Energy measurement

Overview

Energy demand around the world is predicted to increase at a rate that will likely outstrip our ability to generate it. Estimates by the U.S. Department of Energy forecast total energy consumption in the U.S. to increase by 30% to over 5,000 billion kWh in 2035, while new planned generation (including renewable sources) is expected to grow only 22% during this period. Increased energy efficiency and improved energy management are critical to averting this potential energy crisis.

Traditional open-loop strategies for managing power usage are crude and inefficient, resulting in lower reliability and reduced distribution stability. Engineers are working to improve power efficiency in all electronic applications—commercial equipment, home appliances, industrial motors, and network equipment. Increasing efficiency, however, is only part of the equation. Better energy management and, consequently, comprehensive measurement systems are essential. Incorporating feedback about how power is consumed yields the benefits of a closed-loop system and reduces waste. Additionally, giving energy users greater visibility into their power consumption can help overcome consumer indifference to energy concerns.

Accurate measurement provides the feedback necessary to understand, confirm, and modify our power consumption. It is critical to implementing an energy-management control loop and providing insight for maintenance and failure diagnostics.

This chapter addresses two key areas that benefit from new energy-measurement technologies: residential/commercial point of loads (POLs) and data centers.

Measuring point-of–load efficiency

Intelligent power-management schemes require accurate energy measurement, not only at an aggregate level (e.g., an entire building) but also at the POL (e.g., air conditioner, lighting, dishwasher, or computer).

Smart meters can track time-of-day power consumption and enable utilities to offer incentives to consumers to change their usage patterns. To improve automation we need to equip consumers with choices and enhanced services. Individual POLs must be tied to a local data and control network that monitors and allows control of the various loads within a building or household. Services can be enhanced through power-quality measurements and usage statistics, which can be used to schedule maintenance. Such a network can be implemented using a wide variety of configurations and protocols, depending upon the application.

A local data and control network that includes accurate power measurement can enable significant cost savings by identifying how power is being used. Consumers who can see that running the air conditioner costs $200/month (value of use) or quantify the cost difference between running the dryer at noon instead of 7 p.m. (time-value of use) are more likely to change their usage patterns.

Data that used to be acquired by expensive high-end utility meters is now available for an order-of-magnitude less cost. Power factor (PF), harmonic distortion, active power (watts), and apparent power (VA) information can be readily available for optimizing power-delivery

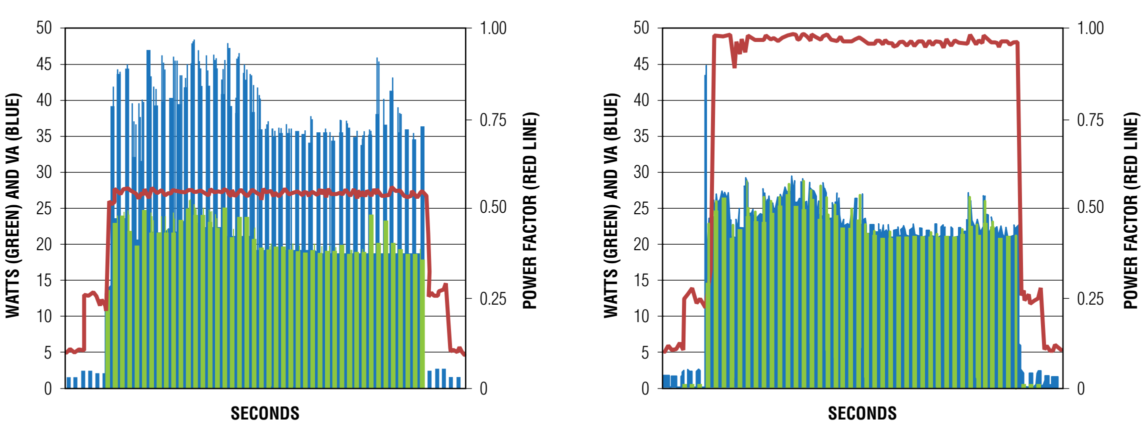


Figure 1. The power profile of a laptop computer during power-up, steady-state, and power-down using two different plug-in power supplies.

budgets, for predicting maintenance, and for understanding the strain on a system.

Figure 1 shows the power consumption of a laptop computer using two different plug-in power supplies. Even though the actual load is the same, the power supplied from the line by the utility, called apparent power, is substantially different from the power consumed by the load, called active power. Such differences lead to unnecessary and unaccounted for power loss. With energy-measurement solutions, statistics can be used to adjust device operating behavior to optimize energy efficiency.

Measurement accuracy is important to effectively protect against power failures and safeguard equipment. Small drops in voltage or line frequency can indicate pending power failure, enabling devices to switch into a protection mode. Additionally, voltage zero-crossing information can be used to time when relays should be turned on and off to reduce wear from arcing.

