Application Note

3-Phase Total Power Parameters & Configurations

In the text below it is assumed that the power into a load is being measured. If the power drawn from a source is being measured, then replace "load" with "source" in each applicable text position when deciding which configuration/method to use.

2503AH Wiring Methods

There are 4 basic methods of wiring the 2503AH for 3-phase applications :

1. ***3-phase 4-wire 3-channel***. In this case each channel has its' voltage HI terminal connected to a phase of the supply, where the current terminals of the same channel is monitoring the current in that phase. The Voltage LO terminals of all channels are connected together, and are connected to a neutral connection. This method is signified by configuring the group of three channels as 3p4w in the "Channel Grouping" Menu.
2. ***3-phase 3-wire 2-channel***. In this case the two channels are connected in the same manner as for the 3-phase 4-wire 3-channel method above, but only 2 channels are used, and the common Voltage LO point is taken to the remaining phase voltage. This method is signified by configuring the group of two channels as 3p3w in the "Channel Grouping" Menu, and setting only one of these channels as being "in rotation" in the detailed menu for this group..
3. ***3-phase 3-wire 3-channel***. In this case each channel has its' voltage terminals connected between consecutive pairs of phase voltages, with each channels' current monitoring the flow in the phase connected to its' respective Voltage HI terminal. This method is signified by configuring the group of three channels as 3p3w in the "Channel Grouping" Menu, and setting all channels (or none) as being "in rotation" in the detailed menu for this group.
4. A combination of methods #2 and #3. If the method #2 is used with two of the channels, and the third channel is wired with its' Voltage terminals between the phases being monitored by the first two channels, and its' current monitoring the third phase current, then this achieves the advantages of method #2, while offering the actual current in the remaining phase, and also the remaining inter-phase voltage. The power reading of this third channel should be ignored, and will not be included in the 2503AH's total power indications. This method is signified by configuring the group of three channels as 3p3w in the "Channel Grouping" Menu, and setting only one or two of these channels as being "in rotation" in the detailed menu for this group.

3-Phase 4-Wire (Wye) Loads

Method 1 (3p4w, 3-channel)

This is the recommended method in virtually all cases of load. The 2503AH will correctly compute total power within the group, and will yield correct total VAR and Power Factor data also. If only 1 or 2 channels are actually available then the instrument will automatically assume that the unmeasured phase(s) is similar to the measured phases and will cause the correct total to be estimated. This has the advantage of yielding the best estimated results (assuming a balanced load) even should one or two channel(s) fail. Unlike other power analyzers (which assume 120° phase rotation and a balanced load) the 2503AH automatically compensates the total VAR, VA and Power Factor data for the actual conditions. Other than when operating with fewer than 3 channels, the 2503AH makes no assumptions regarding signal content, phasing or load balance when using this method, the total Watts being simply the addition of each channels' Watts, similarly for VARs (thus VA and Power Factor).

Method 2 (3p3w 2-channel)

This method will only yield adequate results if there is negligible neutral current, the phases are well balanced, and there is negligible voltage and/or current at frequencies other than fundamental. The 2503AH will automatically compute the information for the missing phase current from the two measured phases. If the VAR result from these channels' power analysis is not being caused by load phase shift and/or inter-phase 120°, then this computation will not yield the correct results. It should be noted that VARs are not only caused by phase shift in the load, but also by distortion in the load or source and by non-harmonic signal content (e.g., DC or high frequency switching) in the source or load.

Method 3 (3p3w 3-channel)

This method will rarely yield adequate results and is definitely not recommended. The 2503AH will automatically compute the information for each phase load current and voltage from the measured voltages and currents. If the VAR result from these channels' power analysis is not being caused by load phase shift and/or inter-phase 120°, then this computation will not yield the correct results. It should be noted that VARs are not only caused by phase shift in the load, but also by distortion in the load or source and by non-harmonic signal content (e.g., DC or high frequency switching) in the source or load. Although made available, the total group VAR data is invalid in most cases (and thus VA and Power Factor).

Method 4 (3p3w 2/3-channel)

This method is essentially the same as Method #2 and has the same limitations.

3-Phase 3-Wire (Delta) Loads

Method 1 (3p4w, 3-channel)

This method performs very well with this type of load, the user should simply connect the Voltage LO terminals to any suitable point. For interpretation of individual channel results, it is recommended that this be a “dummy” neutral formed by resistive dividers from the 3 phase voltages (it is recommended to connect a small value capacitor to ground from this node to prevent high frequency interference). In all circumstances the 2503AH will correctly total power within the group, and will yield correct total VAR and Power Factor data also. If only 1 or 2 channel are actually available then the instrument will automatically assume that the unmeasured phase(s) is/are similar to the measured phase(s) and cause the correct total to be obtained. This has the advantage of yielding the correct results (assuming a balanced load) even should one or two channel(s) fail. Unlike other power analyzers (which assume 120° phase rotation and a balanced load) the 2503AH automatically compensates the total VAR, VA and Power Factor data for the actual conditions. The mathematical proof that the neutral may be at any potential is available from Xitron Technologies Inc. upon request. Other than when operating with fewer than 3 channels, the 2503AH makes no assumptions regarding signal content, phasing or load balance when using this method, the total Watts being simply the addition of each channels’ Watts, similarly for VARs (thus VA and Power Factor).

