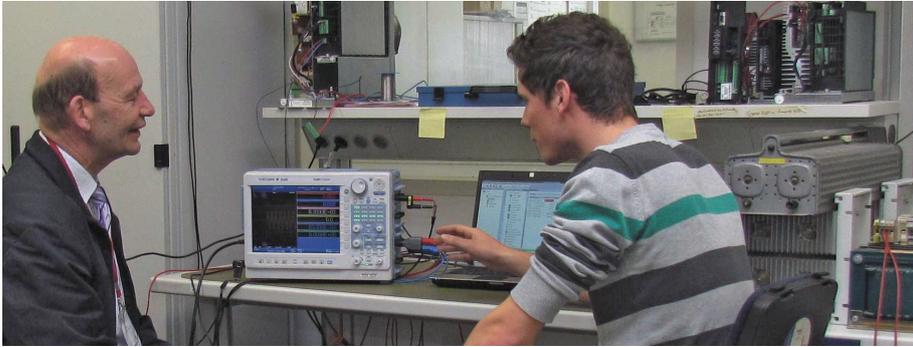


# Precision power measurements for megawatt heating controls



Lars Alsdorf (right) explains Jürgen Hillebrand (Yokogawa) the test of the power controller.

Precision power measurements carried out using Yokogawa's DL850 ScopeCorder are playing a key part in the development of high-current power controllers by AEG Power Solutions.

## Introduction

AEG Power Solutions manufactures power controls that allow large electrical currents in industrial processes to be precisely controlled.

A typical application of these controllers is in the manufacturing of glass, where the temperature of the molten glass must be precisely set, according to the type of glass, over a range of 800° to 1600°C to an accuracy of within 1°C. To achieve such precise temperature control, AEG's thyristor power controllers are used in conjunction with electric heaters. Other typical

Comparison of different clock and phase control method.

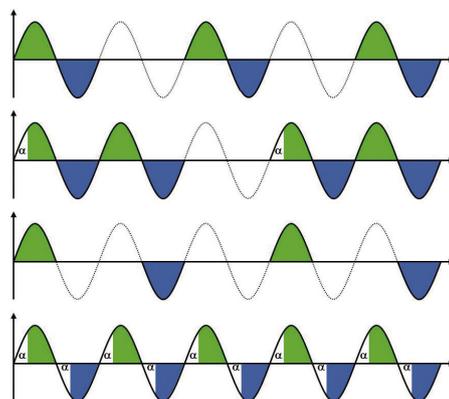
## Modes:

Full vibrational CLOCK for thermal inertia loads such as ohmic resistance.

Full vibrational CLOCK for thermal inertia loads such as transformer load.

Half-wave mode QTM eg for loads with high dynamic IR or UV radiation.

Phase angle VAR for loads with high dynamic.



application areas for these digital power controllers include hydrogen electrolysis, polysilicon deposition, paint drying in the automotive industry and electric furnaces. A typical industrial application might use up to 60 or more power controllers with current ratings from 2 A to 2900 A and voltages from 24 V to 690 V. As a result, depending on the application, different units can be combined for overall power ratings up to tens of megawatts.

Load control in these units is achieved by a clock or a phase control method. With the clock method, during an operating cycle one or more full or half waves of the sinusoidal mains voltage can be switched to the output, allowing the power to be controlled precisely through the number of switched waves. If, for example, only each fourth wave cycle reaches the load, the power is reduced to 25%. By contrast, using the phase control method, only a part of the full-wave power at all cycles reaches the load. Which method is used depends, among other things, on the type of load (either purely resistive or with inductive parts) and the stability of the grid.

The clock operation method has the advantage that only whole sine waves are switched, and thus no harmonics arise. In purely resistive loads, the switching point is always at the zero crossing, whereas with inductive loads it is usually at 60° (single-phase) or 90° (three-phase). The clock method, however, can lead to power flicker, especially for very large systems with many power controllers and weak networks.

To address this challenge, AEG Power Solutions has developed an automatic



network load optimisation system in which the individual control devices are synchronised via control lines. This allows the switch-on points of the various power controllers to be controlled in such a way that peak loads and high inrush currents are reduced, resulting in an essentially constant power output. The power controller can also be equipped with a communication interface such as PROFIBUS, Ethernet/IP, PROFINET, DeviceNet, Modbus or CANopen. This allows communication between multiple power controllers and automation and process control systems.

of the input voltage. This capability offers advantages in applications such as slowly changing thermal systems, where a follow-up to the temperature control loop would not work quickly enough.

