

Meter Testing Concepts

Integrated Site Testing



**Southwest Electrical
Metering Association**



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Why do we test a site?

- To protect OUR revenue stream.
- To ensure we fairly bill the customer.
- To assure site is wired safely and to codes.
- To meet PSC mandated requirements



What do we need to know to succeed?

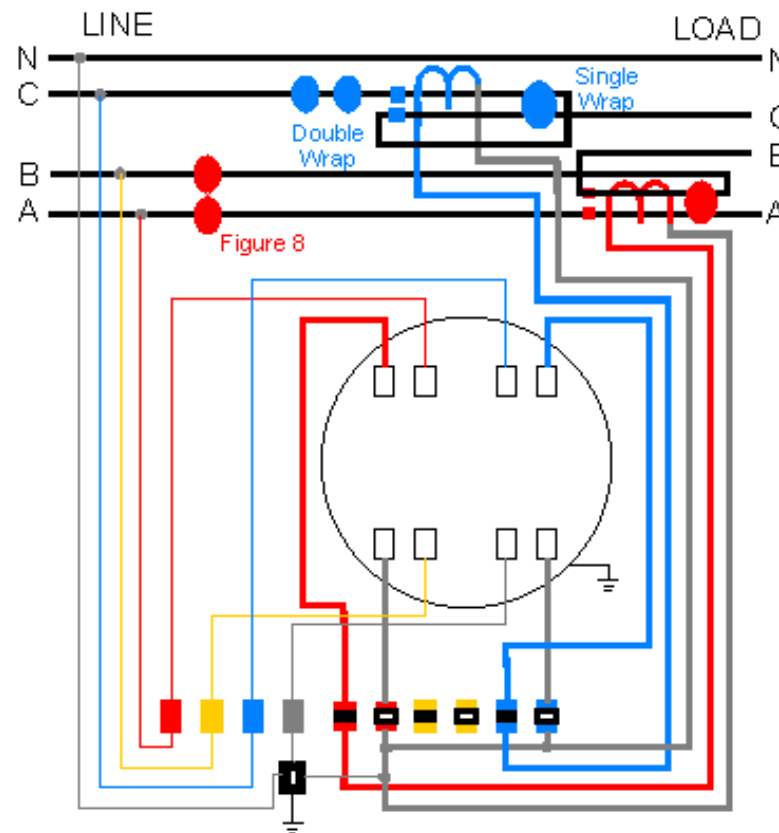
- What service type site we are testing?
- What form meter we are using?
 - What is the Kt?
- Do we have CTs?
 - What is the ratio?
 - Burden class?
- Do we have PTs?
 - What is the ratio?
 - Burden class?



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What is the Service Type?

- To understand a vector diagram we must understand the service type.
- Service type is defined by:
 - The transformer configuration: 4-Wire Wye, 3-Wire Delta, etc
 - The form of meter: 5S, 8S, 9S, etc.
 - The configuration of CTs & PTs
 - The wiring



4-Wire Wye, Form 5, 2 CT, No PT, Wired Z-Coil

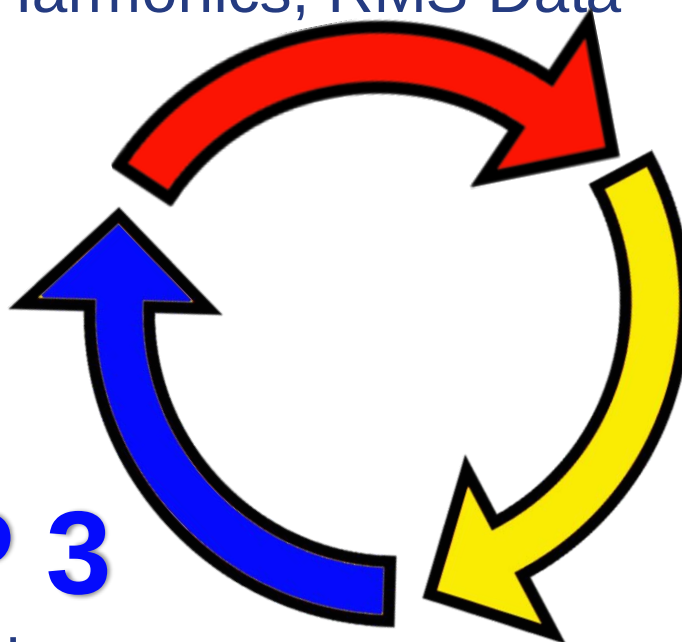


INTEGRATED SITE TEST PHILOSOPHY

STEP 1

Site Analysis:

Vectors, Waveforms, Harmonics, RMS Data



STEP 3

Meter Testing:

Customer Load & Phantom Load

STEP 2

CT & PT Testing



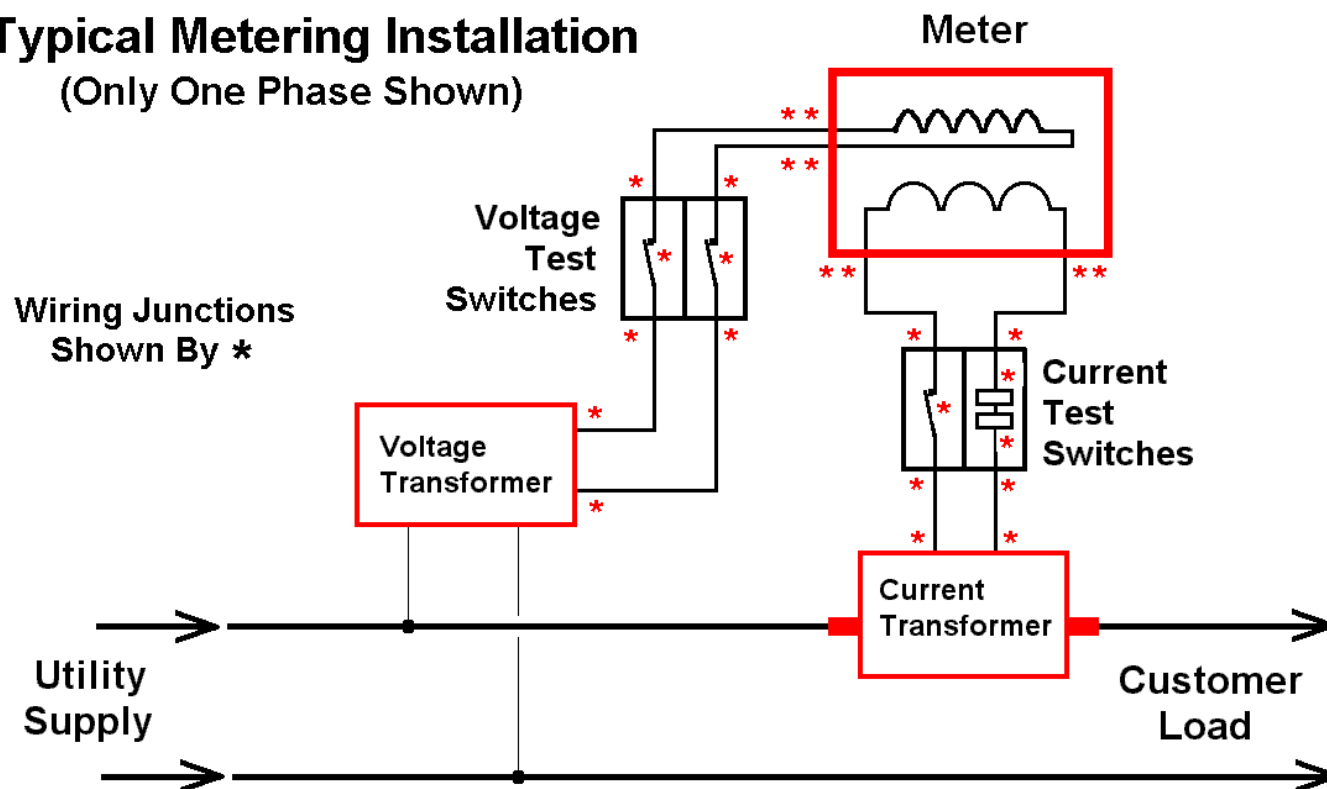


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Consider a Typical Metering Installation

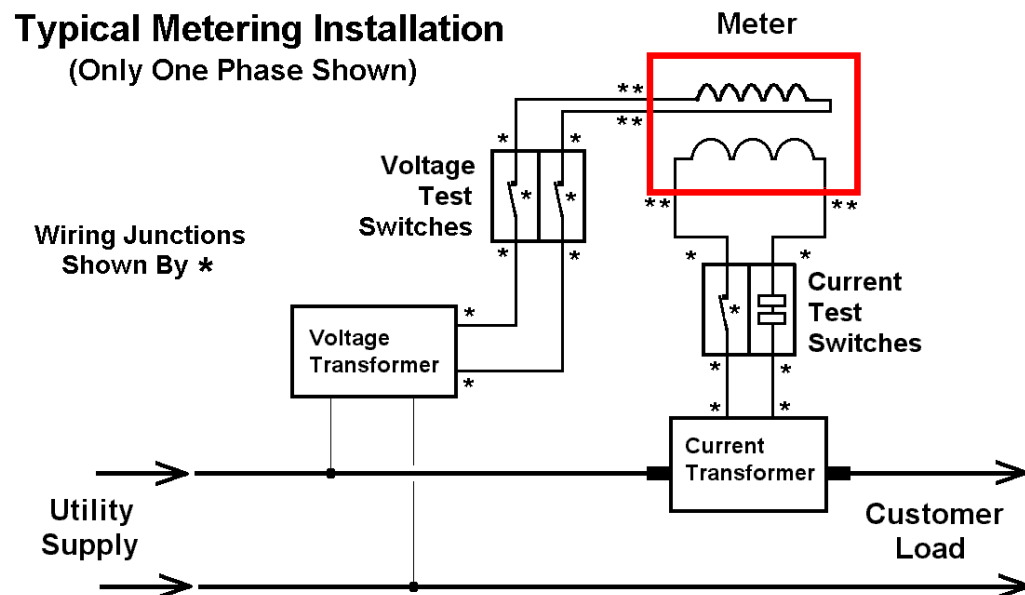
A complex system with many opportunities for error.

