Integrated Site Testing

Billing vs Metering Accuracy

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Why Metering Accuracy

- To ensure that a meter is meeting the accuracy requirements mandated by the PSC and management, we test it in the lab under conditions mandated by ANSI C12.20 and the metering manufacturer.
- Generally for a Class 20 CT Rated meter this means:
  - Testing at FL=2.5A, LL=0.25, FLPF=2.5A @PF=0.5 at 120V
  - These points do not match the optimum operating points in the real world. CT has optimum accuracy only above 5.0A.

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Why Metering Accuracy

- ANSI testing covers limited conditions
  - Sinusoidal waveforms.
  - 0.25A and 2.5A
- Electronic meters generally either work correctly or fail drastically.
- It should be a **rare occasion** that a meter fails to meet these accuracy standards in the lab.

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Metering Accuracy

If the meter is functioning accurately, what does that say about whether or not the customer is getting the correct bill?

NOT MUCH!

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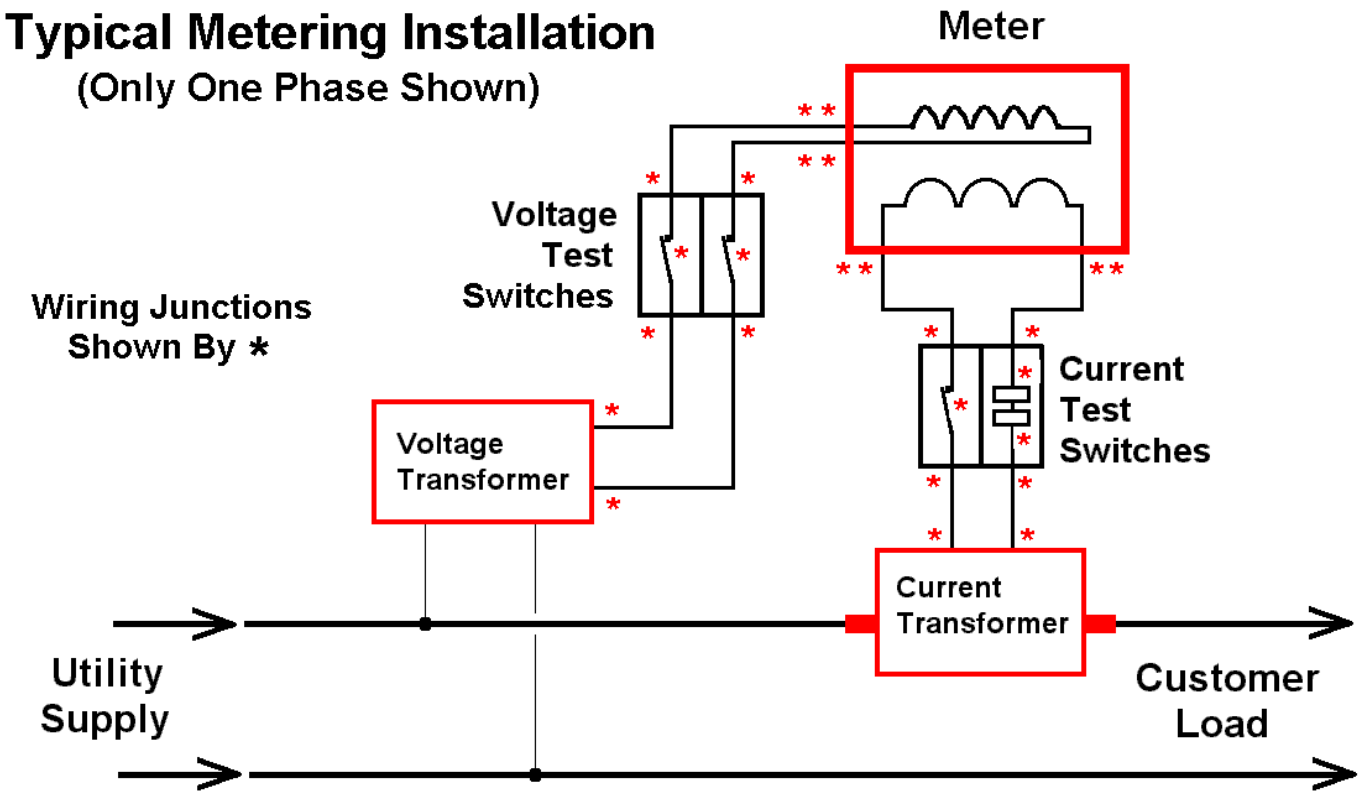
Consider a Typical Metering Installation

