ALCAP GROUP

ALCAP EDUCATIONAL DOCUMENT | POWER QUALITY

Multiple Inverters and Grid Harmonics

What happens as solar, battery, UPS and variable-speed systems scale - and what it means for equipment life

Solar PV, battery storage, UPS systems and variable-speed equipment are placing more inverters on commercial and industrial electrical networks. Each inverter may be compliant when tested as an individual product, but the power-quality result at a real site depends on how all the inverters, loads and network impedances interact.

The key point is simple: harmonic emissions from multiple inverters do not always add in a straight line. Some components can reinforce one another, some can partially cancel, and some can excite a resonant frequency that makes the resulting voltage distortion much larger than the individual inverter data would suggest.

THE KEY POINT

Harmonic risk is a system property. The number of inverters matters, but so do their topology, operating point, control software, filters, phase angles, connection points, transformer and cable impedance, background distortion, power-factor capacitors and the strength of the upstream grid.

Prepared for South African commercial and industrial energy users

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What is harmonic distortion?

South Africa's public electricity system operates at a fundamental frequency of 50 Hz. An ideal supply voltage is a smooth sinusoidal waveform at that frequency. Harmonics are components at integer multiples of the fundamental: the 3rd harmonic is 150 Hz, the 5th is 250 Hz, the 7th is 350 Hz, and so on.

Inverters use high-speed electronic switching to convert DC power into AC power or to control the frequency and voltage supplied to a load. Their output filters remove most switching ripple, but no real converter is completely distortion-free. Harmonic current can also come from rectifiers, variable-speed drives, LED drivers, computer power supplies, welding equipment and other non-linear loads.

It is important to separate **harmonic current** from **harmonic voltage**. Equipment injects harmonic current into the network. That current produces harmonic voltage as it flows through the frequency-dependent impedance of transformers, cables and the upstream grid. A useful simplified relationship for each harmonic order is:

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Harmonic voltage (Vh) approximately equals harmonic current (Ih) x network
impedance at that frequency (Zh)
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This is why the same collection of inverters can perform acceptably on a strong network yet produce excessive voltage distortion on a weaker connection.

What changes when several inverters operate together?

Harmonic quantities have both magnitude and phase angle. They therefore combine as vectors, not simply as unsigned numbers. If a particular harmonic from several inverters is closely aligned in phase, the aggregate can approach the arithmetic sum. If the phase angles differ, partial cancellation can occur.

Research on distributed inverter systems has shown that older line-commutated designs can have low-order harmonics that add more directly, while modern pulse-width-modulated units often show greater phase diversity and partial cancellation. A commonly used statistical reference for similar, randomly phased components is growth in proportion to the square root of the number of units rather than the number itself. This is a reference, not a design guarantee.[1]

