N4L Newtons4th Ltd

UKAS CALIBRATION 7949

THE QUEEN'S AWARDS FOR ENTERPRISE: INNOVATION 2010

Closed Loop Calorimetry

Technical note 003

Meeting the challenge of traceable, High Frequency Power Calibration - what bandwidth do you need?

Newtons4th are not a "typical" instrumentation manufacturer. Established in 1997 by digital and power electronics design engineers, the mission of N4L was to design, manufacture and support measurement instrumentation products that would address the fast changing world of power conversion. It was apparent to the engineers at N4L that while established power measurement instrument manufacturers were extending the frequency range of their products to follow a growing demand, this was based upon the modification of designs that were not initially intended for the applications that they would soon face.

N4L approached this challenge in a different way, by developing completely new instruments specifically designed to meet the demands of these emerging applications, introducing unique attenuators, shunts, isolation techniques and digital processing never used before and which remain exclusive to N4L today. With over 20 years of ongoing development, we continue to provide world leading power measurement instrumentation; breaking boundaries is part of our DNA. In common with many advances in design, the techniques introduced by N4L not only provided a step change in performance compared to established products but by virtue of modern design efficiencies, this was achieved at a lower build cost. While sometimes dismissed by those who continue to use older technology, we can all easily recognise the benefit of modern electronic design in items such as phones, domestic electronics or any of the modern electronic devices we all use that offer superior performance without greater cost.

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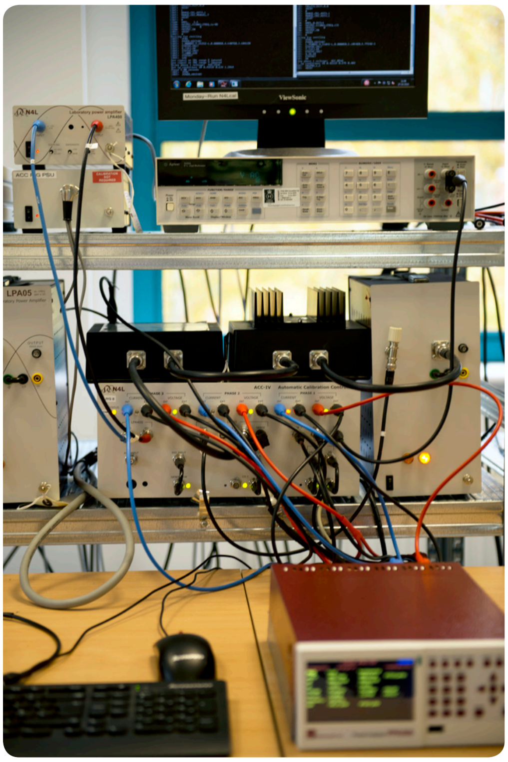
An Innovator in full specification calibration



ACCIV Automatic Calibration Controller System

Recognising that any measurement product should be judged by the accuracy that is 'proven' rather than the accuracy that is 'claimed', N4L started business with a philosophy that was unique at the time and remains unique today. Every measurement instrument supplied by N4L would be shipped as standard with detailed and traceable calibration covering the complete operating range.

So for example, N4L power analyzers offer a measurement frequency range from DC to 2MHz and yet there was no commercially available calibrator with sufficient accuracy to cover this frequency range. N4L therefore designed a calibrator system that incorporates voltage amplifiers, current amplifiers, ISO17025 traceable shunts and ISO17025 traceable reference DVM's to meet this need. Such is the commitment to our philosophy of calibration evidence, N4L now operate 12 'ACCIV', fully automatic calibration systems, so that we can maintain our policy of full spec. certification with every instrument shipped despite our significant increase in product volume.

Some may seek to dismiss the merit of calibration that is not directly 'accredited' to ISO17025 but of course, 'traceability' via an ISO17025 traceable reference DVM with defined uncertainty in each and every rig is completely valid and is of infinitely greater value than the absence of an equivalent calibration from other suppliers who, not surprisingly, may try to dismiss something that they do not have.

While our automated wideband calibrators already differentiate N4L from any other supplier, this is only part of the N4L calibration facility. In 2013, our UK headquarters laboratory was awarded UKAS ISO17025 accreditation and from that time onward, each and every power analyzer has been supplied with both our standard wideband calibration and also, ISO17025 accredited calibration attainted from a Fluke 6105A, the world's leading Electrical Power Standard.

