of permanent power quality monitoring has frequently limited early detection of progressive electrical stress. As a result, degradation has often remained latent until manifested through nuisance tripping, equipment malfunction, thermal damage, or premature component failure.

These observations are consistent with established electrical engineering principles and published industry guidance relating to the interaction between non-linear loads, harmonic distortion, and voltage stability within LV distribution systems.

5. Solution to the Problem: Managing Power Quality Risk

Effective mitigation relies on long-term visibility of actual power quality conditions. Technik therefore recommends permanent fixed power quality monitoring as a foundational control measure.

Permanent monitoring does not in itself mitigate power quality issues, but provides the evidential basis required to justify, design, and verify appropriate corrective measures.

It should be noted that harmonic analysis using typical fixed power quality meters generally extends to the 50th–63rd harmonic order and therefore does not directly capture supraharmonics or high frequency transient phenomena. While the underlying measurement data supports assessment of harmonic loading, transformer thermal risk, and planning compliance, parameters such as K Factor or Harmonic Loss Factor are not usually presented as direct outputs and require engineering interpretation where appropriate.

Technical Notes and Observational Basis

The observations referenced in Section 4 are derived from post-incident electrical investigations, temporary power quality monitoring campaigns, and established industry guidance (including IEC, IEEE, and CIBSE publications). Specific site data and client identifiers are excluded for reasons of commercial confidentiality.

Correct installation practices, including appropriate shielding, earthing, and grounding of inverter-driven equipment, are critical in controlling high frequency emissions and electromagnetic interference. Inadequate EMC installation can give rise to power quality and EMI issues extending beyond conventional harmonic ranges and outside the measurement capability of standard power quality monitoring systems.

Disclaimer

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References

More information on this topic can be found:

- https://renewableheatinghub.co.uk/harmonics-solar-pv-heat-pumps/
- https://blog.armstrongfluidtechnology.com/harmonics-causes-effects-and-remedies-in-commercial-buildings
- https://www.mscnj.com/post/harmonic-distortion-a-hidden-challenge-for-hvac-systems
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