The meter measures ONLY the voltage and current reaching the meter terminals. Wiring errors result in incorrect metering. Degraded wiring overburdens CTs or allows current to bypass the meter.



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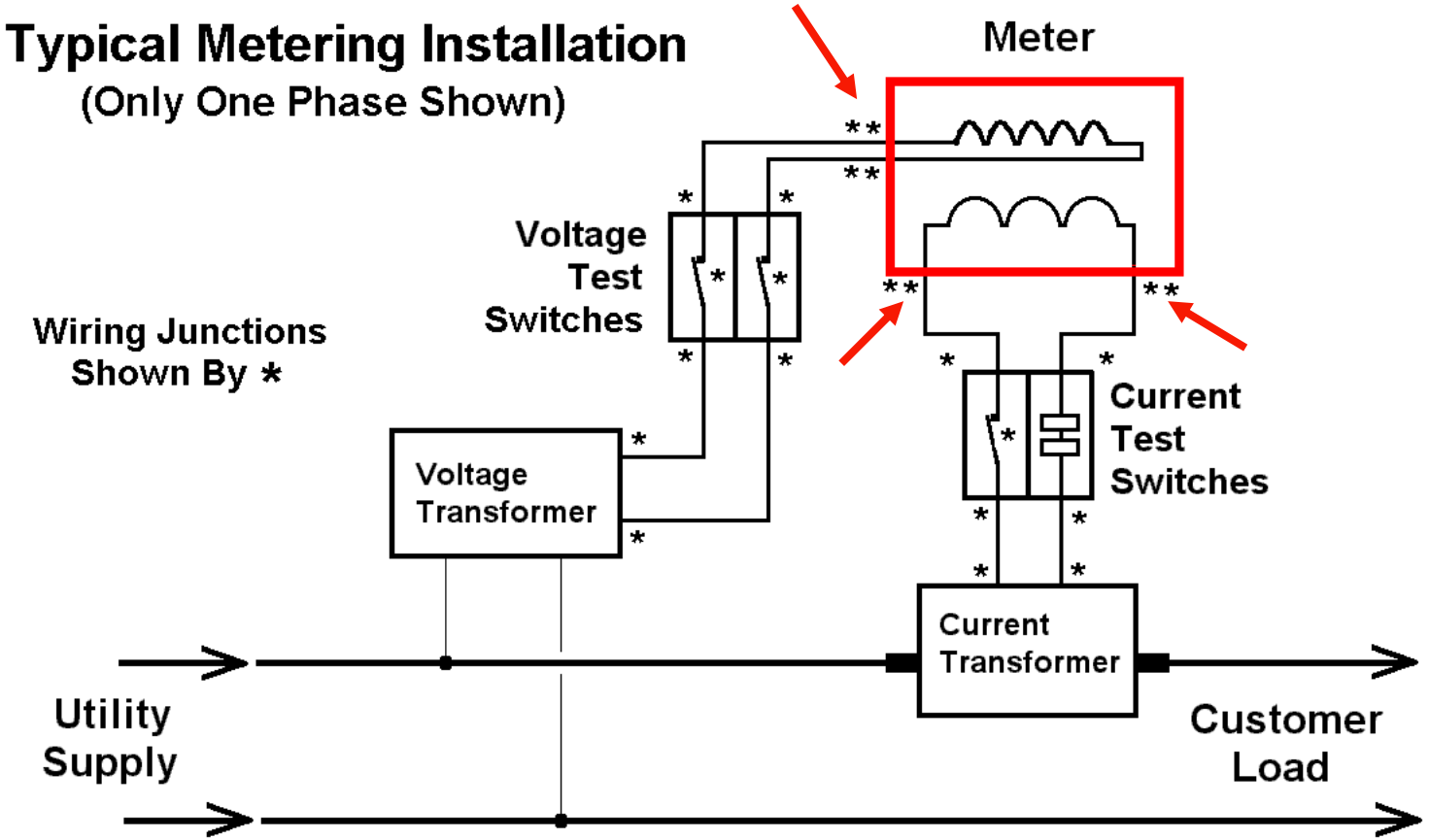
Traditionally Only The Meter Is Tested

