Yokogawa's Power Calibration Technology to Support High-Precision Power Analyzer

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While the world's energy consumption is increasing on an annual basis, the issues of fossil fuel depletion and global warming need immediate attention. Given this situation, the measurement technology that precisely can evaluate electric power is becoming more important to efficient use of electrical energy.

This paper introduces a calibration technology that is comparable to national standards for calibrating a high-precision power analyzer that can evaluate even a slight improvement in power generation, storage and consumption of electrical equipment.

1. Development of a power analyzer and power calibration system

Yokogawa has been developing power analyzers and corresponding calibration systems for many years.

In 2004, during the first phase of the development of a power analyzer with a basic power accuracy of +/- 0.06% at 60Hz, Yokogawa developed a reference power standard sufficient to guarantee that accuracy. In the second phase, in 2018, Yokogawa developed a new reference power standard to achieve a basic power accuracy of +/- 0.03% at 60Hz in a higher precision power analyzer.

To guarantee the accuracy of such a high precision power analyzer, which did not previously exist in the market, it was necessary to establish a new calibration system.

2. Conventional Yokogawa power calibration system

The power calibration system is in the form of an phantom power, which is a calibration system that uses voltage/current sources. Power is not supplied across an actual load.

In the conventional calibration system from the first phase, a reference power analyzer serves as a reference standard that traces physical quantities from a higher order standard. Calibration is performed by supplying the same power signals to the reference power analyzer and the power analyzer being calibrated (the "device under test" or DUT). The measured values of the standard power analyzer are compared directly with those of the DUT.

Generally, in power measuring instrumentation, calibration is performed under the conditions of a power factor of 1 and a power factor of 0. The conventional power calibration system configuration uses standards that differ depending on the power factor.

3. Calibration range and uncertainty of the conventional power calibration system

At a power factor of 1, 100 V / 5 A was measured by the reference power analyzer and the uncertainty was approximately 60 ppm.

Figure 1. WT5000 Precision Power Analyzer

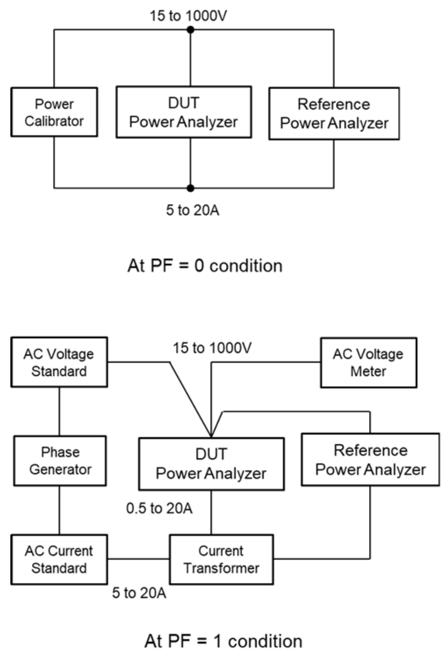

Figure 2. Conventional power calibration system configuration

Expanding the calibration range beyond 100 V / 5 A required changing the voltage range of the reference power analyzer and, for current, the current transformation ratio. By changing the range in this way, the uncertainty increased up to approximately 80 ppm.

At a power factor of 0, the specifications of the power calibrator were left as they were and the uncertainty was approximately 70 ppm at the minimum and approximately 90 ppm at the maximum.

Figure 3. Conventional power calibration system

As shown in Figure 2, the conventional power calibration system combines a reference power analyzer and equipment to expand the calibration range. The number of devices for current calibration and power calibration has been a factor that increases the uncertainty when expanding the power range.

4. New power calibration system

What should be done to obtain an uncertainty that is independent of the set range of a device even if the calibration range is expanded? The uncertainties of the reference power analyzer and the power calibrator, which are the core, essential equipment in the conventional power calibration system, must be reduced. Otherwise, a drastic shift to a new method that does not use a reference power analyzer or power calibrator is needed.

Yokogawa chose the latter as a new power calibration system and decided to adopt a method of power calibration by combining physical quantities used to calculate power in stead of using a reference power analyzer.

Unlike other physical standards, power consists of three physical quantities: voltage, current and power factor. Power (P) can be expressed by the following equation where U is voltage, I is current, Φ is phase angle and cosΦ is the power factor:

$$P = U \times I \times \cos\Phi$$

For the new power calibration system, improvements were made to the uncertainty by returning to these three individual physical quantities.

For a power factor of 1, Yokogawa examined a method to achieve very precise calibration uncertainty on voltage and current amplitudes. Sufficient uncertainty can be obtained in voltage calibration by using a higher-level standard.

The conventional power calibration system performed current calibration by power-current conversion from the calibration values of a reference power analyzer. However, the new power calibration system performs current calibration via a newly developed and highly stable shunt resistor that is unaffected by the surrounding environment.

When the power factor is 0, it is important to control the phase, which is the time difference between voltage and current. Therefore, Yokogawa constructed a high-resolution phase generation system to increase the phase setting accuracy.

