

PowerMonitor 5000 – The Next Generation

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The PowerMonitor™ 5000 is the next generation of high-end metering products from Rockwell Automation. This new family of meters provides advanced technology, new functionality, faster response, and superior accuracy.

The PowerMonitor 5000 family provides three levels of functionality: M5, M6, and M8. The 5000 M5 is the base model and provides an extensive range of metering functions. The 5000 M5 is the first member of the new family to be released. This publication describes the changes and improvements that the PowerMonitor 5000 M5 has compared to the PowerMonitor 3000 M5.

What the PowerMonitor 3000 Measures

The PowerMonitor 3000 M5 measures three voltages (three line-to-neutral or three line-to-line) and four currents (one per line and the neutral). The 3000 M5 can also be used for single phase systems. Line-to-line voltages up to 600V AC can be directly connected to the meter while higher voltages require external potential transformers. The current inputs are rated 5 amps nominal and require external current transformers. Both voltage and current inputs are landed on screw terminals on the front of the meter. The monitor uses analog circuitry to condition and filter the voltage and current input signals. The output of the filters is sampled and converted to digital values by a multi-channel, 14-bit analog to digital converter. The multiple-pole input filter is necessary to prevent any high frequency signals present from aliasing into the operating bandwidth of the product. As with any realizable filter, the frequency response is not ideal. The filter creates both magnitude and phase distortion that varies with frequency. The introduced magnitude and phase distortion produces some small metering errors and also reduces the fidelity of any waveform captures. All of the inputs are simultaneously sampled to prevent time skew between the signals. It is important to minimize the time skew between the voltage and current because this creates phase shift error in the real and reactive power calculations.



PowerMonitor 3000



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What the PowerMonitor 5000 Measures

The PowerMonitor 5000 family of meters starts out in a similar manner with analog circuitry for conditioning and filtering the voltage and current inputs and a multi-channel analog-to-digital converter to transform the inputs into a digital signal stream. However, the similarity between the two products ends there. The new family of power monitor products measures four voltages (three line-to-neutral or three line-to-line, one neutral-to-ground) and four currents (one per line and the neutral). The monitor can also be used for single-phase systems. Line-to-line voltages up to 690V AC can be directly connected to the meter. Higher voltages require external potential transformers. The current inputs are rated 5 amps nominal and require external current transformers. The voltage inputs are landed on screw terminals on the front of the meter. The secondaries of the external current transformers are passed through the center of one of four internal, toroidal, current transformers in the meter, there are no screw connections. This reduces heat dissipation within the meter and improves accuracy. The analog-to-digital converter is upgraded to 16 bits.

PowerMonitor 5000 has the “Virtual Wiring Connection,” which eliminates the need to physically change meter connections.

A fourth voltage input and changes in the analog input structure provide significant new capability to the PowerMonitor 5000. When used with an impedance grounded four-wire system, the meter is now capable of measuring line-to-neutral, line-to-line, and neutral-to-ground voltages. Line-to-ground voltage can easily be computed with the appropriate vector math, which provides additional capability to determine the health of the monitored power system as well as identify faults or other system anomalies. Line-to-line and line-to-ground voltages can be monitored for three-wire systems to detect the presence of an unintended ground in a delta system.

In most instances, a meter is properly connected to the power system. However, there are instances when correct installation is difficult (for example, the necessary labels or drawings are incorrect or missing). These situations require knowledgeable analysis or trial and error to resolve, which usually requires the power system to be shut down to change connections to the meter. There can be significant restrictions or delays before the power can be shut down. Even when shutdown is not required, bulky and hot protective gear can be needed by the person who changes the meter connections.

The PowerMonitor 5000 has two enhancements that can reduce or eliminate this problem. The first enhancement is a wiring diagnostics capability that analyzes the connected signals, identifies missing or incorrect connections, and provides an indication to help you fix any incorrectly wired conditions. The second enhancement is the “Virtual Wiring Correction,” which eliminates the need to physically change meter connections and lets you direct the meter to individually invert any voltage or current inputs as needed. To correct for incorrect phase rotation or a mismatch between voltage and current phases, the order of each voltage and current input can be changed “virtually” so any condition other than missing inputs are corrected without a physical change at the meter. The changes can be implemented remotely via the web-page interface. When a “virtual” change has been enabled, the meter provides an LED indication on the meter and a status indication via communications.