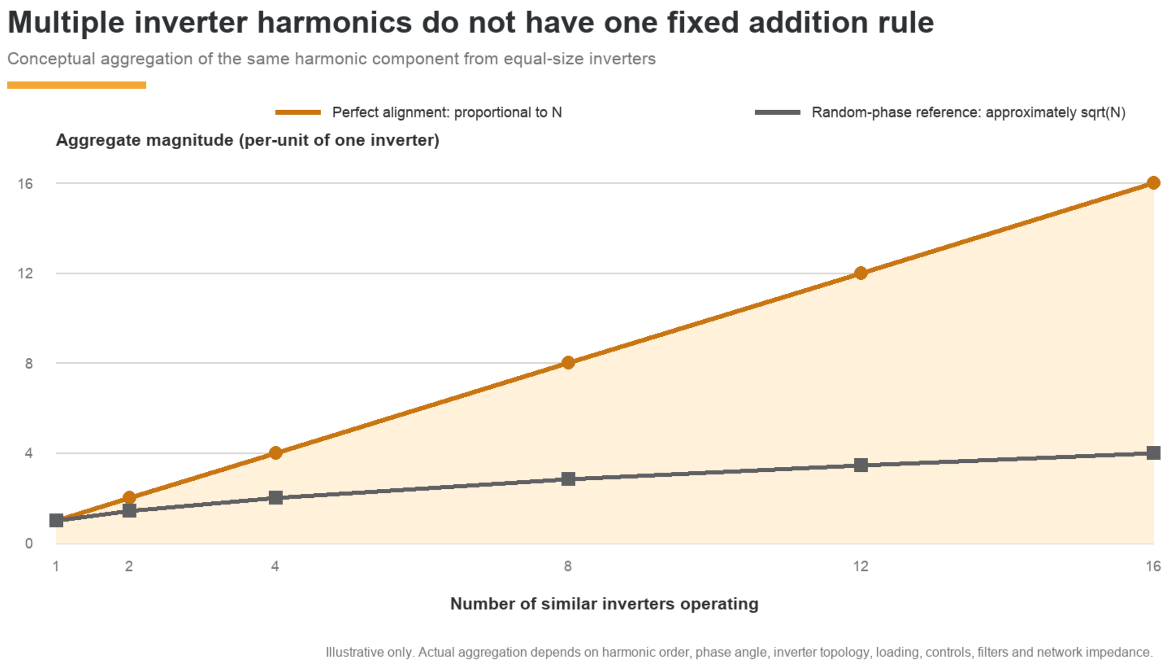

Figure 1: Conceptual harmonic aggregation. Actual results must be calculated or measured for the specific inverter fleet and network.

Real sites are more complicated because:

- Different inverter makes and models produce different spectra.
- The spectrum changes with power output; distortion percentage can rise during light-load operation even when absolute current is lower.
- Single-phase inverters may be unevenly distributed across phases.
- Control loops and phase-locked loops can interact through the network.
- L, LC and LCL output filters change the frequency response.
- Background distortion from the utility and other site loads is already present.
- Network switching, transformer changes and capacitor-bank steps alter the harmonic impedance.

Consequently, adding the ninth or tenth inverter can have a different effect from adding the second. Multiple inverter-based resources can change the effective dynamic grid impedance, and experimental research has shown that the number of connected units and their filter designs can influence both harmonic behaviour and stability.[2]

Why weak grids and resonance matter

A strong grid has relatively low impedance at the point of common coupling (PCC). A weak grid has higher impedance, so the same harmonic current creates a larger harmonic voltage. Long feeders, smaller transformers, high source impedance, islanded operation, standby generators and lightly interconnected networks can all change the result.

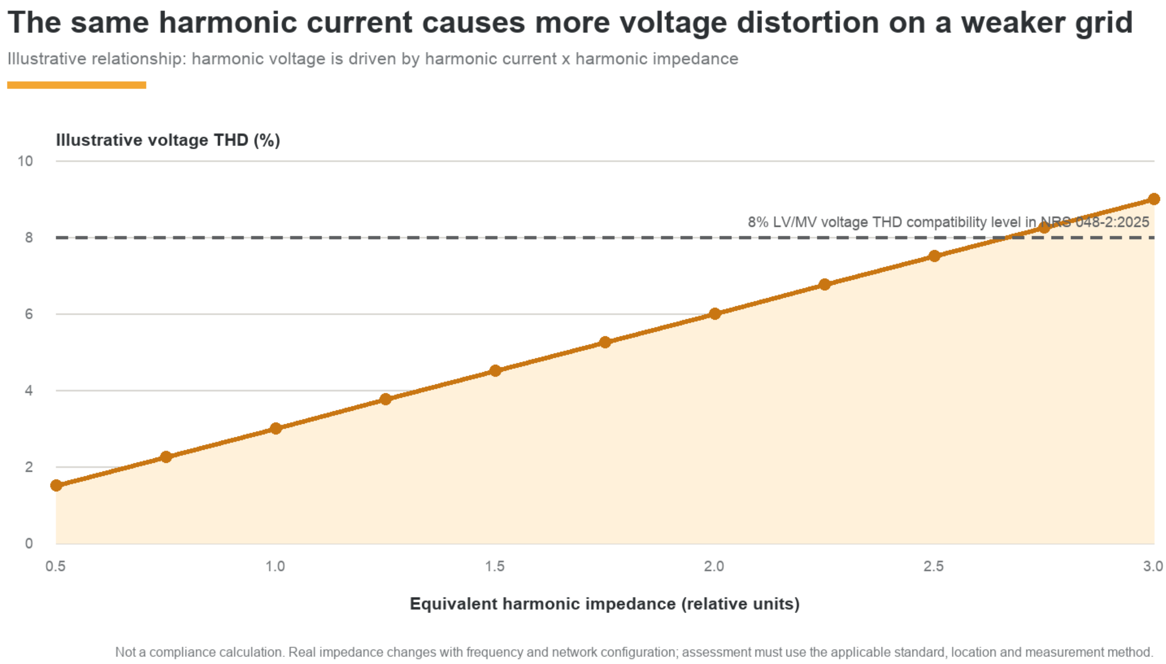

Figure 2: Illustrative relationship between harmonic impedance and voltage distortion. This is not a compliance calculation.

