With Respect to Different Input Configurations

In the Arbiter Systems® Model 1133A Power Sentinel™, certain conventions are followed in determining the various power, energy, and sequence components. Where the installation meets the requirements of Blondel's Theorem, the results will correspond exactly with physical quantities (watts and watt-hours, for example). In other modes, the results will be in accordance with industry standards and subject to errors due to imbalance. In all cases, we will attempt to provide as much useful information as is possible. For example, in 3-phase, 3-wire, 2-element mode, I_B and V_{AC} are calculated internally, not for use in power measurements (where they are not needed), but rather for measurements of harmonics, flicker and power quality.

3-Phase, 4-Wire, 3-Element

Energy Quantities:
The definitions are relatively straightforward in this configuration, and follow industry conventions. Active energy (watts, watt-hours) is obtained as the summed (point-by-point) product of the voltage and current, by phase. This quantity will always correspond to actual watts delivered (or received) in the real world, in accordance with Blondel's Theorem. Reactive energy (VARs) is defined as the imaginary component of the vector product of the voltage and current, each expressed as a vector. Apparent power (volt-amps) is defined as the magnitude of the vector having a real component equal to watts, and an imaginary component equal to VARs. Power factor is the ratio of active power to apparent power. Total quantities are obtained by adding the results for the three phases together.

Sequence Components:
Sequence components of voltage and current are obtained by transformation using a three-phase vector having a magnitude of 1/3 (per channel) and a phase angle of zero, +120 and -120 degrees. Zero sequence is the algebraic sum of the three vector phases, divided by three, and in a balanced system, should be zero. Positive sequence is the product of the three-phase signal vector, multiplied by a vector with reverse phase rotation; in a balanced system, positive sequence should be equal to the voltage (current) of each phase with the same phase angle (relative to GPS) as the A-phase signal. Negative sequence is the product of the three-phase signal vector, multiplied by a vector with normal phase rotation; in a balanced system, negative sequence should be equal to zero.

3-Phase, 4-Wire, 2½-Element

Energy Quantities:
The calculations for energy quantities in 2½ element are the same as for 3 element, with the exception that the B-phase voltage is synthesized internally as -(A+C). This is done on a point-by-point basis prior to any other calculations. Therefore, all measurements available in 3-element mode are available in 2½-element mode; however, measurements related to the B-phase voltage must be understood to be derived from the A and C phases. Accuracy in this mode depends entirely on the phase balance of the system. Any difference (expressed as a vector error) between -(A+C) and the actual B-phase voltage will cause corresponding errors in measurement. This mode is provided for applications where those errors are known to be inconsequential, or where the user is not concerned with them. For best accuracy, 3-element mode is recommended.

Sequence Components:
Sequence components are calculated as for 3-element mode. As with energy quantities, the results for voltage are not valid in the event of imbalance; since the reason for determining sequence components is to evaluate imbalance, their usefulness is questionable. In particular, because of the internal definition of $V_B = -(V_A+V_C)$, zero-sequence voltage will always be calculated as zero. For accurate and useful voltage sequence component measurements, 4-wire mode must be used. However, we try to provide results for this configuration which are as useful as is possible.

3-Phase, 3-Wire, 2-Element

Energy Quantities:
Definitions in this mode are complicated somewhat due to the 30 degree phase angle between the phase-to-phase voltages and the currents. However, unlike the 2½-element mode, 2-element mode meets the requirements of Blondel's Theorem, and accurate active

power measurements are assured. Active power is determined as the summed (point-by-point) product of the voltage and current, by element. Reactive power (VARs) is determined as the imaginary component of the vector product of the voltage, the current, and a vector having a magnitude of $\sqrt{3}/2$ (0.866) and a phase angle of +30 or -30 degrees. In a system having nominal phase relationships, the result of this calculation will yield zero for each element. Apparent power (volt-amps) is defined as the magnitude of the vector having a real component equal to watts, and an imaginary component equal to VARs. Power factor is the ratio of active power to apparent power. Total quantities are obtained by adding the results for the two elements together.

Sequence Components:
As in 2½-element mode, sequence components are not well defined due to the loss of information caused by not having a neutral voltage. However, we attempt to make a measurement which is useful by summing the product of the V_{AB} and V_{CB} inputs, with the V_{CB} input multiplied by a unit vector having either +120 degrees (positive sequence) or -120 degrees (negative sequence) phase angle. The sum is divided by three, yielding a result which is nominally equal to the V_{AN} voltage (positive sequence). For current, the calculation is the same as for 3-element; however, because there is no neutral for zero sequence return currents, zero sequence current is always zero by definition. Negative sequence (for both voltage and current) is nominally zero in a balanced system.

