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Tuning into Harmonics: How Metrology Helps Seamless Integration of Renewable Energy Sources into Electricity Grids

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Supporting renewables in electricity grids

Access to affordable, reliable, sustainable and modern energy for all is one of the most critical challenges facing humanity in the 21st century. As part of the energy transition, electrical energy is increasingly generated from renewable energy sources such as solar panels and wind turbines rather than from fossil fuels.

To deliver the energy to electricity grids the direct (DC) voltage generated by these renewable sources must be converted to alternating (AC) voltage using power electronics devices called inverters. These high-frequency switches produce increasingly complex electrical waveforms. Consequently, high-voltage transmission and distribution systems now carry not only sinusoidal AC voltages but also harmonics with frequencies reaching several kilohertz.

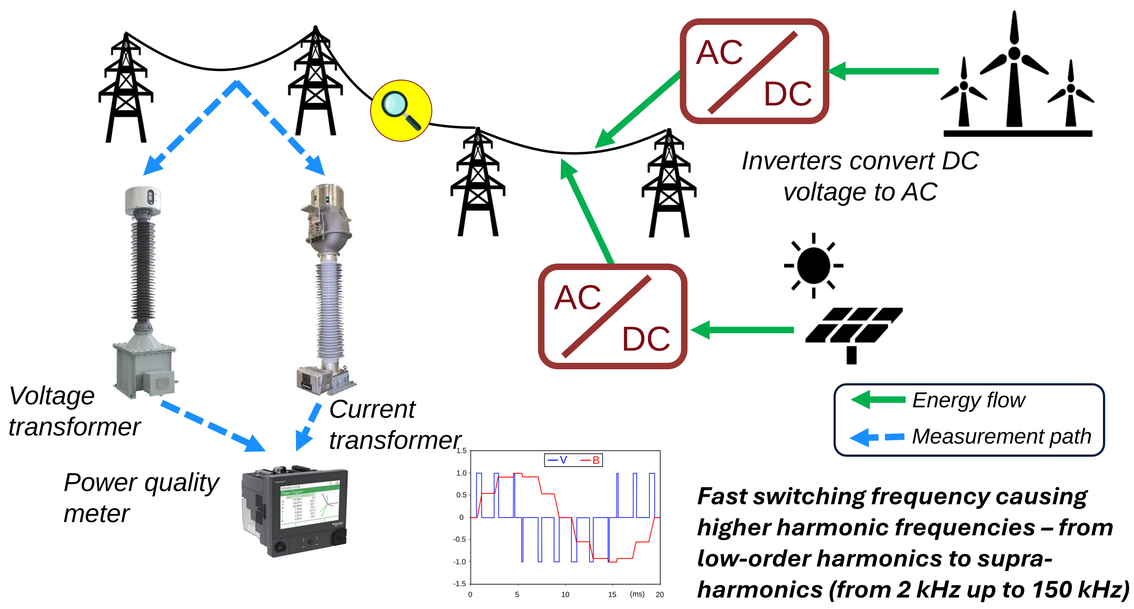
Harmonics and their mitigation

Harmonics can degrade power quality, reduce the efficiency of energy transmission, shorten the lifespan of critical high-voltage equipment, and interfere with power line communication systems.

Therefore, it is essential to understand and mitigate harmonics in electricity networks. This requires the ability to accurately measure complex high-voltage and high-current waveforms, and to evaluate the measurement equipment used in electrical grids with high voltages and currents that are close to the ones they measure in service, i.e. composite waveforms with high magnitude of the fundamental frequency and relatively low magnitudes of the harmonic frequencies with any combination of harmonic amplitudes and phases.

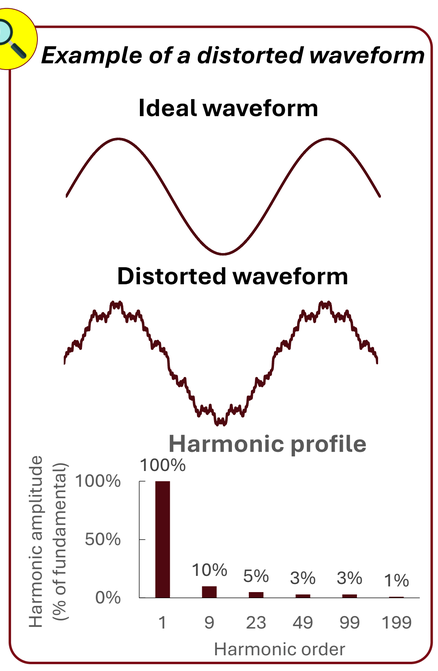
How metrology helps

- Two new measurement systems, developed at NMI Australia, for voltages up to 100 kV and currents up to 4 kA, respectively.
- Waveforms contain both the fundamental and arbitrary harmonics, up to 1000 V rms and 800 A rms, with frequencies up to 10 kHz.
- Both laboratory or field operation, to characterise grid measurement equipment on site.
- Calibration of traditional high-voltage instrument transformers and the new types of sensors with higher bandwidth that are specifically designed for complex waveform measurement.



