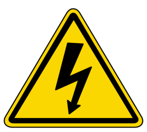
Safety Information

Please read these instructions carefully before trying to install, operate, service or maintain the ZDR. The following special notes may appear throughout the user guide (or on the equipment labels) to warn of potential hazards or to call attention to information that clarifies or simplifies a procedure for users.

Symbol	Description
	The addition of either symbol to a “Danger” or “Warning” safety label indicates that an electrical hazard exists which will result in personal injury if the instructions are not followed.
	This is the safety alert symbol. It is used to alert you to potential personal injury hazards. Obey all safety messages that follow this symbol to avoid possible injury or death.

Electrical Installation

Electrical equipment should be installed, operated, serviced and maintained only by qualified personnel. No responsibility is assumed by EpiSensor for any consequences arising out of the use of this material.

A qualified person is one who has skills and knowledge related to the construction, installation, and operation of electrical equipment and has received safety training to recognize and avoid the hazards involved.

Installation, wiring, testing and service must be performed in accordance with all local and national electrical codes.

HAZARD OF ELECTRIC SHOCK, EXPLOSION, OR ARC FLASH

- NEVER work alone.
- Use appropriate personal protective equipment (PPE) and follow safe electrical work practices.
- Only qualified electrical workers should install this equipment. Such work should be performed only after reading the entire set of installation instructions.
- If the equipment is not used in a manner specified by EpiSensor, the protection provided by the equipment may be impaired.
- Before performing visual inspections, tests, or maintenance on this equipment, disconnect all sources of electric power. Assume that all circuits are live until they have been completely de-energized, tested, and tagged. Pay particular attention to the design of the power system. Consider all sources of power, including the possibility of backfeeding.
- Turn off all power supplying the meter and the equipment in which it is installed before working on it.
- Always use a properly rated voltage sensing device to confirm that all power is off.
- Before closing all covers and doors, inspect the work area for tools and objects that may have been left inside the equipment or panel.
- When removing or installing metering or other equipment, do not allow it to extend into the energised bus.
- The successful operation of this equipment depends upon proper handling,
- Neglecting fundamental installation requirements may lead to personal injury as well as damage to electrical equipment or other property.

- ➔ Before performing Dielectric (Hi-Pot) or Megger testing on any equipment in which the energy meter is installed, disconnect all input and output wires to the energy meter.
- ➔ High voltage testing may damage electronic components contained in the meter.
- ➔ Failure to follow these instructions will result in death or serious injury.

Installation & Safety Notes
➔ EpiSensor equipment should be installed, operated, serviced and maintained only by qualified personnel. EpiSensor does not assume any responsibility for any consequences arising out of the use of this equipment. ➔ Consult the ZDR datasheet and user guide for further installation and safety information. ➔ Each ZDR meter is individually calibrated and the current transformer cables should not be extended or interchanged.

Intended Use

Do not use this device for critical control or protection applications where human or equipment safety relies on the operation of the control circuit. Failure to follow these instructions can result in death, serious injury, or equipment damage.

Related Documents

Related installation and configuration documents are listed in the following table:

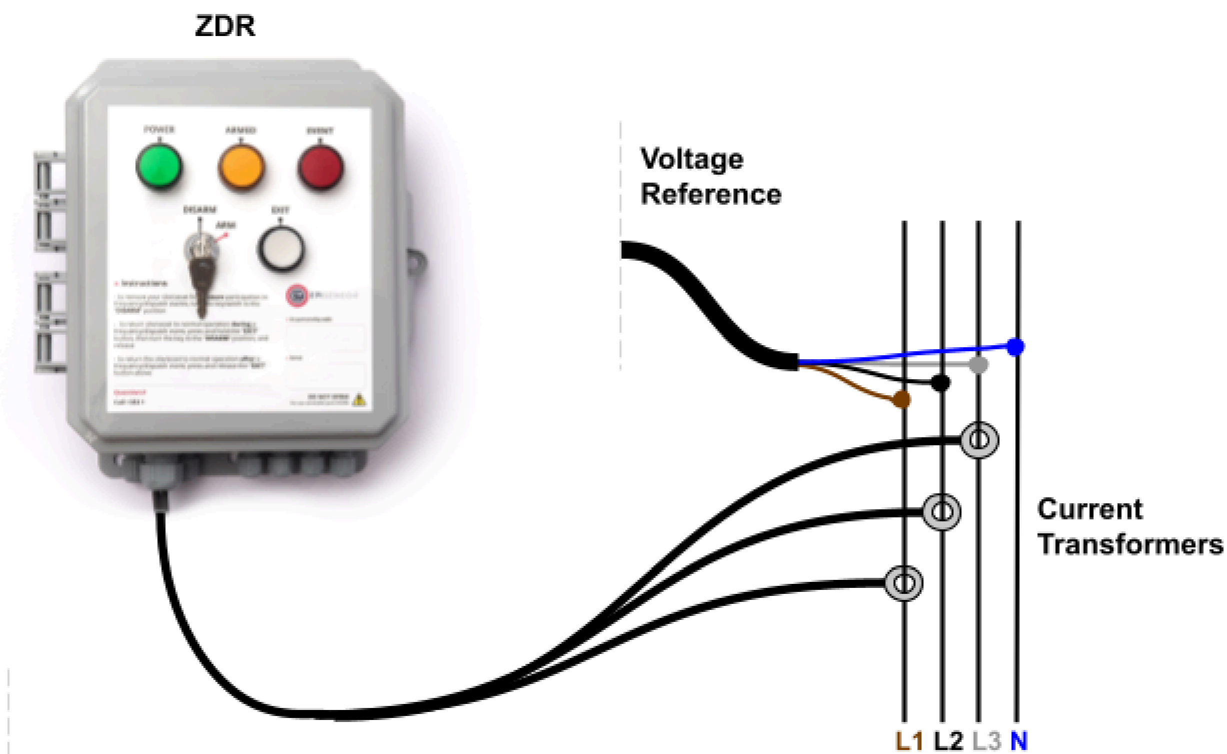
Document	Reference No.
EpiSensor ZDR Datasheet	EPI-066-00
EpiSensor ZDR User Guide	EPI-078-00

Introduction

This document describes how to use the Frequency Analysis settings to analyse and correct potential installation errors with a ZDR.

Electrical Installation

The following diagram describes how to connect the Mini CT's of the ZDR to the Phase wires for a 4 wire system.



Related Documents

Related installation and configuration documents are listed in the following table:

Document	Reference No.
Gateway User Guide	EPI-075-03
Gateway API User Guide	EPI-009-10

Supported Hardware

Frequency Analysis functionality is supported on the following EpiSensor hardware products, with node firmware versions **3.60** and higher.

EpiSensor Product	SKU
Demand Response	ZDR-16

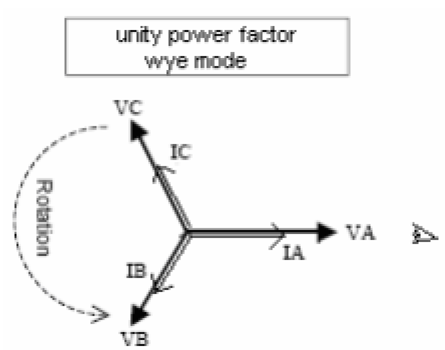
Gateway software version **V04.01.00.03** or higher is required.