Modern power electronics create the need for traceable wideband power accuracy on complex waveforms.

While we can easily identify the complexity of power switching techniques used to achieve the increased flexibility and efficiency that we see in modern power electronics devices, less obvious is the challenge that this presents for measurement instrumentation and the associated calibration. N4L engineers recognised that while the calibration facility described above provides class leading assurance of sine-wave calibration over the complete operating range of our instruments, the special nature of switching devices in modern power electronics required a different approach to power accuracy calibration.

In order to define the optimum solution to wideband power calibration, N4L engineers first considered the nature of modern power electronic applications and the demand that this places on the calibration environment. Here, we use an analysis of waveforms commonly found in a PWM drive system to illustrate primary technical considerations.

Fig.1 illustrates harmonic content caused by the switching frequencies of a PWM motor drive with 30kHz switching frequency. Harmonics of this switching frequency extend toward 1MHz and it is these harmonics that the power analyzer must accurately measure. It is easy to recognise that since the analyzer voltage and current ranges must include the fundamental component, harmonics of the carrier frequency will be low in the power analyzers range - so good dynamic range capabilities and low noise are essential for accurate power analysis.

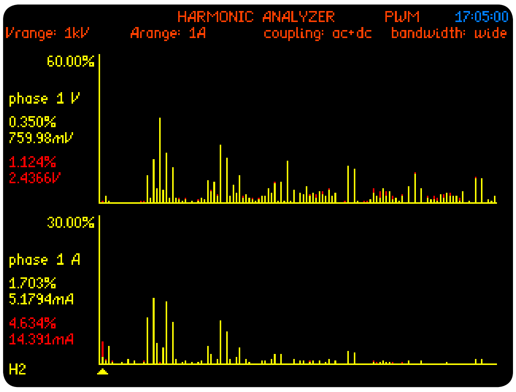


Fig.1 Harmonic Analysis of PWM Inverter displaying harmonics of switching frequency

Typical Levels of Harmonic Power

The same levels seen in Fig.1 were monitored with a PPA5530 in "harmonic series phase" mode, which includes the phase angle between the voltage and current of each harmonic from which harmonic power (Watts), can be derived.

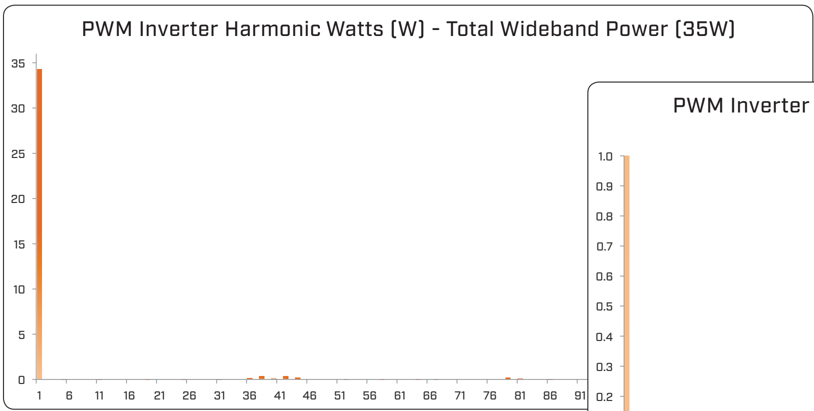


Fig.2 Harmonic Power of PWM motor drive, off-load

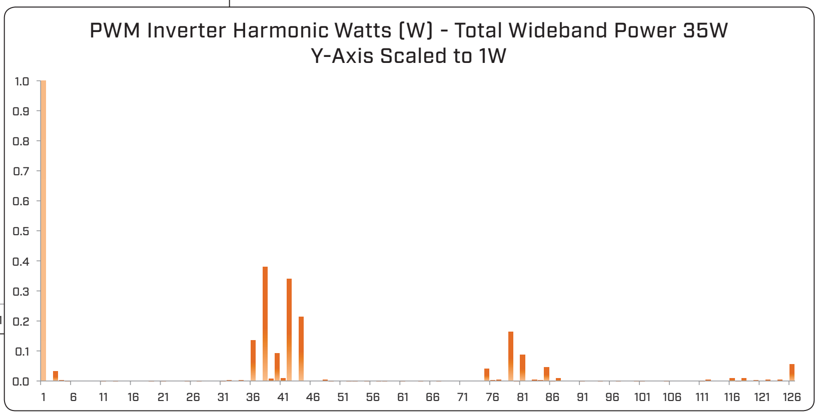


Fig.3 Harmonic Power of PWM motor drive, off-load (graph scaled to 1% of fundamental)