… But the meter measures only what reaches its terminals



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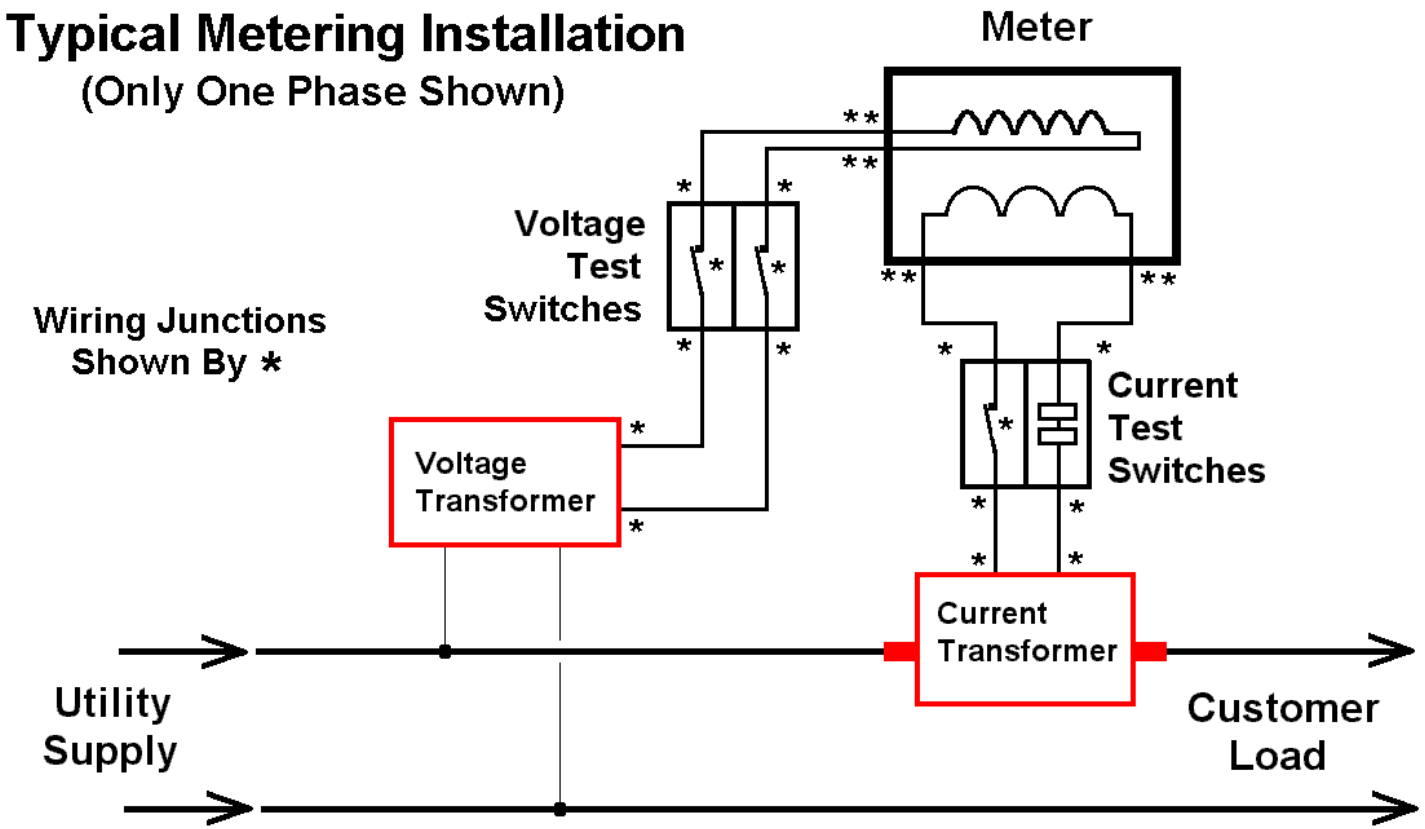
Instrument Transformers Control Metered Values