Understanding phasors in wye and delta mode

This section has been adapted from the following web page

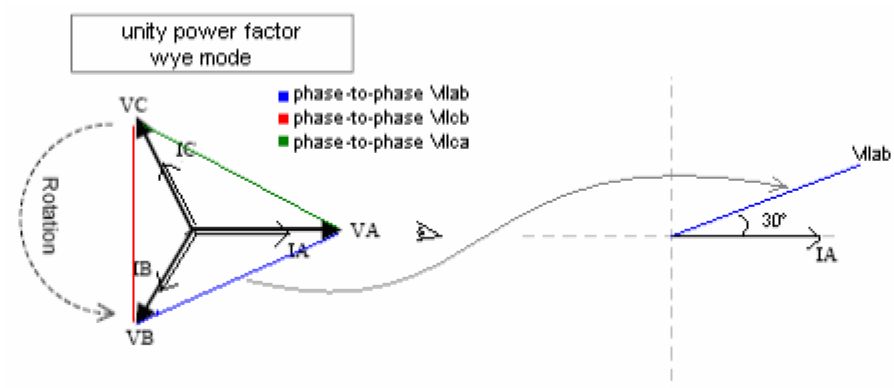
https://www.se.com/library/SCHNEIDER_ELECTRIC/SE_LOCAL/APS/205246_1676/Theory_and_instructions_on_how_to_use_the_phasor_tool.pdf

When the ZDR measures voltage on phase A, the angle used will start at zero degrees. Phase B will take on a -120° (from 0° where phase A is located) and phase C will take on a +120° angle from 0°. This corresponds to an ABC rotation where as time goes on, one will see Phase A voltage pass by the 0° point, then phase B voltage and finally phase C voltage in that order. The following figure illustrates this:



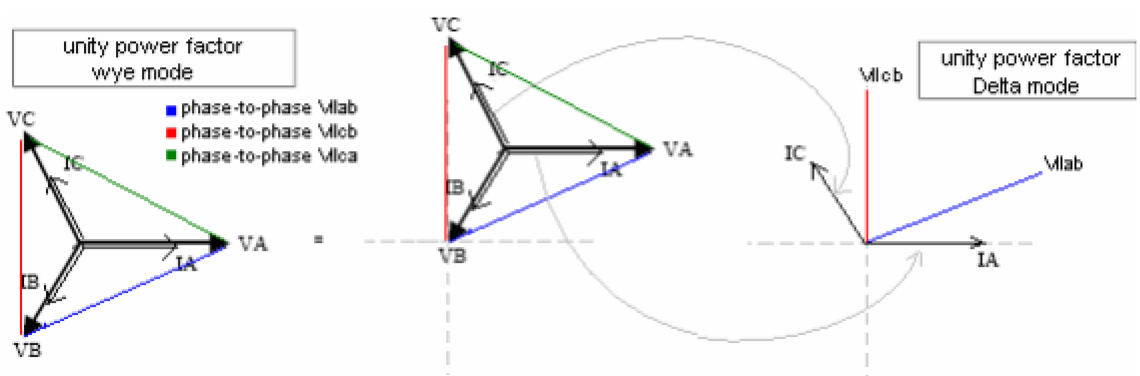
(WYE) In ABC rotation, the eye at the right side of the diagram will see phase a, b, then c in that order.

When a delta system is considered, the phase-to-phase voltages are now used and the Vllab is 30° phase shifted. This is a property of vector addition. Notice however, that Ia is still sitting at zero degrees.



Delta mode Vllab is 30° phase shifted from the Vlna counterpart

After connecting the tips of each per-phase (line-to-neutral) voltages, a new reference is made at the phase B point. Now, in the middle image of the next figure, it is clear to see how Vllab is now 30° from the zero. However, the currents do not change angle.

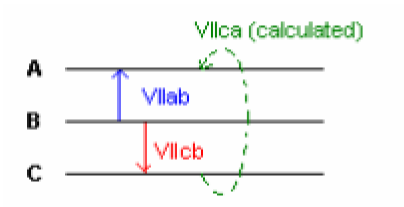


(Delta) Constructing delta phasors from a wye system.

Now, instead of have all line-to-neutral phases 120° from each other, the delta line-to-line phases are 60° from each other. Note, an inversion of Vllcb to Vllbc is required.

Question. Where are Ib and Vllca?

Answer. In delta mode, the ZDR will measure phase A in reference to phase B, hence Vllab. The meter will also measure phase C in reference to phase B, hence Vllcb. Below in the next figure one will see how the ZDR measures these phases.



(Delta) Vllab and Vllcb are measured quantities whereas Vllca is calculated using Blondel's theorem.

Question. What about Vllca?

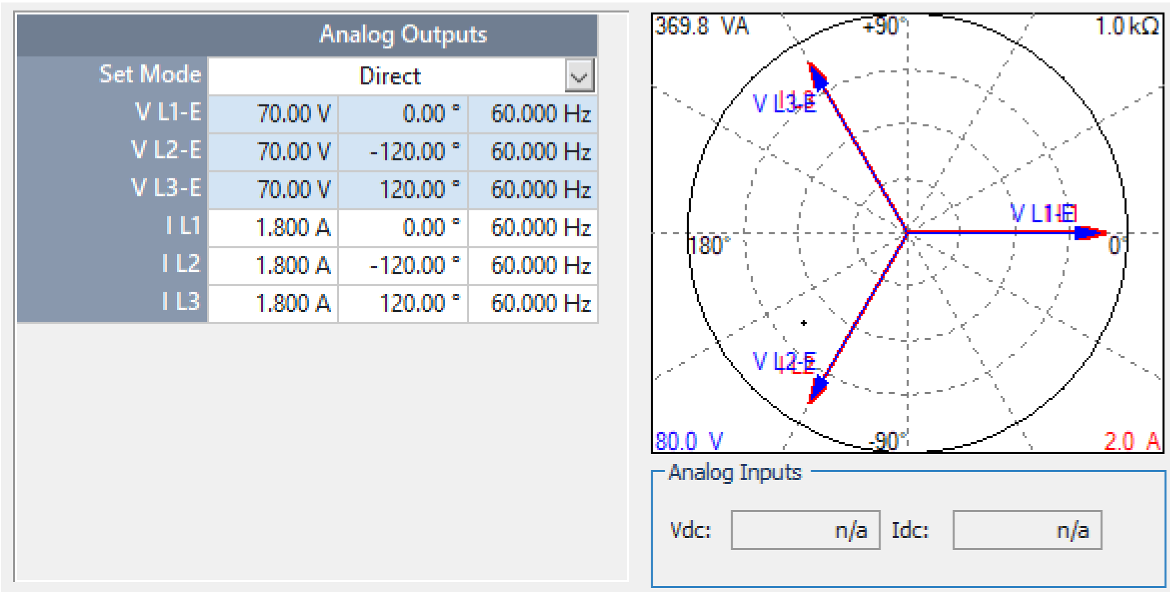
Answer. Blondel's theorem indicates that if a power system consists of n wires, then only (n-1) values are required to provide a full description of the system.

"If this[B] common point is on one of the N wires, the measurement may be made with N-1 wattmeters" (Andre E. Blondel, 1893)

Therefore, the meter measures only Phase A and C using one wattmeter for each. Phase B is the reference point. This can be seen by a typical 2-element, two wattmeter, 3-wire Delta, or simply a Delta wiring diagram.

