Power Analyzer PW6001

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***Abstract*—**The Power Analyzer PW6001, which features a newly developed high-speed power analysis engine, is a power meter that delivers both accuracy of 0.05%—the highest of any Hioki power meter—and a measurement band of 2 MHz. This paper describes the product's features and architecture and provides example characteristics.

Appearance of the PW6001.

I. Introduction

Hioki has consistently worked to incorporate new functions and features into its power meters by leveraging innovative technologies related to power measurement.

For example, the AC/DC Digital Power HiTester 3192, which Hioki launched in 1991, was the first power meter in the world to include efficiency as a measurement parameter. With the Power HiTester 3193, which was launched in 1998, Hioki delivered a high-accuracy, broadband, high-current-input power meter with six channels of input and the world's first functionality for simultaneously measuring the input and output sides of a 3-phase inverter. Then in 2009, Hioki launched the Power Analyzer 3390, a compact, portable instrument that nonetheless delivered high accuracy.

The goal of this development project was to carry on that tradition while enhancing the power meter's oscilloscope-like waveform analysis as well as power analysis functionality such as FFT analysis and simultaneously refining and extending the instrument's measurement accuracy, measurement bandwidth, and stability.

II. Features

A. *High Accuracy, Broad Bandwidth, and High Stability*

The PW6001 measures signals across a broad 2 MHz band at 18 bits and 5 MS/s with ±0.05% accuracy, giving it the highest sampling performance of any power meter in the world. The instrument also delivers dramatically improved DC accuracy, which has typically been worse than AC accuracy in previous instruments, allowing it to measure AC/DC conversion efficiency at a high degree of accuracy.

In addition, accurate zero-cross detection functionality allows the PW6001 to measure high-frequency switching waveforms and dynamically changing waveforms with a high level of stability and without sacrificing accuracy, even at its fastest data refresh interval of 10 ms.

B. *High Noise Resistance*

Thanks to isolation that uses Hioki's first photonic devices to deliver a high withstanding voltage and low capacitive coupling along with proprietary shielding made of machined aluminum, the PW6001 achieves a common-mode rejection ratio (CMRR) of 80 dB at 100 kHz. This level of noise resistance enables the instrument to deliver stable, high-accuracy measurement even in the vicinity of increasingly high-speed switching devices.

C. *Functionality to Take Maximum Advantage of Current Sensor Performance*

The PW6001 provides dedicated inputs for high-accuracy sensors as well as broadband sensors, and it provides power to both. In addition, proprietary functionality for correcting the phase characteristics of high-accuracy sensors enables high-accuracy measurement of power at frequencies of up to dozens of kilohertz.

D. *Advanced Waveform Observation Functionality*

The PW6001 delivers high-capacity storage capable of recording 1 megawords of voltage and current waveform data from six channels along with four channels of motor input at 5 MS/s (for CH A and CH B analog waveforms, 50 kS/s), enabling waveforms to be observed with oscilloscope-like operability. The instrument also provides waveform zoom and FFT analysis functionality, enabling advanced waveform observation at the same time as power measurement.

E. *High-Performance Synchronization Using Optical Fiber*

Data from two PW6001 instruments separated by up to 500 m can be synchronized using optical fiber. Two modes of operation are available: numerical value synchronization mode, in which measured values are collected at one instrument so that efficiency can be calculated between the two instruments; and waveform synchronization mode, in which synchronization occurs on the sampling waveform level so that waveforms from the two instruments can be compared.