… What If They Do Not Produce The Expected Outputs



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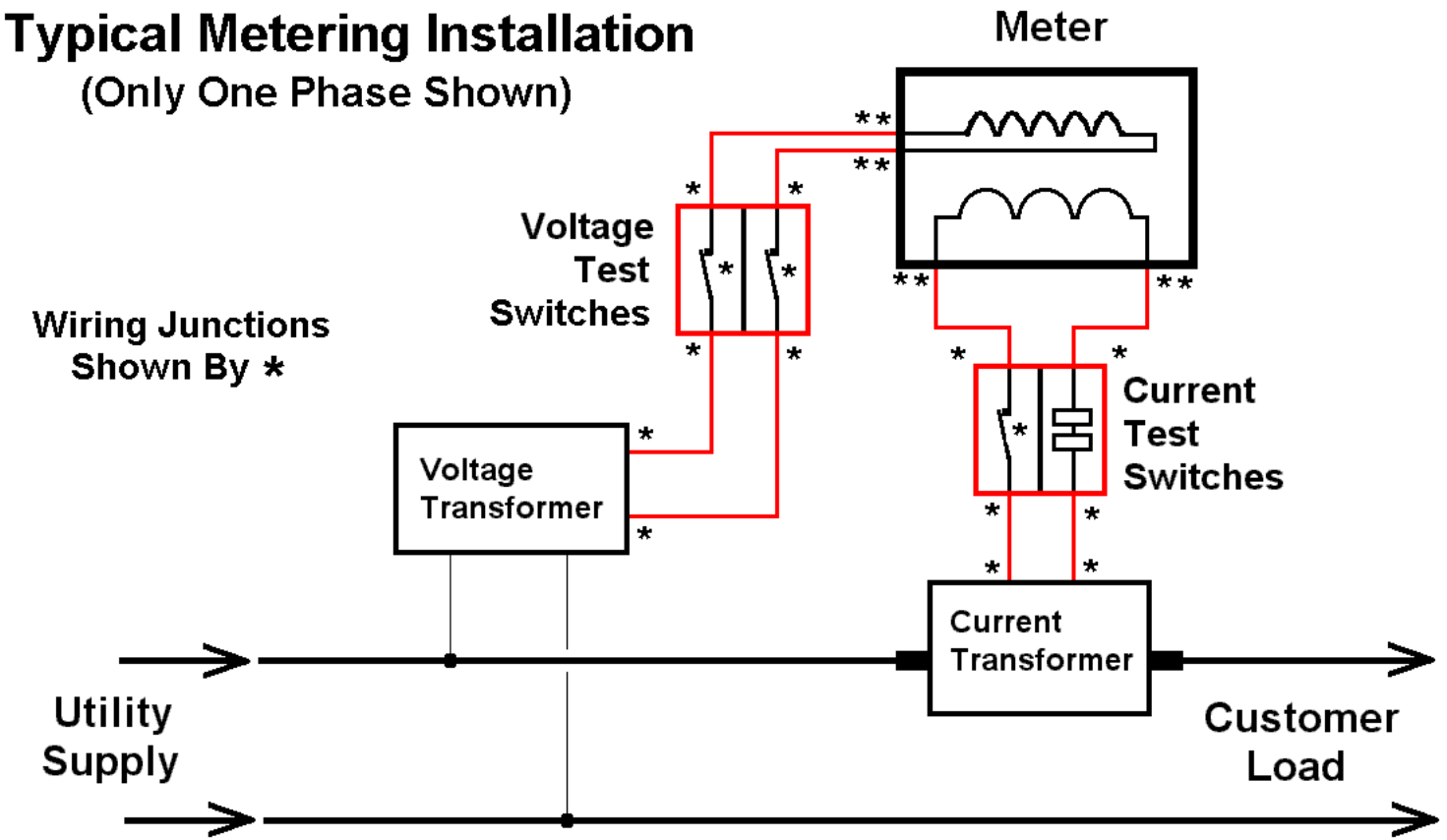
Wiring And Junctions Connect The Meter