To check the function of this integrated power measurement function in the development process, AEG Power Solutions had for some time used measuring devices incorporating adjustable filters. However, these were not very accurate and were also too slow for many applications. To find a better solution, comparison tests were carried out with different types of measuring instruments. Among these was a power analyser, in which the clock method showed significant deviations in the measurement results. Investigations showed that this was due to the fixed integration time of the instrument. A power analyser is mainly used for continuous processes, such as phase control, but has limitations in measuring the performance of a varying number of full or half waves over any period of time.

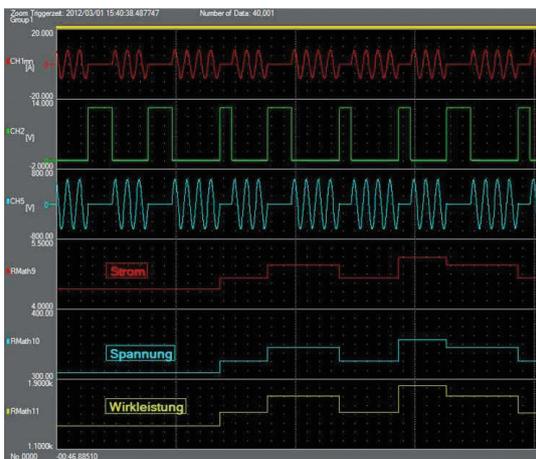
It is precisely in this area, however, where the strength of the AEG power controllers lies. In these units, it is possible to set not only the number of circuit-switched full or half waves in a time period, but also the length of time within certain limits (typically several seconds).

### Measurement solution

The solution to this problem was found in the Yokogawa DL50 ScopeCorder with its real-time mathematics option. The DL50, a modular transient recorder, is configured for

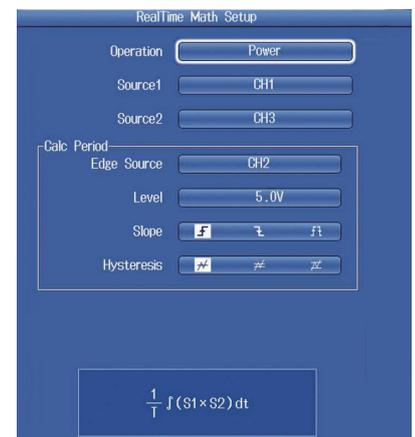
The measurement setup (from left to right) : DL50 ScopeCorder, Notebook with control software, Power controller Thyro-AX for three phases and load.

Example of the single phase waveforms measured with the DL50 and displayed by the Yokogawa Xviewer Software. Current (CH1) and voltage (CH3) are measured for the main cycle of channel 2 (CH2). The Real-time math channels (Channels 9, 10, 11) show the calculated effective values of current and voltage per main cycle (CH2) and the calculated active power. (Left)



### Power measurement

In order to determine the real power delivered to the load, the power controller incorporates built-in measurement functions for voltage and current to allow the overall performance to be calculated. The user can display these values on the display of the power controller or download them via the built-in communication interface. Using these measurement functions, the device can also compensate independently for variations



Real-time math setup on the DL50. The power can be calculated over an adjustable period.

AEG Power Solutions with six input channels for voltage measurements at up to 850 V and an additional eight analogue channels for voltages up to 140 V, each with a resolution of 16 bits. Using an input module rated at up to 850 V, the supply voltage of the power controller can be directly measured, while the other channels are used together with clamps or shunts for current measurement to determine the control order of the clock signals. Using the calculation methods incorporated in the real-time mathematics option, the DL850 can be set up so that, over a given time or a higher-level clock, the voltage and current are measured, followed by the power parameters being calculated and displayed in real time.

"We thoroughly tested the ScopeCorders after the demonstration by Yokogawa and determined that the device met all our requirements perfectly", says Frank Schlieper, the Senior German Sales Manager for Power Controllers at AEG Power Solutions. His comments are supported by Lars Alsdorf, a development engineer at AEG Power Solutions, who adds: "A big advantage is the plug-in modules, which are isolated and are suitable for input voltages up to 850 V. We need many channels, and we need to measure the net voltage directly. Since testing the controllers is a relatively slow process, we need long integration times: a feature which is supported by very few instruments."

The DL850 ScopeCorder is also very flexible in that it can be applied for different applications, and is used at AEG Power Solutions as an oscilloscope and for longer recordings: in temperature tests, for example. In addition, the instrument can be equipped with eight different application-specific input modules.

The calculation of power using the current and voltage measurements is carried out over several clock periods, where the measurement time ranges from about 100



ms to a few seconds. Although the standard measurement time is one second, in the development process different time periods need to be measured. Only by doing this can the engineers ensure that the power delivered to the load is accurately measured by an integrated measuring function in the various modes of operation. The power determined by the internal power controller is then compared with the measured value of the ScopeCorder.