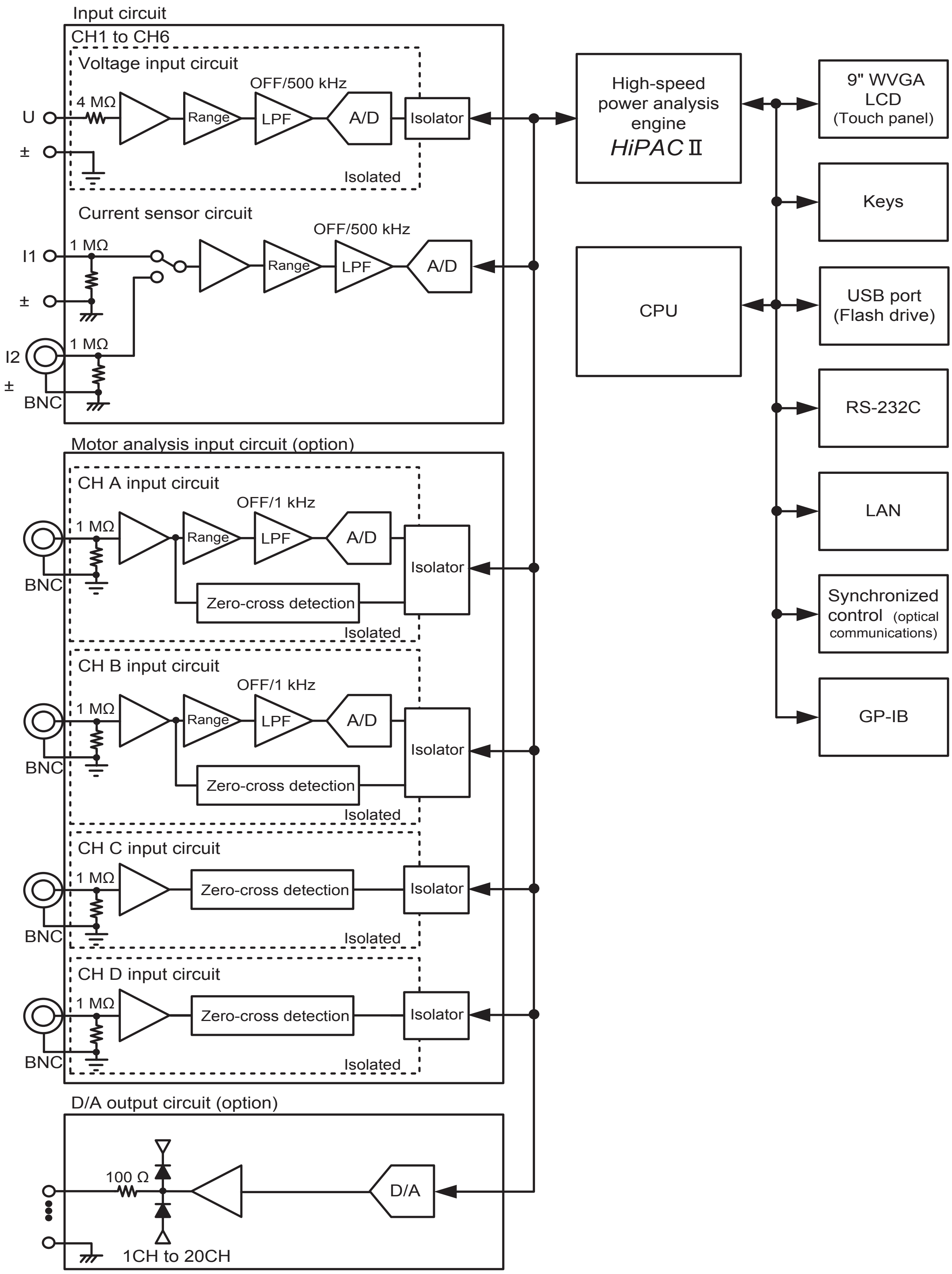

Fig. 1. Block diagram.

III. Architecture

Fig. 1 provides a block diagram from the PW6001. The left side of the diagram consists primarily of analog measurement circuitry, which yields measurement signals that are digitized by each channel's A/D converter. On the right side of the diagram, all measurement data is subject to fully digital processing by the instrument's high-speed power analysis engine before being passed to digital control circuitry to be finalized as measured values and output via the screen or one of the instrument's interfaces.

A. Measurement Circuitry

1) Voltage and current measurement circuits: The voltage input block consists of single-end input in which all channels are isolated by means of photonic isolation devices. Current sensor input uses input circuitry that has been designed to maximize accommodation of high-accuracy current sensors, and the range circuits used in voltage and current measurement circuitry use discrete composite amplifier circuits in order to deliver a high level of stability along with broadband performance. The low-pass filter functions primarily as an anti-aliasing filter, eliminating the effects of aliasing noise on mathematical operations. The 18-bit, 5 MS/s A/D converters simultaneously sample voltage and current signals from all channels, converting them into digital signals and passing them on to the instrument's high-speed power analysis engine.