Typical Metering Installation (Only One Phase Shown)



YET - Traditionally Only The Meter Is Tested

... But the meter measures only what reaches its terminals



How do we know that the signals
are correct?



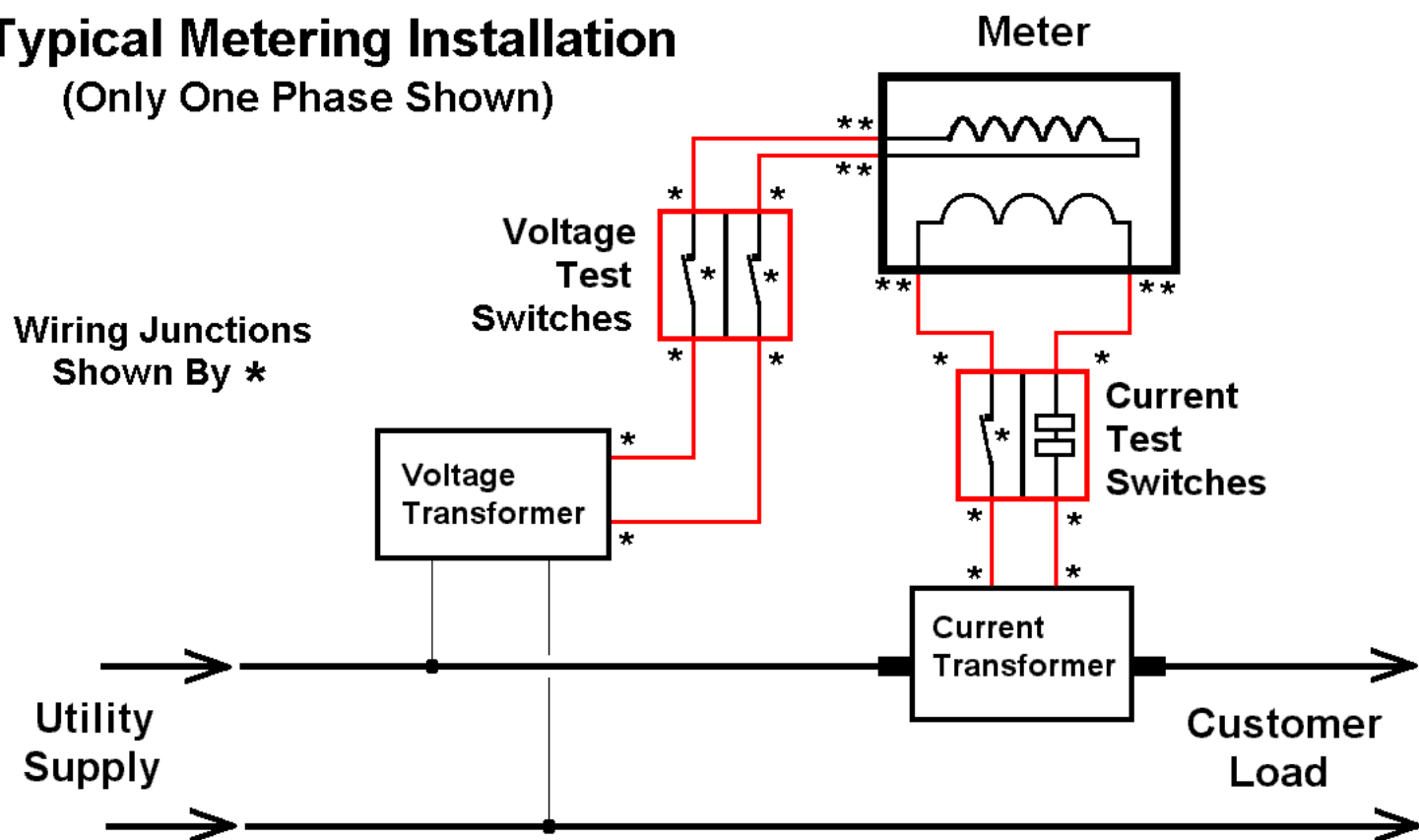
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Wiring And Junctions Connect The Meter

... What If There Are Wiring Errors Or Poor Connections
Poor Junctions Will Over-Burden The CTs And Reduce Revenue

Typical Metering Installation

(Only One Phase Shown)





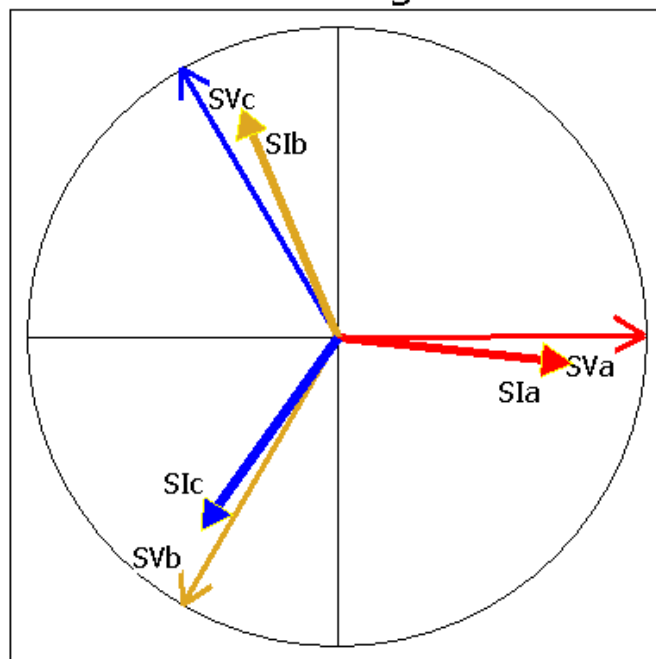
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The Vector Diagram

Your best site analysis tool

Vector Graph BETA TEST - p24.11M/v20.19M/c#225.06K - Selected Site: *NONE*

Vector Diagram



Φ SVaSIa

SVa	118.611	0.00°
SIa	2.488	6.30°
PF =	0.994	6.30°
Lag		

Φ SVbSIb

SVb	119.436	119.80°
SIb	2.602	247.29°
PF =	0.609	127.49°
Lag		

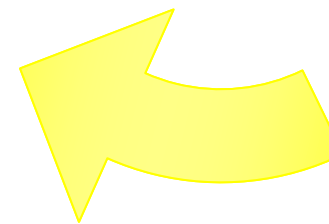
Φ SVcSIc

SVc	119.715	239.87°
SIc	2.469	124.83°
PF =	0.423	-115.04°
Lead		

SYS

Vsys =	119.254
Isys =	2.520
PF =	0.675
ROT =	ABC

Site Analysis



Measurement: Live Test, Sec V/Sec I, Instantaneous

Reference

Show Wiring

Interval

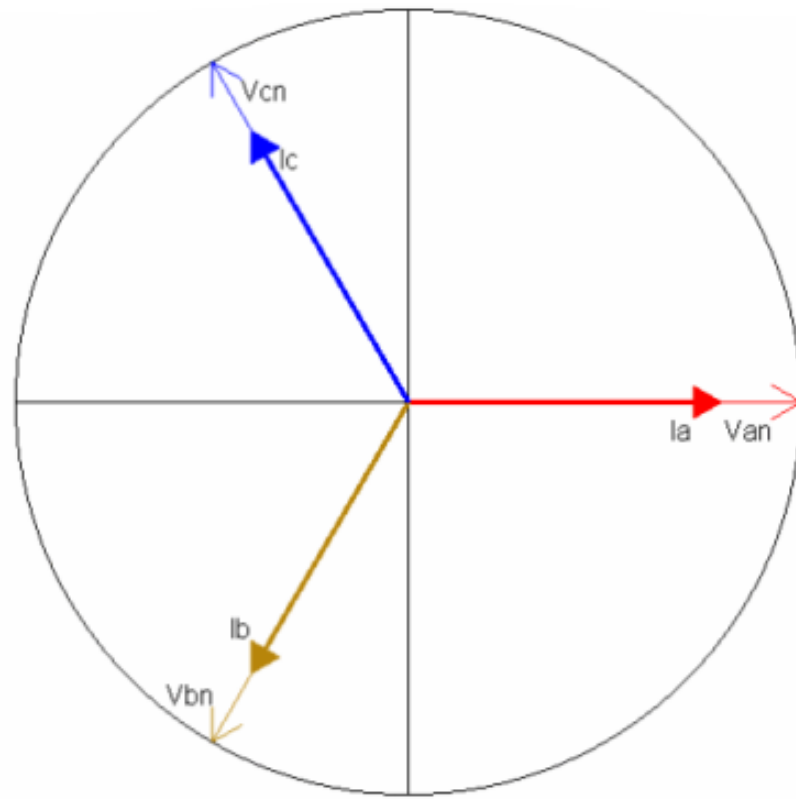
Sec V/Pri I

Stop

Vector Diagrams are a Powerful Tool

They show everything you need

- Voltage Amplitude
 - Voltage Phases
 - Current Amplitudes
 - Current Phases
 - Relationship of Voltage to Current
-
- If we know what we should see
 - We can detect many problems

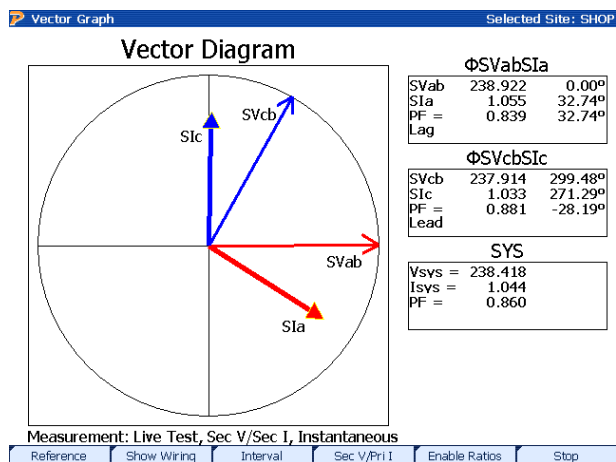




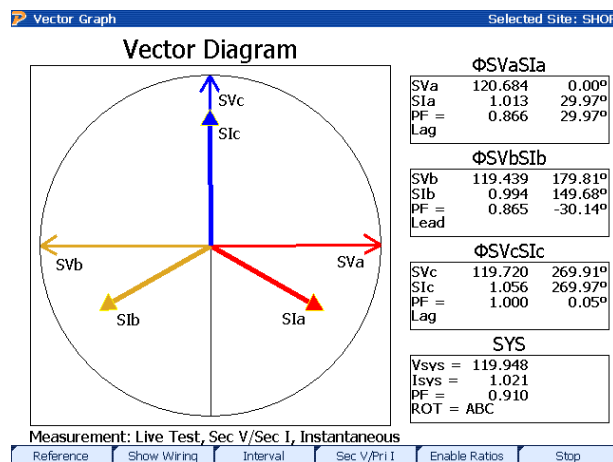
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What should the vector diagram look like?