Balanced Network Analysis on 4 Wire Wye and 3 Wire Delta

Here is a balanced network configured using an Omicron 356



Analog Outputs			
Set Mode	Direct		
V L1-E	70.00 V	0.00 °	60.000 Hz
V L2-E	70.00 V	-120.00 °	60.000 Hz
V L3-E	70.00 V	120.00 °	60.000 Hz
I L1	1.800 A	0.00 °	60.000 Hz
I L2	1.800 A	-120.00 °	60.000 Hz
I L3	1.800 A	120.00 °	60.000 Hz

4 Wire Wye

The ZDR is configured for 4 Wire Wye reporting and has a Voltage Multiplier of 100, and a Current Multiplier of 30

CT Ratio	30 : 1
VT Ratio	100 : 1
Voltage Measurement Range	60-300 VAC (L-L)
Configuration	9S/16S 4-wire Wye

The output from the ZDR Voltage, Power and Power Factor sensors is as follows …

- The current is 54Amps, which is CT Ratio multiplied by 1.8Amps from the Omicron
- The voltage is 7000V, which is the VT Ratio multiplied by 70V from the Omicron

- Active Power is within tolerances
- All three phases have Power Factor = 1

Phase A RMS Current	A	54.0	13:16:17 (
Phase B RMS Current	A	54.0	13:16:17 (
Phase C RMS Current	A	53.9	13:16:17 (
Phase A RMS Voltage	V	7015.5	13:16:17 (
Phase B RMS Voltage	V	7002.3	13:16:17 (
Phase C RMS Voltage	V	7004.3	13:16:17 (
Phase A Active Power	W	380636	13:16:17 (
Phase B Active Power	W	379561	13:16:17 (
Phase C Active Power	W	376872	13:16:17 (
Phase A Power Factor	PF	1.00	13:16:17 (
Phase B Power Factor	PF	1.00	13:16:17 (
Phase C Power Factor	PF	1.00	13:16:17 (
Total kWh	kWh	2403.0	13:00:00 (
Total Active Power	kW	1136.531	13:16:17 (
Interval Phase A kWh	kWh	0.43	13:15:00 (
Interval Phase B kWh	kWh	0.43	13:15:00 (
Interval Phase C kWh	kWh	0.42	13:15:00 (
Interval Total kWh	kWh	1.3	13:15:00 (
Line Frequency	Hertz	59.995	13:16:17 (

Further, on checking the Voltage To Current Phase Angles we get all values less than 1 degree

Phase A Voltage to Current Θ	Degrees	1.01
Phase B Voltage to Current Θ	Degrees	-0.17
Phase C Voltage to Current Θ	Degrees	0.67

Voltage to Voltage Phase Angles are all correct to within 1 degree

Phase A-C Voltage to Voltage Θ	Degrees	239.85
Phase B-C Voltage to Voltage Θ	Degrees	119.88
Phase A-B Voltage to Voltage Θ	Degrees	119.88

Current to Current Phase Angles are all correct to within 1 degree

Phase A-C Voltage to Voltage Θ	Degrees	239.85
Phase B-C Voltage to Voltage Θ	Degrees	119.88
Phase A-B Voltage to Voltage Θ	Degrees	119.88

3 Wire Delta

Rewiring the ZDR

The ZDR is rewired so the Neutral is removed. Phase B is applied as the reference voltage to the “N” connection and Phase L2 is left with no connection.

The ZDR is left in the same 4 Wire Wye configuration. The sensors report the following values;

Phase A RMS Current	A	54.0	13:27:34
Phase B RMS Current	A	54.0	13:27:34
Phase C RMS Current	A	53.9	13:27:34
Phase A RMS Voltage	V	12113.8	13:27:34
Phase B RMS Voltage	V	6412.0	13:27:34
Phase C RMS Voltage	V	12113.9	13:27:34
Phase A Active Power	W	563965	13:27:34
Phase B Active Power	W	-347303	13:27:34
Phase C Active Power	W	569879	13:27:34
Phase A Power Factor	PF	0.86	13:27:34
Phase B Power Factor	PF	-1.00	13:27:34
Phase C Power Factor	PF	0.87	13:27:34
Total kWh	kWh	2403.0	13:00:00
Total Active Power	kW	786.541	13:27:34

- The current is 54Amps, which is CT Ratio multiplied by 1.8Amps from the Omicron
- The voltage is 12100V, which is the VT Ratio multiplied by 70V multiplied by $\sqrt{3}$ from the Omicron, However Phase B Voltage is showing a strange value due to signals reaching the Electricity chip on the ZDR board through different paths.
- Active Power is within tolerances for Phase A and Phase C, but Phase B shows strange power readings.
- Total Active Power is the sum of all 3 Phase Active Powers, and is including the negative Phase B Active Power.
- Power Factors for Phases A and C are showing a 30 degree phase shift

Again, looking at the Voltage to Current phase angles we get the following

Phase A Voltage to Current Θ	Degrees	30.71
Phase B Voltage to Current Θ	Degrees	176.83
Phase C Voltage to Current Θ	Degrees	-29.11

Voltage to Voltage Phase Angles are as follows

Phase A-C Voltage to Voltage Θ	Degrees	299.83
Phase B-C Voltage to Voltage Θ	Degrees	327.00
Phase A-B Voltage to Voltage Θ	Degrees	332.74

Current to Current Phase Angles are;

Phase A-C Current to Current Θ	Degrees	239.52
Phase B-C Current to Current Θ	Degrees	120.64
Phase A-B Current to Current Θ	Degrees	118.79

Reconfigure the ZDR for 3 Wire Wye

The ZDR is configured for 3 Wire Wye reporting and has the same Voltage Multiplier of 100, and a Current Multiplier of 30

CT Ratio	30	: 1
VT Ratio	100	: 1
Voltage Measurement Range	60-300	VAC (L-L)
Configuration	5S/13S 3-wire Delta	

The Sensors produce the following values

Phase A RMS Current	A	54.1
Phase B RMS Current	A	54.0
Phase C RMS Current	A	53.9
Phase A RMS Voltage	V	12116.1
Phase B RMS Voltage	V	12140.5
Phase C RMS Voltage	V	12109.7
Phase A Active Power	W	564502
Phase B Active Power	W	0
Phase C Active Power	W	570416
Phase A Power Factor	PF	1.00
Phase B Power Factor	PF	0.00
Phase C Power Factor	PF	1.00
Total kWh	kWh	4481.3
Total Active Power	kW	1135.456

- The current is 54Amps, which is CT Ratio multiplied by 1.8Amps from the Omicron

- The voltage is 12100V, which is the VT Ratio multiplied by 70V multiplied by $\sqrt{3}$ from the Omicron, And Phase B Voltage is showing a correct reading for Voltage across Phases A and C.
- Active Power is within tolerances for Phase A and Phase C, and Phase B is zero
- Total Active Power is correct and is the same as 4 Wire Wye mode
- Power Factors for Phases A and C are showing a value of 1. The ZDR internally takes the 30 degree phase shift between the current and voltage into consideration when calculating this value.