Measuring data center efficiency

Data centers are getting a lot of attention. The Environmental Protection Agency (EPA) estimates that data centers accounted for 1.5% of U.S. electricity consumption in 2006, and this demand is expected to nearly double by 2011, necessitating the development of an additional 10 power plants. Increasing data center energy efficiency can help avoid these infrastructural costs, while offering data center operators significant savings on their electricity bills.

ENERGY STAR recently released guidelines for data centers to mitigate this demand through increased energy efficiency. Key to these guidelines is a new metric called power usage effectiveness (PUE), which measures facility infrastructure efficiency. PUE is calculated by dividing total data center energy consumption by the IT equipment energy consumption. This requires metering at multiple locations within the data center, including the uninterruptible power supply (UPS) and power distribution units (PDUs).

Real-time power consumption data is needed to prevent costly overloading of breakers, as well as overallocation to equipment in idle or standby modes. Armed with this information, data center managers can implement operational strategies for dynamic power capping and reallocation to maximize PUE.

An added benefit of energy-measurement systems is that they give data center managers early failure notification so that preventative maintenance can be scheduled. Early-warning notification provides the extra time needed to seamlessly utilize a redundant option before failure. Energy-measurement systems enable continuous monitoring of the health of the power network. This capability is especially important as equipment is sequenced, because it can allow mechanisms that avoid circuit overloads such as those found during a black-start recovery.

Energy-measurement SoCs

Implementation of intelligent power-management algorithms requires clear representation of both actual power consumption and actual demand. This necessitates high accuracy and multiple metrology functions, including: distortion; active, reactive, and apparent power; energy; RMS voltage and current; and frequency. This information provides valuable feedback for improving operating efficiency, preventing power failure, and facilitating power-up sequencing during a black start.

Measurement accuracy is determined by resolution, precision, and dynamic range. Many general-purpose MCUs are limited in their accuracy and dynamic range because of their 10- or 12-bit ADCs. Discrete designs, meanwhile, require multiple components, in-depth knowledge of AC metering, and extensive development time.

Today, SoCs are available that bring the capabilities of intelligent metering to individual devices, from POLs to PDUs. Advances in manufacturing and design technology enable the metrology contained in a single SoC to meet critical cost, functionality, robustness, and size requirements. Today's state-of-the-art SoCs can now be integrated into server cabinets, UPSs, AC-DC power modules, PDUs, smart appliances, and luminaires.

Figure 2. A ZigBee®-based outlet-monitoring unit.

Figure 2 shows an easy-to-use data collection system for POLs. This low-cost outlet-monitoring unit demonstrates the capabilities of the 78M6612 energy-measurement SoC. It allows users to collect time-stamped data from a power outlet and wirelessly transfer it for graphical analysis or comparison to a reference meter.

The 78M6612 AC-power-monitoring SoC can measure from 10mA to 20A with less than 0.5% measurement error across a wide -40°C to +85°C temperature range. Its onboard 22-bit ADC enables this wide dynamic range and accuracy, allowing the device to detect various POL low-power modes. Additionally, the wide dynamic range allows the same circuitry to monitor a diverse range of applications, providing economy-of-scale cost savings.

Technical benefits of using an energy-measurement SoC

- Accurate power measurement across a wide current dynamic range can be used to confirm different low-power modes. For example, a single SoC can measure from 10mA to 20A with 0.5% accuracy.
- Voltage and line-frequency measurements can be used to determine the appropriate time to use power, especially when the source is not the local utility supplier. Small drops in voltage or line frequency are an indication of pending power failure.
- AC-voltage zero crossing can be used to synchronize when switches should be turned off or on—an opportunity that occurs every 8ms to 10ms, depending on the line frequency.
- Statistical data can be collected to detect early failure of a local AC-DC power-supply module or to provide information about the type of load that was just plugged into the outlet.

A single chip implements a highly integrated outlet-monitoring system, saving the time, space, and cost of a multichip solution

78M6612/78M6613

The 78M6612/78M6613 are highly integrated, single-phase AC power-measurement and monitoring (AC-PMON) ICs for consumer and enterprise applications. While the 78M6612 targets general-purpose AC power-measurement applications, the 78M6613 provides a simplified integration of single-phase AC power measurement for the power-supply market. With accuracy of 0.5% Wh or better over a 2000:1 current range and over temperature, each single chip provides the metrology data typically found in complex, multichip metering systems.

Featuring four analog inputs, both devices use Teridian's Single Converter Technology® design and an integrated 32-bit computation engine (CE) to measure up to two AC loads or wall outlets. The devices are highly integrated, which reduces board space and lowers costs. Each includes an 8-bit MPU core with 32KB of embedded flash memory, a UART interface, and multiple GPIOs for easy integration into any power supply or outlet-monitoring unit. The 78M6612/78M6613 consume roughly 30mW under typical operating conditions. The 78M6612 is available in 64-pin LQFP and 68-pin QFN lead-free packages, while the 78M6613 is available in a 32-pin QFN lead-free package.