What the PowerMonitor 3000 Samples

In the PowerMonitor 3000, data is electronically sampled at 5.4 kHz regardless of the input frequency and then re-sampled in firmware to provide a fixed number of samples per cycle, typically 61 samples. The samples are processed in the time-domain to obtain the desired metering quantities. The true RMS voltage and current values are computed based on the following formula:

$$\text{RMS} = \sqrt{\frac{1}{T} \cdot \int_0^T x(t)^2 dt}$$

Where:

T = period of input signal
 $x(t)$ = value of voltage or current input at time "t"

The integral value is computed by using the Simpson's Rule approximation. By using the digitally sampled data, the equation becomes as follows:

$$\text{RMS} = \sqrt{\frac{(x_0)^2 + 2 \sum_{(n=1)}^{(N-1)/2-1} (x_{2 \cdot n})^2 + 4 \cdot \sum_{(n=1)}^{(N-1)/2} (x_{2 \cdot n-1})^2 + (x_{N-1})^2}{3 \cdot N}}$$

Where:

N = the number of equally spaced samples in the period "T"
 x_n = the value of the digital sample at sample number "n"

* The value of "N" is always an odd number.

What the PowerMonitor 5000 Samples

Unlike the PowerMonitor 3000, the PowerMonitor 5000 sample frequency is not fixed. The applied input frequency is constantly measured and used to adjust the sample frequency to provide 1,024 samples per cycle. The significantly higher number of samples provides improved accuracy and more closely replicates the input waveforms. Instead of processing the digital data in the time-domain, computations are now performed in the frequency-domain. The voltage and current data is processed with a Fast Fourier Transform (FFT) that provides the magnitudes and phase angles for DC through the 127th harmonic of the fundamental. Keeping the number of samples per cycle fixed at 1,024 (210) uses a simpler FFT algorithm and provides a factor of four times over-sampling. Because the individual magnitudes and phase angles for the fundamental and each of the harmonics present are computed, the gain roll-off and phase shift errors due to the frequency response of the input anti-alias filters and other parts of the analog input path can be compensated. This improves overall accuracy for all measurements, reduces signal distortion, and increases the fidelity of any waveform captures.

The peak magnitude of the fundamental and each of the harmonic frequency components returned from FFT are used to compute RMS values. The total true RMS value for the input is computed as follows:

$$\text{RMS} = \sqrt{\frac{1}{2} \left[\sum_h (X_h)^2 \right]}$$

Where:

h = harmonic number (1...127)
 X_h = magnitude of the "hth" harmonic

How the PowerMonitor 3000 Calculates Power

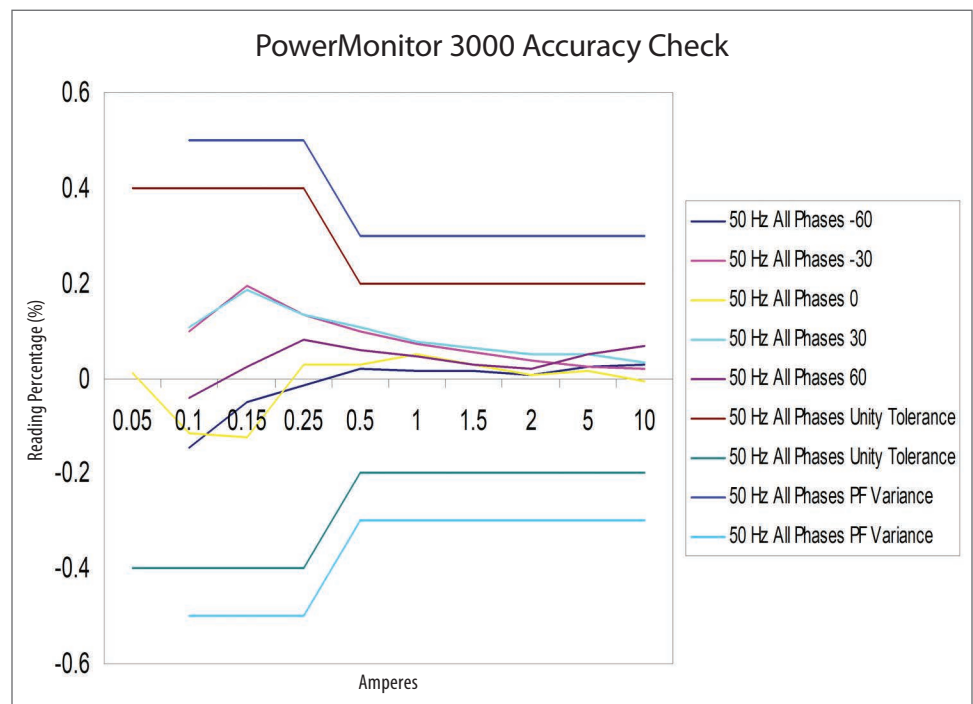
The power calculations performed by the PowerMonitor 3000 are also done in the time-domain. Real power is calculated by multiplying each voltage sample in a line cycle by the coincident current sample and computing the result via the following formula:

$$\text{Real_Power} = \frac{1}{N} \left[\sum_{(n=1)}^N (V_n \cdot I_n) \right]$$

Where:
 V_n = voltage value at sample number "n"
 I_n = current value at sample number "n"

Reactive power is calculated similarly to the real power except the current is shifted by one-quarter cycle of the fundamental frequency before multiplying by the voltage sample. Because the number of samples per cycle is always odd, a one-quarter cycle shift is not exact and introduces a small error in the reactive power calculation. In addition, the 90 degree shift of the fundamental is not always equal to a 90 degree shift of any harmonics that are present, which is another small source of error. Calculation of apparent power uses the previously calculated voltage and current values and is simply the product of the RMS voltage and current magnitudes. The remaining quantities provided by the meter are derived from these base measurements.

The energy calculation performed by the PowerMonitor 3000 meets the Class 0.5% accuracy requirements of ANSI C12.20 and EN 62053-22. The meter can also be ordered to meet the Class 0.2% requirements. This level of accuracy requires significant increase in testing. Due to variations in components tolerances and performance, not every PowerMonitor 3000 is capable of meeting the Class 0.2% requirements. The graph below shows the typical accuracy performance of the energy measurement for a Class 0.2% meter vs. different levels of current input. The two upper and lower lines show the tolerance limits at unity power factor and at a power factor of 30% leading or 50% lagging.



How the PowerMonitor 5000 Calculates Power

In the PowerMonitor 5000, the real, reactive, and apparent powers are computed from the frequency-domain quantities as follows:

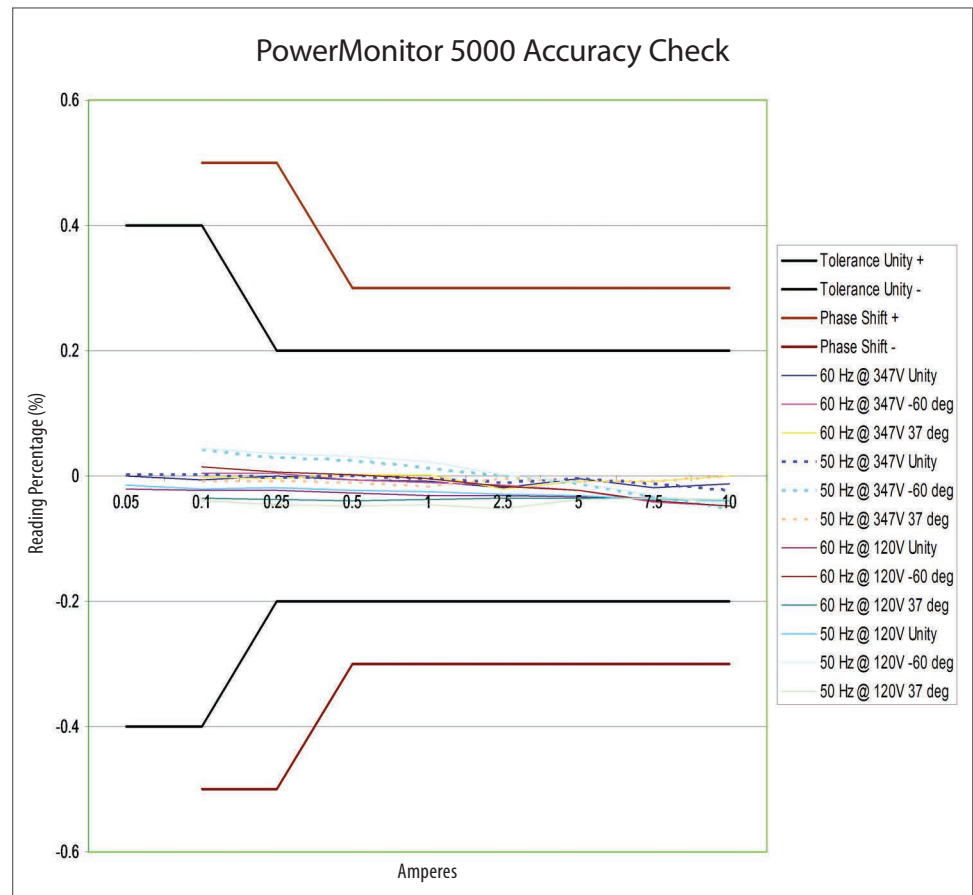
$$\text{Real_Power} = \sum_h (V_{\text{RMS}_h} \cdot I_{\text{RMS}_h} \cdot \cos[V_{\text{angle}_h} \cdot I_{\text{angle}_h}])$$

