APPLICATION NOTE 42

Understanding high accuracy wideband power measurement

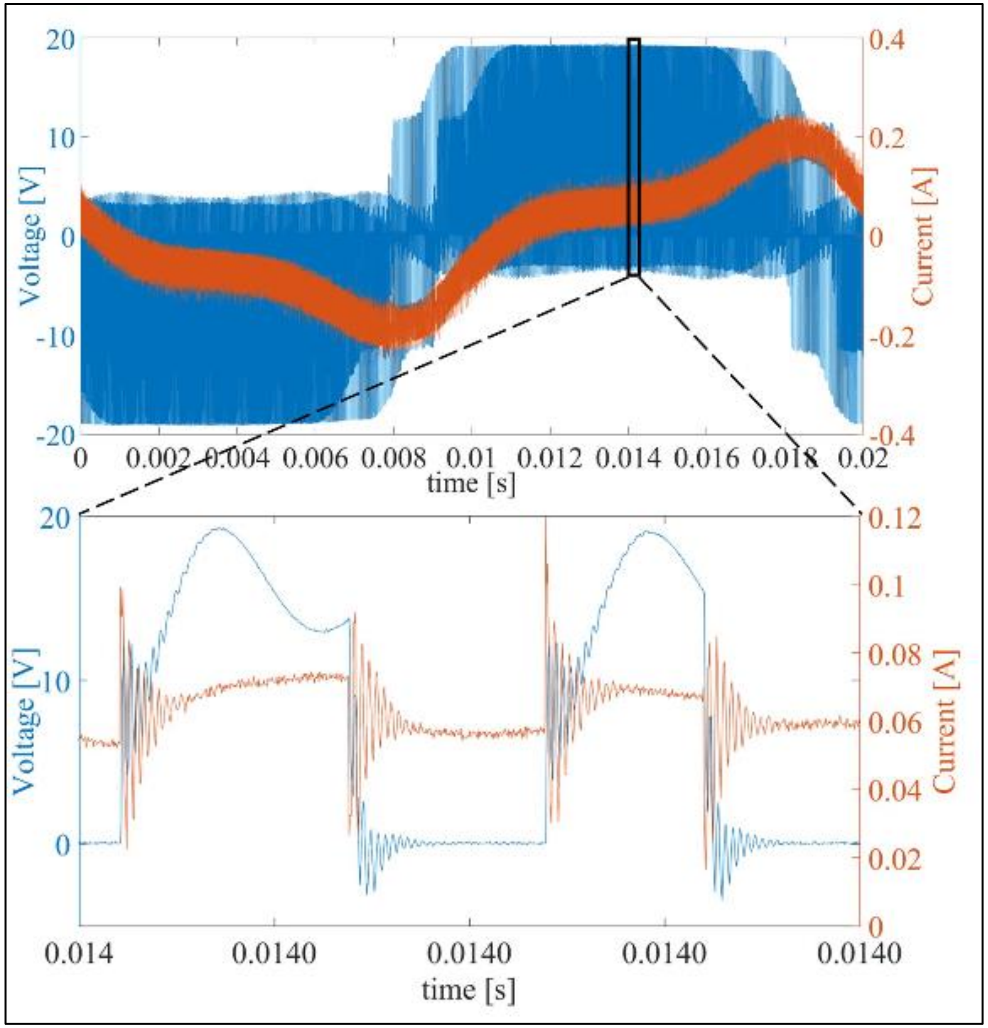
For AC power applications involving only low frequency components and a power factor near unity, there are many power measurement products that can be considered as a suitable measurement solution.

However, an ever-increasing proportion of power electronic applications involve distorted waveforms that cannot be measured correctly with conventional power analyzers. These applications require a level of wideband power accuracy that is achieved and proven by very few commercially available power measurement instruments.

Identifying the most suitable instrument for such applications becomes particularly difficult, because the headline accuracy stated on power analyzer marketing materials usually refer only to a fundamental component.

In this document, we consider the importance of quantifying wideband power accuracy and explain why a focus on headline accuracy can be misleading, or completely meaningless to a power electronics engineer.

GaN inverter waveform example



The development and use of fast switching devices such as SiC and GaN Mosfets has inevitably increased the frequency components within power electronic circuits.

From this example of the voltage and current waveforms on a GaN inverter design, it is clear that accurate power measurement will require the inclusion of both the carrier frequency and its harmonic components.