Again, looking at the Voltage to Current phase angles we get the following

Phase A Voltage to Current Θ	Degrees	31.04
Phase B Voltage to Current Θ	Degrees	89.85
Phase C Voltage to Current Θ	Degrees	-29.20

Voltage to Voltage Phase Angles are as follows

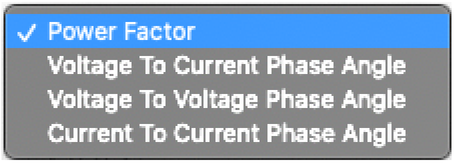
Phase A-C Voltage to Voltage Θ	Degrees	299.84
Phase B-C Voltage to Voltage Θ	Degrees	0.00
Phase A-B Voltage to Voltage Θ	Degrees	0.00

Current to Current Phase Angles are;

Phase A-C Current to Current Θ	Degrees	239.69
Phase B-C Current to Current Θ	Degrees	0.00
Phase A-B Current to Current Θ	Degrees	0.00

Frequency Analysis Property

Using this property, it is possible to reconfigure the values reported by the “Power Factor” sensors. By default these are configured to report the Power Factor on each phase. However they can be reconfigured to the following settings;



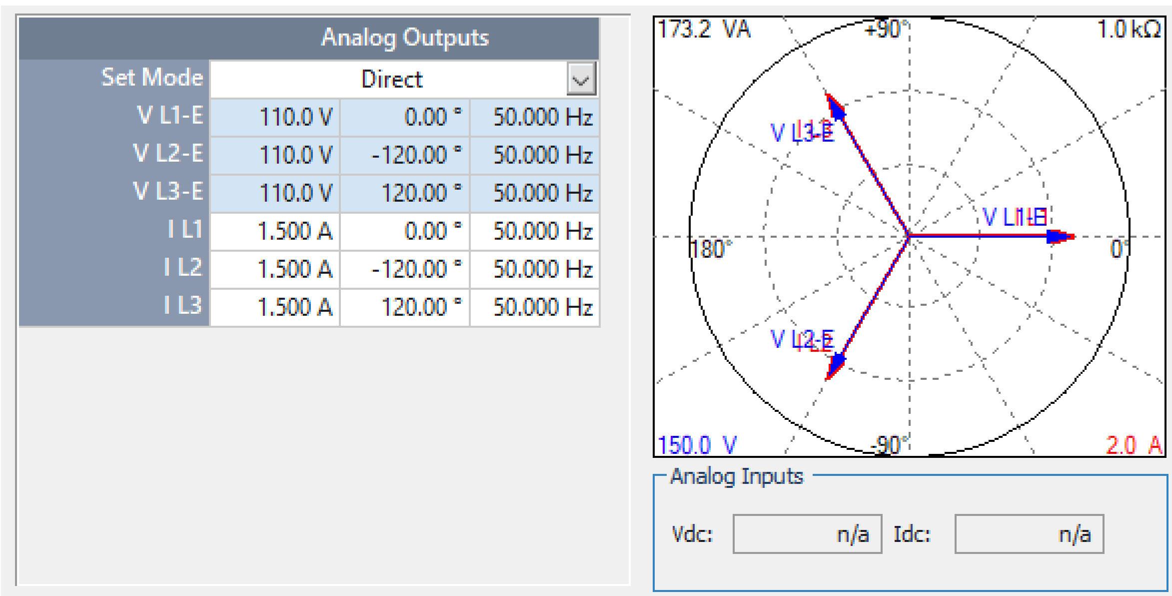
The Power Factor sensors then report the following data depending on the choice made;

	Phase A Power Factor	**Phase B Power Factor**	**Phase C Power Factor**
	Sensor ID 330	Sensor ID 331	Sensor ID 332
Power Factor	Actual Power Factor of PhaseA Voltage to Current. Should be a value between -1.00 and 1.00. The ZDR adds 30 degrees in 3 Wire Delta to give unity Power Factor in this mode	Actual Power Factor of PhaseB Voltage to Current. Should be a value between -1.00 and 1.00 Will be set to zero in 3 Wire Delta	Actual Power Factor of PhaseC Voltage to Current. Should be a value between -1.00 and 1.00 The ZDR subtracts 30 degrees in 3 Wire Delta to give unity Power Factor in this mode
Voltage To Current Phase Angle	The Delay between the Voltage and Current waveforms in Degrees. The better the Power Factor, the closer to 0 degrees this will be. Remember - 359 is almost 0 degrees.	The Delay between the Voltage and Current waveforms in Degrees. The better the Power Factor, the closer to 0 degrees this will be. Remember - 359 is almost 0 degrees.	The Delay between the Voltage and Current waveforms in Degrees. The better the Power Factor, the closer to 0 degrees this will be. Remember - 359 is almost 0 degrees.
Voltage To Voltage Phase Angle	The delay between the Phase A voltage and the Phase C voltage, *Should be 240 degrees in 4 Wire Wye, 300 degrees in 3 Wire Delta*	The delay between Phase B voltage and Phase C voltage. Should be 120 degrees in 4 Wire Wye, 0 degrees in 3 Wire Delta	The delay between Phase A voltage and Phase B voltage. Should be 120 degrees in 4 Wire Wye, 0 degrees in 3 Wire Delta
Current To Current Phase	The delay between the	The delay between Phase B	The delay between Phase A

Angle	Phase A current and the Phase C current. Should be 240 degrees	current and Phase C current. Should be 120 degrees in 4 wire wye, 0 degrees in 3 Wire Delta	current and Phase B current. Should be 120 degrees in 4 wire wye, 0 degrees in 3 Wire Delta

Ideal System

The following is a sample setup for an ideal system.



The following screenshots show the different sensor values that are reported for the different configurations;

Power Factor

Phase A Power Factor	PF	1.00	14:03:50
Phase B Power Factor	PF	1.00	14:03:50
Phase C Power Factor	PF	1.00	14:03:50

Voltage To Current Phase Angle

Phase A Voltage to Current Θ	Degrees	0.42
Phase B Voltage to Current Θ	Degrees	-0.43
Phase C Voltage to Current Θ	Degrees	0.14

Voltage To Voltage Phase Angle

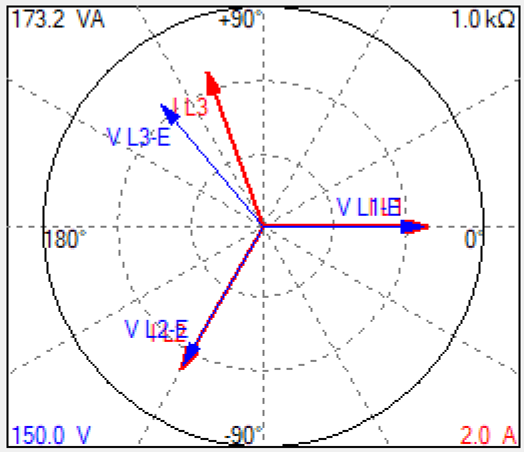
Phase A-C Voltage to Voltage Θ	Degrees	239.90
Phase B-C Voltage to Voltage Θ	Degrees	119.95
Phase A-B Voltage to Voltage Θ	Degrees	119.95

Current To Current Phase Angle

Phase A-C Current to Current Θ	Degrees	239.64
Phase B-C Current to Current Θ	Degrees	120.42
Phase A-B Current to Current Θ	Degrees	119.15

Phase C Voltage Lead by 10 degrees, Current Lag by 10 degrees

Analog Outputs			
Set Mode	Direct		
V L1-E	110.0 V	0.00 °	50.000 Hz
V L2-E	110.0 V	-120.00 °	50.000 Hz
V L3-E	110.0 V	130.00 °	50.000 Hz
I L1	1.500 A	0.00 °	50.000 Hz
I L2	1.500 A	-120.00 °	50.000 Hz
I L3	1.500 A	110.00 °	50.000 Hz



Analog Inputs

Vdc: n/a Idc: n/a

The following screenshots show the different sensor values that are reported for the different configurations;

Power Factor

Phase A Power Factor	PF	1.00	14:11:57
Phase B Power Factor	PF	1.00	14:11:57
Phase C Power Factor	PF	0.94	14:11:57

As there is a 20 degree difference between Phase C Voltage and Current, this equates to a Power Factor of 0.93969, shown here as 0.94

Voltage To Current Phase Angle

Phase A Voltage to Current Θ	Degrees	0.49
Phase B Voltage to Current Θ	Degrees	-0.43
Phase C Voltage to Current Θ	Degrees	20.25

Here you can see that the Voltage to Current Phase Angle on Phase C is 20 degrees.

