Technical Notes

Digital Phase Detector PD3259

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***Abstract*—**The Digital Phase Detector PD3259 is a phase detector with an integrated AC voltmeter that can check the phase order and line voltage in 3-phase circuits by making measurements from outside cable insulation. This paper describes the product's features, architecture, and characteristics.

Appearance of the PD3259.

I. Introduction

Phase detectors and digital multimeters (DMMs) are required equipment for technicians performing electrical work, where they are used to check the wiring in 3-phase circuits. First, a phase detector is used to check the phase order in the circuit. Incorrect phase order in a 3-phase circuit can damage equipment, so phase detectors play an important role as a tool for verifying that circuits have been wired properly. In addition, distribution panels, junction boxes, and wiring circuits can contain multiple 3-phase circuits operating at different voltages, and those circuits are identified by measuring line voltages between phases with an instrument such as a DMM. In this way, phase detectors and DMMs are used for different tasks performed as part of electrical work.

Until now, this work has posed the risk of a short-circuit or electric shock if technicians inadvertently make contact with a live wire or metal terminal, leading many in the industry to call for greater safety. Hioki has launched a series of instruments to address this issue, including the Phase Detector PD3129 and the Clamp On Power Logger PW3365, to which the Safety Voltage Sensor PW9020 can be connected to benefit from the PW9020's no-metal-contact voltage measurement technology. Today, these measuring instruments, which improve work safety, are attracting a growing amount of attention.

It is against this backdrop that Hioki developed the Digital Phase Detector PD3259 in an effort to bring no-metal-contact voltage measuring technology to a field measuring instrument.

II. Overview

Having developed no-metal-contact voltage measurement technology, which enables voltage to be measured from outside cable insulation without making direct contact with a metal terminal, Hioki has begun utilizing the technology in its measuring instruments. This technology makes it possible to avoid the hazards of short-circuits and electric shock. Furthermore, because it is no longer necessary to make measurements at points where metal is exposed, the technology offers the additional advantage of dramatically improved work efficiency. Most recently, the PW9020 utilizes Hioki's no-metal-contact technology, and the PW3365, which makes it safe and easy to measure power, has been greeted enthusiastically by the market.

The newly developed PD3259 is a measuring instrument that combines an AC voltmeter and phase detector. The product lets workers simultaneously and safely measure voltage and check phase order while performing electrical work. In this way, it utilizes Hioki's no-metal-contact voltage measurement technology to maximum effect.

III. Functions and Features

A. Phase Detection Function

The PD3259's phase detection function checks phase order in a 3-phase circuit. To utilize the function, the user connects each of the instrument's three voltage sensors to each one of the circuit's phases.

The phase detection function determines whether the circuit has normal or reverse phase order and displays the result with an arrow indicating the order on the instrument's LCD along with a "POS" icon to indicate normal order or a "REV" icon to indicate reverse order (Fig. 1); however, it is preferable that judgment results be easy to ascertain at a glance. The PD3259's dual-color backlight also indicates the results, with yellow-green indicating normal phase order and red alerting the user to reverse phase order.

The large LCD features a backlit area of 45 mm × 60 mm (1.77″ × 2.36″), and the user can check phase order based solely on the backlight color, eliminating the need to look for a small icon. The instrument's beep pattern also changes according to the detected order, providing an aural indication at the same time. A series of beeps indicates normal order, while a continuous tone alerts the user to reverse order. In this way, light and sound combine to help the user check phase order.

B. Line Voltage Measurement Function

The PD3259 incorporates three voltage sensors. The instrument measures the voltage between pairs of sensors and displays each value in one of its three voltage value display areas, each of which consists of four 7-segment digits.

If the measurement target is a 3-phase circuit, all line voltages are shown at the same time. If the measurement target is a 1-phase/3-wire circuit, the N–L1, N–L2, and L1–L2 voltages are shown at the time. In this way, the instrument can display multiple line voltage measured values at the same time for a variety of circuit types including 3-phase circuits.

C. Frequency Measurement Function

The PD3259 can also measure the frequency of the line voltage V_{RS} ($V_{1\text{-}2}$). In this way, two voltage sensors are used to check the voltage frequency by measuring the frequency of the differential signal from the R (1) and S (2) voltage sensors.