The PW6001's analog circuitry has been simplified to the greatest extent possible, and the engine has been given functionality for detecting measurement waveform zero-cross events and performing a variety of complex calculations. The result is high accuracy and broadband performance.

The input resistance, which is the greatest source of heat in the voltage measurement block, has been integrated with a shielding case consisting of aluminum that has been machined into a proprietary shape, helping to ensure high stability by dissipating the generated heat.

The current sensor input block is designed specifically for use with sensor input, which it measures with a high degree of accuracy. This design assumption makes it possible to eliminate the shunt resistance, which is the greatest source of heat, from the current sensor input block, enabling highly stable measurement across a broad range of frequencies.

2) Motor analysis input circuit: The motor analysis input block consists of single-end input in which all channels are isolated by means of isolation devices. By isolating all input channels, it is possible to eliminate cross-talk between channels caused by a common ground. In this way, it is possible to analyze two separate motor analysis circuits.

In addition, the instrument provides functionality that allows these inputs to be used as analog signal input or waveform trigger input.

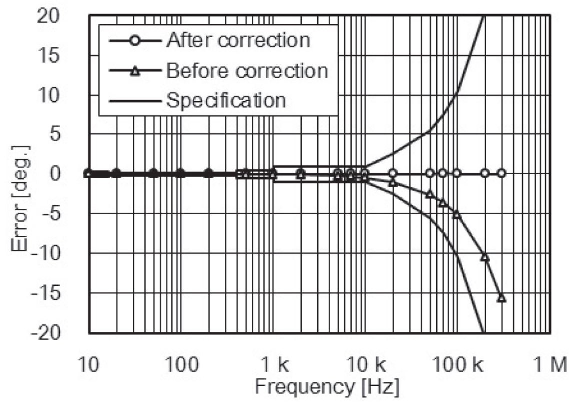

Fig. 2. CT6862 phase characteristics correction.

B. High-Speed Power Analysis Engine

The principal determinants of power meter performance are the voltage, current, and motor analysis analog input block as well as the high-speed power analysis engine. Hioki has developed a proprietary high-speed power analysis engine while also developing high-accuracy, broadband analog input circuitry. The high-speed power analysis engine analyzes all measurements independently and concurrently in real time, including performing period detection, broadband power analysis, harmonic analysis, FFT analysis, and waveform display for all data from the analog input block. The PW6001's engine provides 15 times the processing performance of the first-generation engine used in the 3390. This section describes some of the engine's most noteworthy features.

1) Current sensor phase characteristics correction: High-accuracy current sensors tend to exhibit a phase error component that increases gradually in proportion to frequency in the high-frequency portion of the frequency domain, with the result that measurement accuracy may deteriorate for high-frequency measurement targets with a low power factor. The PW6001's phase characteristics correction block performs proprietary signal processing in real time to correct the phase characteristics of the 5 MS/s current waveform. Current sensor phase characteristics information is configured by entering values for frequency and phase error from the sensor's test results. The instrument determines time lag, which is calculated from the input frequency and phase difference, and performs processing to correct to the equivalent time. This approach makes it possible to perform optimal correction for Hioki's various current sensors based on each sensor's characteristics.

Fig. 2 illustrates phase characteristics reference data for the AC/DC Current Sensor CT6862 along with the characteristics that are anticipated following correction.

2) Broadband harmonic analysis: The harmonic calculation block converts 5 MS/s waveforms to the optimal sampling rate based on the fundamental wave frequency. To limit the aliasing that occurs during this conversion process, the band is limited initially with a digital anti-aliasing filter. Since this filter is used exclusively for harmonic analysis, it is possible to simultaneously perform broadband power measurement and accurate, aliasing-free harmonic analysis. By augmenting optimization through sampling rate conversion and the instrument's digital anti-aliasing filter with a more capable high-speed power analysis engine, Hioki succeeded in boosting analysis performance for fundamental wave frequencies from 0.1 Hz to 300 kHz across an analysis band of 1.5 MHz and up to 100th order harmonics. Thanks to these enhancements, it is possible to measure the distortion and phase difference of wireless power transmission waveforms.