Method 2 (3p3w 2-channel)

This method also yields the correct total results (similar to method #1 above) in all circumstances. However the method offers no failure tolerance capability such as method #1 does, and the individual channel power measurements are not generally very meaningful. Unlike other power analyzers, the 2503AH operates in all four power quadrants, thus this method even yields the correct results when operating with very low power factors, when the phase shift of the load plus the 30° offset in the phase current exceeds 90° most power analyzers incorrectly fail to invert the polarity of Watts and when the phase shift is leading/lagging most power analyzers do not reverse the polarity of VARs. The 2503AH makes no assumptions regarding signal content, phasing or load balance when using this method, the total Watts being simply the addition of each channels’ Watts, similarly for VARs (thus VA and Power Factor). The 2503AH checks the validity of the inter-voltage phase shift when using this method, thus it is necessary to have harmonic analysis enabled and a stable fundamental frequency for fully compliant operation.

Method 3 (3p3w 3-channel)

This method will rarely yield adequate results and is definitely not recommended. The 2503AH can obtain each individual inter-phase voltage directly, but is forced to compute each inter-phase current by assuming that the VAR content is being caused by phase shift in the load and by the inter-phase 60°. It should be noted that VARs are not only caused by phase shift in the load, but also by distortion in the load or source and by non-harmonic signal content (e.g., DC or high frequency switching) in the source or load. Although made available, the total group VAR data is invalid in most cases (and thus VA and Power Factor).

Method 4 (3p3w 2/3-channel)

This method is essentially the same as Method #2 and yields the same results.

Other Considerations

Although not limited to 3p3w and 3p4w environments, there are several other concerns which may be of interest to the reader.

Common Mode Effects

Although every effort has been made to limit the effects of common mode signals and interferences, there may be some small effects caused by common mode voltages appearing on the current low terminals. If the user is using external magnetic CT or Hall Effect devices, then the current low terminal should be tied directly to the adjacent chassis ground terminal at the rear panel of the instrument.
A further common mode effect, common in high frequency switchmode motor sources, is that of wiring ringing. With voltage slew rates in the order of 2000 to 15000V/us, even short wiring can produce extremely high voltage overshooting and ringing. The user should ensure that every effort is made to reduce these effects (e.g. use twisted pair cables, maintain the shortest possible wiring lengths), otherwise the accuracy of the measurements may be impaired. In extreme cases this may involve regular transients exceeding the 3000V limitation of the instrument, thus causing long term damage to the internal isolation of the instrument and subsequent failure. It should also be noted that the capacitance charging/discharging currents associated with these slew rates will pass through the system ground wiring, which can cause severe problems with IEEE488 bus "lockup" in some circumstances.

Cabling

High accuracy power measurements, particularly at lower power factors, requires extreme isolation between the voltage and current measurement waveforms. Although care has been taken with the internal wiring in the 2503AH, there remains slightly less than 1pF of capacitance between the voltage current wiring internal to the instrument. In most circumstances this is of little significance, but when measuring low level voltages representing current signals, and these signals have a significant source impedance then this can yield severe accuracy degradation at high frequencies and/or low power factors. Of particular importance in this regard is to ensure that the outputs of Hall Effect Transducers and "shunted" CT devices (e.g. Pearson) are fully shielded both electrostatically and magnetically from the main wiring between the source and the load, and from the voltage sense leads to the 2503AH. When using high ratio Hall Effect devices (e.g. 100:1 or higher) this is of considerable importance as only a few femptofarads can cause severe inaccuracies at frequencies above a few 10's of KHz

(0.2pf capacitance from a 5000V/us signal to the output of a 100:1 Hall Effect will cause a 0.2A error in the current indication)..

Conclusions

In all cases method #1 (3p4w 3-channel) should be used (Wye and/or Delta load/source configurations), constructing a dummy neutral if required. This offers many advantages, although has the slight disadvantages of not offering inter-phase phase relationships or phase voltage balance results (as does method #4).

If a true 3p3w (Delta) load is being used then methods #2 or #4 may be used, although high frequency sources/loads may be problematic when using these methods because the overall "leakage" in capacitance to ground is not properly accounted for. Also this method is more heavily reliant on phase measurement accuracy than method #1, thus yields slightly inferior results, particularly at high frequencies and/or in the presence of noise or high dv/dt signals.

Method #3 can only be used with a 3p3w (Delta) load when using a sinewave source and with a load having little distortion and being well balanced.

If total VAR, VA and/or Power Factor data is of significance to the user, then method #3 cannot generally be used, and only method #1 yields accurate results for these parameters in all configurations and circumstances.

The 2503AH power analyzers offer a comprehensive selection of configurations which yeild the best possible results, even with distorted source and/or loads, multiple frequency signal content, and unbalanced loads or source phasing. In most cases the instruments employ true vector mathematics to compute the total VAR, VA and Power Factor results, giving vastly superior results to the simpler approaches employed by other power analyzers.