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



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Billing Accuracy

- **Even if the meter is perfect, the billing may not be correct.**
- **Sources of billing errors include:**
  - CT – bad, over burdened, shunted, simply not correct accuracy class
  - PT – bad, overburdened, simply not correct accuracy class
  - Faulty or incorrect wiring
  - Meter not accurate under actual customer load conditions
  - Clerical error
  - Theft

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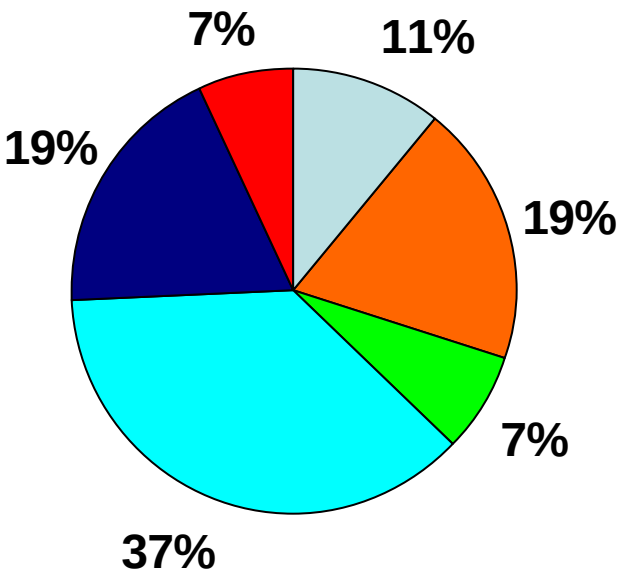
3 Year Study from a Municipal with 35,000 Transformer Rated Installations



- Administrative Error
- Wiring Error
- Faulty Meter
- Theft of Service
- CT Problem
- PT Problem

Any guesses???

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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 ÷ 3,500 ≈ 2.7%

Total Lost Revenue Found:
$ 2,248,354

Average Lost Revenue Found per Problem:
≈ $ 23,420

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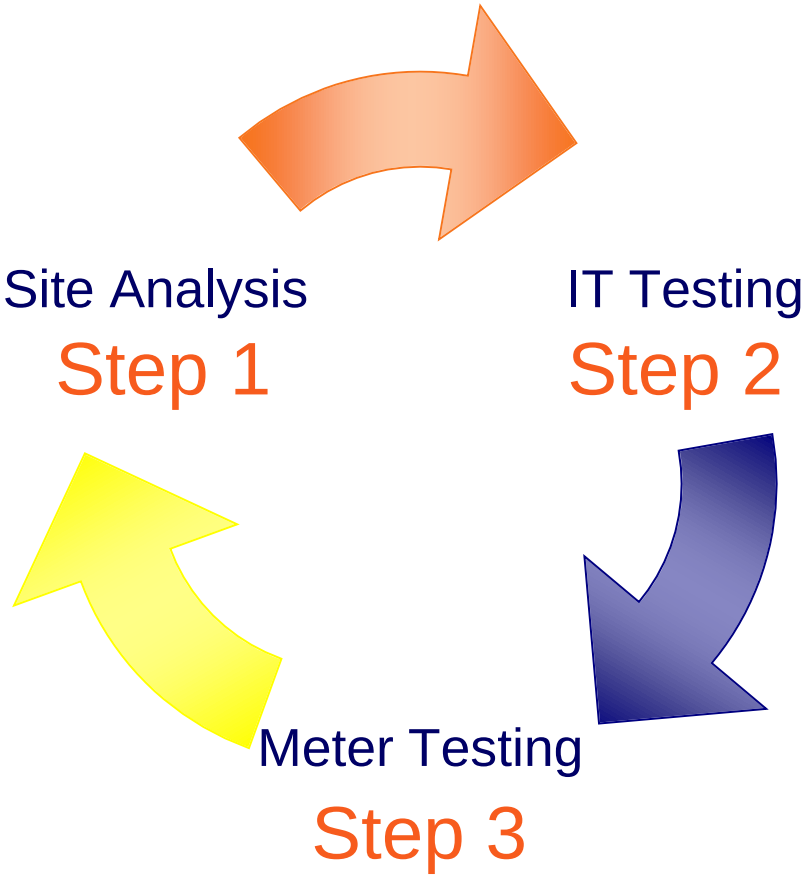
Integrated Site Test Philosophy