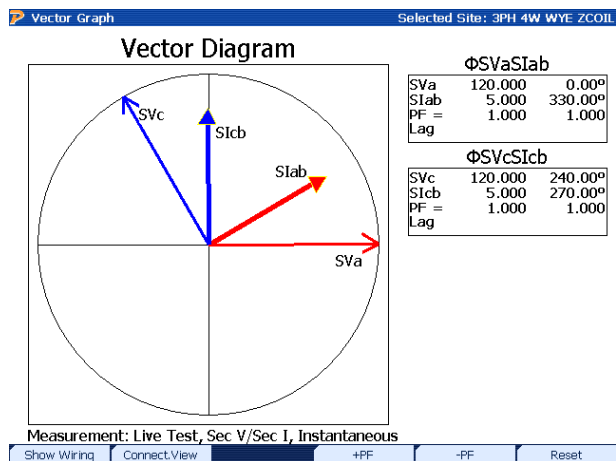
3-Wire Delta Form 5S 2CT 2V



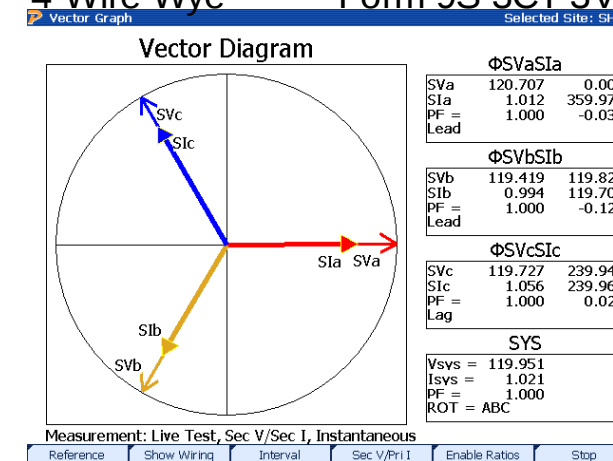
4-Wire Delta Form 9S 3CT 3V



4-Wire Wye Form 6S 3CT 2V



4-Wire Wye Form 9S 3CT 3V



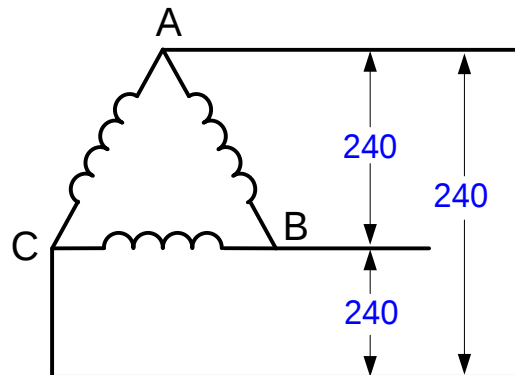
Connect View



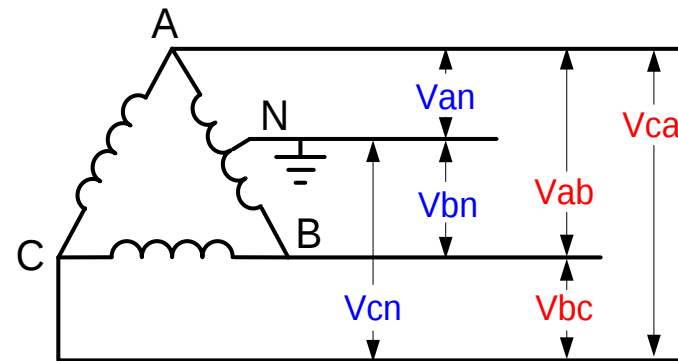
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Services are Generally Simple

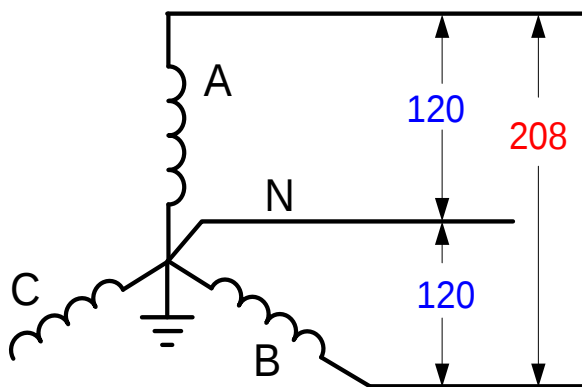
3-Wire Delta



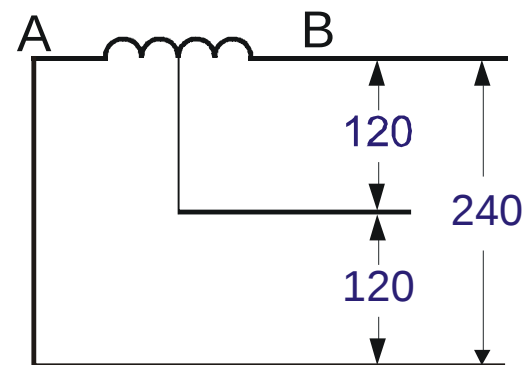
4-Wire Delta



4-Wire Wye



Single Phase



Our metering choices make them complex.

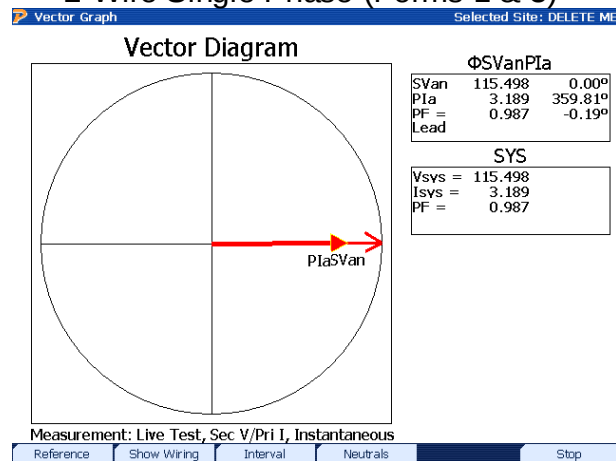


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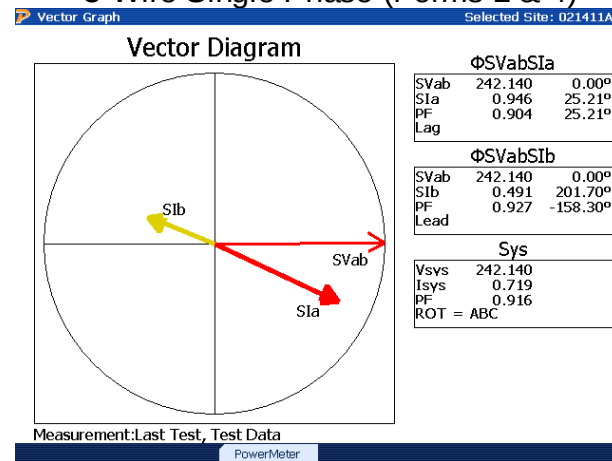
Vector Diagrams Can be Confusing

But they show everything you need

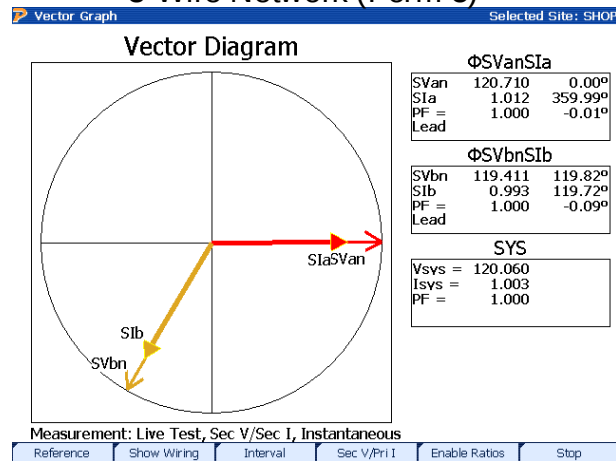
2-Wire Single Phase (Forms 1 & 3)