It follows, that to quantify the total accuracy of any power measurement instrument in distorted power applications, we cannot base our decision on only the fundamental frequency component. We must consider the accuracy over a wide frequency range.

Fig. 1

[1] : W. Martinez, S. Odawara, K. Fujisaki, “Characteristics Evaluation Using a High Frequency GaN Inverter Excitation”, Toyota Technological Institute, Japan, nov. 2017

Wideband power accuracy comparison

In the graph below, we compare the published 12-month power accuracy of the PPA5500 with its nearest competitor.

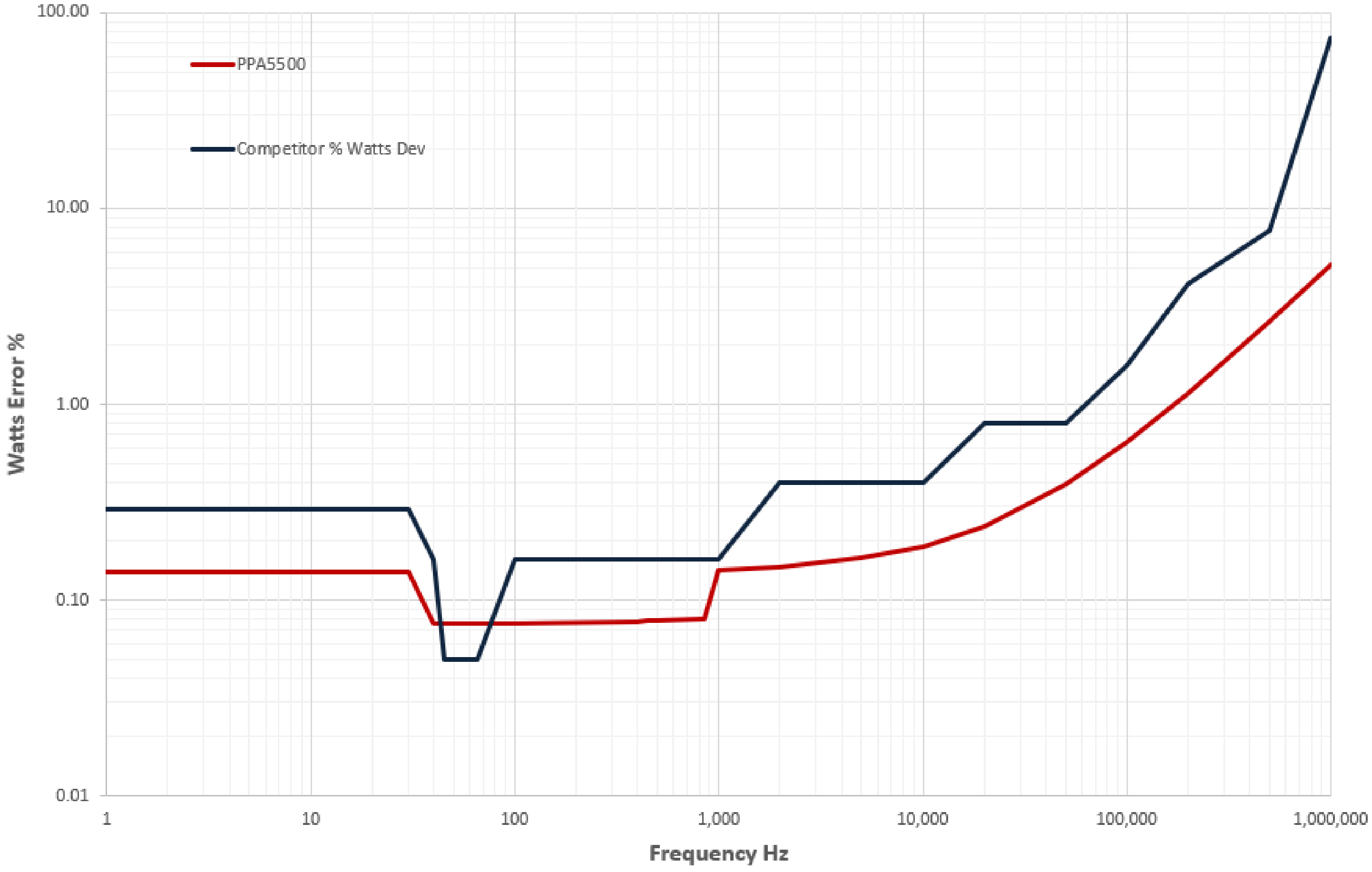


Fig. 2

Applied signal 230V @ 1.5A

OBSERVATION

Power measurement instrumentation companies increasingly use the marketing technique of optimising the low frequency accuracy specification of their products to improve the headline accuracy they can claim.