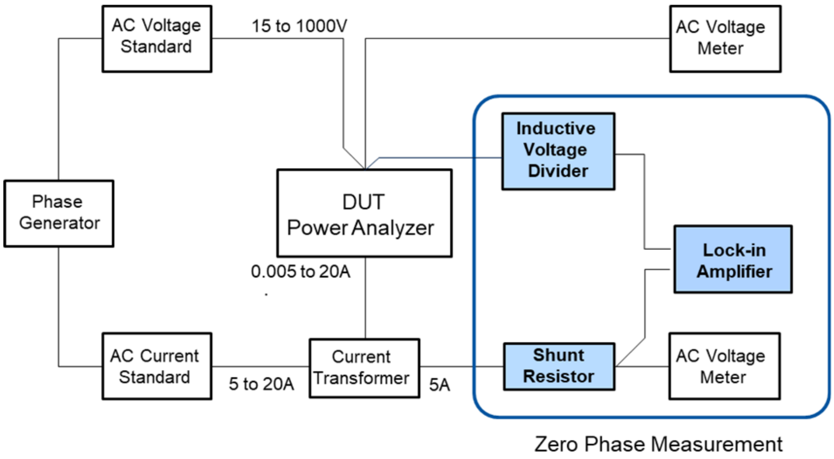

Figure 4. New power calibration system configuration

To improve uncertainty when setting the phase difference required the shunt resistor on the current side and an inductive voltage divider with low capacity and high voltage division ratio on the voltage side. Yokogawa further adopted a method to control the phase between voltage and current by using a lock-in amplifier and performing "Zero Phase Measurement" with the phase difference of zero as the reference.

Figure 4 shows the new power calibration system configuration. Instead of a conventional, reference power analyzer, the new power calibration system uses an inductive voltage divider, shunt resistor, lock-in amplifier and an instrument to measure AC voltage. The measurement uncertainty is determined by a combination of the following components:

-Shunt resistor

The shunt resistor is a coaxial structure component with excellent frequency characteristics and is not easily affected by temperature changes. The nominal value is 0.2 Ω, and it is designed with 5 A input and 1 V output as the conversion ratio. The resistance uncertainty is 23 μΩ / Ω (*k*=2), phase error at 60Hz is - 0.2 μrad and uncertainty is 9.4 μrad (*k*=2). The temperature characteristics are less than 5 ppm / °C and the temporal change of resistance value has been confirmed to be sufficiently small.

-Inductive voltage divider

The inductive voltage divider has a voltage division ratio that ranges from 10:1 to 1000:1, corresponding to each voltage range. It offers a lower capacitance of several hundred pF and is designed to be easily driven by the voltage source. The phase voltage linearity is approximately 1 mdeg.

-High-resolution phase generator

The voltage / current phase resolution on the power generation side is 0.1 mdeg and allows a desired phase to be set. This setting resolution is equivalent to 1.7 ppm at a power factor of 0. The voltage / current phase stability is 0.38 mdeg / h and equivalent to approximately 7 ppm at a power factor of 0.

-Zero phase setting

The voltage signal and current signal are normalized by the inductive voltage divider. The shunt resistor and the zero phase are set by controlling the phase and amplitude so that the phase difference between these normalized signals becomes zero.

Figure 5. New power calibration system

The phase is controlled by the high-resolution phase generation system with a resolution of 0.1 mdeg and the amplitude is controlled by the voltage / current sources. The lock-in amplifier is used for differential voltage measurement and the phase difference is measured accurately.

This is a configuration to correct the phase error of each device and set the voltage and current at which the phase difference at the input position to the DUT under calibration becomes zero.

In this way, it is now possible to construct a power calibration system by voltage, current, and phase and to determine the uncertainty of power from those three individual physical quantities.

The uncertainty at a power factor of 1 was between 60 and 80 ppm in the conventional system, but improved to between 50 and 60 ppm in the new system. At zero power factor, the uncertainty was improved from between 70 and 90 ppm down to 30 ppm.

In particular, the difference in uncertainty among calibration ranges has been reduced and the same level of uncertainty has been achieved in all the ranges. This allows power analyzer calibration of +/- 0.03% at a power factor of 1 and of +/- 0.02% at a power factor of 0.

For reference, a traceability system diagram is shown in figure 6. In the new system, the physical quantities—voltage, current and phase—are traced to the national standards.

Since the working reference standard of power analyzers for a DUT to be calibrated are used for production, repair and calibration, they are deployed not only at Yokogawa Manufacturing Corporation in Japan but also at Yokogawa Electric Corporation's major overseas affiliates and used as power reference standards for Yokogawa Test & Measurement Corporation power measurement instruments.

5. Conclusion

Yokogawa has established the power calibration system by combining physical quantities from the conventional comparison method of power calibration using a reference standard of power analyzer. In building the new system, Yokogawa has improved the uncertainty of voltage calibration and developed the shunt resistor, inductive voltage divider and high-resolution phase generator. Yokogawa also established a new way to calibrate phase and developed the "Zero Phase Measurement" method that sets the phase at a power factor of 1.

This newly developed power calibration technology has enabled basic power accuracy of +/- 0.03% at 60Hz in a high-precision power analyzer. This allows the development of industrial equipment, home appliances, transportation and power equipment with increased power efficiency throughout the world.

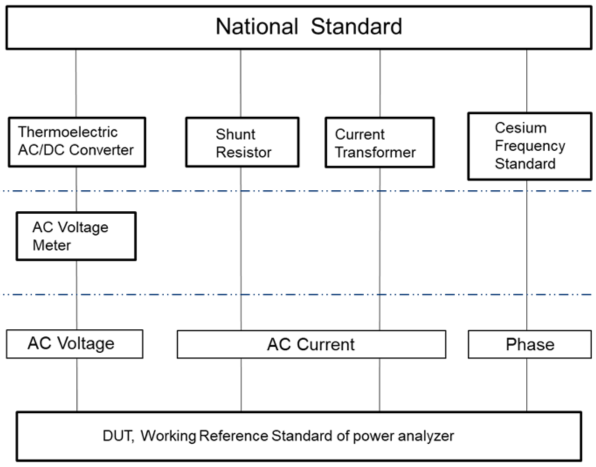

Figure 6. Traceability diagram of new power calibration system