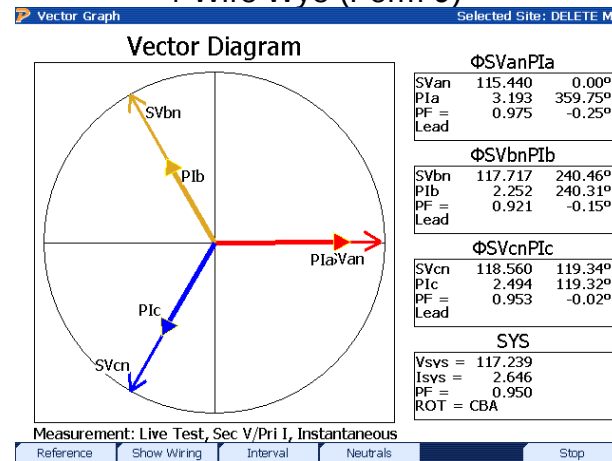
3-Wire Single Phase (Forms 2 & 4)



3-Wire Network (Form 5)



4-Wire Wye (Form 9)



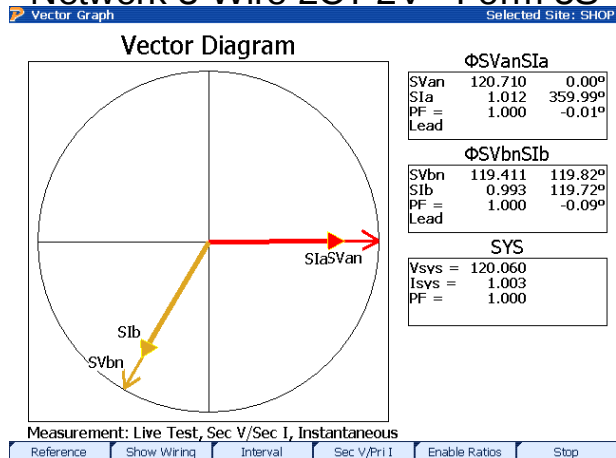


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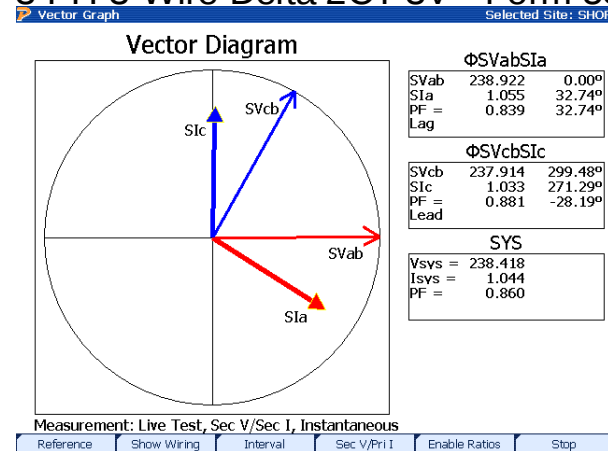
Vector Diagrams Tell You Everything

One Meter Form – Many Diagrams

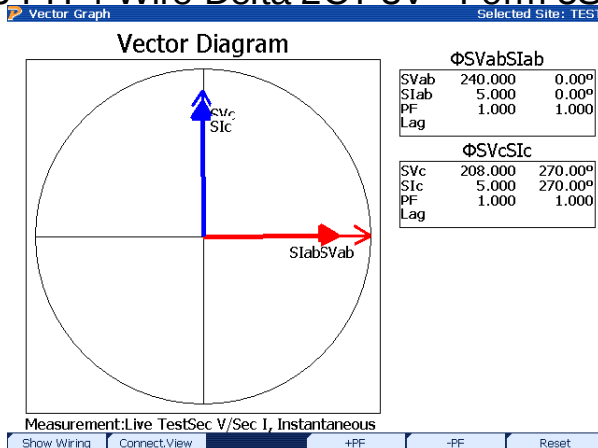
Network 3-Wire 2CT 2V - Form 5S



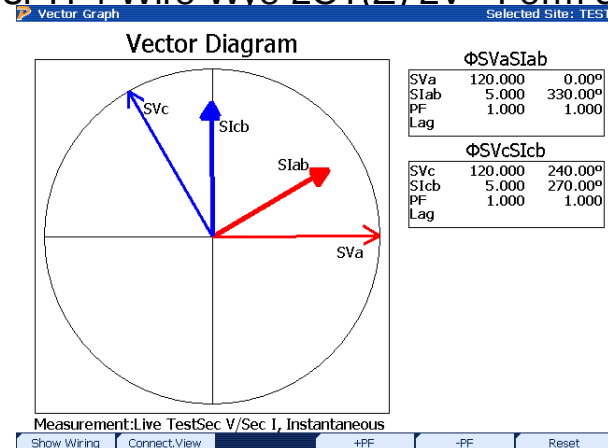
3 PH 3-Wire Delta 2CT 3V - Form 5S



3 PH 4-Wire Delta 2CT 3V - Form 5S



3PH 4-Wire Wye 2CT(Z) 2V - Form 5S



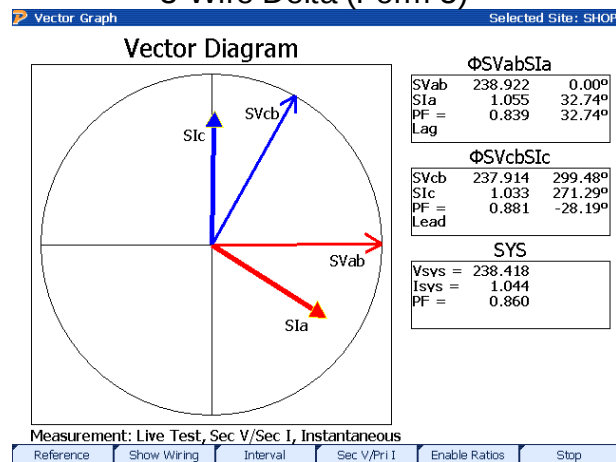


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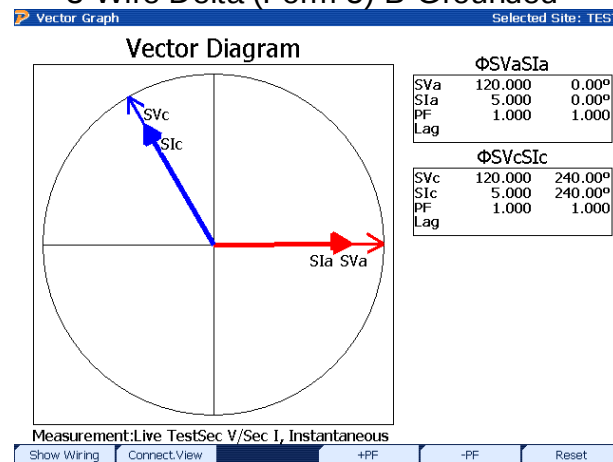
Vector Diagrams are a Powerful Tool

They show everything you need

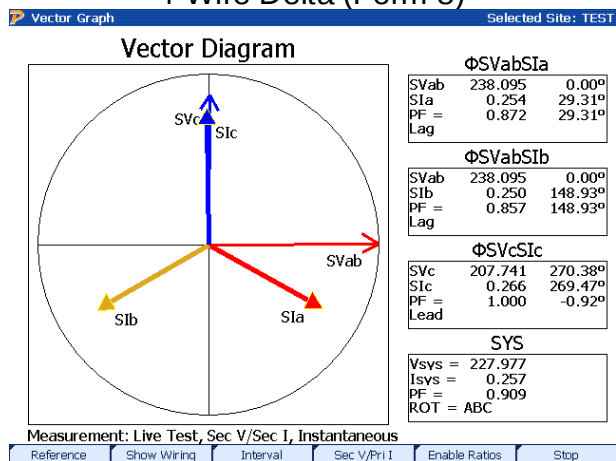
3-Wire Delta (Form 5)



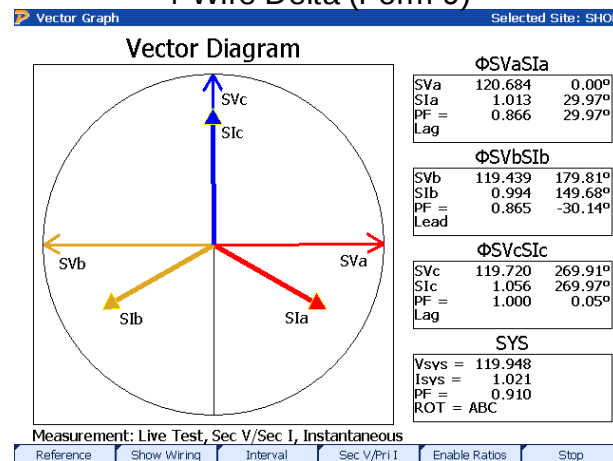
3-Wire Delta (Form 5) B-Grounded



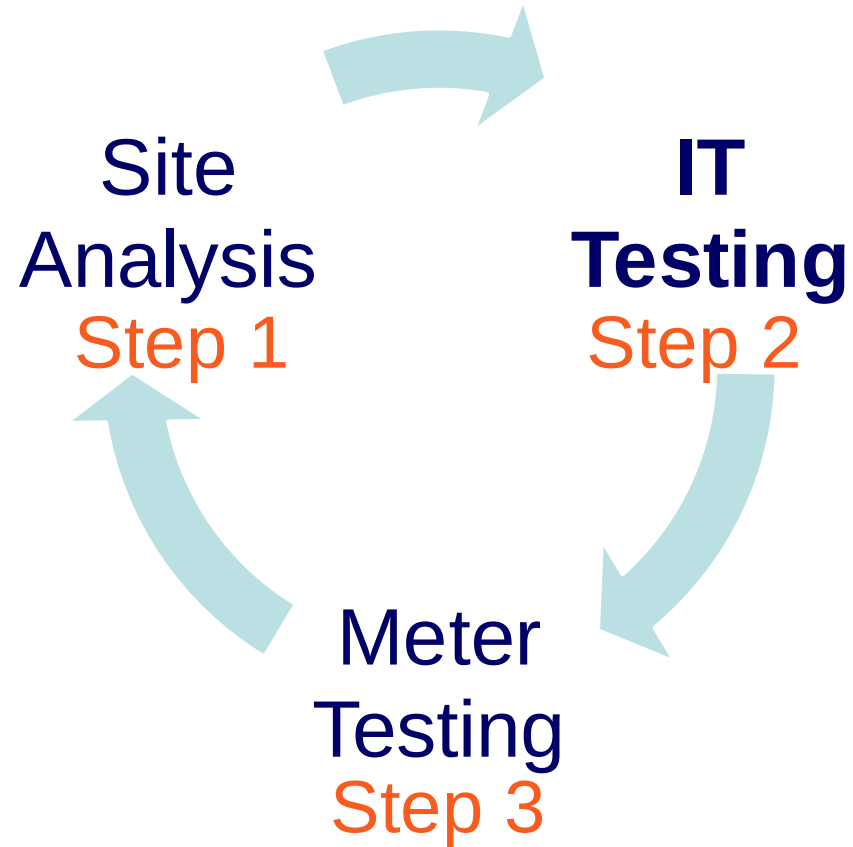
4-Wire Delta (Form 8)