This is achieved by calibrating an instrument over a narrow frequency range [Blue trace in fig.3 below] to achieve a specification that is impressive, but way below its broadband accuracy, highlighted in Fig.4 below.

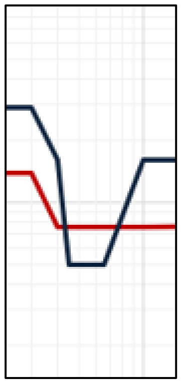


Fig. 3

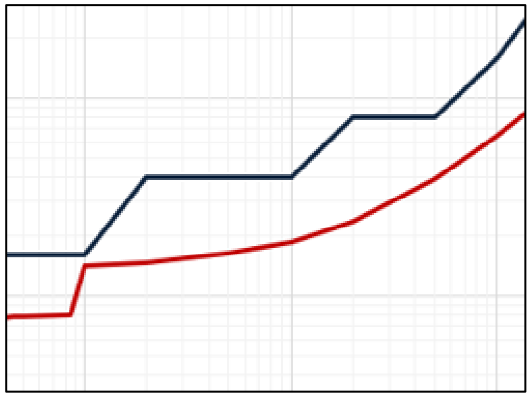


Fig. 4

COMMENT

For a user that only operates within this narrow frequency range and who works only with pure sinusoidal waveforms, this technique may be of interest. However, for most real power measurement applications, for example: variable speed motor drives, lighting ballasts, ultrasonic devices and many more, the low frequency headline accuracy is largely meaningless and completely misleading

QUESTION

In a real-world power application such as a motor drive, what proportion of the total power measurement error is attributable to an optimised accuracy frequency range and how do you derive the true total accuracy?

Distorted power worked example - PWM Inverter Drive

Here, we look at the voltage and current waveforms of an IGBT based inverter with a fundamental sine component of 40Hz generated from PWM carrier modulation.