Voltage To Voltage Phase Angle

Phase A-C Voltage to Voltage Θ	Degrees	229.99
Phase B-C Voltage to Voltage Θ	Degrees	109.96
Phase A-B Voltage to Voltage Θ	Degrees	119.95

Here there is a reduction of 10 degrees between Phases A and C, and Phases B and C, however Phases A and B remain at 120 degrees. So the voltage on Phase C is advanced.

Current To Current Phase Angle

Phase A-C Current to Current Θ	Degrees	249.84
Phase B-C Current to Current Θ	Degrees	130.68
Phase A-B Current to Current Θ	Degrees	119.08

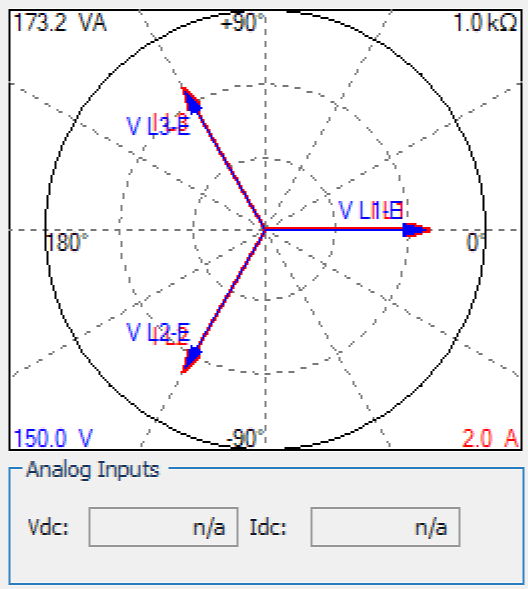
Here there is an extra 10 degrees between Phases A and C, and Phases B and C, however Phases A and B remain at 120 degrees. So the current on Phase C is delayed.

CT Direction

It is possible using the Gateway to change the orientation of the CTs on the ZDR. In normal operation, the Active Power sensors should be reading a positive value when the ZDR is monitoring a load. The following screenshot shows the A negative Active Power may be due to an inverted CT.

In the following example, the ZDR is installed incorrectly monitoring an ideal load.

Analog Outputs			
Set Mode	Direct		
V L1-E	110.0 V	0.00 °	50.000 Hz
V L2-E	110.0 V	-120.00 °	50.000 Hz
V L3-E	110.0 V	120.00 °	50.000 Hz
I L1	1.500 A	0.00 °	50.000 Hz
I L2	1.500 A	-120.00 °	50.000 Hz
I L3	1.500 A	120.00 °	50.000 Hz



However, the CT monitoring the current on Phase B has been installed in reverse. The following shows the sensor values for this situation;

Phase A RMS Current	A	1500.1	14:23:26
Phase B RMS Current	A	1500.4	14:23:26
Phase C RMS Current	A	1495.6	14:23:26
Phase A RMS Voltage	V	110.4	14:23:26
Phase B RMS Voltage	V	110.2	14:23:26
Phase C RMS Voltage	V	110.2	14:23:26
Phase A Active Power	W	165936	14:23:26
Phase B Active Power	W	-166295	14:23:26
Phase C Active Power	W	164503	14:23:26
Phase A Power Factor	PF	1.00	14:23:26
Phase B Power Factor	PF	-1.00	14:23:26
Phase C Power Factor	PF	1.00	14:23:26
Total kWh	kWh	120.5	14:15:00
Total Active Power	kW	164.503	14:23:26
Interval Phase A kWh	kWh	2.72	14:22:00
Interval Phase B kWh	kWh	-2.72	14:22:00
Interval Phase C kWh	kWh	2.70	14:22:00
Interval Total kWh	kWh	2.7	14:22:00

Analysis

Here we can see that the Phase B Active Power is negative, the Phase B Power Factor is negative and the Interval Phase B kWh is also negative. If we believe that the CT is installed in reverse, we can correct for this by changing the CT Direction property for Phase B.

Further, we can see the following Phase Values;

Voltage To Current Phase Angle

Phase A Voltage to Current Θ	Degrees	0.14
Phase B Voltage to Current Θ	Degrees	179.57
Phase C Voltage to Current Θ	Degrees	0.21

Voltage To Voltage Phase Angle

Phase A-C Voltage to Voltage Θ	Degrees	239.97
Phase B-C Voltage to Voltage Θ	Degrees	119.95
Phase A-B Voltage to Voltage Θ	Degrees	119.95

All looks fine here on the Voltage channels.

Current To Current Phase Angle

Phase A-C Current to Current Θ	Degrees	240.18
Phase B-C Current to Current Θ	Degrees	300.51
Phase A-B Current to Current Θ	Degrees	299.6

Phase A-C looks fine at 240 degrees, however Phase B-C is off by 180 degrees, And Phase A-B is also off by 180 degrees.

Correcting The CT Direction

There are 8 possible combinations for the CT Direction and all are listed in the property drop down menu.

- ✓ A Fwd, B Fwd, C Fwd
- A Fwd, B Fwd, C Rev
- A Fwd, B Rev, C Fwd
- A Fwd, B Rev, C Rev
- A Rev, B Fwd, C Fwd
- A Rev, B Fwd, C Rev
- A Rev, B Rev, C Fwd
- A Rev, B Rev, C Rev

By selecting the appropriate setting, we can invert the calculated values for Phase B. Here are the values from the Sensors following a change to force Phase B into Reverse.

Power Factor

Phase A Power Factor	PF	1.00
Phase B Power Factor	PF	1.00
Phase C Power Factor	PF	1.00

Voltage To Current Phase Angle

Phase A Voltage to Current Θ	Degrees	0.14
Phase B Voltage to Current Θ	Degrees	-0.42
Phase C Voltage to Current Θ	Degrees	0.00

Voltage To Voltage Phase Angle

Phase A-C Voltage to Voltage Θ	Degrees	239.97
Phase B-C Voltage to Voltage Θ	Degrees	119.95
Phase A-B Voltage to Voltage Θ	Degrees	119.95

Current To Current Phase Angle

Phase A-C Current to Current Θ	Degrees	239.90
Phase B-C Current to Current Θ	Degrees	120.23
Phase A-B Current to Current Θ	Degrees	119.60

Strange Sensor Value

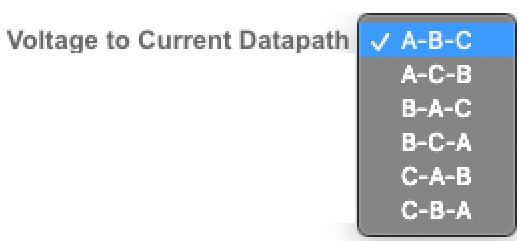
Following a reversal, the Interval value will report a large erroneous value at the next report. This is the difference between the last reported KWH value for that phase, and the new reversed value for that phase.

Interval Phase A kWh	kWh	2.72	14:36:00
Interval Phase B kWh	kWh	-19.54	14:36:00
Interval Phase C kWh	kWh	2.70	14:36:00

The Phase Total values will also start to creep from a negative value to a positive value.