4-Wire Delta (Form 9)



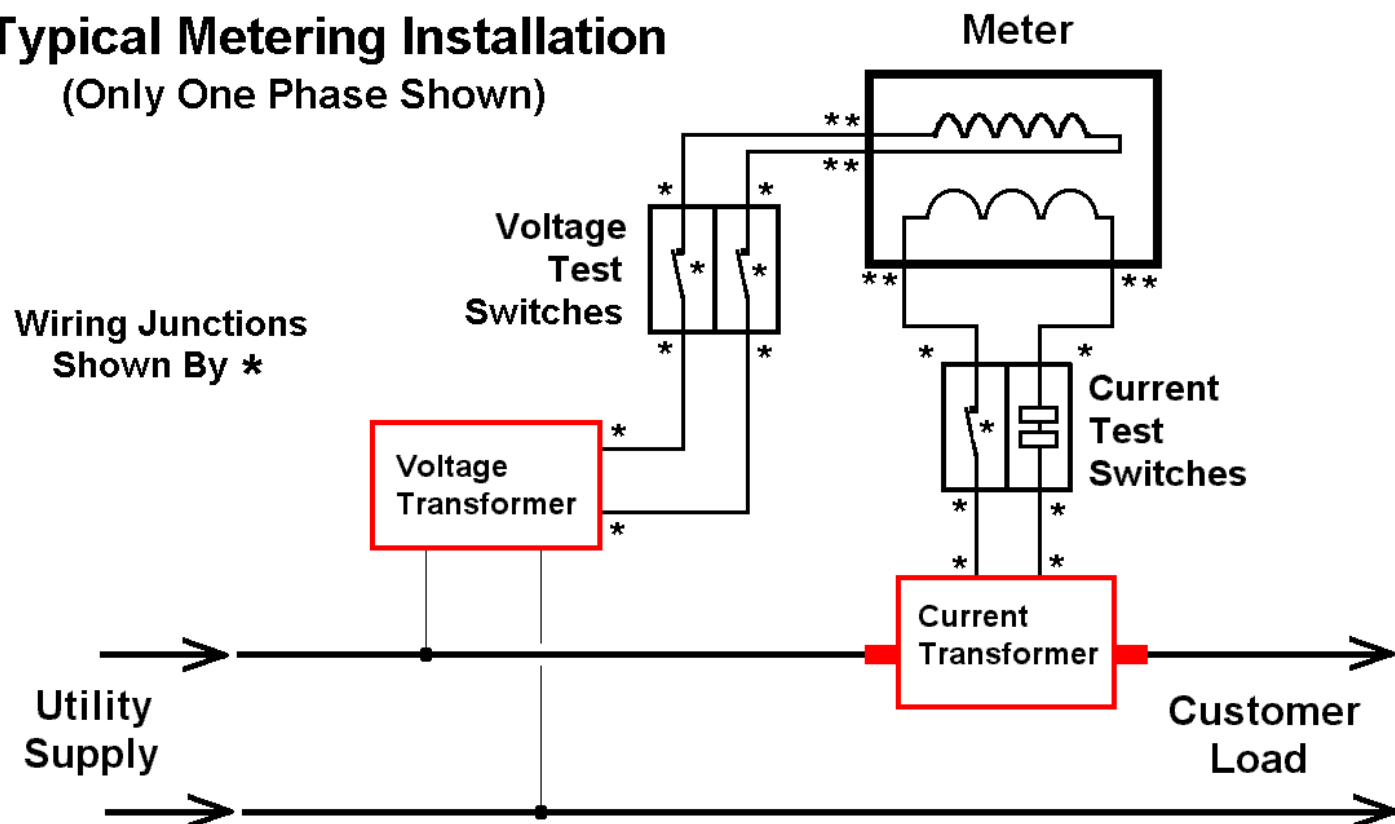
Integrated Site Test Philosophy



Instrument Transformers Control Metered Values

... What If They Do Not Produce The Expected Outputs

Typical Metering Installation (Only One Phase Shown)



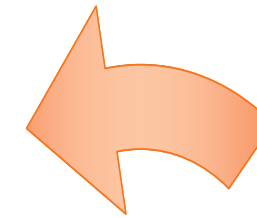


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Integrated Site Test Philosophy

CT Testing Results		BETA TEST - 238464 - Selected Site: TEST		
Measured Ratio: 49.93		PASS	A	
Nameplate Ratio: 50 : 5	Primary Amps: 9.99			
Ratio Error (%): -0.14%	Secondary Amps: 1.001			
Phase Error (degrees): 0.100°	Phase Error (minutes): 6' 1"			
Measured Ratio: 50.03		PASS	B	
Nameplate Ratio: 50 : 5	Primary Amps: 10.01			
Ratio Error (%): 0.06%	Secondary Amps: 1.001			
Phase Error (degrees): -0.050°	Phase Error (minutes): -2' 59"			
Measured Ratio: 49.66		PASS	C	
Nameplate Ratio: 50 : 5	Primary Amps: 9.94			
Ratio Error (%): -0.69%	Secondary Amps: 1.001			
Phase Error (degrees): 0.183°	Phase Error (minutes): 10' 58"			
Test Complete				
Retest	Retest All	Graphs	Data	Done

CT
Testing





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CT Ratio with Burden Testing



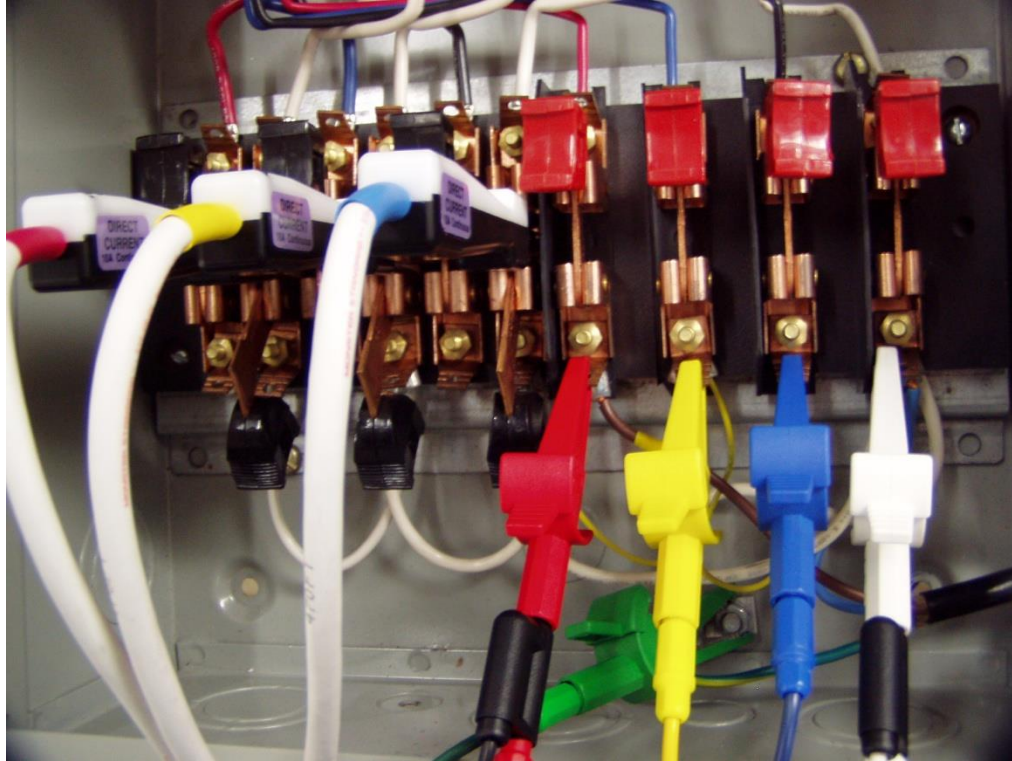
- Ratio Testing is the preferred approach when we can gain access to the CT primary.
- Various types of probes can be used for primary side.
 - Flex
 - HV





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CT Ratio with Burden Testing



- Secondary connection is made through the test switch
- Same connection that is used for the rest of the site testing.

Ratio Testing with applied burden is the most accurate and complete approach for testing at CT in service.