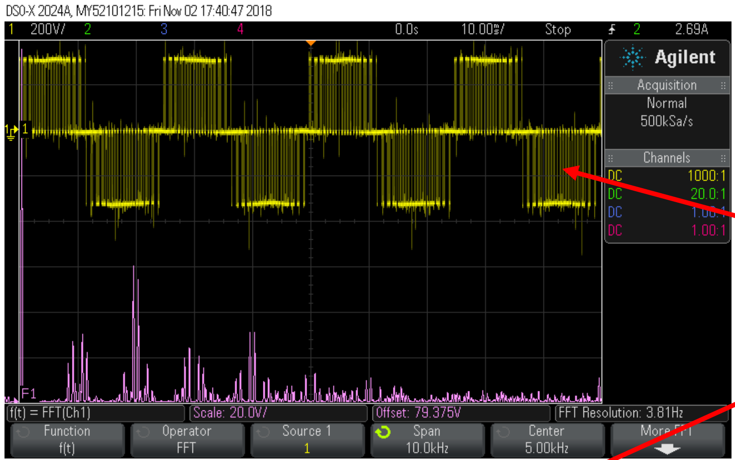


Fig. 5

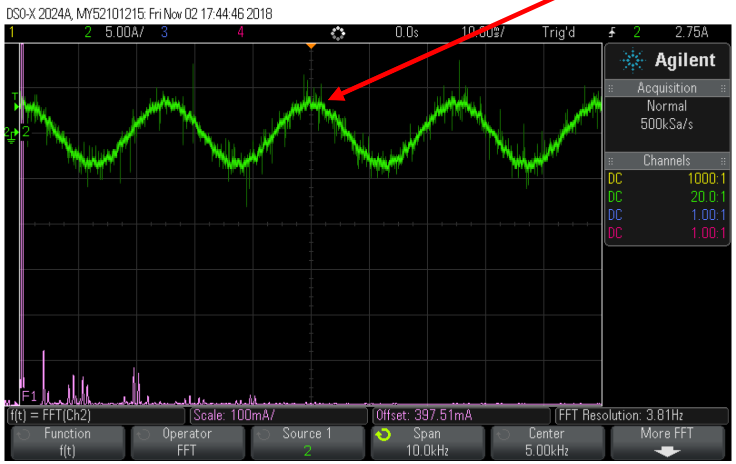


Fig. 6

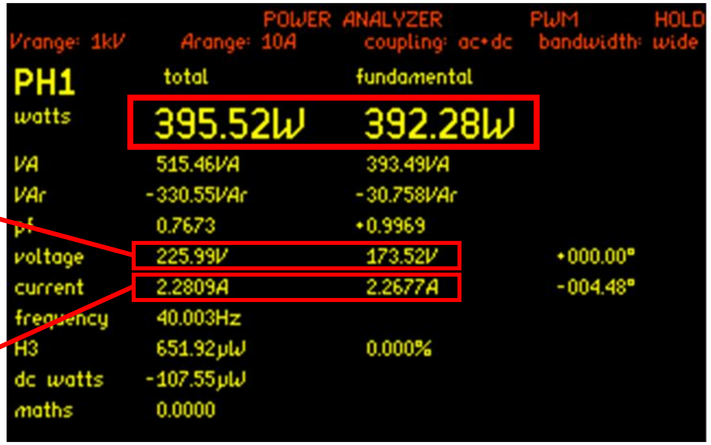


Fig. 7

From analysis of the wideband **total** power (DC—2MHz) relative to the **fundamental** component (40Hz), we can see that 0.82% of total power (3.24W in 395.52W) is attributable to frequency components above an optimised accuracy frequency range.

An FFT analysis of the voltage and current signals confirms that wideband power loss is dominated by the PWM switching frequency and harmonics of this switching frequency.

It follows, that we will only obtain an accurate understanding of the wideband power from which we can then compute the true power efficiency of a device, if we quantify the accuracy of any measurement instrument over a frequency range that includes the carrier and its harmonics.

The carrier frequency in typical power conversion devices will range from 2kHz to 100kHz (The GaN switching example shown in Fig.1 is 100kHz), so for the purpose of this paper, we will consider a carrier frequency of 50kHz.

Deriving high frequency power accuracy in a meaningful way

From the measurement example above, we know that 0.82% of total measured power comes from the carrier and harmonics of the carrier.

To derive the meaningful accuracy of any power analyzer in a distorted power environment, we should make tests with a real power signal on which we can independently quantify the true total power with known uncertainty.

We can do this by applying a 50kHz square wave across a resistive load and using an ISO17025 accredited power calorimeter (N4L Tech Note 003), from which we can precisely quantify the true power of this simulated carrier signal.

In Fig.9, we show the result of a PPA5530 power calibration using an accredited calorimeter when applying the square wave signal illustrated in Fig. 8

It can be seen, that the total power deviation (error) is -0.424% from the traceably measured total power of 2.2179 Watts.

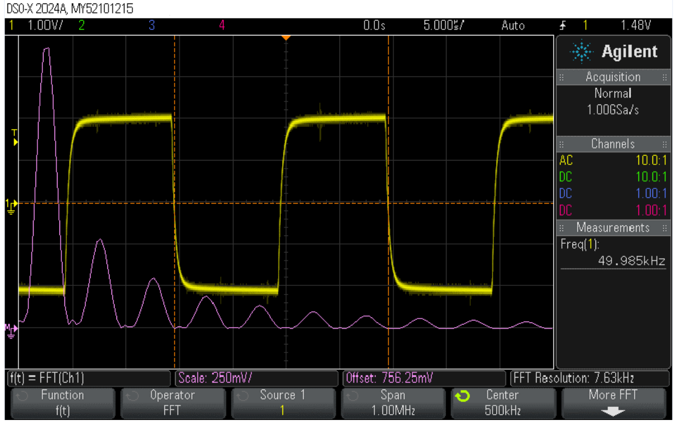


Fig. 8

[------------------ applied	------------------]			[----------------- measured	----------------]		
RESULT	Freq (Hz)	Power Range (W)	Power (W)	Power(W)	Dev	Spec*	Uncert
OK	5.00e+04	2.12 to 2.34	2.2179	2.2085	<-0.424%>	[0.72%]	{0.21%}

Note* The Spec value refers to the single frequency component defined in the Freq (Hz) column.
Measured Power(W) and Uncertainty (Uncert(%)) both include frequency components up to 2MHz.