Designing with the 78M6612/78M6613 is greatly simplified with a complimentary suite of development tools. Complete energy-measurement firmware supports the serial UART interface and simplifies calibration, configuration, and data extraction. Firmware options are available for emulating I^2C, PMBus™, or SMBus interfaces using the onboard GPIOs. Firmware can be preloaded during IC manufacture or modified by customers as needed. Software libraries greatly expedite the development process.

Benefits

- **Single-chip solution provides the metrology accuracy typically found in multichip metering systems**
  - 0.5% Wh accuracy over 2000:1 current range and over temperature
- **Adds intelligence to energy monitoring**
  - Full range of embedded energy diagnostics (power factor, harmonic distortion, voltage sag and dip) for each outlet
  - Predicts power-supply failures
  - Intelligent switch relay control, including zero-crossing detection for each outlet
- **High integration reduces the bill-of-materials (BOM) cost**
  - Monitors two outlets simultaneously
  - Dual-outlet power reduces cost per outlet
  - Complete energy-measurement communication protocol
  - Eliminates the need for external components to boot or load calibration parameters
- **Reduces time to market**
  - Software support tools simplify design cycles
  - No code development is required by the customer
  - Complete energy-measurement and host-interface firmware available

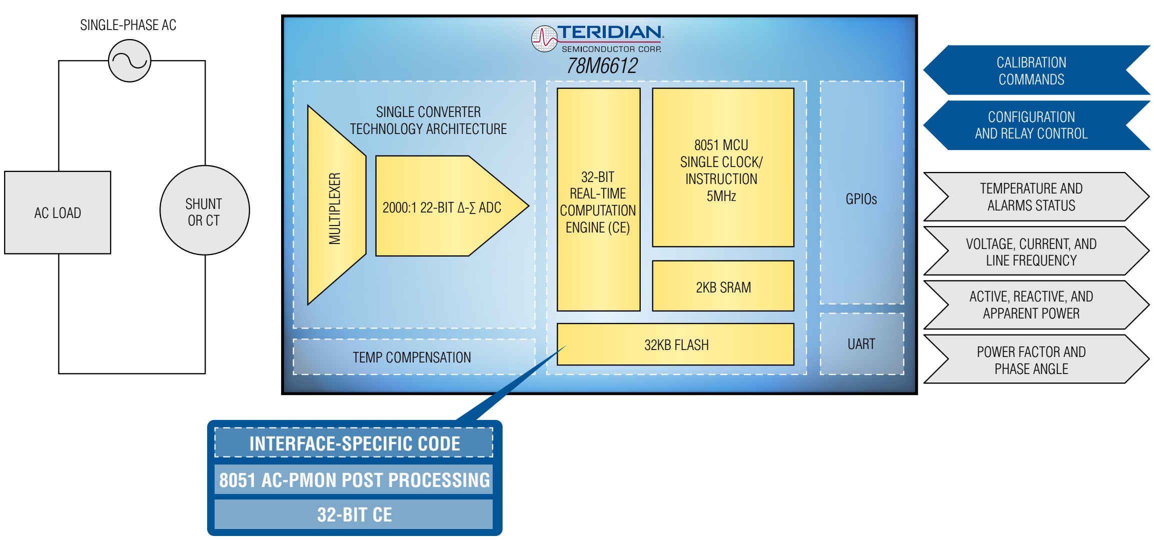


Diagram of a typical energy-measurement SoC embedded in a single-phase application.

8-channel energy-measurement IC simplifies complex server PDU system design while reducing costs

78M6618

The 78M6618 is a highly integrated, single-phase, 8-outlet, power-measurement and monitoring SoC. It is designed for multichannel power monitoring in PDUs, smart breakers and relay panels for homes, and building automation.

The 78M6618's accuracy is 0.5% Wh over a 2000:1 current range and over temperature—what one would typically find in multichip metering systems. It has unprecedented integration in an energy-measurement IC: a 32-bit CE, an MPU core, 128KB flash memory, 4KB shared RAM, and an RTC; three low-power modes with internal timer or external event wake-up; two UARTs; and an I^2C/MICROWIRE® EEPROM interface or an SPI™ interface. The SoC also features Teridian's Single Converter Technology design, which incorporates a 22-bit delta-sigma ADC, 10 analog inputs, digital temperature compensation, and a precision voltage reference. With these many capabilities, the 78M6618 supports a wide range of single-phase metering applications. Needing very few external components, this single chip also greatly reduces the cost of implementing complex PDU systems.