D. Three-phase Circuit State Prediction Function (Used Only in Japan)

The instrument predicts the state of 3-phase circuits and displays the results using a variety of icons on its LCD (Fig. 2).

The LCD incorporates an R/S/T phase display underneath the phase order detection arrow icon. If measurement results suggest that a phase may be missing, the icon corresponding to that phase will turn off. Missing phases are predicted based on all information acquired by the instrument, including 3-phase circuit phase voltages, line voltages, and phase data.

For 3-phase delta-wired circuits, the instrument predicts the ground phase and displays an "N" icon underneath the phase display on the LCD.

E. Phase Display Switching Function

The names and colors used to distinguish the phases in 3-phase circuits vary by geographical region and power company. Some conventions name the phases R/S/T in order starting with the first phase in the circuit, while others use consecutive letters or numbers, as in A/B/C, U/V/W, or L1/L2/L3. In addition, colors are sometimes used along with names to identify phases. These colors may be used on cable insulation or as markers on terminals in distribution

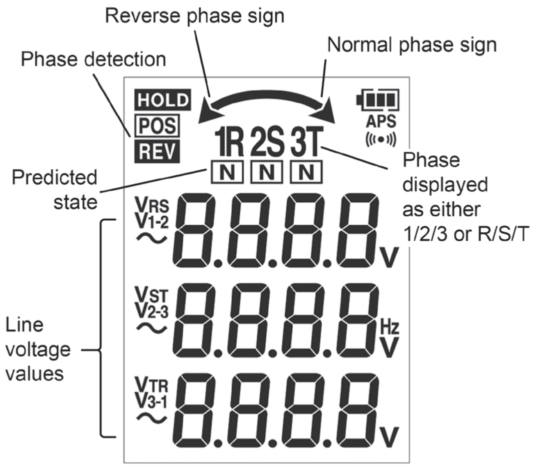

Fig. 1. LCD display.

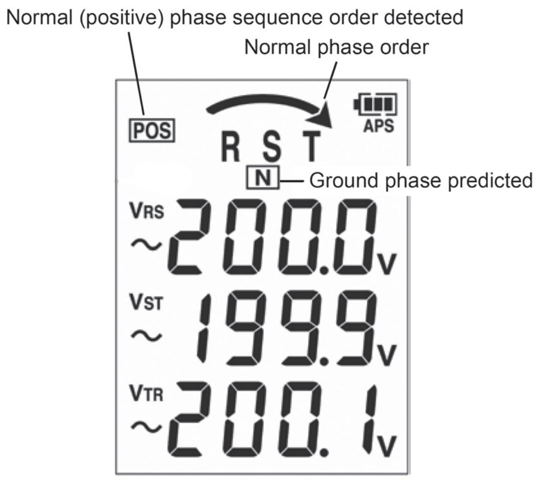

Fig. 2. Three-phase circuit state prediction display.

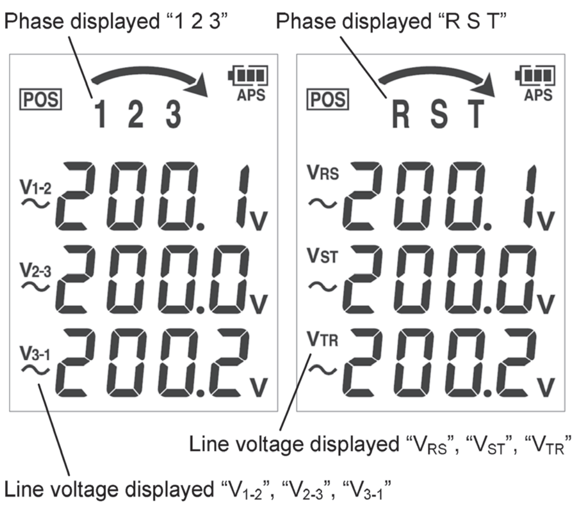

Fig. 3. Phase display switching.