Voltage to Current Datapath

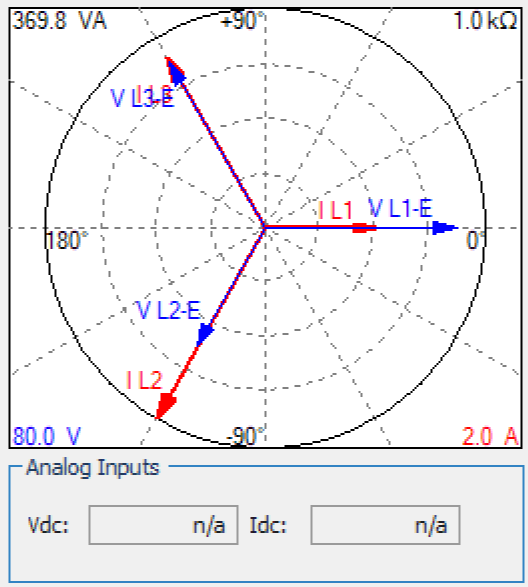
The ZDR can direct one phase voltage input to the computational datapath of another phase. For example, Phase A voltage can be introduced in the Phase B computational datapath, which means all powers computed by the ZDR in Phase B are based on Phase A voltage and Phase B current. The ZDR achieves this using the "Voltage to Current Datapath" property. The property can be configured using one of the following 8 values;



4 Wire Wye

Starting with a network where Phase A has 70V and 1Amp, and Phase B has 50V and 2 Amps.

Analog Outputs			
Set Mode	Direct		
V L1-E	70.00 V	0.00 °	60.000 Hz
V L2-E	50.00 V	-120.00 °	60.000 Hz
V L3-E	70.00 V	120.00 °	60.000 Hz
I L1	1.000 A	0.00 °	60.000 Hz
I L2	2.000 A	-120.00 °	60.000 Hz
I L3	1.800 A	120.00 °	60.000 Hz



The ZDR is configured with a CT Ratio of 10:1 and VT Ratio of 100:1

Initial analysis on the ZDR shows Phase A and B Currents and Voltages are not as expected. The power calculations for Phase A and B are also incorrect.

Phase A RMS Current	A	20.0
Phase B RMS Current	A	10.0
Phase C RMS Current	A	18.0
Phase A RMS Voltage	V	7013.8
Phase B RMS Voltage	V	5004.9
Phase C RMS Voltage	V	7001.6
Phase A Active Power	W	-72220
Phase B Active Power	W	-25268
Phase C Active Power	W	125624

On analysing the Power Factor, one can see the Power Factor on Phase A and B is not what we would expect.

Phase A Power Factor	PF	-0.51
Phase B Power Factor	PF	-0.50
Phase C Power Factor	PF	1.00

Voltage to Current analysis shows that Phase A Voltage is ahead of Phase A Current by 120 degrees, while Phase B Voltage is behind Phase B Current by 120 degrees.

Phase A Voltage to Current Θ	Degrees	120.89
Phase B Voltage to Current Θ	Degrees	-120.31
Phase C Voltage to Current Θ	Degrees	0.92

Voltage to Voltage analysis shows that all is as expected

Phase A-C Voltage to Voltage Θ	Degrees	239.85
Phase B-C Voltage to Voltage Θ	Degrees	119.88
Phase A-B Voltage to Voltage Θ	Degrees	119.88

And Current to Current Analysis shows the following

Phase A-C Current to Current Θ	Degrees	119.55
Phase B-C Current to Current Θ	Degrees	240.61
Phase A-B Current to Current Θ	Degrees	238.93

Here Phase A-C Current is 120 degrees when it should be 240, Phase B-C Current is 240 degrees when it should be 120, and Phase A-B Current is 240 when it should be 120.

Voltage to Current Analysis would indicate that Phase A and B are reversed.

THis can be corrected on the ZDR by setting the Voltage to Current Datapath to B-A-C, in effect pushing Phase A voltage into Phase B, and Phase B voltage into Phase A.

Voltage to Current Datapath B-A-C

Once this change is made, the following sensor values are reported from the ZDR;

Phase A RMS Current	A	20.0
Phase B RMS Current	A	10.0
Phase C RMS Current	A	18.0
Phase A RMS Voltage	V	5012.7
Phase B RMS Voltage	V	7009.2
Phase C RMS Voltage	V	7000.6
Phase A Active Power	W	99639
Phase B Active Power	W	70070
Phase C Active Power	W	125624

One can now see that the Phase A Voltage has swapped with Phase B. It's as though we have swapped the phase voltage wires for Phase A and B. Calculations in the ZDR beyond this change should remain the same and the Active Power calculations are as expected. The only thing to remember is that values appearing on Phase B are actually for Phase A and vice-versa.

Power Factors are correct

Phase A Power Factor	PF	1.00
Phase B Power Factor	PF	1.00
Phase C Power Factor	PF	1.00

Voltage to Current Phase Angles are correct

Phase A Voltage to Current Θ	Degrees	0.75
Phase B Voltage to Current Θ	Degrees	-0.34
Phase C Voltage to Current Θ	Degrees	0.84

Voltage to Voltage Phase Angles which were correct in the earlier analysis, are now showing that Phase A and B are swapped

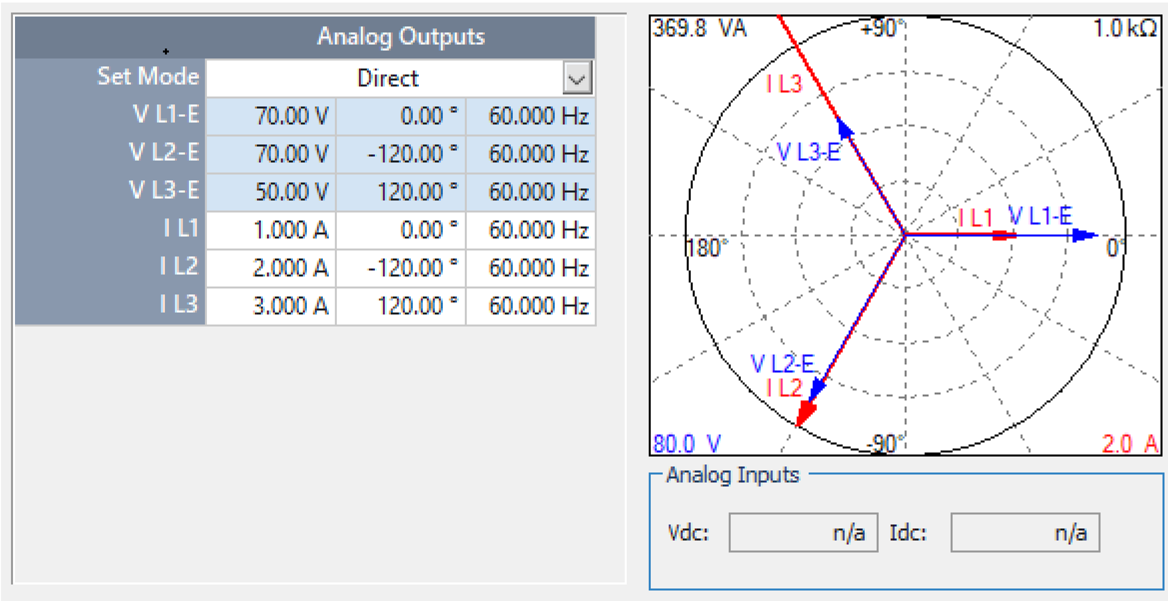
Phase A-C Voltage to Voltage Θ	Degrees	119.88
Phase B-C Voltage to Voltage Θ	Degrees	239.85
Phase A-B Voltage to Voltage Θ	Degrees	239.94

And finally Current to Current Phase Angles remain incorrect as they were previously, since we have done nothing with the CTs and there's no way to correct them in software.

Phase A-C Current to Current Θ	Degrees	119.71
Phase B-C Current to Current Θ	Degrees	240.70
Phase A-B Current to Current Θ	Degrees	239.18

3 Wire Delta

Starting with a network where Phase A has 70V and 1Amp, and Phase B has 70V and 2 Amps and Phase C has 50V and 3 Amps.