3) Two-instrument synchronized measurement: Due to the use of electrical signals to connect instruments for synchronized measurement in the past, the distance over which communications could be carried out while maintaining noise resistance during inverter measurement was limited, as was communications speed. The PW6001 addresses this issue by adding an SFP optical module that converts electrical signals to optical signals, allowing use of optical instead of electrical cables. This change makes it possible to link two PW6001 high-speed power analysis engines that are 500 m (546.8 yd.) apart with a connection that boasts 1 Gbps communications speed and high noise resistance. The increased communications speed makes it possible to send the slave instrument's waveform data and measurement data to the master instrument. Although there is a transmission delay of up to approximately 2.5 μs depending on the length of the optical cable, the instrument incorporates automatic correction functionality for canceling this delay to improve synchronization accuracy.

C. Software

Although the PW6001 has more channels than the previous model and provides more extensive functionality, for example in the form of advanced waveform observation capabilities, it uses a touch panel to deliver simple, intuitive operation. As a result, operability has improved dramatically compared to the previous model. The new instrument provides the following functional improvements:

1) Harmonic measurement: Whereas the previous model could perform synchronized harmonic analysis for one circuit, the PW6001 can do so for six circuits. In addition, capabilities such as IEC mode, Wide Band mode, and a grouping setting enable the instrument to meet the full array of user requests for harmonic measurement.

2) Averaging: The PW6001 augments the indexed averaging used in the previous model with simple addition averaging, which was requested by many users. This enhancement enables the instrument to perform averaging for longer periods of time than the previous model, helping it to deliver more stable measured values.

3) Data refresh rate: Whereas the previous model had a minimum data refresh rate of 50 ms, the PW6001 can refresh data at an interval as short as 10 ms, excluding harmonics. This capability enables it to analyze transient-state power, for example motor behavior when starting and while under acceleration, at a higher level of detail.

4) Two-instrument synchronized measurement: Whereas the previous model supported only timing synchronization, the PW6001 adds support for measured value transmission (in numerical value synchronization mode) and waveform transmission (in waveform synchronization mode). In numerical value synchronization mode, the instrument supports data synchronization at an interval as short as 50 ms.

5) User-defined calculations: The PW6001 can evaluate complex calculation formulas that in the past could only be recalculated after data had been downloaded to a computer on its own in real time. Measured values from a slave instrument acquired during synchronized measurement can also be used in calculation formulas.

6) Waveform display and FFT analysis: The PW6001 offers waveform display and analysis functionality that has been dramatically improved compared to what was provided by the previous model, allowing it to perform cursor measurement of 5 MS/s waveforms and to display user-specified ranges of waveforms.

In addition, since the user can specify the analysis range during FFT analysis at up to 2 MHz, the PW6001 is capable of fine-grained waveform analysis and noise analysis.

This diverse range of functionality is provided with operability that approaches that of an oscilloscope.

D. Hardware

Hioki designed the EIA 4U-size enclosure so that it could provide high-accuracy, broadband measurement of six channels of input.

To yield improved measurement stability and noise resistance, inputs use a newly designed solid shielding case consisting of aluminum that has been machined into a proprietary shape. There are also shielding plates between inputs in order to reduce cross-talk.

The enclosure's sheet metal components are bonded more strongly to each other than their counterparts on the previous model to yield more stable measured values as well as improved enclosure rigidity and durability. In addition, the PW6001 uses air cooling by an optimally positioned internal fan as well as a design that isolates sources of heat to deliver a more stable, uniform distribution of temperature around measurement circuits for improved temperature characteristics.

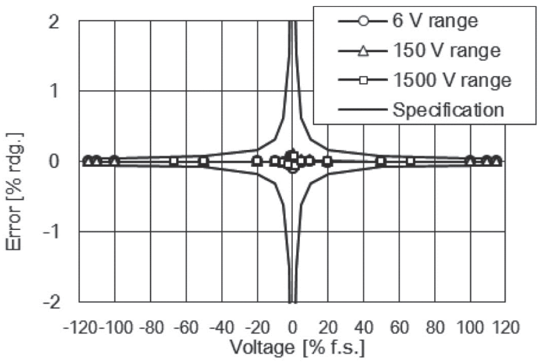

Fig. 3. Voltage linearity: DC.