$$\text{Reactive_Power} = \sum_h (V_{\text{RMS}_h} \cdot I_{\text{RMS}_h} \cdot \sin[V_{\text{angle}_h} \cdot I_{\text{angle}_h}])$$

$$\text{Apparent_Power} = \sum_h (V_{\text{RMS}_h} \cdot I_{\text{RMS}_h})$$

Because the calculations do not require any phase shifts and they are individually computed for the fundamental and each harmonic before summing the results, the small errors present in the PowerMonitor 3000 are eliminated from the PowerMonitor 5000.

Once again, these base values are used to compute the remaining metering quantities. The energy calculation performed by the PowerMonitor 5000 exceeds the Class 0.2% accuracy requirements of ANSI C12.20 and EN 62053-22. There is no special testing required and every device is capable of meeting this level of performance. The graph below shows the performance of the PowerMonitor 5000 under the same conditions as shown earlier for the PowerMonitor 3000. The following graph shows the significant improvement of the new technology.



How the PowerMonitor 3000 Calculates Sequence Values

Positive and negative sequence components of a three-phase system are important measurements for determining the true unbalance of the system. Unbalance creates significant heating in rotating equipment such as a motor and can result in early motor failure. The PowerMonitor 3000 computes both the positive and negative sequence values for voltage and current. The equations for these calculations are as follows:

$$V_{\text{pos_seq}} = \frac{(V_{\text{ab}} \angle 0_1 \cdot 1 \angle 0_1 + V_{\text{bc}} \angle 0_2 \cdot 1 \angle 120 + V_{\text{ca}} \angle 0_3 \cdot 1 \angle 240)}{3}$$

$$V_{\text{neg_seq}} = \frac{(V_{\text{ab}} \angle 0_1 \cdot 1 \angle 0_1 + V_{\text{bc}} \angle 0_2 \cdot 1 \angle 240 + V_{\text{ca}} \angle 0_3 \cdot 1 \angle 120)}{3}$$

Each sequence calculation creates a new sine wave by combining the individual sine waves of the three phases into a single new waveform per the above formulas. The sequence calculations are only valid at one frequency. Therefore, each of the inputs must first be filtered so that only the fundamental frequency component remains. The data set used consists of one complete cycle of coincident samples for each of the three phases. The above equations show that two phase angle transformations, one by 120 degrees and one by 240 degrees, are required. The 120 degree transformation is accomplished by dividing the number of samples per cycle by three. The result is the number of data samples that represent the desired phase transformation. This number is used as an "offset" into the data sample set. For example, to determine the phase-transformed Vbc value shifted by 120 degrees for sample number "zero" of the positive sequence waveform, the Vbc value at sample number "offset" is used. If the "offset" value is not an integer, then the shifted sample value is determined by interpolating between the two adjacent samples.