Fig.4

Variable Speed Motor Drive Technology is rapidly advancing, with ever increasing switching frequencies, the need for high frequency power accuracy is becoming more and more important.

Note: Test data in Fig 1~3 not related to Fig.4

Calibration design for a real world power profile.

We know that total real power is derived from all in-phase voltage and current components over the frequency range of interest, therefore meaningful power analysis should cover the same frequency range. We also know that frequency components of voltage and current in distorted power applications like a PWM drive are interactive, so ideal calibration would be wideband.

The wideband motor test in Fig.1~3 was operating 'off load', so the high frequency losses measured here will represent a higher proportion of the total power than we would expect with an on-load test. As the motor is loaded, the fundamental power will rise significantly, yet the rise in harmonic power will be relatively small. It follows that as the motor power increases, the high frequency losses will become a lower proportion of the total power.

In the tests made here, total wideband power was 35W, of which 1.39W was harmonic power to the 125th harmonic and 0.29W was higher order harmonics and non-harmonic power.

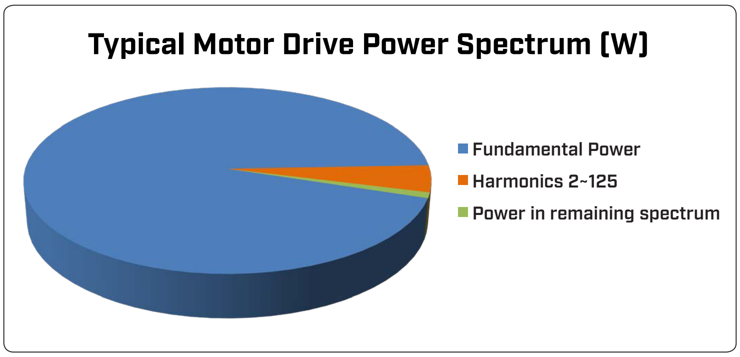


Fig.5 Power Spectrum

There are two common measurement configurations when measuring the output of an inverter drive;

- Power Analyzer + Internal Resistive shunts (typically for current levels below 30-50Arms total)
- Power Analyzer + External Current Measurement Transducer (for current levels exceeding 30-50Arms total)

When using internal shunts, total harmonic power will commonly be in the order of 5-10W level or lower which is illustrated by the 1.39W of our example here. For larger drives operating in the tens of kW range, harmonic losses will be correspondingly higher but for such an application, the power analyzer will usually monitor current through an externally connected step down transducer. In this case, the current measured by the internal shunts on the power analyzer will again be a low level signal. Harmonic content in such a wideband RMS signal will typically be in the 10's of mA range, again illustrating the importance of measurement accuracy on low levels of harmonic power in the presence of a much larger fundamental power component.

It is clear that the optimum solution to calibration in this environment would achieve suitable accuracy of power components over a wide frequency range at levels that would be low in the power analyzer range. This would be true with either direct input current measurement or where external current transducers are used, since the transducer output would also be low in the associated range.

The ideal power calibration environment would be one in which traceable power measurements are made irrespective of frequency, distortion or phase shift. It was on this basis that N4L worked together with Oxford University on a two-year project to develop a high speed **closed loop calorimeter**.

An Innovation in wideband ISO17025 accredited power metrology

Given that harmonic power is usually a small proportion of total power, a calorimeter capable of calibrating up to 5 Watts at high frequencies (up to 2MHz) would be ideal for verifying the wideband capability of a power analyzer to correctly measure the switching losses. This would also answer the problem of traceability and verification of the true wideband watts performance. Existing commercially available calibration equipment such as the Fluke 6105A (As used within N4L's UKAS laboratory) already caters for the fundamental (<850Hz) power calibration and this calibration is performed on all N4L Power Analyzers that leave the factory.