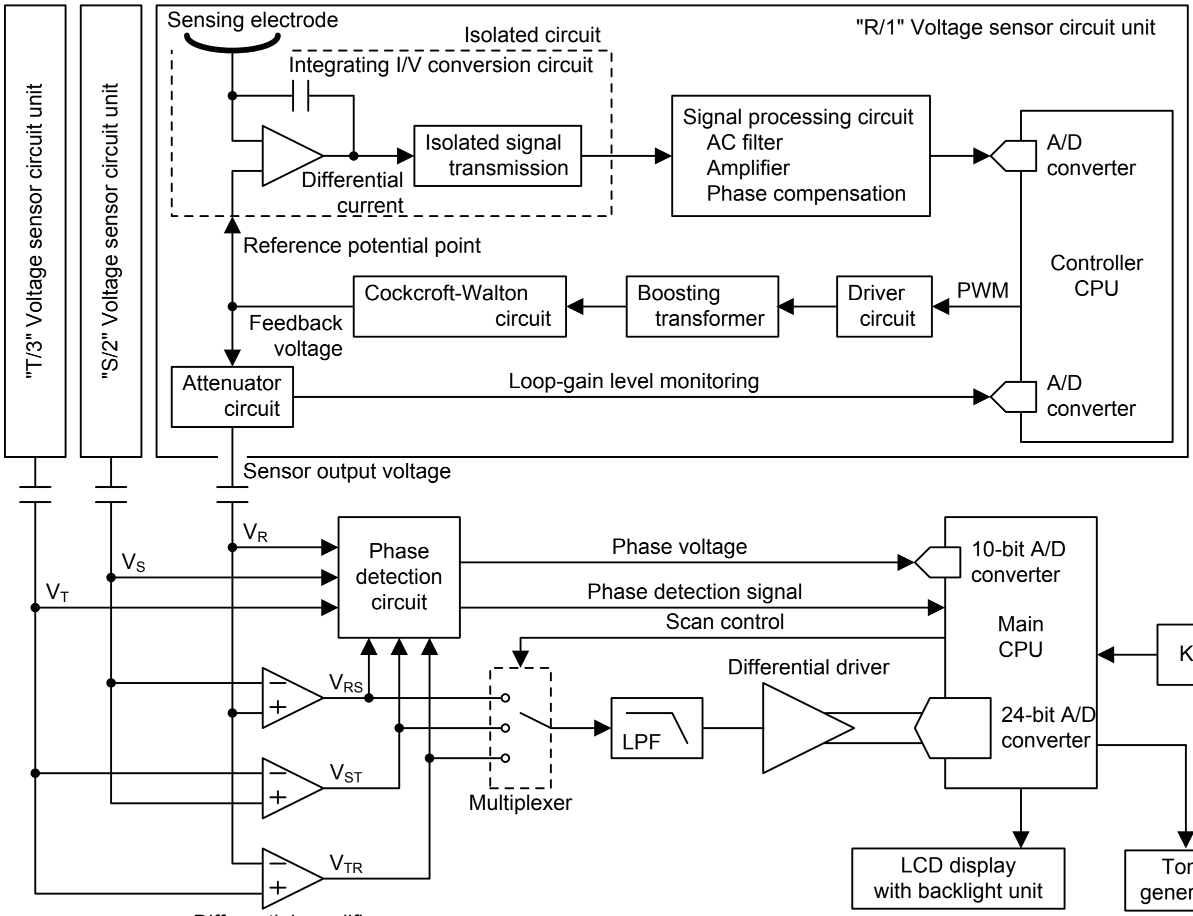

Fig. 4. Block diagram.

panels or junction boxes. A variety of colors may be used along with names depending on the geographical region and power company.

The PD3259 accommodates this variation by allowing the user to switch the phase indicator icons on the LCD between R/S/T and 1/2/3. It is difficult to accommodate all naming conventions, but this function helps users identify the correct order starting with the first phase (Fig. 3).

In addition, the instrument comes with red, blue, and yellow spiral tubes (two of each color). These tubes can be wrapped around the voltage sensor cables to provide an additional visual aid.

In this way, the PD3259 incorporates a number of design features to help ensure workers do not misidentify wiring when working with name and color conventions for 3-phase circuit phases that vary by geographical region and power company.