The Vca value shifted by 240 degrees is obtained in a similar manner. The value of sample number zero of the positive sequence waveform is equal to the sum of the value of Vab at sample number zero plus the value of Vbc at sample number "offset" plus the value of Vca at sample number "2 * offset" divided by three. To compute the magnitude of the positive sequence value for voltage, two points that are 90 degrees apart on the positive sequence waveform are required. The first point is created as just described. The second point is created in a very similar manner except an additional offset equal to the number of samples per cycle divided by 4 (90 degrees) is added to the sample number for each of the three inputs. Once these two points have been created, the magnitude is computed by squaring the value of each of the points, adding them together, and then taking the square root. The negative sequence magnitude is derived in the same manner except the phase transformations are adjusted per the above formulas. While this calculation produces good results, it is complicated and the required interpolations result in some error.

How the PowerMonitor 5000 Calculates Sequence Values

Symmetrical component analysis performed with the new technology is much simpler and more accurate. The PowerMonitor 5000 computes the positive, negative, and zero sequence values for both voltage and current. The zero sequence calculation is similar to the calculation for the positive/negative sequence except there is no phase angle transformation required. Instead of using the complex process described above, the required phase angle transformations use the magnitude and angle of the fundamental values from the FFT and apply simple vector math to compute the desired sequence value. There is no interpolation or approximations required. The result is more accurate and consistent values.

How the PowerMonitor 3000 Is Network Configured

The PowerMonitor 3000 is configured through either a local display or a communication network. There is always an RS-485 port available and one factory installed optional communication port. The optional ports are EtherNet I/P, DeviceNet, and ControlNet. The PowerMonitor 3000 uses a SLC500 style user interface to address data items. Configuration and access to the metering results are available via the network interface. You can use either a programmable controller or a computer to communicate to the meter. There are various software products available to help you configure the meter and make better use of the supplied metering results. The meter also has a built-in web-page interface that can be used to review the metering results but it cannot be used for configuring the device. Each set of metering results provided by the monitor is time-stamped so you can compare data between multiple meters or correlate power system events with anomalies that occur in a process that is connected to the power system. The clock used for the time stamp is maintained internal to the powermonitor. For more accurate time-keeping the clock can be periodically updated from an external computer, or if desired the meter can communicate with an SNTP time server. Typically, new metering data is provided approximately every 100 milliseconds.

How the PowerMonitor 5000 Is Network Configured

The PowerMonitor 5000 has a native USB port and a native EtherNet I/P port that can be used for configuration or viewing metering data. There is also an optional communication port that lets you install a second EtherNet I/P, DeviceNet, or ControlNet connection. The meter uses a Logix-style user interface to address data items. This provides improved alignment with Integrated Architecture. There is also the addition of a file transfer mechanism to greatly speed up the acquisition of large files such as log files. Configuration and access to the metering results are available via the network interface. Either a programmable controller or a computer is used to communicate to the meter. There are various software products available to help you configure the meter and make better use of the supplied metering results. The meter also has a built-in web page interface that can be used to review the metering results. The web interface is enhanced to also allow configuration of the meter.

Tighter time synchronization and faster updates improve the ability to determine the sequence of events when multiple meters are present.

To prevent unauthorized changes to the meter configuration or resetting of the energy counters, there is a configuration lock switch on the device. When this switch is activated, all configuration and metering data is available from the monitor, but none of the configuration data that affects metering or none of the energy counters can be altered. In addition to the normal data provided by the meter, you can also access the calibration data stored in the meter during manufacturing.

The PowerMonitor 5000 provides the same time stamping capabilities as the PowerMonitor 3000 and adds an additional capability. The new meter supports the Precision Time Protocol used in CIP Sync and defined by IEEE 1588. This capability provides much tighter time synchronization with other devices on the network. Performance of the time synchronization is dependent on how many system clocks are used, the quality of the clocks, and the network topology. A well designed and implemented system can achieve clock synchronization in the microsecond range. The update rate of the PowerMonitor 5000 is much faster, too. New metering data is computed every line cycle, 16.7 milliseconds for a 60 Hz system. The combination of tighter time synchronization and faster updates improve the ability to determine the sequence of events when multiple meters are present.

Summary

This publication provided an overview of the major differences in metering technology between the PowerMonitor 3000 M5 and the PowerMonitor 5000 M5. When available, the PowerMonitor 5000 M6 and M8 models add significant new metering functions and power quality capabilities.

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