Yokogawa's power calibration technology to support high-precision power analyzer

Yokogawa Test & Measurement Corporation
Technical Development Division Development & Engineering Dept. 1
Katsuya Tachibana

While the world's energy consumption is increasing year by year, the issues of the depletion of fossil fuels and the climate warming cannot wait any longer. In this situation, the measurement technology that can correctly evaluate electric power is becoming more important to efficiently use the electricity as energy.

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

1. Development of power analyzer and power calibration system

Yokogawa has been developing power analyzers and calibration systems thereof over the years.

In the first phase, 2004, for the development of a power analyzer with a basic power accuracy of +/- 0.06 %, we developed power standards sufficient to guarantee the accuracy. In the second phase, 2018, we developed new power standards to achieve a basic power accuracy of +/- 0.03 % in developing a higher precision power analyzer.

To guarantee the accuracy of such high precision power analyzer that does not exist in the market, it was necessary to establish a system to calibrate it each time.

2. Conventional Yokogawa power calibration system

The power calibration system is in the form of imaginary load test using voltage/current sources, in which the power supplied is not an actual load.

The first phase: In the conventional calibration system, similarly to other physical standards, a standard power analyzer serves as a reference standard that traces physical quantities from a higher order standard. Calibration is performed by supplying the same imaginary load power to the standard power analyzer and the DUT to be calibrated and then directly comparing the measured values of the standard power analyzer with those of the DUT being calibrated.

Generally, in power calibration, calibration is performed under the conditions of a power factor of 1 and a power factor of 0. The conventional power calibration system has a system configuration using different standards depending on whether the power factor is 1 or 0.

3. Calibration range and uncertainty of conventional power calibration system

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

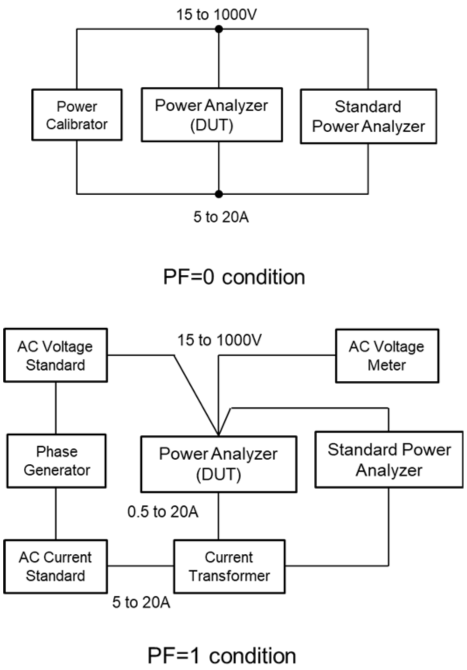

Figure 1. Conventional power calibration system configuration

When expanding the calibration range from 100 V / 5 A, the voltage range of a standard power analyzer is to be changed and for current, the current transformation ratio is to be changed. By changing the range in this way, the uncertainty increased up to approximately 80 ppm.

Figure 2. Conventional power calibration system

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

As shown in Figure 1, the conventional power calibration system is a system that combines a standard power analyzer and equipment to expand the range, so it includes many devices that are used for current calibration and power calibration. This has been a factor in increasing 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 uncertainty of each of a standard power analyzer and a power calibrator, which were the core and essential equipment of the conventional power calibration system, should be reduced or a drastic shift to a new method that does not use a standard 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.

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 power factor:

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

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

For a power factor of 1, we examined a method to achieve highly precise calibration uncertainty on voltage and current amplitude respectively.

Sufficient uncertainty can be obtained in voltage calibration by using a higher-order standard.

The conventional power calibration system performed current calibration by power-current conversion from the calibration values of a standard power analyzer. However, the new power calibration system performs current calibration via a newly developed and highly stable shunt resistor that is not easily affected by the surrounding environment.

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

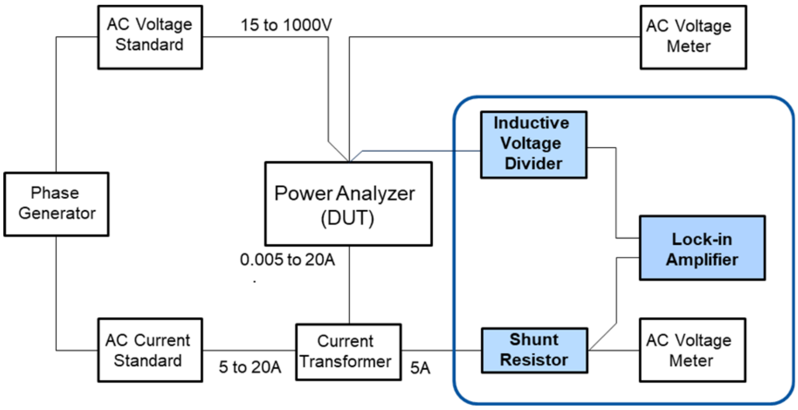

Figure 3. New power calibration system configuration

To improve the setting uncertainty of phase difference, the required uncertainty was secured by the method using the shunt resistor on the current side, and an inductive voltage divider with low capacity and high voltage division ratio was developed on the voltage side.

