High-speed, Real-time Power Measurement Technologies of WT1800 Precision Power Analyzer

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To keep pace with the increasing speed of switching devices in inverters, Yokogawa has developed the WT1800 precision power analyzer with 10 times faster sampling speed and 5 times wider frequency bandwidth compared with previous models. Its basic accuracy is 0.15% and the frequency bandwidth of voltage and current is 0.1 Hz to 5 MHz (-3 dB, Typical) including the DC component. With up to six inputs, a single WT1800 unit can measure the efficiency of three-phase inverters. In addition, the high-speed data capturing mode allows the WT1800 to measure transient power. This paper describes the high-speed, real-time power measurement technologies underlying these functions.

INTRODUCTION

With an increasing concern about global warming and depletion of fossil fuels, solar power generation and electric/hybrid vehicles are attracting attention. The solar power generation system converts DC voltage from solar cells into AC voltage and supplies it to the power grid. In electric/hybrid vehicles, DC voltage from batteries is converted into AC voltage to drive the motor. Power meters are mainly used for measuring the power consumption of inverters used in these conversions. To improve the efficiency of inverters, switching devices in inverters are being made to operate faster, and thus power meters are required to expand their frequency bandwidth. Moreover, for electric/hybrid vehicles, power meters are required to measure power not only in the steady state with small fluctuations in frequency and amplitude, but also in the transient state when the motor is accelerating or decelerating.

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The WT1800, a newly developed power analyzer shown in Figure 1, satisfies these requirements; it features a wider frequency band and higher sampling rate. The WT1800 also provides a high-speed data capturing mode to measure power during the transient state. This paper describes the high-speed, real-time power measurement technologies that achieve high-speed data sampling and high-speed data capturing.