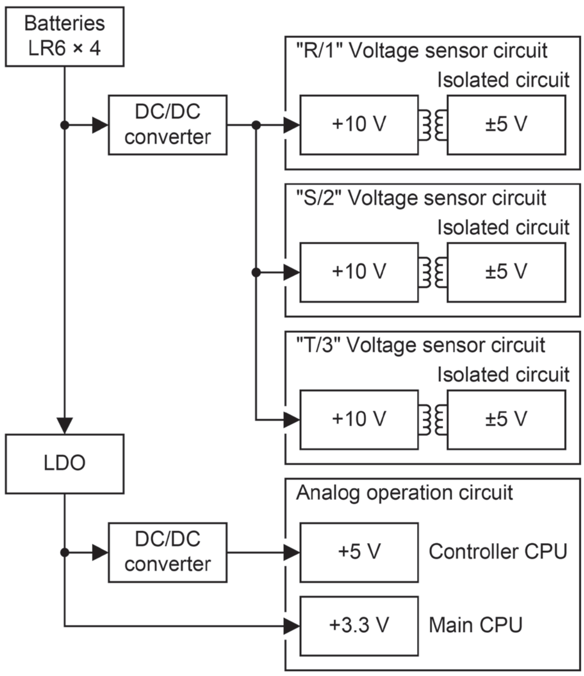

Fig. 5. Power supply block diagram.

IV. Architecture

A. Hardware

Fig. 4 provides a block diagram with a focus on electric circuit signal transmission. The instrument has three voltage sensors, but the block diagram provides a schematic for the circuitry for one voltage sensor.

Fig. 5 provides a power supply block diagram, illustrating how the instrument has multiple supply voltages despite its portable design.

1) Voltage sensors: Due to the principle on which they operate, the PD3259's voltage sensors acquire line-to-earth voltage. The voltage sensors' measurement reference is always ground, and the sensors are designed so that line voltages can be measured by acquiring the vector differences between voltage sensors. The instrument incorporates three voltage sensor circuits of the same design, which shares its basic architecture and operating principles with the PW9020. This paper includes only a brief description of those principles since a more detailed account is available in the references [1]).

Assume that the wire being measured carries the voltage v_1, as illustrated in Fig. 6. When one of the PD3259's voltage sensors is affixed to this wire, the metal portion of the wire and the electrode inside the voltage sensor undergo capacitive coupling. For a given coupling capacitance of C, a minuscule current i will flow between the metal portion of the wire and the electrode inside the voltage sensor via C. This can be expressed as Equation (1):

$$i = 2\pi f C v \qquad (1)$$

$$v = v_1 - v_2 \qquad (2)$$

The voltage v_2 at the electrode inside the voltage sensor is controlled so that $i = 0$ (i.e., the voltage v_2 is generated inside the voltage sensor such that $v_1 = v_2$). Consequently, when $i = 0$, v_2 is the same voltage as the wire. This is the mechanism that allows no-metal-contact voltage measurement, and it is known as the coupling capacitance cancelation method.

2) Electric circuitry: The three voltage-to-ground signals from the voltage sensors are split between two paths, one that is input to the CPU's built-in 10-bit A/D converter and another that is transmitted to the CPU's built-in 24-bit A/D converter via a differential circuit that converts line-to-earth voltage to line voltage. The circuitry is designed to take maximum advantage of the CPU's built-in A/D converters for both signals in order to minimize its scale.

To perform three-circuit line voltage measurement, which is one of the PD3259's key features, a differential circuit is used to convert the line-to-earth voltage from each voltage sensor into a line voltage signal. Next, the three line voltage signals are sent in order to a differential driver by

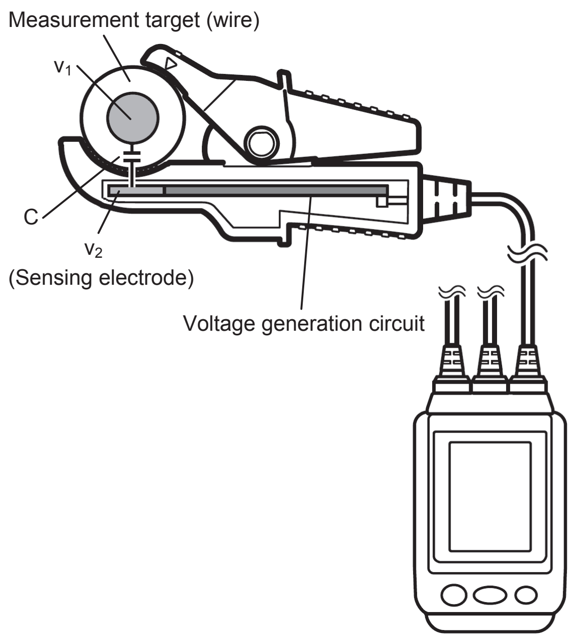

Fig. 6. Voltage sensor principles.