Resonance can be even more important. The inductance of transformers and cables interacts with capacitance from power-factor correction banks, long cables, filters and equipment. At or near a resonant frequency, a relatively small harmonic source can produce large current or voltage amplification.

This is why adding conventional capacitor banks to a site with many inverters or drives without a harmonic study can create problems. The solution may require detuned capacitor banks, reactors, active filtering or a different connection arrangement - but the correct response depends on the measured spectrum and an impedance or resonance assessment.

How harmonics affect equipment life and reliability

Harmonics do not automatically destroy equipment. The effect depends on distortion magnitude, duration, loading, temperature, equipment design and immunity. Persistent distortion can nevertheless increase electrical and thermal stress, creating failures that appear unrelated until power-quality data is examined.

Transformers

Harmonic currents increase winding, eddy-current and stray losses. This produces additional heating, reduces the loading margin and accelerates insulation ageing when temperatures remain elevated. Inverter-based resources can also excite existing system resonances, increasing transformer stress.[3] Transformer selection or derating should consider the expected harmonic spectrum rather than only fundamental-frequency kVA.

Refrigeration and air-conditioning compressors

For a fixed-speed compressor motor connected directly to the mains, voltage harmonics produce additional motor currents, losses and temperature rise. They can also create torque ripple, noise and vibration. NEMA motor guidance recognises that motors on a bus with harmonic content can run hotter and may require derating to reduce the risk of damage.[4]

The result can be shortened insulation life, more frequent thermal trips and reduced reliability - particularly where the compressor already operates near its thermal limit, starts frequently, has poor cooling or sees voltage imbalance.

An inverter-driven refrigerator or HVAC unit is different. Its internal drive controls the compressor motor, so the motor does not see the grid waveform directly in the same way. However, the appliance's input rectifier, DC-link capacitors, electromagnetic-interference filter, surge components and control electronics can still be stressed by a distorted supply or resonance. At the same time, the appliance's own drive contributes harmonic current to the installation. Manufacturer guidance for compressor drives notes that harmonics increase RMS input current and heat losses in transformers and cables.[5]

Cables and neutral conductors

Higher-frequency currents increase conductor losses through skin and proximity effects. Triplen harmonics - particularly the 3rd, 9th and 15th - can add in the neutral of a three-phase four-wire system instead of cancelling. This can cause unexpectedly high neutral current and heating.

Power-factor correction capacitors

Capacitors present lower impedance at higher frequencies. Harmonic current can therefore overload capacitors and their switching components. If the capacitor bank forms a resonant circuit with the supply, current and voltage can be amplified, leading to fuse operation, bulging, overheating or premature failure.

Switchgear, fuses and circuit breakers

Higher RMS current and distorted peaks can increase heating and contribute to nuisance operation. Protection devices must be selected and coordinated for the actual waveform, fault level and operating modes, including PV generation, battery operation and standby generation.

PLCs, controls, laboratory instruments and other sensitive equipment

Sensitive electronics may be affected by distorted peak voltage, zero-crossing errors, conducted interference, control-power dips or repeated switching events. Symptoms can include unexplained resets, communication faults, unstable measurements, contactor dropout, UPS alarms, flicker and intermittent process trips. Modern equipment often has good immunity, so a symptom alone is not proof of a harmonic problem; event and waveform measurements are required.

UPS systems and electronic power supplies

A UPS or switch-mode power supply is both a non-linear load and a potentially sensitive device. Harmonic voltage can increase front-end current stress, heat input components, interfere with bypass transfer conditions and contribute to nuisance alarms. Several UPSs operating in parallel can also become a significant aggregate harmonic source.