Testing Current Transformers

Ratio vs Applied Burden

- CTs installations can be fully verified in the field

CT Testing Results BETA TEST - p17.26M/v15.88M/c#268.88K - Selected Site: *NONE*

Measured Ratio: 5.03	PASS	A
Nameplate Ratio: 5 : 5	Primary Amps: 1.83	
Ratio Error (%): 0.54%	Secondary Amps: 1.822	
Phase Error (degrees): 0.273°	Phase Error (minutes): 16' 23"	

Measured Ratio: 5.06	PASS	B
Nameplate Ratio: 5 : 5	Primary Amps: 2.09	
Ratio Error (%): 1.19%	Secondary Amps: 2.061	
Phase Error (degrees): 0.025°	Phase Error (minutes): 1' 31"	

Measured Ratio: 5.04	PASS	C
Nameplate Ratio: 5 : 5	Primary Amps: 1.64	
Ratio Error (%): 0.76%	Secondary Amps: 1.631	
Phase Error (degrees): 0.334°	Phase Error (minutes): 20' 2"	

Original Test: Site '4WY' at 6/25/2010 3:58 PM

Graphs Data Exit

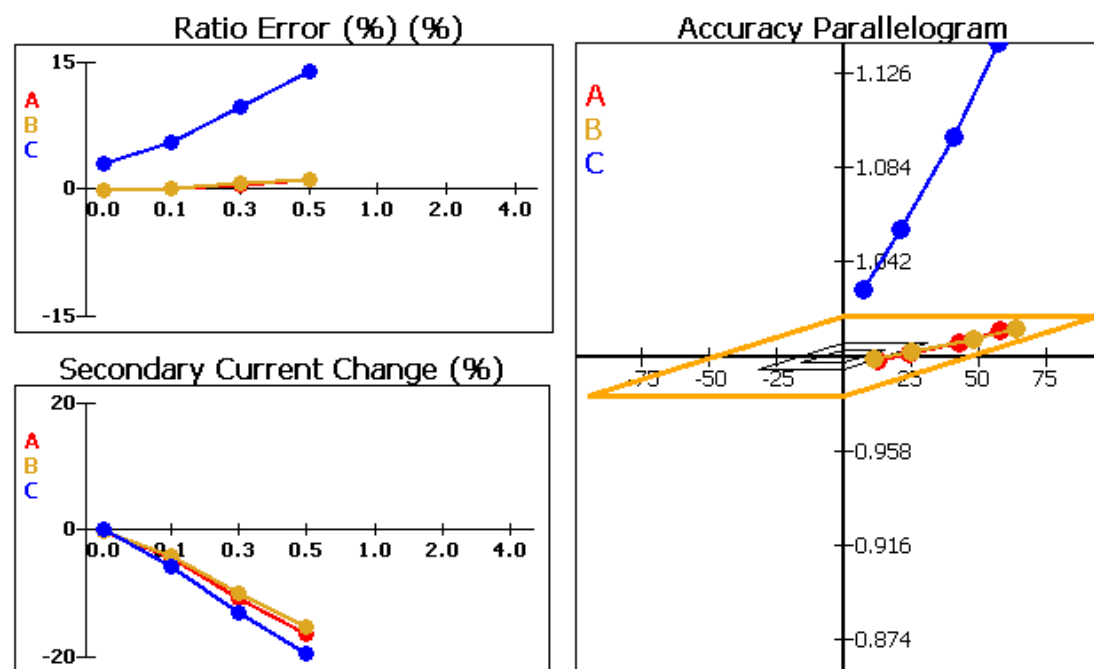
Without the harmonic load this CT passed its test.

Testing Current Transformers

Ratio vs Applied Burden

- Arrived at site and ran a CT test

CT Testing Results Graph TEST - p15.67M/v16.19M/c#381.40K - Selected Site: 04/26/11A1



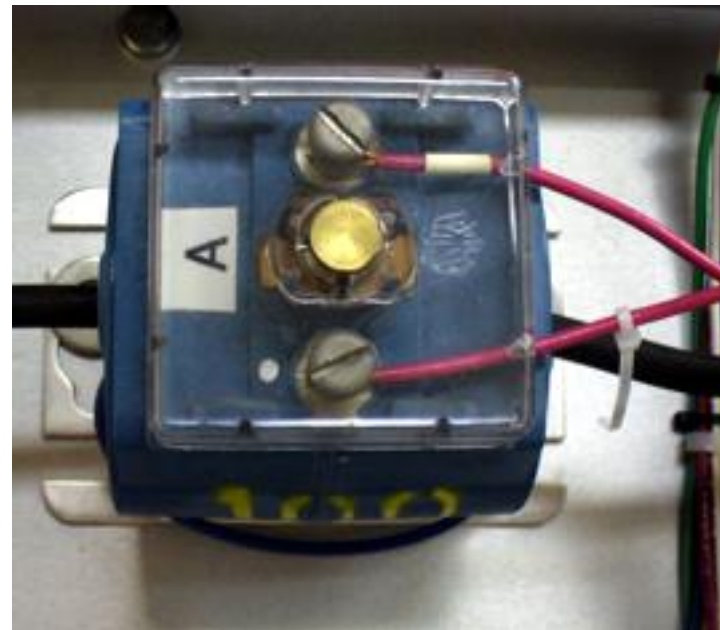
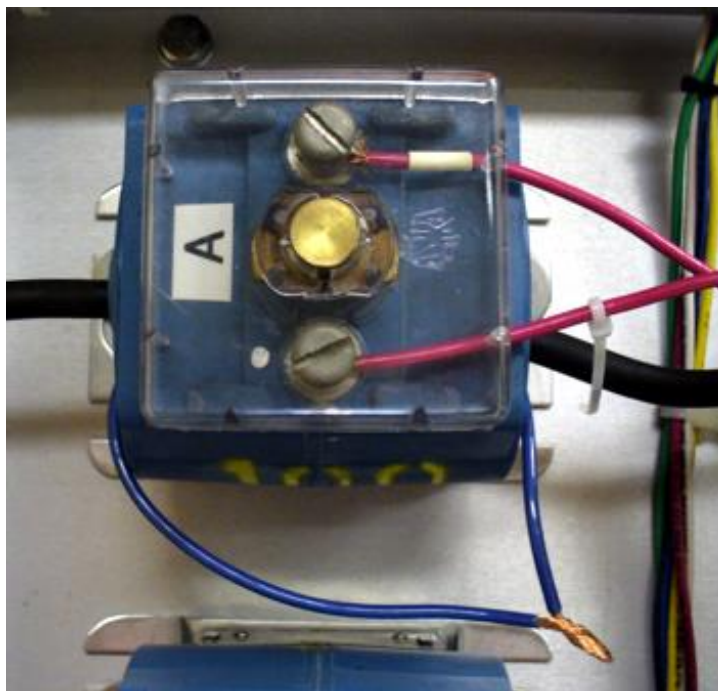
Φ A Φ B Φ C All Data

- Now Phase C looks really bad.

Testing Current Transformers

What's Wrong? → Power Theft

A simple piece of wire wrapped around the CT.



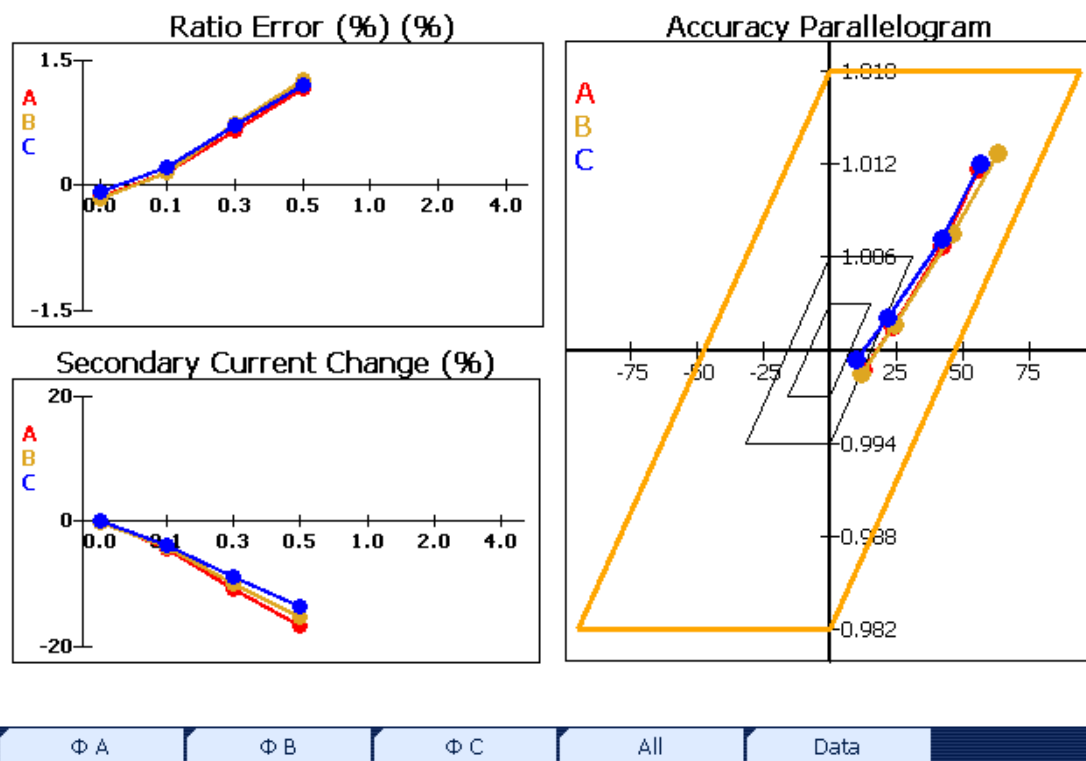
Would you spot it?

Testing Current Transformers

Ratio vs Applied Burden

- Removed wire.

CT Testing Results Graphs TEST - p16.55M/v17.00M/c#380.85K - Selected Site: 04/26/11A1



- Everything tests OK.

Testing Current Transformers

Ratio Error – In Whose Favor?

I did at CT ratio test. What does it mean when I measure a ratio of 99.68:5 on a 100:5 CT?

