PX8000 Precision Power Scope with Features of High-accuracy Power Meter and Waveform Measuring Instrument

Osamu Itou [*1] *Satoru Suzuki* [*1]
Hiroshi Yagyuu [*2] *Kazuo Kawasumi* [*1]

Yokogawa developed the PX8000 precision power scope, a high-accuracy power meter, which can measure reactor losses in inverters, motors and the like, by analyzing waveforms. The major specifications of the instrument are as follows: basic accuracy is 0.2%, voltage measurement bandwidth is DC and 0.1 Hz to 20 MHz (-3dB, typical), and current measurement bandwidth is DC and 0.1 Hz to 10 MHz (-3dB, typical). The PX8000 offers the functionality usually provided by a waveform measuring instrument, such as a variety of triggers, tracking, statistical processing, and waveform parameter calculation functions. Furthermore, to improve measurement accuracy at low power ratios this product comes with a de-skew function for correcting signal delays from the current sensor and a data latency adjustment function. This paper describes the PX8000, focusing on a newly developed element dedicated for power measurement and technology for phase correction.

INTRODUCTION

Along with the development of power electronics technology, microcontrollers are used for electronic control in every area of electrical energy conversion. As a result, non-conventional electric power measurement technology and analysis functions are required for measuring instruments.

The power meters generally used for measuring electric power are suitable for measuring signals that slowly change, but not for evaluating dynamic characteristics including rapidly changing signals, nor for targets with high-frequency signals. In contrast, oscilloscopes are designed for observing high-frequency waveforms, and are therefore not suitable for accurately measuring electric power. Power meters are preferred for measuring electric power in terms of traceability for which AC accuracy is required. The newly developed PX8000 precision power scope shown in Figure 1 has the advantages of both measuring instruments. The PX8000 can perform high-precision measuring of electric power in devices with rapid signal fluctuation in them or those driven at high frequencies, which was difficult for existing measuring instruments to do.

*1 Development & Engineering Department 1,
Yokogawa Meters & Instruments Corporation
*2 Marketing Department,
Yokogawa Meters & Instruments Corporation

Figure 1 External view of the PX8000

DEVELOPING ELEMENTS FOR MEASURING ELECTRIC POWER

The PX8000 was developed based on the DL850 ScopeCorder(1), and existing waveform measuring instruments. Although the DL850 can measure voltage, current (by using a current probe) and electric power, it does not conform to the accuracy standard required for power meters, and does not have the function of directly inputting DC, nor of matching voltage and current phases. The PX8000 is designed in a manner where a high-precision electric power measuring element, a set comprising a voltage module and a current module, is inserted into two slots of the input module section of the DL850. Some portions of the DL850 components, including the peripheral circuit of the CPU, field programmable gate array (FPGA) for waveform processing, housing and firmware were reused. As a result, the number of man hours required for development was halved. The majority of the effort required to develop the PX8000 was made in the development of the electric power measuring elements.

The market is demanding higher sampling rates and wider bandwidth. Therefore, the sampling rate was determined to be 100 MS/s (mega samples/second), which is 20 times higher than that of existing models, and is a sampling rate required for measuring inverters and similar components. In addition, the PX8000 has achieved the bandwidth for voltage measurement of DC and 0.1 to 20 MHz, which is 4 times wider than that of existing models, and the bandwidth for current measurement of DC and 0.1 to 10 MHz, which is twice as wide as that of existing models.

Optical Transmission Technology for High-speed Sampling

To achieve the sampling rate of 100 MS/s, the isoPRO technology, a high-speed and high-voltage isolation technology using optical transmission, was used. This technology was originally developed for the 720210, which is the isolation module of the DL850 with a high-speed sampling rate of 100 MS/s and 12-bit width. This enabled high-voltage isolation of 1000 Vrms. Figure 2 shows the optical transmission part of the PX8000, and Figure 3 shows a block diagram of the isolating part of the electric power measuring element.

Figure 2 Optical transmission part of the PX8000

Electric Power Measuring Element

The PX8000 is based on the DL850, but the following specifications have been modified to meet the requirements as an electric power meter.