Furthermore, we adopted a method of controlling 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 3 shows the new power calibration system configuration. The new power calibration system uses, instead of the conventional standard power analyzer, an inductive voltage divider, shunt resistor, lock-in amplifier and voltage measuring instrument to construct the functions on the standard measuring side. The measurement uncertainty is to be determined by the combination of the following components.

・Shunt resistor

The shunt resistor has a coaxial type structure with excellent frequency characteristics and is not easily affected by temperature changes. The nominal value is 0.1 Ω, and it is designed with 5 A input and 1V output as the rating. The resistance uncertainty is 23 μΩ / Ω (k=2), phase error is - 0.2 μ rad and uncertainty is 9.4 μ rad. (k=2). The temperature characteristics are less than 5 ppm / ℃ and the temporal change of resistance value has been confirmed to be sufficiently small.

・Inductive voltage divider

This inductive voltage divider has a voltage division ratio of 10:1 to 1:1000 corresponding to each voltage range. It offers a low input capacity of several hundred pF and is designed so that the voltage source can be easily driven. The phase voltage linearity is approximately 1 m degree.

・High-resolution phase generation

The voltage/current phase resolution on the power generation side is 0.1 m degree and a desired phase can be specified. This setting resolution is equivalent to 1.7 ppm at a power factor of 0. The voltage/current phase stability is 0.38 m degree / 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 and the shunt resistor and the zero

Figure 4. New power calibration system

phase is set by controlling the phase and amplitude so that the difference between these normalized signals becomes zero.

The phase is controlled by the high-resolution phase generation system with a resolution of 0.1 m degree 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 has become possible to construct a power calibration system by voltage, current, phase calibration and to determine the uncertainty of power from three physical quantities.

The uncertainty at a power factor of 1 was 60 to 80 ppm in the conventional system, but improved to 50 to 60 ppm in the new system. At zero power factor, the uncertainty was improved from 70 to 90 ppm 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, enabling 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 5. Instead of power value standards, in the newly developed system to calibrate each of voltage, current and phase, the trace from the national standards is also traced by each physical quantity.

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

5. Conclusion

Yokogawa has established the power standard system by combining physical quantities from the conventional comparison method of power calibration using a standard power analyzer. In building the new system, we have improved the uncertainty of voltage calibration and developed the shunt resistor, inductive voltage divider and high phase resolution setting. We also established a new way of phase calibration and developed the zero phase measurement method that sets the phase at a power factor of 1.

This newly developed power calibration technology has made possible the +/- 0.03 % - level high-precision power analyzer, which contributes to the development of higher power consumption efficiency of industrial equipment, home appliances and power equipment operating in various places in the world.

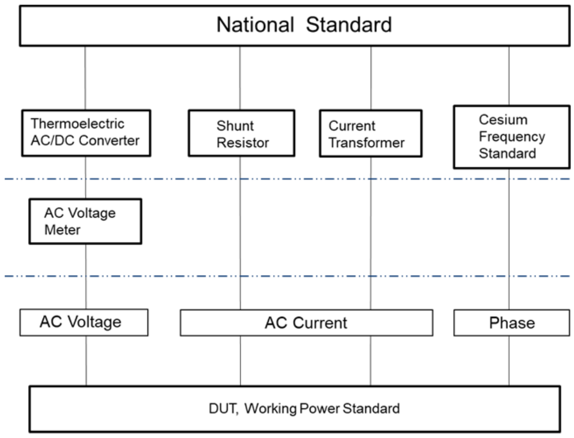

Figure 5. Traceability diagram of new power calibration system

YOKOGAWA TEST & MEASUREMENT CORPORATION
Global Sales Dept. /Phone: +81-42-690-8810 E-mail: tm@cs.jp.yokogawa.com
Facsimile: +81-42-690-8826

YOKOGAWA CORPORATION OF AMERICA	Phone: +1-800-888-6400	E-mail: tmi@us.yokogawa.com	
YOKOGAWA EUROPE B.V.	Phone: +31-88-4641429	E-mail: tmi@nl.yokogawa.com	
YOKOGAWA TEST & MEASUREMENT (SHANGHAI) CO., LTD.	Phone: +86-21-6239-6363	E-mail: tmi@cs.cn.yokogawa.com	Facsimile: +86-21-6880-4987
YOKOGAWA ELECTRIC KOREA CO., LTD.	Phone: +82-2-2628-3810	E-mail: TMI@kr.yokogawa.com	Facsimile: +82-2-2628-3899
YOKOGAWA ENGINEERING ASIA PTE. LTD.	Phone: +65-6241-9933	E-mail: TMI@sg.yokogawa.com	Facsimile: +65-6241-9919
YOKOGAWA INDIA LTD.	Phone: +91-80-4158-6396	E-mail: tmi@in.yokogawa.com	Facsimile: +91-80-2852-1442
YOKOGAWA ELECTRIC CIS LTD.	Phone: +7-495-737-7868	E-mail: info@ru.yokogawa.com	Facsimile: +7-495-737-7869
YOKOGAWA AMERICA DO SUL LTDA.	Phone: +55-11-3513-1300	E-mail: eproc@br.yokogawa.com	
YOKOGAWA MIDDLE EAST & AFRICA B.S.C(c)	Phone: +973-17-358100	E-mail: help.ymatmi@bh.yokogawa.com	Facsimile: +973-17-336100