One big advantage of the DL850 is that the original (raw data) signals and the calculated power curves can be displayed simultaneously. "As we strive for accuracy levels of well below 1%, we have to be able to rely on the measuring instrument", says Christian Schaffarra, Development Manager at AEG Power Controller Module HP: "We therefore use the ScopeCorders not only in the development laboratory but also in the test laboratory in the relatively complex release/approval process."

Read more on Real-time mathematics on the next page.



DL850 ScopeCorder



# Real-time mathematics

Yokogawa's real-time mathematics function for the DL850 ScopeCorder is ideally suited to optimising the performance and efficiency of power electronic devices.

Normally, different instruments are needed to record voltage, current and other parameters. In order to determine the absorbed power and the efficiency and other values recorded by the measuring instruments, original waveform data must be evaluated and calculations have to be performed. For the determination of efficiency, for example, parameters such as the speed and torque of an electric motor often have to be measured. This is done with a sensor that converts the measured physical quantity into electrical signals. However, the output signal of the sensor does not always relate in a linear fashion to the physical quantity measured, and so a lineariser is generally needed between the sensor and the measuring device. Moreover, these measurements are represented by instantaneous values, so that integration over a certain period of time is required to get an overall view of the long-term behaviour of the device under test.

A simple measure for the determination of the pure power levels is therefore inadequate; instead, the synchronously detected measurement signals must be further processed. In conventional measurement setups, this is usually carried by transmitting the data in batches from the instrument to a PC for linearisation and evaluation.

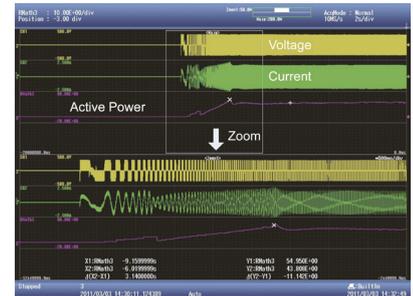
In the Yokogawa DL850 ScopeCorder, however, it is possible to carry out multichannel scans of both very fast and long-term measurements. The extra G3 option allows the mathematical real-time processing of measured data.

The DL850 has a very large storage

capacity of up to 2 gigapoints (optional expansion memory) as well as eight slots for input modules, allowing a choice from 17 different modules which can be combined as desired. Sensors for different physical parameters can be connected this way. The isolated 12-bit module, for example, offers a sampling rate of 100 MS/s and a dielectric strength of 1000 V. This means that the output voltage of an inverter can be reliably and accurately measured with a bandwidth of 20 MHz.

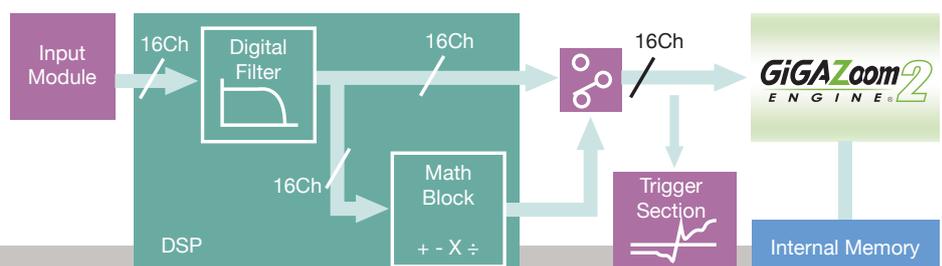
The DL850 incorporates a data-processing module known as the GIGAZoom Engine 2 which transmits the data from the input modules into the acquisition memory and applies a range of trigger functions for storing partial measurements. It also has a special processor for fast data representation on the screen of the DL850.

The real-time mathematics option G3 is inserted between the input module to the A/D converters and the GIGAZoom engine. It includes two sections: the digital filters and a calculation component. The two components can work independently and run on each channel to process data from up to 16 channels simultaneously. This also applies to data that is already stored in acquisition memory or has undergone other mathematical functions. A selection of digital filters is available, including low-pass, high-pass and band-pass, Finite Impulse Response (FIR), Infinite Impulse Response (IIR), Gaussian and moving average filters. The digital filter can process signals up to 1 MS/s over 16 channels simultaneously.

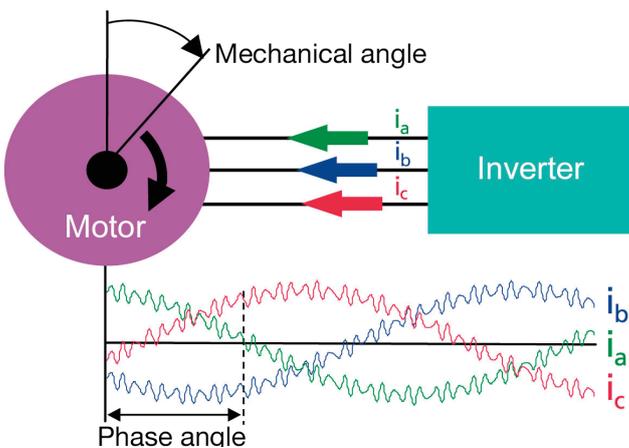


Also during the start up of a motor the DL850 can calculate and view the active power per waveform cycle.