- Improved noise resistance (tolerance to pulse noise)
- Increased internal power consumption (max. 2.5 W per element) caused by inclusion of a shunt resistor
- Added zero-crossing detection circuit (a circuit for detecting the center point of a wave)

To achieve these specifications, the following countermeasures have been implemented.

- Noise resistance was improved as follows: First, analysis of noise flow routes was carried out. Then, based on the results, several parts of the shields were strengthened including the optical transmission part, and noise routes that do not affect the circuits were ensured.
- Measures against increased internal power consumption were taken as follows: First, heat dissipation routes were analyzed. Then, based on the results, the mounting mechanism of the heat exhaust fans and heat dissipation routes was improved.
- To help ensure stable operation of the zero-crossing detection circuit, an input rejection circuit was added in front of it. Because the zero-crossing detection circuit is AC-coupled, it is susceptible to voltage fluctuations caused by internal calibration for measuring the offset in the internal circuits. In particular when an input signal has an offset, it takes time to stabilize, and the correct zero-crossing point cannot be detected. To avoid this problem, an input rejection circuit was added in front of the zero-crossing detection circuit so that it is not affected by the voltage fluctuation caused by the calibration.

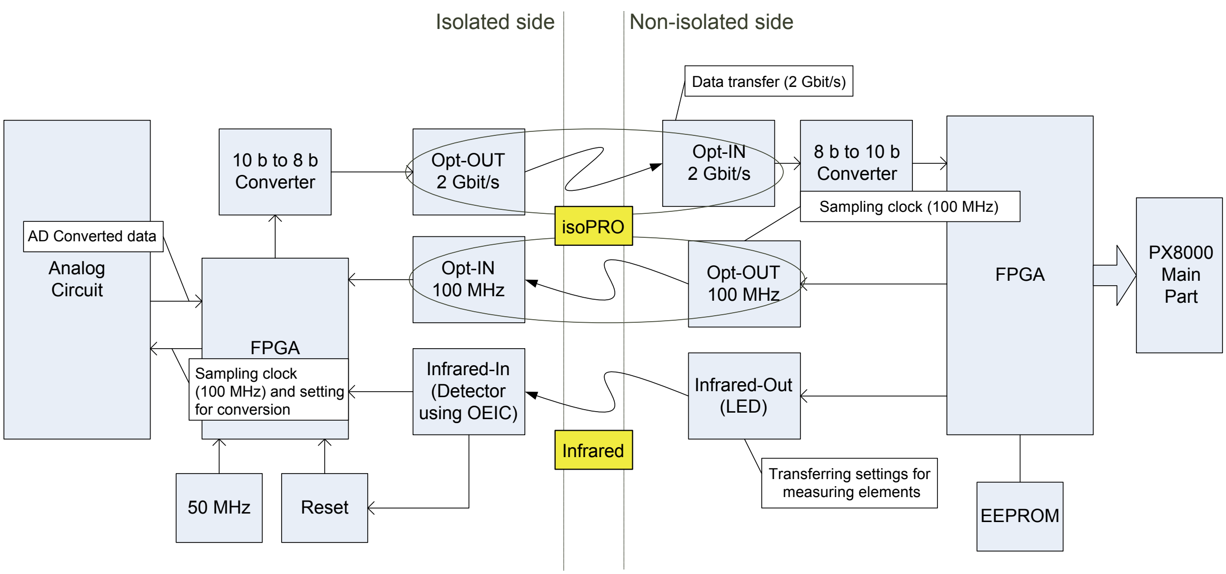

Figure 3 Block diagram of the isolating part of the electric power measuring element

Voltage and Current Frequency Characteristics

Figure 4 shows the frequency characteristics of the voltage and current module. The frequency at which a signal attenuate -3 dB has been made higher, expanding measurement bandwidth sufficiently to respond to high-speed devices such as inverters.

