With increasing concerns about global warming and the depletion of fossil fuels, solar power generation and electric/hybrid vehicles are attracting wider attention. Solar power generation systems convert a DC voltage from solar cells into an AC voltage and supply it to the power grid. In electric/hybrid vehicles, a DC voltage from batteries is converted into an AC voltage to drive the motor. Both these processes require an inverter to convert the DC voltage into AC voltage. The efficiency of these inverters is a key factor in their successful operation, and power meters are normally used to measure the power consumption of the inverter in order to assess its efficiency.

To improve the efficiency of inverters, the switching devices in the 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 under steady-state conditions with small fluctuations in frequency and amplitude, but also in the transient state when the motor is accelerating or decelerating.

This article describes a precision power analyser (Figure 1) which satisfies these requirements by featuring a wider frequency band and higher sampling rate. It also provides a high-speed data-capture mode to measure power during the transient state. This instrument features a basic accuracy of 0.15%, and the frequency bandwidth of voltage and current is 0.1Hz to 5MHz (-3dB typical) including the DC component. With up to six inputs, a single power meter can measure the efficiency of 3-phase inverters. In addition, the high-speed data capture mode allows the instrument to measure transient power.

HIGH-SPEED DATA SAMPLING

To respond to the expanding frequency bandwidth, the sampling rate is increased to 2MS/s (mega samples per second), ten times faster than earlier instruments. To accelerate the sampling rate, the real-time power calculation must also be speeded up in power meters.

Figure 2 shows a block diagram of the data-processing technique used to achieve this speed increase. The components of the system are input elements 1 to 6, which consist of A/D converters for voltage and A/D converters for current; the field programmable gate array.
Voltage and current first pass to the input elements and are normalised at operational amplifiers before being sent to the A/D converters. The analogue 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 the 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 items of data (u1 to u6, i1 to i6) are input to the FPGA after sampling, the selector consecutively inputs to calculators one item of data per clock in a certain order. Since one sampling has 12 data points, 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 samples and sends this mean value to the CPU.

In this way, one FPGA calculates six elements while maintaining real-time features, achieving a sampling rate of 2MS/s.

**HIGH-SPEED DATA-CAPTURE MODE**

The new high-speed data capture mode allows 3-phase electric power to be measured every 5ms. Normally, 3-phase 4-wire electric power (SP) is obtained by adding each phase power (P1, P2, P3). 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 (Figure 4). To obtain this period, the signal cycle time is determined by detecting zero-crossing points.

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

For the 3-phase 4-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 3-phase electric power ($\Sigma P$). The high-speed data capture mode averages this sum at short intervals and outputs it. With internal synchronisation, the power value can be output every 5ms, and with external synchronisation it can be every 1ms at the fastest.

**PROCESSING TECHNIQUE FOR HIGH-SPEED DATA CAPTURE**

Figure 7 shows the processing technique for the high-speed data capture mode. The instantaneous voltage value and instantaneous current value 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 ($\Sigma P$). This is then sent to a digital low-pass filter called the HS filter, averaged every 5ms and then saved to the internal memory. The measurement results of 200 data points per second are saved to an external USB memory or output through a communication link. The HS filter is used to suppress any unwanted fluctuations in the measurement. The cutoff frequency is variable between 1Hz and 1kHz, and can be turned off.

**MEASUREMENT EXAMPLES OF HIGH-SPEED DATA CAPTURE**

Figure 8 shows how two measurement methods track the changes in frequency and amplitude of voltage and current in the 3-phase 4-wire system between 0ms and 100ms. With the conventional measurement method, changes are detected every 50ms, while with the high-speed data-capture mode the 3-phase electric power value is accurately captured between 0ms and 100ms.

A similar technique is also possible for measuring the root-mean-square values of 3-phase voltages and currents. This can be applicable not only to the measurement of a 3-phase 4-wire system but also to that of a 3-phase 3-wire system by the “3-voltage/3-current” method. As in the case with ideal sine waves, the pulse width modulation (PWM) waveform of an inverter output can be measured by suppressing the fluctuation caused by switching the frequency component through the averaging of every 5ms and the HS filter.

Using an FPGA to carry out power...
calculations achieves a 10x faster sampling rate while satisfying real-time operability. The high-speed data-capture mode enables electric power values to be obtained every 5ms, which is impossible with conventional measurement methods.

The high-speed data-capture (HS) option provides fast and accurate measurement of power parameters such as voltage, current, power, torque, speed and mechanical power with millisecond response. For example, it can capture numerical data on the change of status during one rotation of a motor when the motor is started, when the rotation speed changes, or when the load condition varies. It will assist in the analysis of such phenomena or development of new products.

The combination of this function with the power meter’s high sampling frequency and unique calculation performance in real time allows the instrument to capture signals at a high sampling rate of approximately 2M samples per second, enabling it to be used effectively in the development of energy-saving products equipped with power devices, such as the latest generation of inverters with higher switching and driving speeds. Such devices are now found in a wide variety of markets and applications including motor drives, power conditioning, heating and ventilation, aerospace and the rapidly growing alternative energy sector.

This new mode is also expected to enable power measurement during the acceleration and deceleration of the motor in electric/hybrid vehicles.