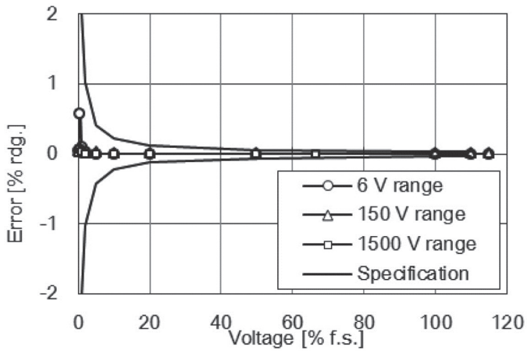

Fig. 4. Voltage linearity: AC+DC.

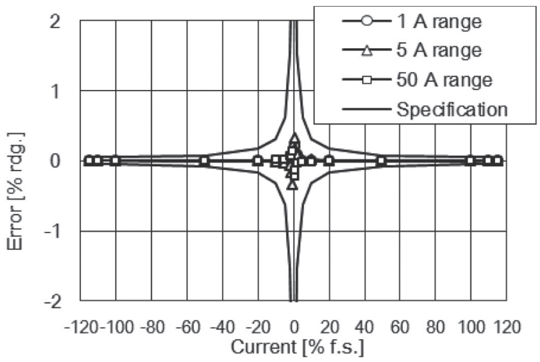

Fig. 5. Current linearity: DC.

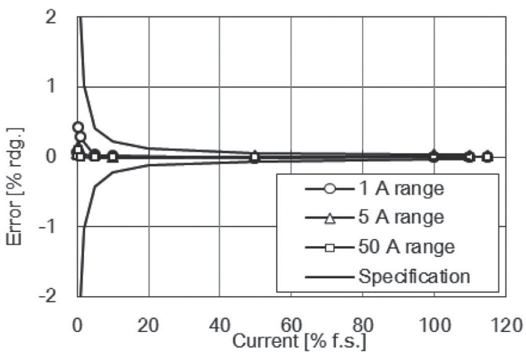

Fig. 6. Current linearity: AC+DC.

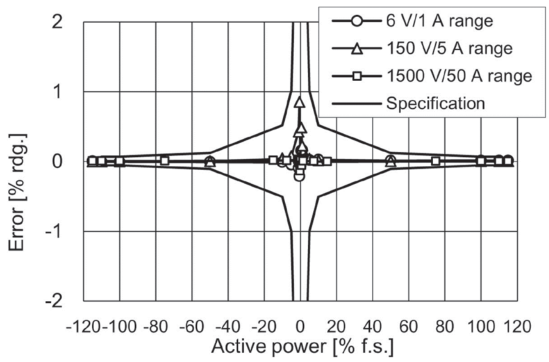

Fig. 7. Active power linearity: DC.

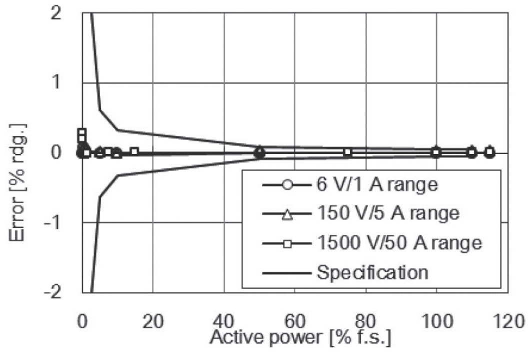

Fig. 8. Active power linearity: AC+DC.

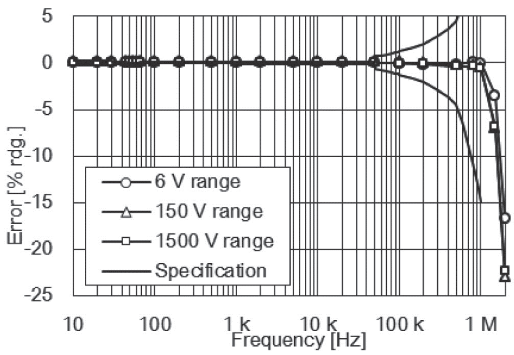

Fig. 9. Voltage frequency characteristics: AC+DC.