1-Phase, 3-Wire, 2-Element and 2-Wire, 1-Element

Energy Quantities:
The definitions are relatively straightforward in this configuration, and follow industry conventions. Active energy (watts, watt-hours) is obtained as the summed (point-by-point) product of the voltage and current, by element. This quantity will always correspond to actual watts delivered (or received) in the real world. Reactive energy (VARs) is defined as the imaginary component of the vector product of the voltage and current, each expressed as a vector. Apparent power (volt-amps) is defined as the magnitude of the vector having a real component equal to watts, and an imaginary component equal to VARs. Power factor is the ratio of active power to apparent power. Total quantities in 2-element mode are obtained by adding the results for the two elements together.

1-Phase, 2-Wire, 1½-Element

Energy Quantities:
Active energy (watts, watt-hours) is obtained as the summed (point-by-point) product of the voltage and current, by element, divided by 2. This quantity will only correspond to actual watts delivered (or received) in the real world when the system is in perfect balance for either voltage or current. Reactive energy (VARs) is defined as the imaginary component of the vector product of the voltage and current, each expressed as a vector, divided again by 2. Apparent power (volt-amps) is defined as the magnitude of the vector having a real component equal to watts, and an imaginary component equal to VARs. Power factor is the ratio of active power to apparent power. Total quantities are obtained by adding the results for the two elements together.

1-Phase Sequence Components

Sequence components are not defined for single-phase measurements. However, in keeping with our goal of providing something useful, in two-element mode, positive-sequence voltage is defined as the vector difference of the L1 and L2 voltages, divided by two; and zero sequence is defined as the vector sum of the L1 and L2 voltages, divided by 2. Positive sequence is equal to the L1-N voltage, and zero sequence zero, in a balanced system. Negative sequence is set to zero by definition. It is impossible to perform any meaningful transformation on a single-phase, one-element or 1½-element system. Positive sequence is set in this case to the L-N or (L1-L2)/2 voltage, and zero and negative sequence to zero.

Registration

Registration is performed on a period-by-period basis, where each measurement period is 50 ms long. Direction of the components is obtained each period and the quantities registered appropriately. Because the total directions are independently determined, the sum of the registered quantities by phase may not be exactly equal to the registered totals. This is in accordance with the definitions, and will occur only when the directions of energy flow for the phases differ over a period. This might occur, for example, when VARs are positive for two phases and negative for the third. The total quantity will be registered according to its direction, and each phase quantity will be registered according to its direction.

Harmonics and Flicker

Harmonic and flicker measurements are performed on the same quantities used to measure energy and sequence components. These measurements are meaningful if the signal being analyzed corresponds to a real-world quantity. Current measurements, for example, are always useful; however, in 3-phase, 4-wire, 2½-element mode, the B-phase voltage is not connected to the instrument, so it is impossible to measure actual harmonics and flicker on it (although these measurements are made on the synthesized B voltage). Measurements on voltage inputs are most useful if the customer's load is connected in the same way as the instrument, i.e. phase to neutral for 3-element mode, and phase-to-phase for 2-element mode. In 2½-element mode, measurements on the A and C phases correspond to actual phase-to-neutral loads, but the B-phase, synthesized as -(A+C), is artificial and therefore no conclusions can be drawn from it, although the results for the synthesized voltage are calculated and displayed. As with power, the most accurate and useful measurements are obtained in 4-wire, 3-element and 3-wire, 2-element modes.

3-Phase, 3-Wire, 2-Element - Special Note:
In this mode, B-phase current is calculated as $I_B = -(I_A + I_C)$, and results are determined for current, phase angle, harmonics, flicker, etc., although this value is not used for energy calculations. Also in this mode, the phase-to-phase voltage V_{AC} is determined by subtraction: $V_{AC} = V_{AB} - V_{CB}$, and measurements made on this as well. These values are accurate, because these identities are exact, in accordance with Kirchhoff's laws (provided that there actually is no neutral return path), unlike the calculation used for 2½ element which makes the assumption of perfect voltage phase balance.

Frequency and Time

Measurements of system frequency and time deviation are made using the positive-sequence voltage, as defined in the paragraphs above. Since the phase angle of this voltage, used to determine frequency and time, is measured using narrow-band filtering performed with a fast Fourier transform, these measurements provide excellent rejection of the effects of harmonics, noise and dc offsets. True fundamental phase angle is determined, and these calculations based on it. Using the positive-sequence voltage corresponds most closely to the actual state of the system, as compared to measurements made on a single phase only. Of course, single-phase measurement of frequency and time is also possible where system requirements dictate its use.

Phasors

Phasors are nominally defined in a four-wire system, as are symmetrical components. The phasor representations provided by the Model 1133A will correspond to the physical quantities provided to the unit; for example, in 3-wire 2-element mode, the voltage phasors will correspond to the line-to-line voltages. As with all other measurement modes, synthesized quantities will be included in the output data stream. These are V_{BN} in 2½-element mode, and V_{AC} and I_B in 2-element mode.