CT Testing Results		Selected Site: CT TEST			
Measured Ratio: 99.93		PASS	A		
Nameplate Ratio: 100 : 5	Primary Amps: 39.72				
Ratio Error (%): -0.07%	Secondary Amps: 1.987				
Phase Error (degrees): -0.190°	Phase Error (minutes): -11' 25"				
Measured Ratio: 99.68		PASS	B		
Nameplate Ratio: 100 : 5	Primary Amps: 35.86				
Ratio Error (%): -0.32%	Secondary Amps: 1.799				
Phase Error (degrees): -0.097°	Phase Error (minutes): -5' 49"				
Measured Ratio: 99.96		PASS	C		
Nameplate Ratio: 100 : 5	Primary Amps: 31.25				
Ratio Error (%): -0.04%	Secondary Amps: 1.563				
Phase Error (degrees): -0.138°	Phase Error (minutes): -8' 18"				
Test Complete					
Retest	Retest All	Demagnetize	Graphs	Data	Done



Testing Current Transformers

Ratio Error – In Whose Favor?

In the phase B test we measured 35.86 amps on the primary and 1.799 secondary amps.

$$\text{Ratio} = 5.0 * (\text{Primary} / \text{Secondary}) = 99.68$$

If the ratio had been 100:5 then, and the primary was 35.86 amps we should have measured 1.793 amps on the secondary.

We measured 1.799 – **MORE** than we should have.

Therefore a tested ratio of 99.68 means that we are measuring more current than we should. **This error is in our favor.**





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Testing Current Transformers

Ratio Error – In Whose Favor?

Suppose we add burden to the metering circuit.

CT Testing Results

Selected Site: CT TEST

% Change in Secondary Amps

Phase	Ref	0.0Ω	0.1Ω	0.3Ω	0.5Ω	1.0Ω	2.0Ω	4.0Ω
A		0.000	-4.468	-10.751	-16.377	N/A	N/A	N/A
B		0.000	-4.072	-9.727	-14.820	N/A	N/A	N/A
C		0.000	-3.490	-8.405	-12.873	N/A	N/A	N/A

Ratio Data

Phase	Ref	0.0Ω	0.1Ω	0.3Ω	0.5Ω	1.0Ω	2.0Ω	4.0Ω
A	100:5	99.93	100.20	100.85	101.42	N/A	N/A	N/A
B	100:5	99.68	99.96	100.54	101.01	N/A	N/A	N/A
C	100:5	99.96	100.17	100.71	101.23	N/A	N/A	N/A

Ratio Error (%)

Phase	Ref	0.0Ω	0.1Ω	0.3Ω	0.5Ω	1.0Ω	2.0Ω	4.0Ω
A		-0.07	0.20	0.85	1.42	N/A	N/A	N/A
B		-0.32	-0.04	0.54	1.01	N/A	N/A	N/A
C		-0.04	0.17	0.71	1.23	N/A	N/A	N/A

Relative Phase Data (degrees)

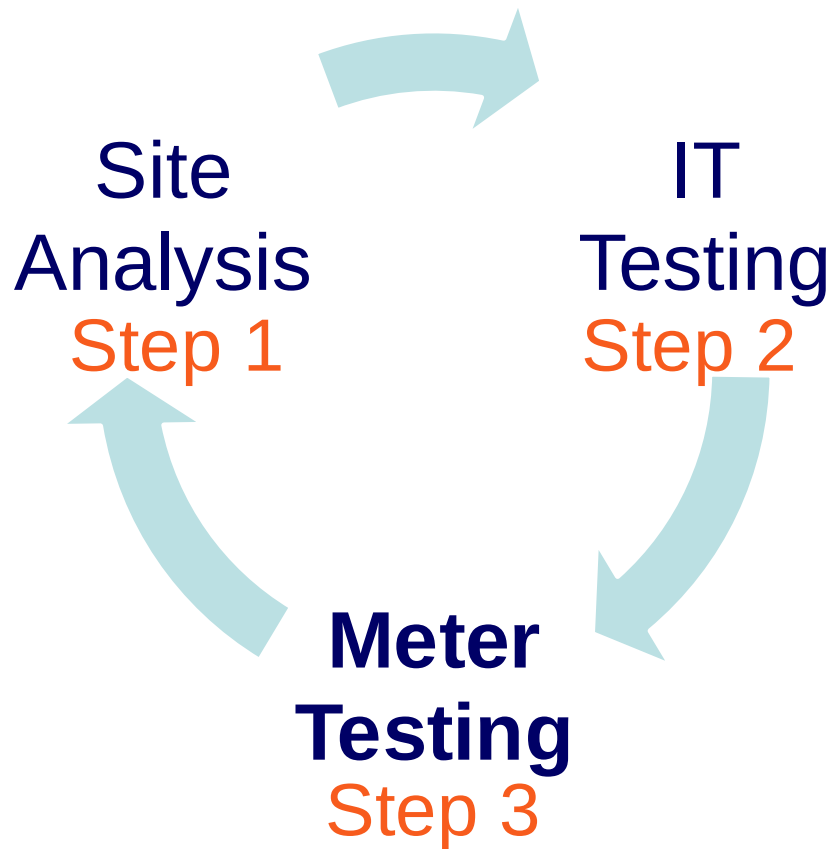
Phase	Ref	0.0Ω	0.1Ω	0.3Ω	0.5Ω	1.0Ω	2.0Ω	4.0Ω
A		-0.19	-0.51	-0.89	-1.17	N/A	N/A	N/A
B		-0.10	-0.38	-0.79	-1.11	N/A	N/A	N/A
C		-0.14	-0.42	-0.81	-1.07	N/A	N/A	N/A

Notice that the ratio increases as we apply burden. With 0.3 Ohms of burden the ratio switches from less than 100:5 to greater than 100:5. This is the point where things swing to being in favor of the customer.

Graphs



Integrated Site Test Philosophy



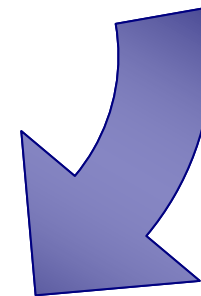


Integrated Site Test Philosophy

Customer Load Test

Real - World Conditions
Voltage and Current Harmonics
Current and Phase Angle Balance

Meter Testing



Load Box Test

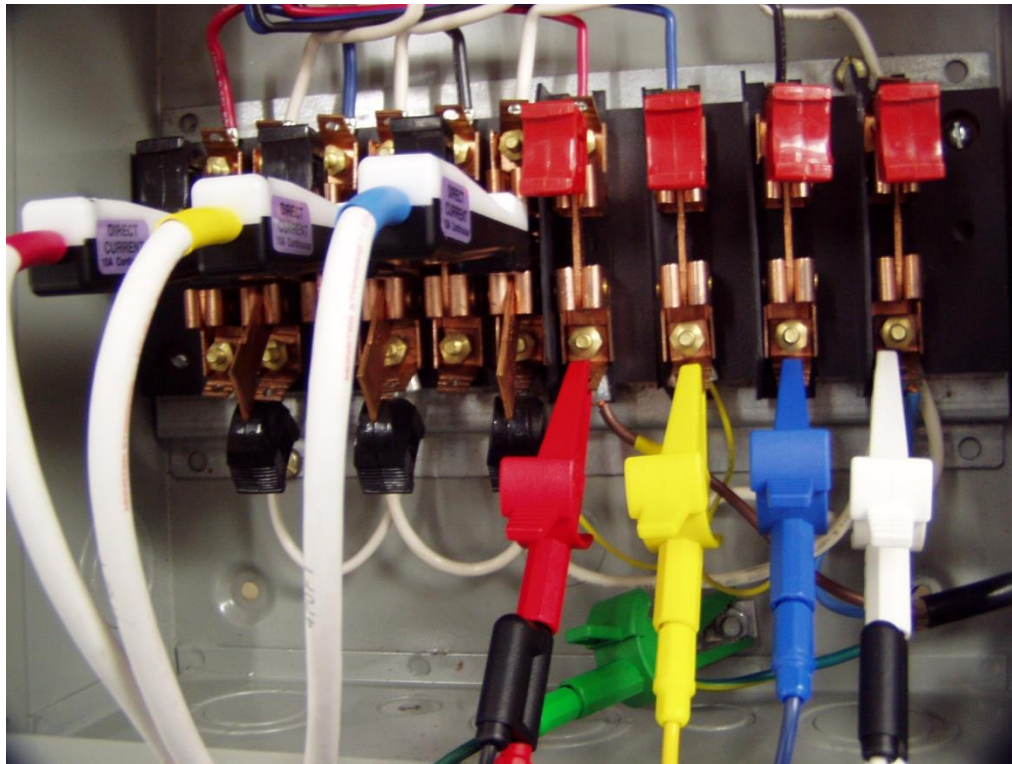
Ideal Current and Voltage Waveforms
ANSI Full Load, Power Factor & Light Load
Custom Test Sequences for Special
Applications





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Customer Load Meter Test



- Secondary connection is made through the test switch
- Same connection that is used for CT testing.

We measure the voltage and current that the meter sees.