Figure 1 External view of WT1800

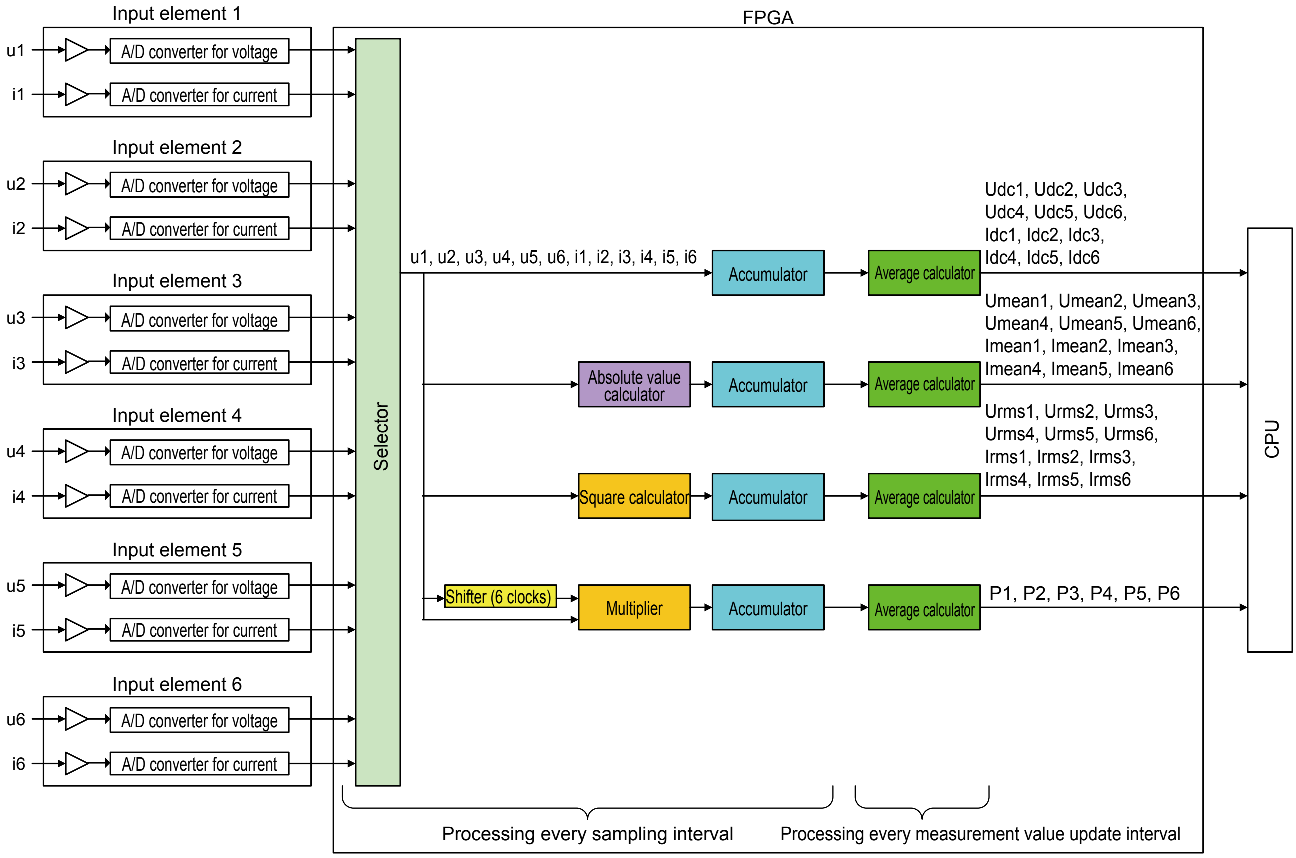

Figure 2 Block diagram of the new data processing method

HIGH-SPEED DATA SAMPLING RATE

To respond to the expanding frequency bandwidth, the sampling rate was sped up to 2 MS/s (mega samples per second), ten times faster than previous models. To accelerate sampling rates, real-time power calculation must be sped up in power meters.

Figure 2 shows a block diagram of the new data processing method. The components are input elements 1 to 6 made up of A/D converters for voltage and A/D converters for current; the field programmable gate array (FPGA); and the central processing unit (CPU).

Voltage u and current i are input to input elements and normalized at operational amplifiers respectively, and sent to A/D converters. The analog signals are sampled and converted into digital values at the A/D converter, and then sent to the FPGA. In the FPGA, various values are calculated such as the simple mean values of voltage and current (DC), the rectified mean value calibrated to the root-mean-square values (MEAN), the true root-mean-square values (RMS), and the active power values (P).

These calculations are usually difficult to speed up because they are carried out by the firmware and the general-purpose digital signal processor (DSP), both of which are not optimal for power calculation. In this new system, the FPGA takes over this part; it is configured as an optimal circuit for faster power calculation. The FPGA includes calculators dedicated for each process, which enables parallel and pipelining processing.

Figure 3 shows the difference between non-pipeline processing and pipeline processing. Assume that it takes five clocks to perform square calculation, where the clock is the master clock of the FPGA. A calculator of non-pipeline processing takes five clocks from the input of data 1 to output of the result. Then, data 2 can be input at the fifth clock and the result of this calculation is output at the tenth clock. Meanwhile, with the calculator for pipeline processing, data 2 can be input at the next clock after the input of data 1. Thus the result of the calculation of data 2 can be obtained at the sixth clock. In this way, calculators for pipeline processing can process data at every consecutive clock.

Therefore, when 12 data (u1 to u6, i1 to i6) are input to the FPGA after sampling, the selector consecutively inputs to calculators one data per clock in a certain order. Since one sampling has 12 data, new sampling data can be input at the 12th clock or later. For each sampling, the accumulator adds all the data.

Then, on the update of measurement values, the averaging calculator divides the sum obtained at the accumulator by the number of samplings and sends this mean value to CPU. In this way, one FPGA calculates 6 elements while maintaining real-time features and achieving a sampling rate of 2 MS/s.