Analog Outputs			
Set Mode	Direct		
V L1-E	70.00 V	0.00 °	60.000 Hz
V L2-E	70.00 V	-120.00 °	60.000 Hz
V L3-E	50.00 V	120.00 °	60.000 Hz
I L1	1.000 A	0.00 °	60.000 Hz
I L2	2.000 A	-120.00 °	60.000 Hz
I L3	3.000 A	120.00 °	60.000 Hz

The ZDR is configured with a CT Ratio of 10:1 and VT Ratio of 100:1

Initial analysis on the ZDR shows Phase A and C Currents and Voltages are not as expected. While we input 70V to Phase A and B, it’s actually V A-B that is calculated in the ZDR. And we input 50V to Phase C, It's actually V C-B that is calculated in the ZDR. One can see then that the Current and Voltage values are actually correct. However, the power calculations for Phase A and C are incorrect.

Phase A RMS Current	A	30.0
Phase B RMS Current	A	20.0
Phase C RMS Current	A	10.0
Phase A RMS Voltage	V	12116.7
Phase B RMS Voltage	V	10455.8
Phase C RMS Voltage	V	10427.6
Phase A Active Power	W	6272
Phase B Active Power	W	0
Phase C Active Power	W	8422

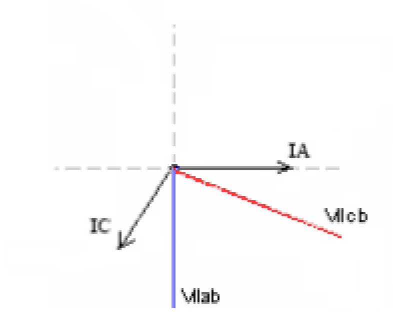
On analysing the Power Factor, one can see the Power Factor on Phase A and C is not what we would expect.

Phase A Power Factor	PF	-0.49
Phase B Power Factor	PF	0.00
Phase C Power Factor	PF	-0.43

Voltage to Current analysis shows that Phase A Voltage is behind Phase A Current by 90 degrees, and Phase C Voltage is ahead of Phase C Current by 90 degrees.

Phase A Voltage to Current Θ	Degrees	-89.18
Phase B Voltage to Current Θ	Degrees	95.50
Phase C Voltage to Current Θ	Degrees	85.54

Here is the Phasor Diagram for such a system starting with IA on the horizontal.



This would indicate that either the Voltages or Currents are backwards. Further inspection of the diagram shows that if all phasors are rotated forward by 120degreees, so IC is in the IA position, that VIlab and VIlac move to their correct positions and IA moves to where IC should be. THerefore we can conclude that the CTs are reversed.

Voltage to Voltage analysis shows that all is as expected

Phase A-C Voltage to Voltage Θ	Degrees	305.32
Phase B-C Voltage to Voltage Θ	Degrees	0.00
Phase A-B Voltage to Voltage Θ	Degrees	0.00

And Current to Current Analysis shows the following

Phase A-C Current to Current Θ	Degrees	119.80
Phase B-C Current to Current Θ	Degrees	0.00
Phase A-B Current to Current Θ	Degrees	0.00

Here Phase A-C Current is 120 degrees when it should be 240, and Voltage to Current Analysis would indicate that Phase A and B are reversed.

THis can be corrected on the ZDR by setting the Voltage to Current Datapath to C-B-A, in effect pushing Phase A voltage into Phase C, and Phase C voltage into Phase A.

Voltage to Current Datapath	C-B-A

Once this change is made, the following sensor values are reported from the ZDR;

Phase A RMS Current	A	30.1
Phase B RMS Current	A	20.0
Phase C RMS Current	A	10.0
Phase A RMS Voltage	V	10392.1
Phase B RMS Voltage	V	10467.0
Phase C RMS Voltage	V	12153.8
Phase A Active Power	W	258416
Phase B Active Power	W	0
Phase C Active Power	W	104477

One can now see that the Phase A Voltage has swapped with Phase C. It's as though we have swapped the phase voltage wires for Phase A and B. Calculations in the ZDR beyond this change should remain the same for a Delta load. The only thing to remember is that values appearing on Phase C are actually for Phase A and vice-versa.

Total Active Power is correct as though the original load were being calculated.

(70 x 10) + (70 x 20) + (50 x 30) = 360

Total Active Power	kW	362.893

Power Factors are correct

Phase A Power Factor	PF	1.00
Phase B Power Factor	PF	0.00
Phase C Power Factor	PF	1.00

Voltage to Current Phase Angles are correct

Phase A Voltage to Current Θ	Degrees	-34.44
Phase B Voltage to Current Θ	Degrees	-84.06
Phase C Voltage to Current Θ	Degrees	30.46

Voltage to Voltage Phase Angles which were correct in the earlier analysis, are now showing that Phase A and B are swapped

Phase A-C Voltage to Voltage Θ	Degrees	54.50
Phase B-C Voltage to Voltage Θ	Degrees	0.00
Phase A-B Voltage to Voltage Θ	Degrees	0.00

And finally Current to Current Phase Angles remain incorrect as they were previously, since we have done nothing with the CTs and there's no way to correct them in software.

Phase A-C Current to Current Θ	Degrees	119.46
Phase B-C Current to Current Θ	Degrees	0.00
Phase A-B Current to Current Θ	Degrees	0.00

CT Angle and VT Angle

Two separate properties are given for CT and VT Phase Angles. These can be used when a given primary CT or VT introduces a known phase shift and each can be input independently. The value is in minutes and there are 60 minutes in one degree of phase angle.

Internally, the ZDR combines these two separate phase angles into a combined phase error using the following formula;

Phase Error = VT Angle - CT Angle

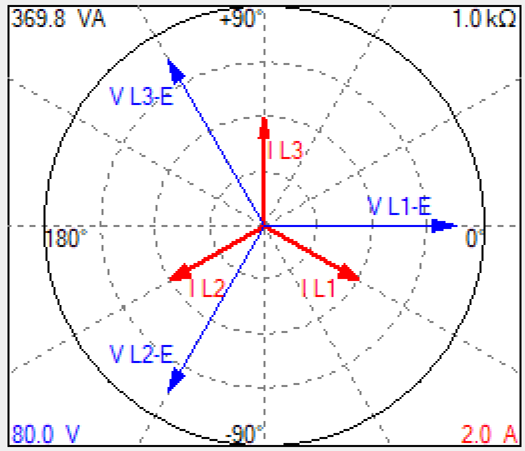
The Phase Error adjusts the following calculations taking this Phase Error into consideration;

- All Watt Hour accumulators (kWh)
- All Power Calculations (W)
- All Power Factor Calculations (PF)
- All Voltage to Current Phase Angles (Degrees)

It does not make any adjustments to the Voltage to Voltage Phase Angles nor the Current To Current Phase Angles.

For this Analysis, the Omicron CMC356 will be configured with a Phase Error on the current of 30 degrees.