a multiplexer. Downstream from the differential driver is a 24-bit A/D converter. Since the 24-bit A/D converter for the three line voltage signals is not integrated into the CPU, the three line voltage signals are subjected to scan processing by the multiplexer and then encoded by the A/D converter. This A/D converter has a higher resolution than the 10-bit A/D converter used to encode the line-to-earth voltage signals. This distinction reflects selection of the optimal component for each use. Whereas line-to-earth voltage data is only used to ascertain the state of the 3-phase circuit and phase order, line voltage values require high-precision processing with defined accuracy. In this way, the two types of A/D converter built into the CPU are used according to the objective at hand.

Apart from the A/D converters, a phase detection signal generated from the line-to-earth voltage and line voltage signals is sent to the CPU. That signal is read by the CPU, and software displays information about the 3-phase circuit on the instrument's LCD.

B. Software

Embedded software processing is performed by two CPUs: a controller CPU in each of the voltage sensors and a main CPU that performs calculations and implements instrument functionality. This section describes the main CPU's embedded software.

1) Line voltage measurement: Of the line voltage signals converted by the differential circuit, the instrument measures the frequency of the V_{RS} ($V_{1\text{-}2}$) signal. A zero-cross event on each line voltage signal triggers the start of A/D converter sampling. The ΔΣ-type A/D converter acquires the three line voltages in order based on a previously set ΔΣ clock. This design serves to stabilize measured values by optimizing the number of sampling points based on the frequency and reducing the error in each sample by using a zero-cross trigger.

2) Moving average processing: Before measured values are displayed on the instrument's LCD, moving average processing is applied to 16 data points generated by the A/D converter. If an instantaneous value obtained from one A/D conversion processing step diverges from the moving average as of the previous value by more than a fixed percentage, the entire array of values used to calculate the moving average is replaced by the instantaneous value. This processing serves to interpolate the voltage sensors' analog response so that displayed measured values more closely track the underlying voltages when input changes significantly, for example when a voltage sensor is first affixed to a cable. The moving average value is discarded, the instantaneous value is displayed immediately, and moving average processing starts again with the first suitable measured value.

C. Construction and Enclosure

Fig. 7 illustrates the construction of the PD3259's main unit, which consists of front and rear enclosures, an electrical board, a battery case lid, and rubber packing. The electrical board incorporates the LCD, backlight unit, and rubber keys, among other components. Although the large number of components are stacked, the assembled device is only about 46 mm (1.81″) thick thanks to a creative design.

1) Dustproof and waterproof construction: The design incorporates rubber packing between the front and rear enclosures as well as between the rear enclosure and battery case lid. In addition, the cables from the voltage sensors are press-fitted into the rubber packing. This construction allows the main unit to deliver IP54 (EN 60529) dust and water protection.

2) Construction of LCD and adjacent components: The PD3259 utilizes a large LCD so that it can show a large amount of information clearly on a single screen. Because it takes up most of the front of the main unit, the screen could be damaged in the event the instrument is dropped or subjected to a strong mechanical shock. To address this concern, cushioning material has been incorporated around the LCD to absorb any impact.

3) Assembly: As illustrated in Fig. 7, components are stacked in one direction in order to facilitate assembly of the instrument. The two electrical boards are connected by a cableless connector.

V. Characteristics

Figs. 8 through 10 illustrate the PD3259's characteristics. All characteristics apply to line voltage measurement.

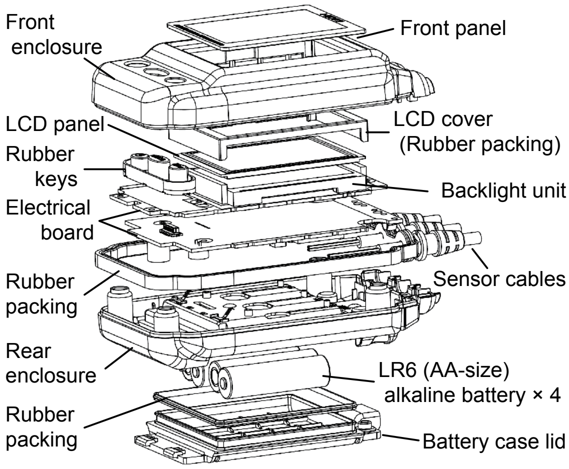

Fig. 7. Main unit construction.