Spec calculated using PPA ranges 10V, 3A

Fig. 9

Note: The PPA measured accuracy is approximately 4 times better than the published specification (Table 1).

Carrier Power - fundamental and harmonic Accuracy

Having measured the total power of a simulated 50kHz carrier using an ISO17025 traceable calorimetry technique, we can verify the harmonic power components by multiplying each of the voltage harmonic magnitudes with the current shunt resistance and confirm that the total computed power correlates with the measured power.

Harmonic	Freq	Voltage	Current (1.65R load)	Applied Harmonic Power (W)	PPA5500 Specified Power Error (W)	Competitor Specified Power Error (W)
1	50000	1.7400	1.0545	1.8349	0.0084	0.0175
3	150000	0.5800	0.3515	0.2039	0.0044	0.0624
5	250000	0.3480	0.2109	0.0734	0.0037	0.0615
7	350000	0.2486	0.1506	0.0374	0.0034	0.0610
9	450000	0.1933	0.1172	0.0227	0.0032	0.0608
11	550000	0.1582	0.0959	0.0152	0.0031	0.0610
13	650000	0.1338	0.0811	0.0109	0.0031	0.0612
15	750000	0.1160	0.0703	0.0082	0.0030	0.0613
17	850000	0.1024	0.0620	0.0063	0.0030	0.0613
19	950000	0.0916	0.0555	0.0051	0.0029	0.0613
			Total	**2.2179**	**0.0381**	**0.5694**
			Specified accuracy		(1.72 %)	(25.67 %)

Table 1

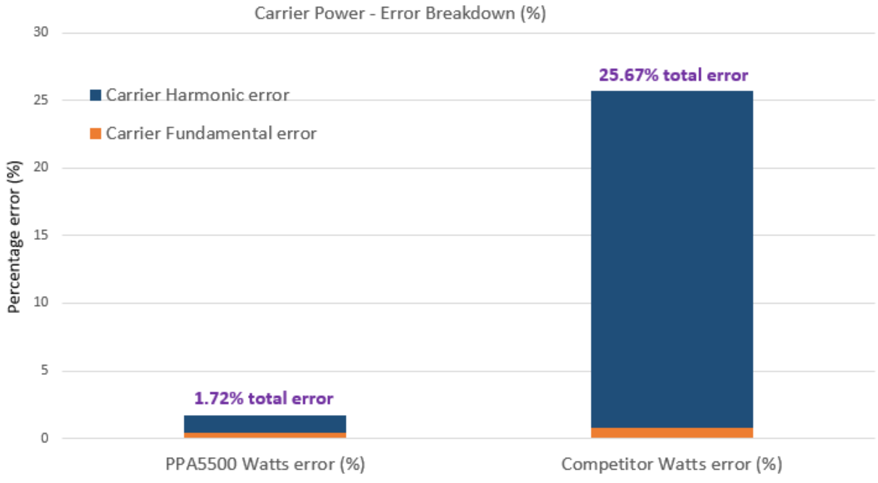


Fig. 10

Composition of total power and total error

We know from the data in our worked example (Fig.7) that we have 395.52 Watts of total power, of which 392.28 Watts is related to the fundamental. This means that 3.24W is related to the Carrier frequency and the associated Harmonics.
Using these known values with the confirmed carrier accuracy values we have established; total power error can be derived.

Competitor

	Watts	Error Specification	Watts Error	Total Error
Fundamental	392.28	0.05%	0.19614	
Carrier	3.24	25.67%	0.83171	
Total	395.52		1.02785	**0.260%**

N4L - PPA5500

	Watts	Error Specification	Watts Error	Total Error
Fundamental	392.28	0.076%	0.29813	
Carrier	3.24	1.72%	0.05573	
Total	395.52		0.35386	**0.089%**

Table 2

We can clearly see that an optimised accuracy specification at the fundamental frequency cannot improve total power measurement accuracy in an inverter power measurement application, because the total power error is dominated by the carrier.

Conclusion

The headline accuracy of most wideband power analyzers is only meaningful for pure sinewave power waveforms within a narrow frequency range.

When selecting a power measurement instrument for use in applications that involve distorted power waveforms, meaningful accuracy can only be obtained by including the error associated with all frequency components.

Traceable verification of wideband power accuracy should include the complete frequency range of interest. It can be seen from examples within this document that traceable power accuracy should include frequencies up to at least 1MHz.