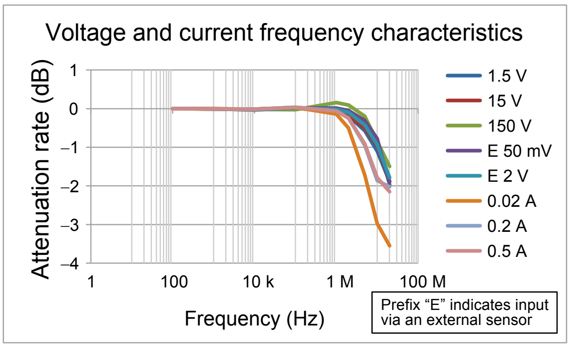

Figure 4 Voltage and current frequency characteristics

Types of Current Terminals

Among conventional power meters, binding post terminals are used for current input, and users could touch their metallic parts. By the way, as for voltage input, there is no need for users to fear touching metallic parts of the terminals because safe terminals — male terminals of plug-in style terminals that have no metal exposure — are used. Although the terminals of conventional power meters for current input are located on the rear, which makes it troublesome for users to access them, the terminals of the PX8000 are located on the side of the housing so that users can access them easily. Therefore, from the viewpoint of safety, female safety terminals of plug-in style terminals are used for current input. The adoption of a female terminal prevents miswiring between current and voltage inputs. Figure 5 shows a view of input terminals.

Figure 5 A view of input terminals (black and red terminals are for voltage input, and yellow ones are for current input)

Data Latency Adjustment

It was confirmed that the 720210 input module for waveform measurement in the DL850, based on which the PX8000 was developed, produces variation in data latencies of the signals described below, depending on the timing of the power-up and the start of the FPGA processing:

- Among signals of multiple electric power measurement elements
- Between signals of voltage and current input modules in an electric power measuring element
- Among signals of different measurement ranges

These variations in data latencies cause large errors in electric power measurement at high frequencies. Countermeasures taken to solve this problem are described below:

Because the data latencies depend on the timing of initialization upon power-up and the fact they are not always the same, they cannot be adjusted in advance. Thus, the data latency of each module is adjusted after all of them have settled after power-up. After the settlement, the data latency of

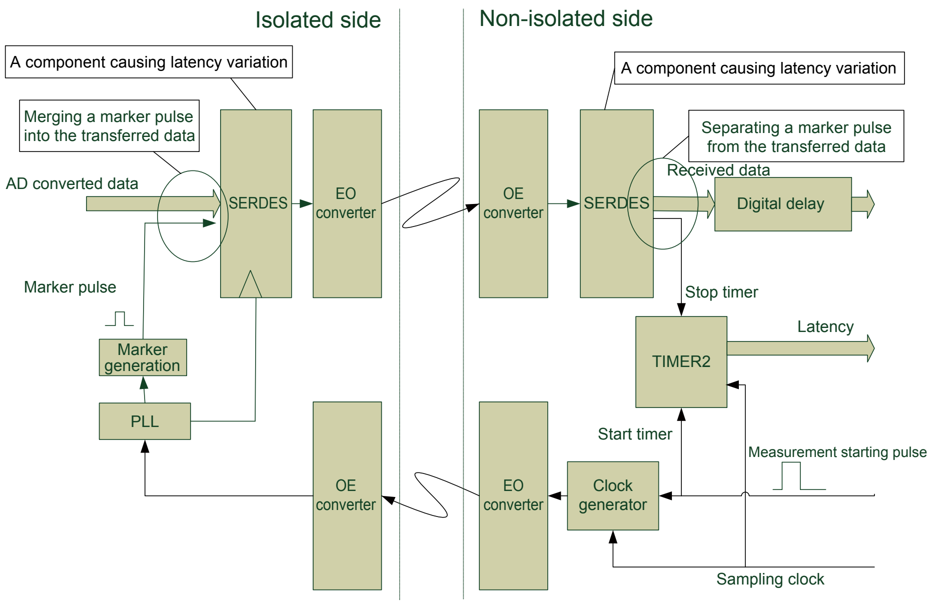

Figure 6 Mechanism of latency measurement

each module is measured, and all of the latencies are adjusted to the longest one in order to minimize the differences between them. The resolution of the latency measurement is 10 ns, thus an adjustment within 10 ns resolution is required.