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Customer Load Meter Test

Customer Load Test Results: TEST - p21.14M/v19.00M/c#275.08K - Selected Site: DELETE

Customer Load Meter Test Wh Test

% Registration 100.015

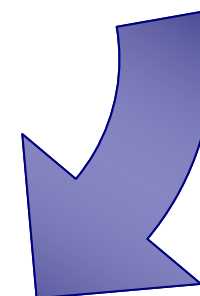
Test Info

Time(sec)	151.427
Time Left	0.000
Pulses Exp	9.9985
Pulses Act	10.0000
Meter PF	0.6416

Sys Info

Wh	17.9973
VAh	24.8777
VARh	4.4997
V	119.259
I	1.6524

Meter
Testing



Test Complete

Restart

View Trend

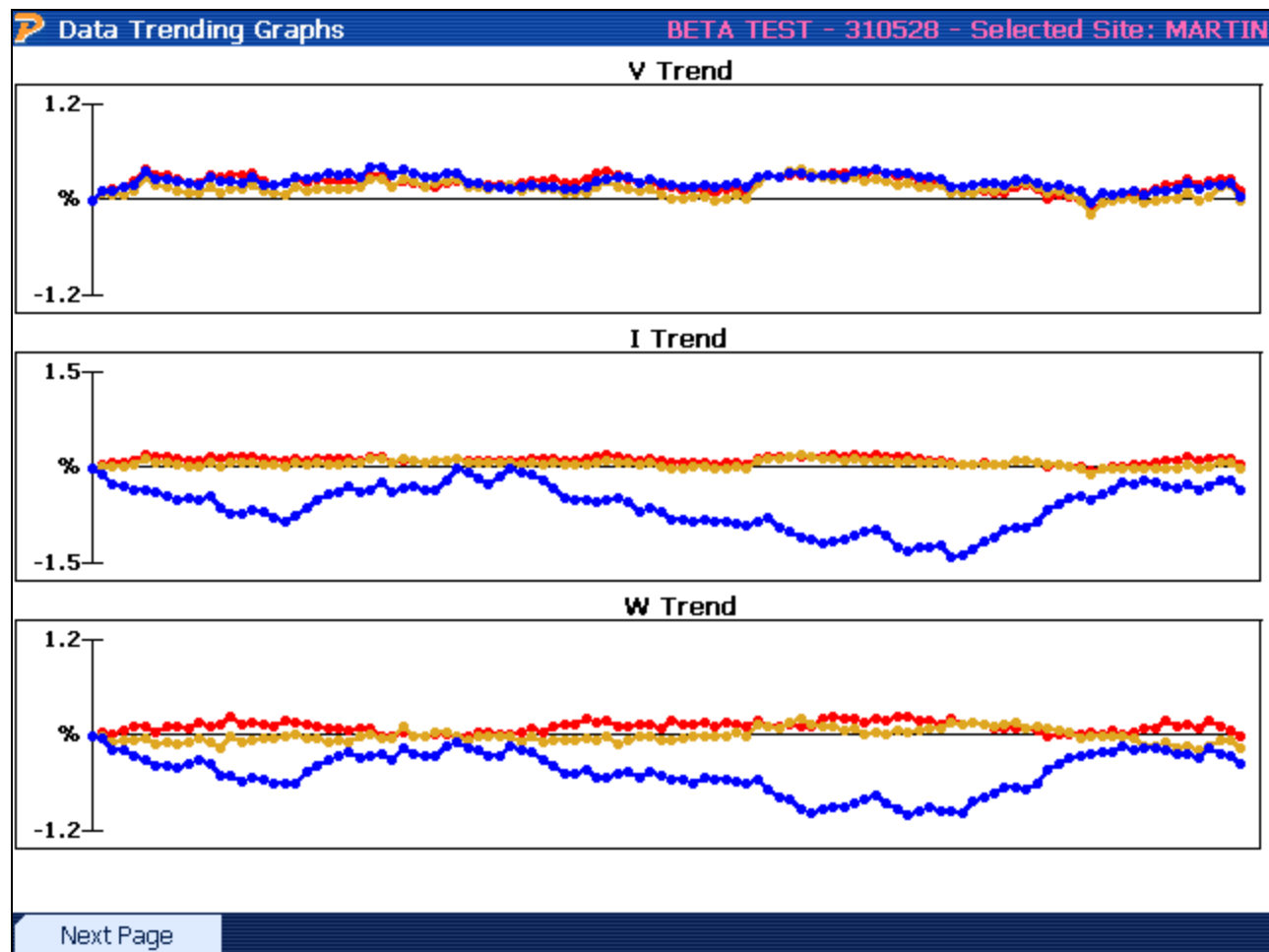
Done



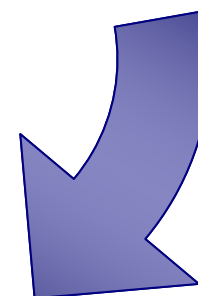


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Customer Load Meter Test



Meter
Testing





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Phantom Load Meter Test

 Phantom Load Results

Selected Site: TEST

FL

99.954

Phase	Voltage	Current	PF	Time	Pulses
All	238.54	4.995	0.868	4.18	2

PF

99.913

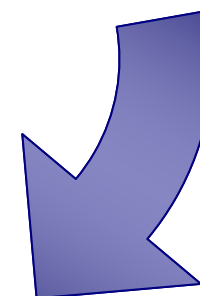
Phase	Voltage	Current	PF	Time	Pulses
All	238.54	4.995	0.441	8.24	2

LL

99.966

Phase	Voltage	Current	PF	Time	Pulses
All	238.51	0.497	0.868	42.03	2

Meter
Testing



Page 1 / 1

Retest

Retest All

Done



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Phantom Load Meter Test Demand Test

Demand Test Results

BETA TEST - 229360 - Selected Site: MARTIN

Demand Test Results

Estimated Time Remaining in Interval:

0:09

Estimated Total Time Remaining:

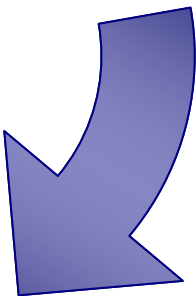
0:09

Intervals Remaining:

1

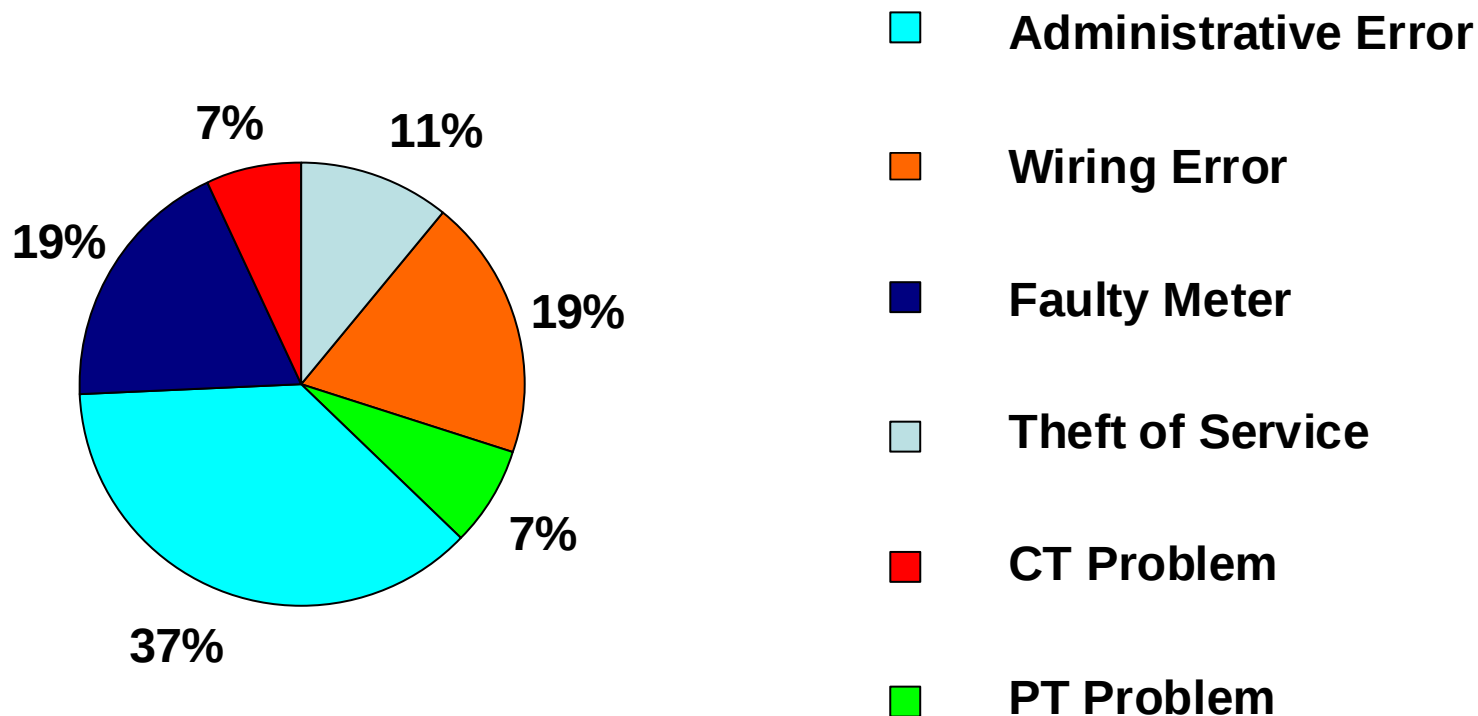
Int	Start Time	Pulses	Voltage	Current	PF	Wh	VAh	mVARh	%REG
1	10:45 AM	35.97	116.580	2.256	0.998	64.77	64.84	-1660.17	99.96
2	10:50 AM	35.95	116.566	2.255	0.998	64.74	64.81	-1639.85	99.96
3	10:55 AM	35.91	116.480	2.255	0.998	64.66	64.73	-1633.58	99.96

Meter
Testing





3 Year Study from a Municipal with 35,000 Transformer Rated Installations



Any guesses???



3 Year Study from a Municipal with 35,000 Transformer Rated Installations

Total Problems Found after 10% of Sites Tested:

96

Percentage of Sites found to have a Problem:

$96 \div 3,500 \approx 2.7\%$

Total Lost Revenue Found:

\$ 2,248,354

Average Lost Revenue Found per Problem:

$\approx \$ 23,420$





Estimating Errors

- **Uncertainty When Nothing is Wrong**
 - Meter – 0.2% or 0.5% accuracy class
 - CT - 0.3% probably 0.6%
 - PT – 0.3%
- **Worse Case Error Estimate**
 - $0.2\% + 0.3\% + 0.3\% = 0.8\%$
 - $0.2\% + 0.6\% + 0.3\% = 1.1\%$
- **If everything is working correctly about 1.0% is the worst error we should find.**



Southwest Electrical
Metering Association

Questions? Comments?
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Thank you for your time!