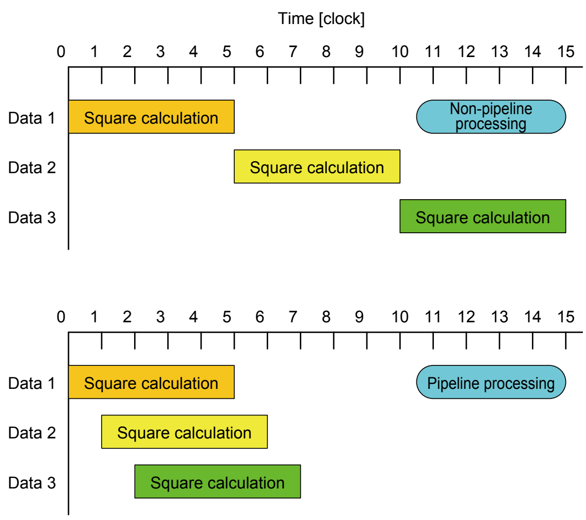

Figure 3 Difference between non-pipeline processing and pipeline processing

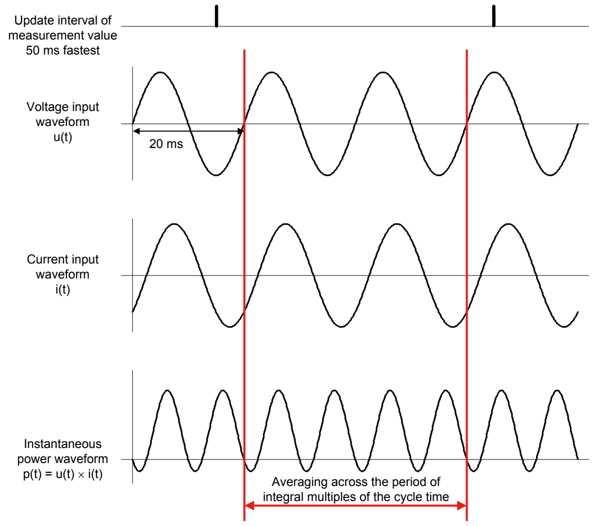

Figure 4 Conventional power measurement principle

HIGH-SPEED DATA CAPTURING MODE

The WT1800 now features a high-speed data capturing mode for measuring three-phase electric power every 5 ms. This section describes the processing method.

Conventional measurement principle of three-phase electric power

First, the conventional measurement principle of three-phase electric power is explained.

As shown in the equation (1), three-phase four-wire electric power (ΣP) is obtained by adding each phase power (P1, P2, P3).

$$\Sigma P = P1 + P2 + P3 \cdots\cdots (1)$$

Since three-phase electric power is an AC signal, each phase power (P) must be averaged across the period of an integral multiple of the cycle time, as shown in the equation (2) and Figure 4. To obtain this period, the signal cycle time is determined by detecting zero-crossing points.

$$P = \frac{1}{T}\int_{t=0}^{T} u(t) \times i(t)dt \cdots\cdots (2)$$

T is the period of an integral multiple of the signal cycle time.

Therefore, in principle, the measurement results of 50 Hz signals cannot be output within 20 ms. The practical update interval of the measurement is maximum 50 ms to accommodate at least two cycles of the 50 Hz commercial frequency.

Measurement principle of high-speed data capturing mode

In the three-phase four-wire system shown in Figure 5, the instantaneous power waveform of each phase is shown in Figure 6.

In this case, the sum of the instantaneous power of the three phases is the three-phase electric power (ΣP). As the measurement principle, the high-speed data capturing mode averages this sum at short intervals and outputs it. With internal synchronization, the power value can be output every 5 ms, and with external synchronization, every 1 ms at the fastest.

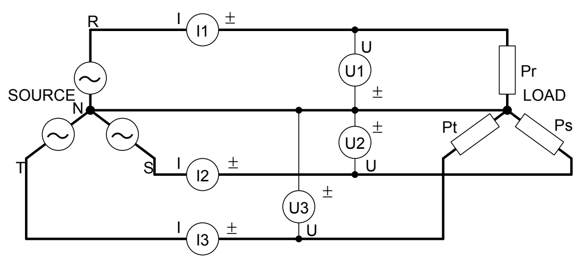

Figure 5 Three-phase four-wire system

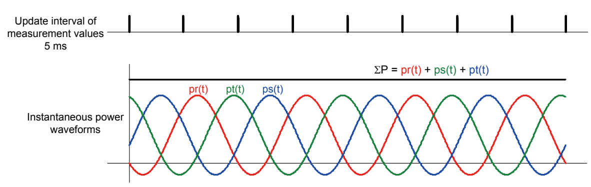

Figure 6 Measurement principle of high-speed data capturing mode

Processing method of high-speed data capturing mode

Figure 7 shows the processing method of the high-speed data capturing mode. The instantaneous voltage value (u) and instantaneous current value (i) of each phase, sent from the input element to the FPGA, are multiplied to obtain the instantaneous power values, which are added for three-phase power (Σp). This is then sent to a digital low-pass filter called the HS filter, averaged every 5 ms, and then saved to the internal memory. The measurement results of 200 data per a second are saved to external USB memory or output through a communication line. The HS filter is used to suppress an unnecessary fluctuation of the measurement. The cutoff frequency is variable between 1 Hz to 1 kHz. It can be turned off.