The latency measurement in the module is described in detail below. Figure 6 shows a block diagram showing the mechanism used to measure latency in the module. A measurement starting pulse is generated by the CPU of the main unit at a certain time. The TIMER2 starts counting from zero, and the starting pulse is transmitted to the isolated side via the electric-optic (EO) and optic-electric (OE) converters to generate a marker pulse. This pulse is transmitted back to the non-isolated side together with the AD converted data via the EO and OE converters. The marker pulse is separated by the serializer/deserializer (SERDES) in the non-isolated side and stops the counting of the TIMER2. The count value of the TIMER2 at this moment can be converted to latency. Because the variation in latencies is created depending on each SERDES, the same measurement is performed on each module. It has been ascertained by the design and evaluation that the latencies created in the section other than the SERDES is the same. Therefore, the time difference to be adjusted is the difference between the latencies measured as described. Because the latency cannot be reduced, a digital delay is inserted at each module to match their latency to the longest one.

The differences among latencies of each module are compensated by the processing described above. Furthermore, to correct the differences in latencies caused by different measurement ranges, the phase of the 10-ns sampling clock of the analog-digital converter (ADC) is fine-tuned by using the phase adjustment function of the phase locked loop (PLL) by the unit of 1/16 cycle.

As a result of the latency adjustment described above, the final differences among the latencies fall within a few ns, although individually different. Figure 7 shows a block diagram of the sampling clock phase adjustment part. In shown in this figure, the DATAPROC receives data from the ADC, and then sends the data to the subsequent SERDES and directs the PLL to control the phase according to the range setting. Figure 8 shows that fine latency adjustment can be achieved by shifting the phase of the sampling clock.

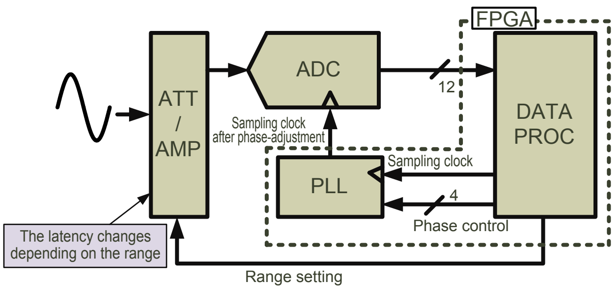

Figure 7 Sampling clock phase adjustment part

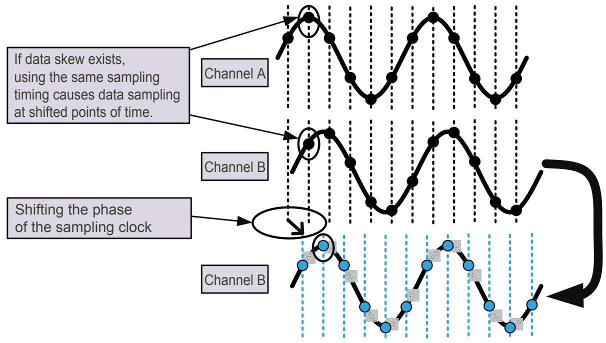

Figure 8 Fine latency adjustment by shifting the phase of the sampling clock

DESKEW FUNCTION

To obtain the correct electric power, impedance, power factor and the like from voltage and current measurements, both the voltage and current signals must be fed to the input terminals without transmission delay skew. The skew within the instrument itself is within a few ns, thanks to the data latency adjustment function described above, which is sufficient for high-precision measuring. In the actual measurement, however, a skew between voltage and current input signals arises when a current sensor such as a through-type current transformer (CT) or a current pickup circuit is used to measure current, or when the cable lengths to the input terminals for voltage and current measurement are different. The deskew function enables users to manually compensate for these physical error factors by setting the skews of the input signals. Setting skews for correction enables further high-precision measuring. Figure 9 shows a skew setting screen.

In the DL850, the basis of the PX8000, deskewing is achieved by software-based phase-shifting by using the waveform calculation function, but the amount of the deskewed results is limited to 1 M points, which is the maximum memory size for measurement data. In contrast, by setting skews for correction, the deskew function of the PX8000 can acquire all skew-corrected waveform data and hence enables longer-term measuring of signals close to true values.

Figure 9 Skew setting screen

MAJOR FUNCTIONS OF THE PX8000

The PX8000 provides various analysis functions for measuring transient electric power fluctuation, in addition to the numerical display as a power meter and waveform displays for analysis.