Where harmonic distortion can create equipment stress

Qualitative screening matrix - actual risk depends on distortion, loading, temperature, immunity and protection

	Extra heating and losses	Torque ripple and vibration	Resonance / overcurrent	Trips or control upset	Accelerated ageing
Transformers	High	Low	Significant	Possible	High
Fixed-speed motors / compressors	High	High	Low	Significant	High
Inverter-driven refrigeration	Significant	Possible	Possible	High	Significant
Cables and neutrals	High	Low	Possible	Significant	Significant
Power-factor capacitors	High	Low	High	Significant	High
PLCs, controls and instruments	Possible	Low	Possible	High	Significant
UPSs and power supplies	Significant	Low	Possible	High	Significant

Screening guide only - confirm actual exposure with power-quality measurements and equipment data.

Figure 3: Qualitative screening matrix. Actual risk must be confirmed with site measurements and equipment data.

Why an inverter certificate is not enough

Product type testing is important, but it cannot reproduce every site. It tests one product under defined conditions. It does not include the site's existing voltage distortion, all other inverters and non-linear loads, actual cable and transformer impedance, capacitor banks, standby-generator operation, unusual load combinations or future expansions.

IEEE 519-2022 assesses steady-state harmonic performance at the PCC between the source and the customer installation.[6] In South Africa, NRS 048-2:2025 defines voltage-quality compatibility levels and assessment methods, including harmonic and interharmonic requirements for public networks.[7] The correct standard, limits, measurement class, assessment period and PCC must be agreed for the particular installation.

The practical inference is that individually compliant inverters can still form a site that requires an aggregate harmonic assessment.

What should a site-level investigation include?

1. **Define the PCC and operating modes.** Include normal grid supply, PV generation, battery charging and discharging, generator operation, export limitation and islanded modes where applicable.
2. **Update the single-line diagram.** Record transformer data, cable sizes and lengths, capacitor banks, filters, inverter connection points, major drives, UPSs and sensitive loads.
3. **Measure before changing equipment.** Log voltage and current waveforms, individual harmonic spectra, voltage THD, current distortion or TDD, RMS current, power factor, unbalance and relevant events.
4. **Capture representative conditions.** Include high solar output, low inverter output, different production states, capacitor switching, night base load and generator operation.
5. **Separate background from site contribution.** Compare conditions with inverters off and on where safely possible, and measure at internal buses as well as the PCC.
6. **Assess resonance and impedance.** This is particularly important before adding capacitor banks, filters, large batteries or additional inverter capacity.
7. **Verify the remedy.** Repeat measurements after changes under comparable operating conditions.

Possible mitigation options

There is no universal harmonic filter. Depending on the study, the appropriate response may include:

- Changing inverter operating settings or firmware under manufacturer guidance.
- Using phase diversity or alternative connection arrangements.
- Installing line reactors, tuned or detuned passive filters, or active harmonic filters.
- Replacing conventional capacitor banks with detuned equipment.
- Separating sensitive control supplies from high-distortion buses.
- Increasing transformer or conductor capacity where thermal loading is the constraint.
- Improving earthing, bonding, cable routing and electromagnetic compatibility practices.
- Specifying lower-emission inverter or active-front-end equipment for future additions.
- Applying equipment-specific ride-through, power conditioning or UPS solutions where process immunity is the real issue.

A filter chosen from THD alone can move the problem to another frequency or create a new resonance. Mitigation should be based on individual harmonic orders, phase angles, system impedance and the actual equipment being protected.

Conclusion

More inverters do not automatically mean unacceptable harmonics, and they do not guarantee cancellation either. The aggregate result depends on the complete electrical system. The safest approach is to measure at the PCC and critical internal buses, study the harmonic impedance and resonance risk, and assess equipment temperature and operating symptoms together.

For facilities adding solar PV, battery storage, UPS capacity or variable-speed equipment, harmonic performance should form part of the design review - before procurement and again during commissioning.

Contact ALCAP to discuss a measurement-led power-quality assessment for an existing installation or planned inverter expansion.

References and further reading

1. NREL - Distributed Resources System Performance: Harmonic Aggregation and Feeder Impedance.
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4. NEMA MG 1 Part 30 - Motors on a Sinusoidal Bus with Harmonic Content.
5. Danfoss - VLT Compressor Drive CDS 803 Design Guide.
6. IEEE 519-2022 - Standard for Harmonic Control in Electric Power Systems.
7. NERSA - NRS 048-2:2025, Electricity Supply Quality and Compatibility Levels.
8. U.S. Department of Energy - Electricity Distribution System Baseline Report.

This article provides general educational information and is not a substitute for a site-specific electrical design, protection study, power-quality assessment or professional engineering advice.