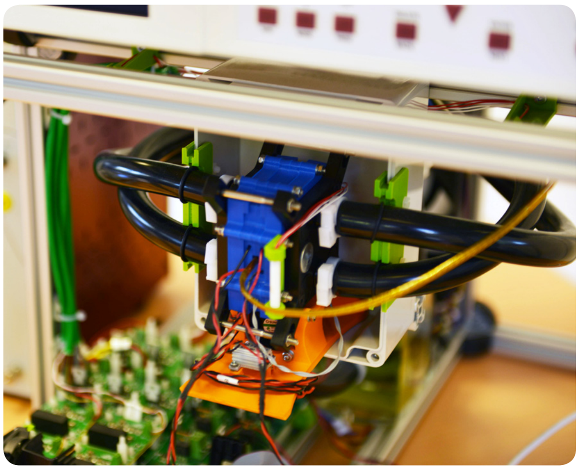
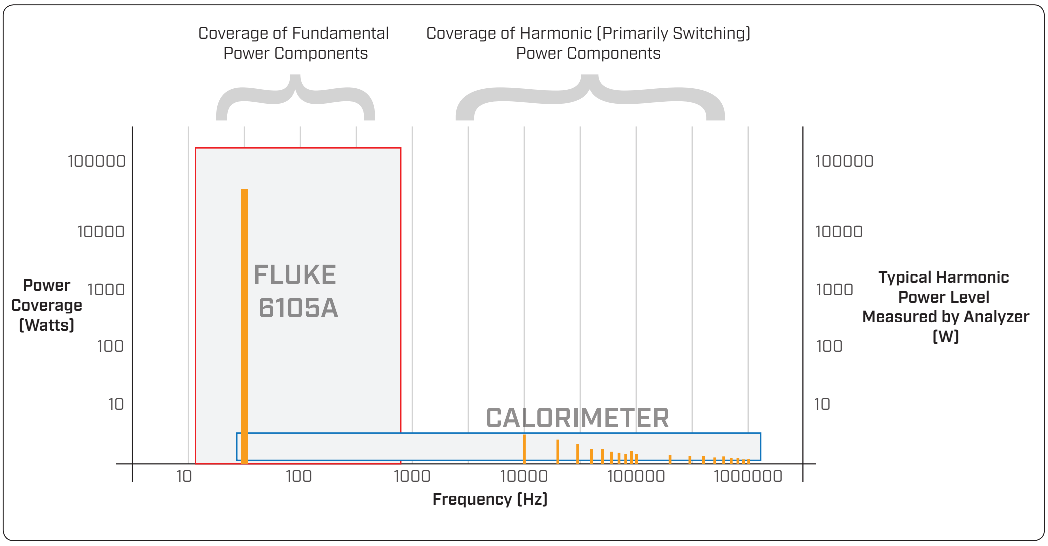


Fig.6 Calorimeter Load Cell with Heat Flux Sensors



The new challenge was to cover the 850Hz ~ 2MHz range with a Calorimeter at a meaningful watts level, while achieving an uncertainty level better than 0.3%. Such a low uncertainty level would be extremely useful in the field of modern power conversion devices, where total electrical efficiencies of inverters are typically greater than 95% including frequency components up to 1MHz and above.

Fig.7 N4L Wideband power accreditation to ISO17025

N4L - Closed Loop Calorimeter

Calorimetry is recognised in the world of metrology as the optimum reference for real power calibration because, in an electrical system generating no light, sound or vibration, real electrical watts will produce only one form of energy, heat. Since temperature can be measured with exceptional precision, it follows that high accuracy fully traceable power calibration can be achieved with no dependency on frequency or phase. Furthermore, such is the independence of calorimetry to frequency components, power measurement is equally accurate on sine-wave or distorted waveforms within the defined frequency range, so calibration is no longer limited to sinusoidal signals.

This is a significant advantage over conventional AC power calibration techniques which are limited to a sine-wave excitation signal and have power calibration uncertainty that is dominated by frequency and phase error. Some may suggest that power calibration up to 100kHz is sufficient but as these tests illustrate, that is commonly untrue.