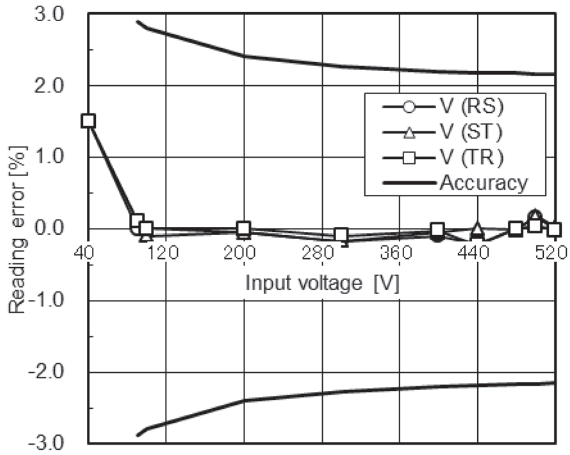

Fig. 8. Line voltage linearity.

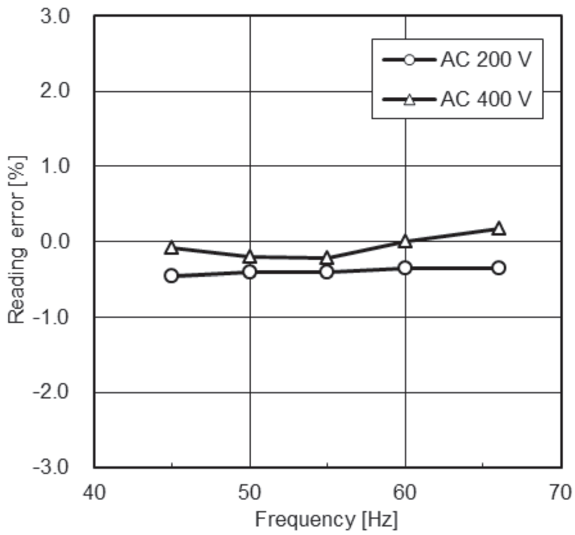

Fig. 9. Effects of voltage frequency.

VI. Conclusion

The PD3259 is a measuring instrument that combines an AC voltmeter utilizing no-metal-contact voltage measurement technology and a phase detector. It can simultaneously measure voltages and check phase order while facilitating safe working conditions. Hioki expects the instrument to see broad application in electrical and equipment maintenance work.

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Shunichi Miyamoto[2]

References

[1] T. Takahashi, “Clamp On Power Logger PW3365/Safety Voltage Sensor PW9020,” *Hioki Giho* (*Hioki Technical Notes*), vol. 36, no. 1, pp. 37-44, 2015. (Japanese, also available in English).

[2] M. Kitazawa, “Overview of No-metal-contact Voltage Measurement Technology and Hioki’s Digital Phase Detector,” Densetsu Shizai (Electrical Construction Design and Material Estimate & Cost Data), vol. 45, no. 3, pp. 29-34, March 2016. (Japanese).

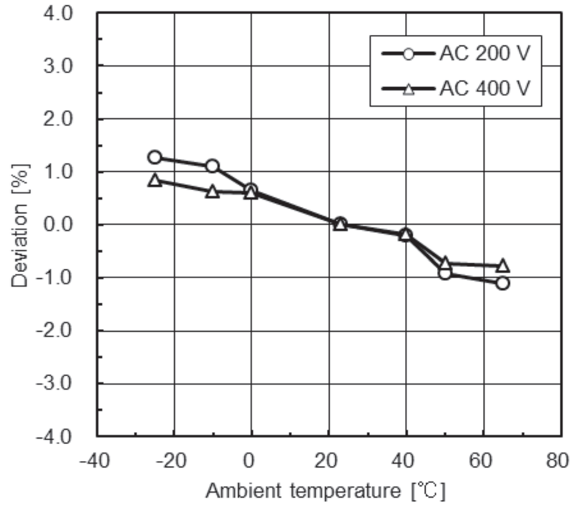

Fig. 10. Effects of ambient temperature.

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