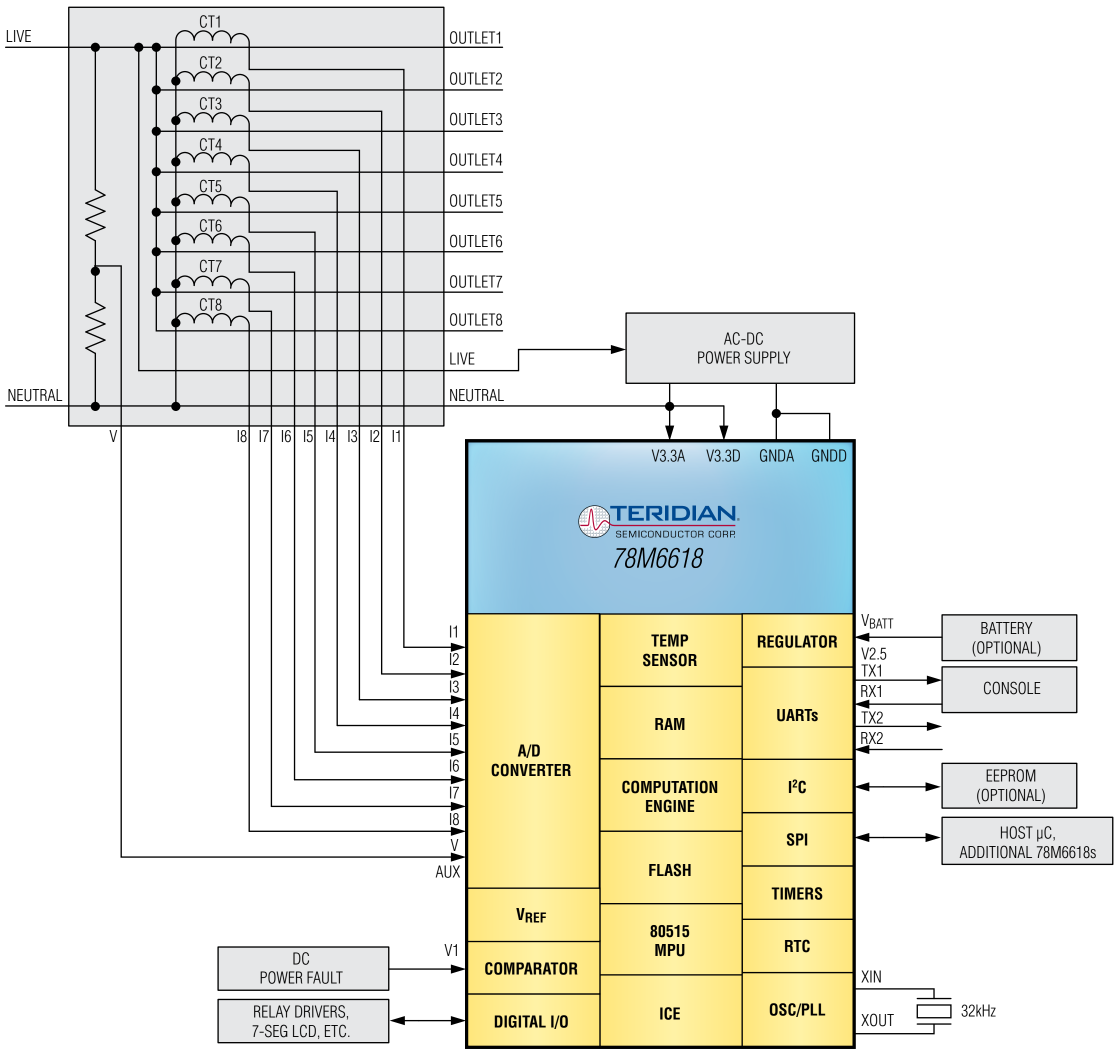
A complete array of in-circuit emulation and development tools assists customers and reduces design time. Metrology libraries are specifically designed for measurement and switch control of eight single-phase AC outlets (same phase). A software development kit, reference designs, and reference manuals expedite development and certification of power and energy measurement.

Benefits

- **Single-chip solution provides the metrology accuracy typically found in multichip metering systems**
  - 0.5% Wh accuracy over 2000:1 current range and over temperature
- **Adds intelligence to energy monitoring**
  - Measures the power factor for each outlet
  - Predicts power-supply failures
  - Intelligent switch relay control, including zero-crossing detection for each outlet
- **High integration reduces BOM cost**
  - Monitors eight outlets simultaneously
  - Octal-outlet power reduces cost per outlet
  - Complete energy-measurement communication protocol in a single chip
- **Shortens time to market**
  - Software support tools simplify design cycles
  - No code development is required by the customer
  - Complete energy-measurement and host-interface firmware available

(Block diagram on next page)

8-channel energy-measurement IC simplifies complex server PDU system design while reducing costs *(continued)*



Block diagram of the 78M6618 power- and energy-measurement IC.