Analog Outputs			
Set Mode	Direct		
V L1-E	70.00 V	0.00 °	50.000 Hz
V L2-E	70.00 V	-120.00 °	50.000 Hz
V L3-E	70.00 V	120.00 °	50.000 Hz
I L1	1.000 A	-30.00 °	50.000 Hz
I L2	1.000 A	-150.00 °	50.000 Hz
I L3	1.000 A	90.00 °	50.000 Hz



Analog Inputs

Vdc: n/a Idc: n/a

The ZDR is configured as follows;

Frequency Analysis	Power Factor
CT Direction	A Fwd, B Fwd, C Fwd
Voltage to Current Datapath	A-B-C
CT Phase Angle	0 minutes
VT Phase Angle	0 minutes
CT Ratio	30 : 1
VT Ratio	100 : 1

4 Wire Wye

The given system is connected to the ZDR-16 in 4 wire wye mode and allowed to settle. The following readings are taken from the ZDR sensors;

Phase A RMS Current	A	30.0
Phase B RMS Current	A	30.0
Phase C RMS Current	A	29.9
Phase A RMS Voltage	V	7016.6
Phase B RMS Voltage	V	7001.8
Phase C RMS Voltage	V	7004.4
Phase A Active Power	W	182253
Phase B Active Power	W	183329
Phase C Active Power	W	180640
Phase A Power Factor	PF	0.86
Phase B Power Factor	PF	0.87
Phase C Power Factor	PF	0.86

It can be seen that the Active Power is lower than would be expected and the Power Factor is indicating a Phase Error.

The Voltage To Current sensors show the current is lagging the voltage by 30 degrees;

Phase A Voltage to Current Θ	Degrees	30.79
Phase B Voltage to Current Θ	Degrees	29.95
Phase C Voltage to Current Θ	Degrees	30.71

Voltage to Voltage values are as expected

Phase A-C Voltage to Voltage Θ	Degrees	240.00
Phase B-C Voltage to Voltage Θ	Degrees	119.91
Phase A-B Voltage to Voltage Θ	Degrees	120.00

Current to Current values are as expected;

Phase A-C Current to Current Θ	Degrees	240.53
Phase B-C Current to Current Θ	Degrees	120.89
Phase A-B Current to Current Θ	Degrees	118.56

The ZDR is reconfigured to adjust for the 30 degree delay between the Voltage and Current by setting the CT Phase Angle to 1800 (30 degrees x 60 = 1800 minutes).

CT Phase Angle 1800 minutes

The same readings are taken again.

Phase A RMS Current	A	30.1
Phase B RMS Current	A	30.0
Phase C RMS Current	A	29.9
Phase A RMS Voltage	V	7015.5
Phase B RMS Voltage	V	7002.1
Phase C RMS Voltage	V	7003.5
Phase A Active Power	W	211069
Phase B Active Power	W	211690
Phase C Active Power	W	208586
Phase A Power Factor	PF	1.00
Phase B Power Factor	PF	1.00
Phase C Power Factor	PF	1.00

The Current and Voltage values remain the same, while the Power and Power Factors have been corrected towards an ideal system.

Voltage to Current Phase Angle has reduced to almost zero;

Phase A Voltage to Current Θ	Degrees	0.87
Phase B Voltage to Current Θ	Degrees	-0.04
Phase C Voltage to Current Θ	Degrees	0.71

Voltage to Voltage Phase Angles have not changed;

Phase A Voltage to Current Θ	Degrees	239.85
Phase B Voltage to Current Θ	Degrees	119.88
Phase C Voltage to Current Θ	Degrees	119.88

Current to Current Phase Angle remains the same;

Phase A-C Current to Current Θ	Degrees	240.02
Phase B-C Current to Current Θ	Degrees	120.56
Phase A-B Current to Current Θ	Degrees	119.04

3 Wire Delta

The same system is rewired to the ZDR as a 3 wire delta system and the ZDR is reconfigured to its default state.

Frequency Analysis	Power Factor
CT Direction	A Fwd, B Fwd, C Fwd
Voltage to Current Datapath	A-B-C
CT Phase Angle	0 minutes
VT Phase Angle	0 minutes
CT Ratio	30 : 1
VT Ratio	100 : 1

The ZDR is next configured to monitor the 3 wire delta system;

Configuration	5S/13S 3-wire Delta

The following readings are taken from the system;

Phase A RMS Current	A	30.1
Phase B RMS Current	A	30.0
Phase C RMS Current	A	29.9
Phase A RMS Voltage	V	12113.5
Phase B RMS Voltage	V	12136.9
Phase C RMS Voltage	V	12114.8
Phase A Active Power	W	182253
Phase B Active Power	W	0
Phase C Active Power	W	361819
Phase A Power Factor	PF	0.87
Phase B Power Factor	PF	0.00
Phase C Power Factor	PF	0.86

Here we can see the Power Factor on Phase A and C is reduced to 0.87 indicating a potential 30 degree phase shift on those phases. Note also that the Active Power is incorrect, and different for Phase A and Phase C. This is because in Delta mode the powers need to consider the 3 Wire Delta phase Angle of 30 degrees.

$$W_1 = V_L I_L \cos(30^\circ - \varphi)$$

$$W_2 = V_L I_L \cos(30^\circ + \varphi)$$

In this example, our Phase Angle is 30 degrees so while one phase almost seems correct, the second phase appears worse.

The KWH sensors are also off by this same degree. In one minute the following are the Interval KWH sensors for this system;

Interval Phase A kWh	kWh	3.03
Interval Phase B kWh	kWh	0.00
Interval Phase C kWh	kWh	6.03
Interval Total kWh	kWh	9.0

Analysing the Voltage to Current Phase Angles shows Phase A to be at 60 degrees when we would expect 30, and Phase C is at 0 degrees when we'd expect -30

Phase A Voltage to Current Θ	Degrees	60.74
Phase B Voltage to Current Θ	Degrees	119.80
Phase C Voltage to Current Θ	Degrees	0.75

Voltage to Voltage Phase Angles are correct;

Phase A-C Voltage to Voltage Θ	Degrees	299.76
Phase B-C Voltage to Voltage Θ	Degrees	0.00
Phase A-B Voltage to Voltage Θ	Degrees	0.00

Current to Current Phase Angles are correct;

Phase A-C Current to Current Θ	Degrees	240.02
Phase B-C Current to Current Θ	Degrees	0.00
Phase A-B Current to Current Θ	Degrees	0.00

On reconfiguring the ZDR to account for the 30 degree phase error we get the following sensor readings;

Phase A RMS Current	A	30.1
Phase B RMS Current	A	30.0
Phase C RMS Current	A	29.9
Phase A RMS Voltage	V	12111.5
Phase B RMS Voltage	V	12140.3
Phase C RMS Voltage	V	12111.5
Phase A Active Power	W	210448
Phase B Active Power	W	0
Phase C Active Power	W	417793
Phase A Power Factor	PF	1.00
Phase B Power Factor	PF	0.00
Phase C Power Factor	PF	1.00

One can see the Power Factor now appears correct. But the Active Power is still not correct. Again this is due to the way the watt values are calculated in the ZDR using the 2 wattmeter method. However it is worth noting that while the Active Power and KWH sensors appear to be incorrect, the totalized values for the meter are in fact correct. Here are the values for 1 minute;

Interval Phase A kWh	kWh	3.50
Interval Phase B kWh	kWh	0.00
Interval Phase C kWh	kWh	6.97
Interval Total kWh	kWh	10.4

Voltage to Current Phase Angles are correct;

Phase A Voltage to Current Θ	Degrees	30.67
Phase B Voltage to Current Θ	Degrees	90.33
Phase C Voltage to Current Θ	Degrees	-29.32

Voltage to Voltage Phase Angles are correct;

Phase A-C Voltage to Voltage Θ	Degrees	299.76
Phase B-C Voltage to Voltage Θ	Degrees	0.00
Phase A-B Voltage to Voltage Θ	Degrees	0.00

Current to Current Phase Angles are correct;

Phase A-C Current to Current Θ	Degrees	239.85
Phase B-C Current to Current Θ	Degrees	0.00
Phase A-B Current to Current Θ	Degrees	0.00