The real-time math function (DSP Digital Signal Processor) is situated between the input channels and the GIGAZOOM Engine 2. This way also calculated signals can be displayed and recorder and used for trigger input.



| Calculation Function                                 | Description   |
|--|---|
| Four basic mathematical operations                   | $S1 \ \$ \ S2$ (for „\$“ items „+“, „-“, „*“, „/“ can be selected)  |
| Four basic mathematical operations with coefficients | $( a * S1 ) \ \$ \ ( b * S2 ) + c$ (for „\$“ items „+“, „-“, „*“, „/“ can be selected)  |
| Integration  | Integrates each sample value  |
| Differentiation                                      | “Performs differentiation on the waveform using a fifth order Lagrange interpolation formula”   |
| Rotary Angle   | Calculates the angle of rotation of phases A, B, and Z of a rotary encoder  |
| DA   | Converts digital logic signals into an analogue waveform  |
| Polynomial   | Performs a quartic polynomial calculation: $a * S1^4 + b * S1^3 + c * S1^2 + d * S1 + e$  |
| RMS  | Calculates the RMS value of the waveform  |
| Power  | Calculates Active Power per waveform cycle  |
| Reactive Power                                       | Calculates Reactive Power   |
| Power Integ  | Calculates the integrated power of the waveforms  |
| Log1   | $a * \log ( S1 / S2 )$  |
| Log2   | $a * \log ( S1 )$   |
| Sqrt1  | “Calculates the square root of the sum (or difference) of the squares of the waveforms that have been assigned to Source1 and Source2. This can be used to analyse displacement and tolerance. $\sqrt{(S1^2 \ \$ \ S2^2)}$ (for „\$“ items „+“, „-“, „*“, „/“ can be selected)” |
| Sqrt2  | $\sqrt{(S1)}$   |
| Cos  | $a * \cos(\text{Angle})$ (An encoder signal can be converted into an angle)   |
| Sin  | $a * \sin(\text{Angle})$ (An encoder signal can be converted into an angle)   |
| Arctan   | $\arctan(S1 / S2)$  |
| Knocking Filter                                      | (Only for DL850V) the Filter forces signals below the set value to zero   |
| Electrical Angle                                     | Calculates the phase difference between the motor's angle of rotation and the motor drive current.  |
| Polynomial Addition und Subtraction                  | $a * ( \$ S1 \ \$ S2 \ \$ S3 \ \$ S4 )$ (for „\$“ items „+“, „-“, „*“, „/“ can be selected)   |
| Edge Count   | Counts the number of slope edges of the waveform  |
| Period:  | Calculates the period of the waveform   |
| Frequency:   | Calculates the frequency of the waveform  |
| Resolver   | Calculates the angle of rotation of a resolver  |
| IIR-Filter   | Low-, high- or band pass filter using Infinite Impulse Response Filter (IIR)  |
| PWM  | Integrates pulse width modulated signals (PWM) within a period and converts this into a sine wave   |
| CAN ID (for DL850V)                                  | Analyses signals of the CAN-BUS and trends a certain CAN ID   |



Measurement of the electrical angle

The processing method is adjustable for each channel, and 35 internal calculation functions are available (see table). These can be selected easily without complicated settings and linked together so that complex operations can be achieved by combining several mathematical functions.

cycle from which the electric power is calculated. For each period, the calculation is repeated and result updated. The period is determined automatically. As this calculation of the electric power curve is updated for each cycle, changes in the electrical power can be registered accurately, even if the period varies. This may be the case, for example, during acceleration of a motor. Because of its high computing power at 10 MS/s, the DL850 is also suitable for power measurements on inverters using pulse-width modulation (PWM).

The mathematical operations are implemented in hardware, allowing rapid and simultaneous calculations at up to 10 MS/s over 16 channels.

### Measurement examples:

**Transient power:** Using the power function, the transient active power for each waveform cycle is determined. For this, the instantaneous value of the power is integrated during the measured waveform

**Electrical angle of motors:** The torque characteristics of motors for converters and vector control motor drives depend on the phase difference between the mechanical angle of the motor (absolute angle of the motor shaft) and the electrical angle of the excitation current. The output signal is supplied from a rotary encoder on the motor shaft to the DL850. The calculation of the phase difference is then carried out using a discrete Fourier transform.