Calculation in the Interval Specified by Using Cursors

Figure 10 is a screen showing the calculation results in the interval specified by using cursors. By specifying the start and end point in the displayed waveform by using cursors, electric power, power factor, and others in the interval can be calculated.

In addition, jumping to a zero-crossing point function is supported. This function searches a zero-crossing point of a waveform and moves the cursor to the point, which is essential for accurate electric power calculations.

Figure 10 A screen showing the calculation results in the interval specified by using cursors

Automatic Calculation of Waveform Parameters

Figure 11 is a screen showing the automatic calculation results of waveform parameters. Waveform parameters such as maximum, minimum, average, integration, or peak value can be calculated quickly by clicking an item listed in the menu. Measured and calculated data can be saved, and statistical processing can be carried out on them.

Figure 11 A screen showing the automatic calculation results of waveform properties

Harmonics Measurement

Figure 12 is a screen showing the harmonic components of a measured waveform. Harmonics calculation up to the 500th harmonic is performed with no special settings. The start point of the harmonic calculation can be specified using the cursor.

Figure 12 A screen showing harmonic components

Average Calculation in Each Consecutive Interval

Figure 13 is a screen that is displayed when printing averages in each consecutive interval.

Transient phenomena of voltage, current and electric power can be observed in detail as waveforms. By selecting an arbitrary range in these waveforms by using cursors, averages of voltage, current and electric power in each consecutive interval contained in the range can be calculated and printed out. The averaging interval can be specified for each instance of printing. In the case of the existing power meter, the minimum averaging interval is 50 ms.

Figure 13 A screen when printing averages in each consecutive interval

Dedicated Software for Waveform Data Calculation and Analysis

The PX8000 offers a user-defined calculation function. Using this function, users can perform calculations on any combination of data contained in the interval specified by cursors. The maximum amount of data allowed in this function is 4 M points for each channel. Meanwhile, the PX8000 can record waveform data of up to 100 M points/channel. This means that waveform data calculation cannot be performed in the entire measured range depending on the memory size or the observation time. To enable waveform data calculation over the entire range, PowerViewerPlus, a dedicated software package running on Windows, was developed.

A PC is connected to the PX8000 via Ethernet, USB, or GPIB. The PowerViewerPlus allows high-speed execution of the various analysis functions of the PX8000, in addition to the user-defined calculation of 100 M points/channel. The waveform data obtained by the PX8000 can be easily converted into CSV data format at high speed. Furthermore, multiple windows can be displayed simultaneously taking advantage of a large PC display.

Figure 14 shows a PowerViewerPlus screen containing multiple windows.

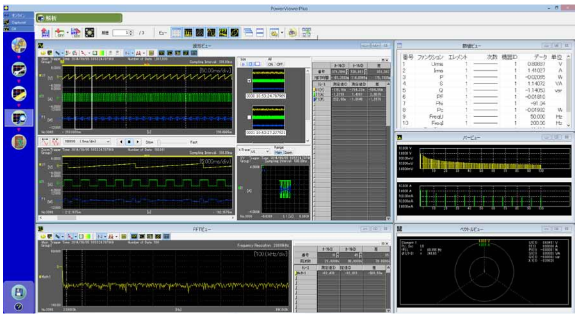

Figure 14 A PowerViewerPlus screen containing multiple windows

CONCLUSION

The measurement of transient phenomena of voltage, current and electric power, which is impossible with the existing measurement method, was achieved by merging the high-precision power measurement technology and the waveform measurement technology at a high level. The PX8000 is expected to be used for measuring electric power and reactor loss during motor acceleration and deceleration in electric and hybrid vehicles.

The PX8000 is expected to contribute to the development of inverter devices, electric and hybrid vehicles, and to further reduce power consumption in a range of devices.

REFERENCES

(1) Etsurou Nakayama, Chiaki Yamamoto, "Real-time Math Function of DL850 ScopeCorder," Yokogawa Technical Report English Edition, Vol. 55, No. 1, 2012, pp. 9-14

* isoPRO is a trademark of Yokogawa Electric Corporation.

* All other company names or product names mentioned in this paper are either trademarks or registered trademarks of their respective holders.