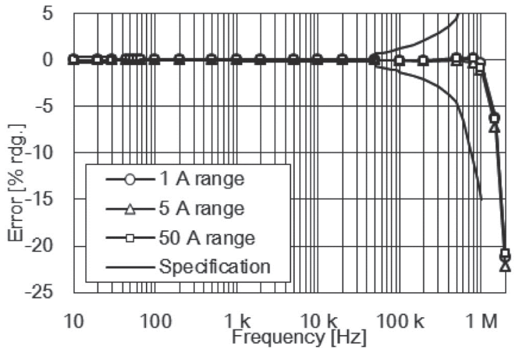

Fig. 10. Current frequency characteristics: AC+DC.

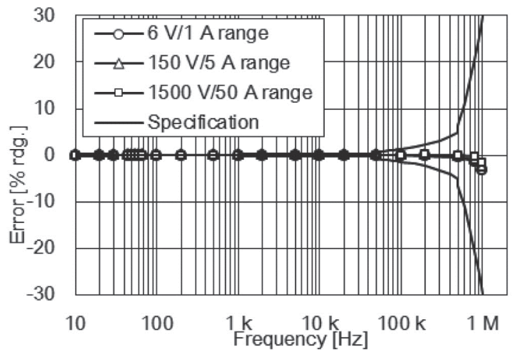

Fig. 11. Active power frequency characteristics: AC+DC.

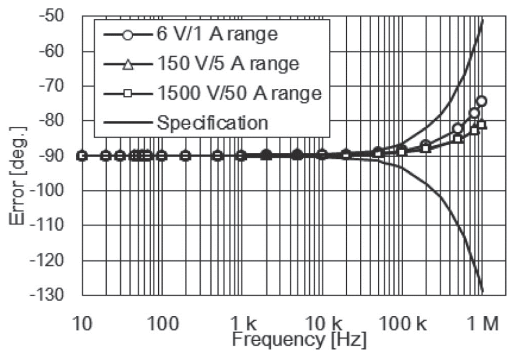

Fig. 12. Phase frequency characteristics: AC+DC.

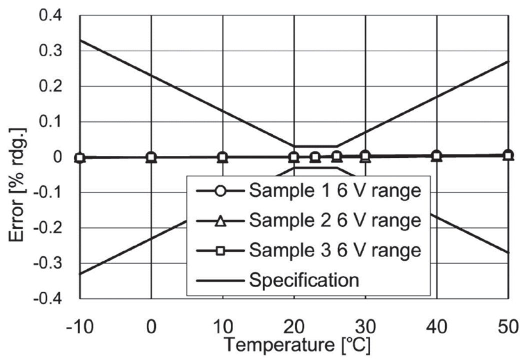

Fig. 13. Voltage temperature characteristics: DC (0% f.s.).

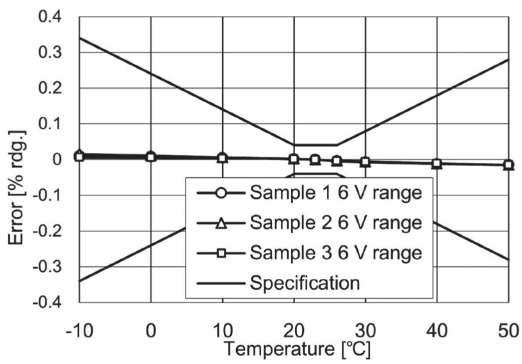

Fig. 14. Voltage temperature characteristics: AC+DC (100% f.s.).

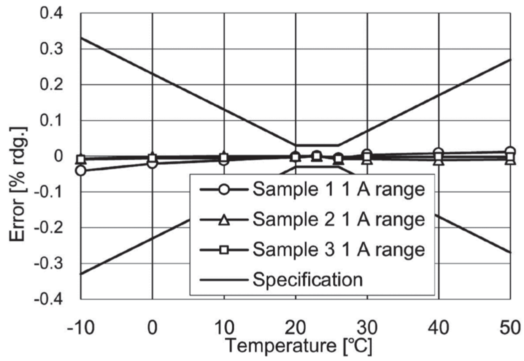

Fig. 15. Current temperature characteristics: DC (0% f.s.).