The unique calorimetry system resulting from the project with Oxford University and subsequent uncertainty budget data that was then analysed by the United Kingdom Accreditation Service (UKAS), resulted in ISO17025 accreditation of the N4L laboratory for power measurement of any frequency or any combination of frequencies between 45Hz to 2MHz with **0.21% uncertainty**. N4L are presently the only power analyzer manufacturer with this facility.

Key to the commercial viability of this system, is a speed of measurement that is not possible in conventional calorimetry systems. The innovative design of this system achieves temperature derived power measurement without the thermal conduction uncertainty or extended test time associated with standard calorimetry techniques.

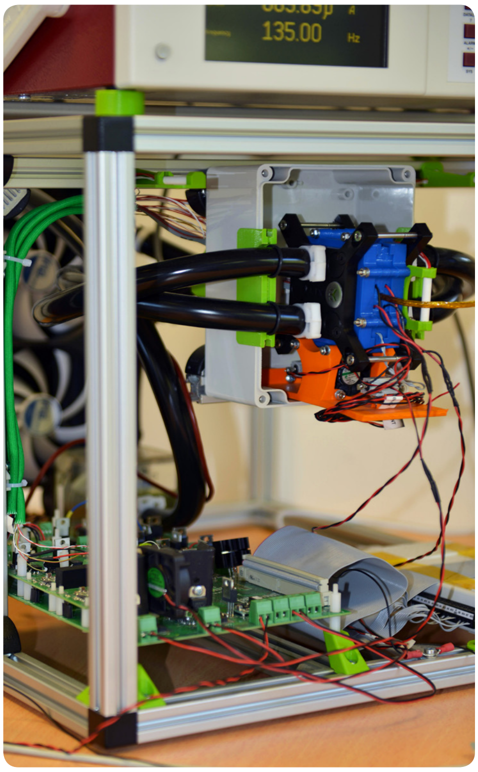


Fig.8 ISO17025 Accredited Calorimeter

Additional note on the measurement of distorted waveforms.

Most design engineers recognise that complex interactions can result from a complex waveform and these interactions go beyond the scope of this document, but a much simpler issue can easily be understood and is worthy of consideration here. This issue is the chosen methodology for voltage and current range selection in a measurement instrument that will be faced with distorted signals. Those whose experience or interest relate to the controlled world of calibration will tend to focus on sine-waves and therefore extol the virtues of range systems that are based upon an RMS value. Of course, a sine-wave has a known ratio of Peak to RMS and we can therefore easily select a range that will accommodate the complete waveform. However, in the world of real power measurement, we are faced with highly distorted waveforms that will by definition have a different ratio to that of a sine-wave. It follows that the voltage or current range selected by a measurement instrument that assumes a sine-wave input is unlikely to be ideal when faced with a harmonically rich distorted wave shape. In order to ensure that a distorted waveform is completely and correctly quantified, a measurement instrument should identify the peak of the applied waveform and select a range that will include that peak. It is for this reason that all N4L power measurement products utilise a peak ranging system and therefore can assure a user that auto ranging will always include the complete waveform, as any precision measurement product should. Given a peak detect range system; it follows that when presented with a sine-wave or any low crest factor signal, the lowest appropriate range will be selected so in all cases, the range will be appropriate to the applied signal. Anyone who argues that an RMS ranging system is inherently preferable in a power measurement environment is either focused so much on the world of calibration that they will promote such ranging despite its detriment to real world measurements, or are simply defending a system because it is the one they have.


Section of the N4L UK Calibration laboratory with 7 of total 12 ACCIV calibration systems and Fluke 6105A Electrical Power Standard

Newtons4th

Newtons4th Ltd (abbreviated to N4L) was established in 1997 to design, manufacture and support innovative electronic equipment to a worldwide market, specialising in sophisticated test equipment particularly related to phase measurement. The company was founded on the principle of using the latest technology and sophisticated analysis techniques in order to provide our customers with accurate, easy to use instruments at a lower price than has been traditionally associated with these types of measurements

Flexibility in our products and an attitude to providing the solutions that our customers really want has allowed us to develop many innovative functions in our ever increasing product range

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