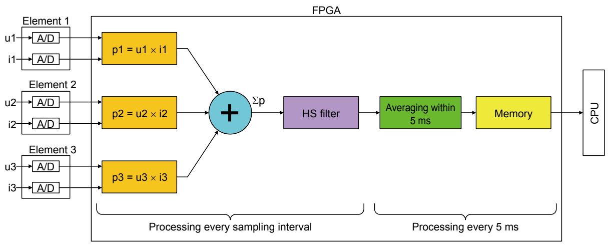

Figure 7 Processing method of high-speed data capturing mode

Measurement example of high-speed data capturing mode

Figure 8 shows how two measurement methods track the changes in frequency and amplitude of voltage and current in the three-phase four-wire system between 0 ms and 100 ms.

With the conventional measurement method, changes are detected every 50 ms, while with the high-speed data capturing mode, the three-phase electric power value is finely captured between 0 ms and 100 ms.

Here, the electric power value of the three-phase system has been described. A similar processing is also possible for the measurement of root-mean-square values of three-phase voltages and currents. In addition, this can be applicable not only to the measurement of a three-phase four-wire system but also to that of a three-phase three-wire system by the three-voltage three-current method. As in the case with ideal sine waves, the pulse width modulation (PWM) waveform of inverter output can be measured by suppressing the fluctuation caused by switching the frequency component through the averaging of every 5 ms and the HS filter.

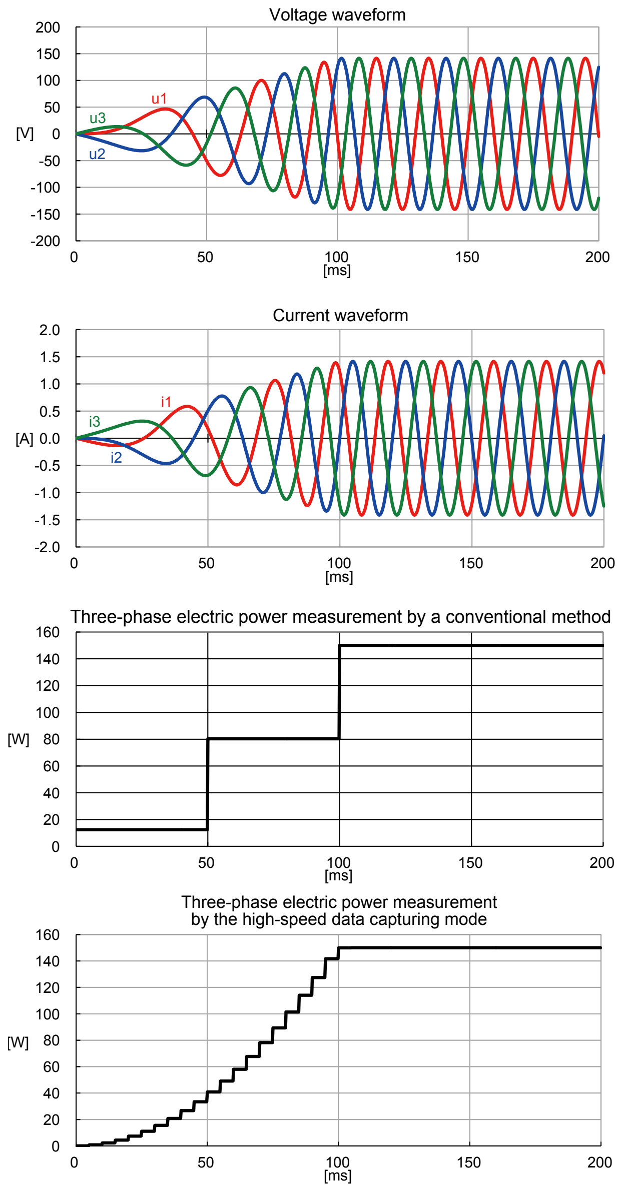

Figure 8 Measurement example by high-speed data capturing mode

CONCLUSION

The power calculation in the FPGA achieves a 10 times faster sampling rate while satisfying real-time operability. The high-speed data capturing mode enables electric power values to be obtained every 5 ms, which is impossible with conventional measurement methods. This new mode is expected to achieve power measurement during acceleration and deceleration of the motor in electric/hybrid vehicles.

Featuring these functions, the WT1800 will enhance the development of inverters and electric/hybrid vehicles.