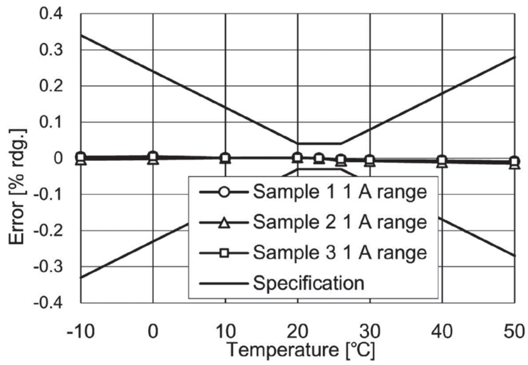

Fig. 16. Current temperature characteristics: AC+DC (100% f.s.).

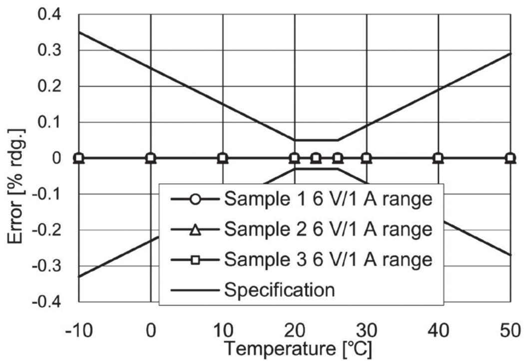

Fig. 17. Active power temperature characteristics: DC (0% f.s.).

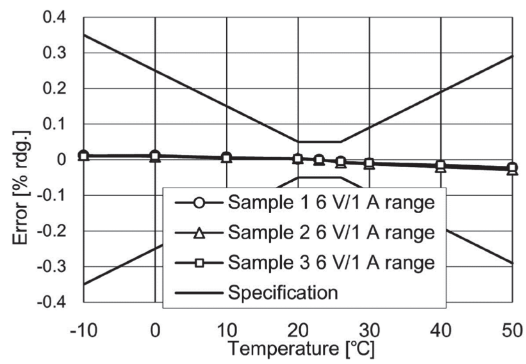

Fig. 18. Active power temperature characteristics: AC+DC (100% f.s.).

The instrument's internal fan also has a longer service life, yielding more stable measured values over extended use and reducing the number of times the instrument must undergo maintenance compared to the previous model.

The molded front panel features a simple, linear design that gives the PW6001 an appearance that befits its status as Hioki's flagship instrument. The two knobs used in waveform analysis have been accentuated with LEDs around their periphery. By illuminating during knob operation to give the user a visual understanding of the process being performed, these lights help make complex operations more intuitive.

Integral-molded handles with metal inserts have been added to the enclosure's top four corners, and the grips use blue TPE to provide adequate strength and ease of grip.

In the PW6001, Hioki has worked to provide a simple combination of required functionality, utility, high-accuracy measurement capability, and durability, and the resulting design concept was recognized with a 2015 Good Design Award.

IV. Example Characteristics

Fig. 3 through 18 illustrate the PW6001's characteristics. The instrument's characteristics are much improved compared to those of the previous model, including linearity characteristics, temperature stability, and frequency characteristics.

When measuring the efficiency across inputs and outputs of devices such as inverters and power conditions, which require measurement starting at DC and extending across a broad range of frequencies, these characteristics translate to dramatically improved measurement accuracy and reproducibility.

This characteristics data constitutes reference data that was measured using a Hioki-owned PW6001. It does not constitute a guarantee of product characteristics. In addition, current sensor characteristics must be added to the relevant current, active power, and phase characteristics.

V. Conclusion

In the PW6001, Hioki has developed a power meter that combines the latest technology with the company's expertise in order to provide the ultimate tool for use by people who develop technologies to ensure equipment operates in an efficient, energy-saving manner. Hioki hopes that the instrument will help protect the Earth's environment by playing a useful role in the drive to improve energy efficiency worldwide.

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