Fast switching frequency causing higher harmonic frequencies – from low-order harmonics to supra-harmonics (from 2 kHz up to 150 kHz)

Example of a distorted waveform

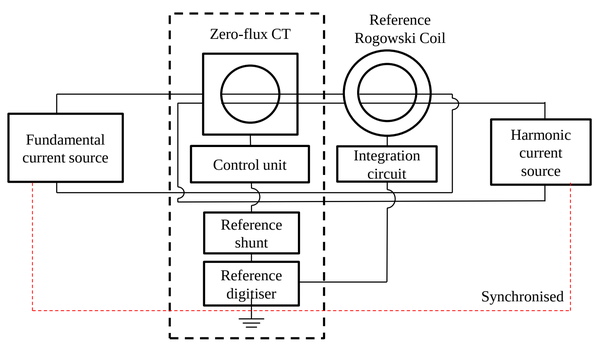


4000 A harmonic current measurement system

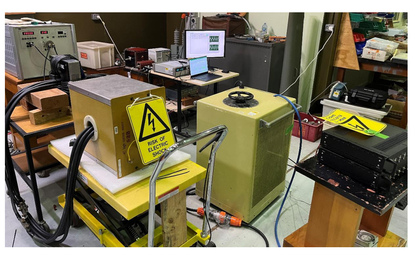
- Consists of a zero-flux current transformer, a reference current shunt, a high-precision digitiser and test software.
- Uses a double-loop current source – one carries the low frequency current at high magnitude, the other carries high-frequency currents at lower magnitudes. The overall waveform is a distorted waveform.
- Traceability to the SI has been established through a series of novel verification measurements.

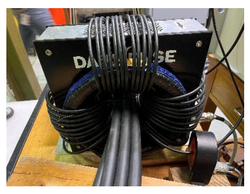
Performance evaluation

- Compare with a reference at 1000 A using the double-loop circuit.
- Evaluate the uncertainty introduced by the double-loop circuit.
- Extend the range with a linearity test using a Rogowski coil up to 4000 A.



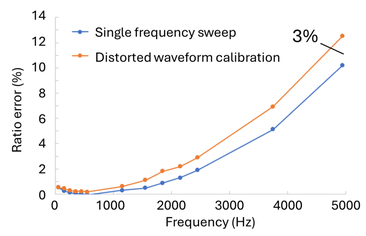
Performance verification using the double-loop method



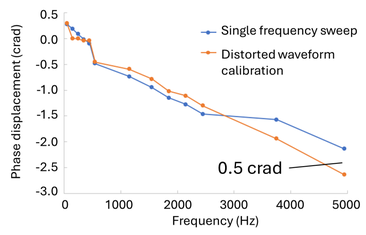


Using the double-loop circuit to evaluate the performance of the measurement system

Calibration of an inductive current transformer



Ratio error



Phase displacement

Best overall measurement uncertainties

	Ratio error (%)	Phase displacement (crad)
Power frequency and low-frequency harmonics	0.03	0.06
High-frequency harmonics	0.03	0.37

100 kV harmonic voltage measurement system

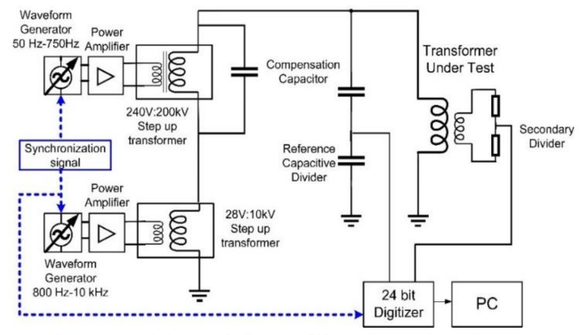
- Consists of a capacitive voltage divider, a high-precision digitiser, and test software.
- A series combination of two voltage sources is used to supply distorted waveforms. One circuit creates the low frequency voltage while the other generates high-frequency harmonic voltages.
- Traceability to the SI has been established through a series of novel verification measurements.

Performance evaluation

- Compare with a reference voltage divider at 1000 V.
- Impact of fundamental voltage on harmonic measurement.
- Voltage linearity with single frequency harmonics and distorted waveforms.

Best overall measurement uncertainties

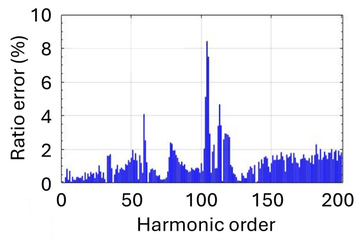
	Ratio error (%)	Phase displacement (crad)
Power frequency	0.01	0.03
Harmonics	0.1	0.16



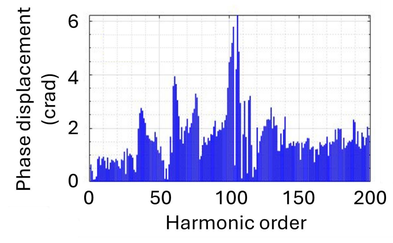
Composition of the calibration circuit

Calibration of an inductive voltage transformer

Ratio error difference



Phase displacement difference



Conclusion

NMIA has established two novel measurement systems high-voltage and high-current harmonics calibration with arbitrary waveforms [1]. The new standards have been used for the calibration of inductive voltage and current transformers, demonstrating critical differences between their errors measured with real-life distorted voltages and currents and those estimated using single frequencies [2].

References:

[1] W. Yan, I. Dewayalage, I. Budovsky, F. Emms and Y. Li, "A Reference Measurement System for Calibration of High-Voltage Transducers at Frequencies Up to 10 kHz," *2023 IEEE 13th International Workshop on Applied Measurements for Power Systems (AMPS)*, Bern, Switzerland, 2023, pp. 01-06.

[2] Wei Yan, Tri Hai Vu, Ilya Budovsky, Frederick Emms and Yi Li, "Calibration of Current Transformers Using Distorted Current Waveforms with Multiple Harmonic Components up to 5 kHz," 2023 CIGRE International Symposium, Cairns, Australia, 2023.