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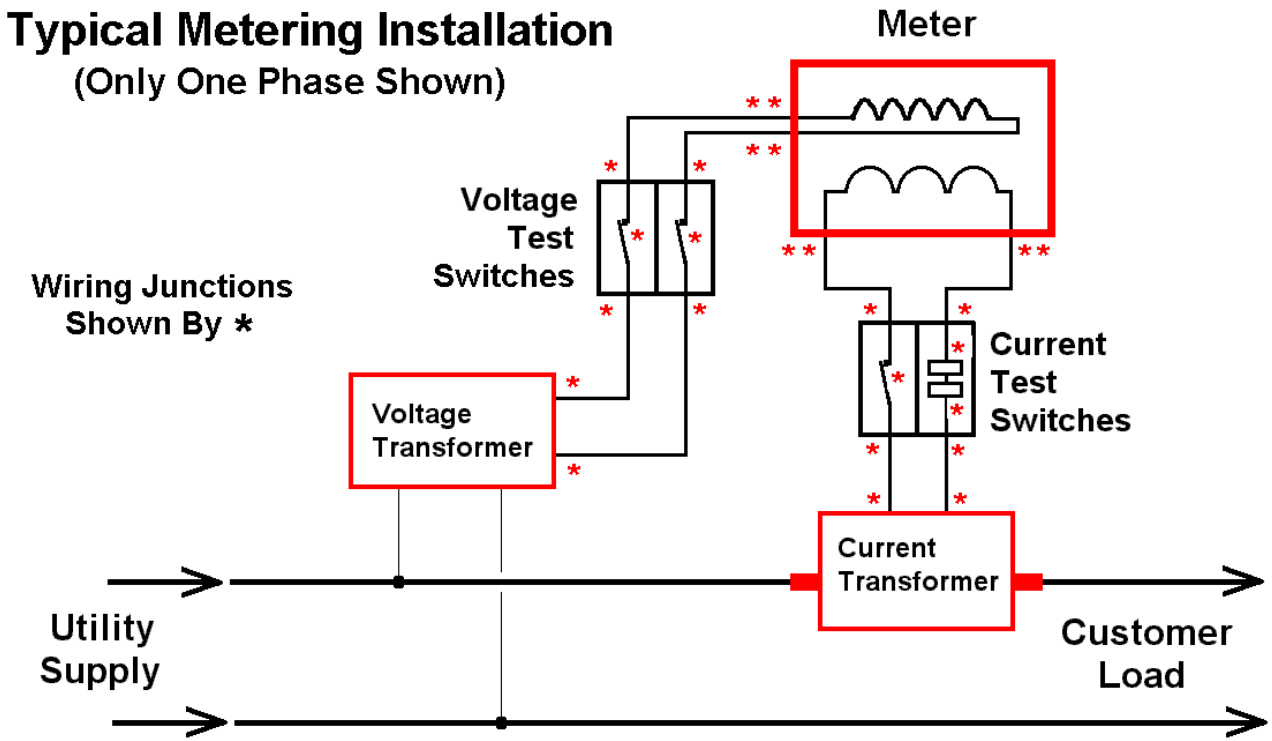
Wiring can be wrong or faulty

- The meter measures ONLY the voltage and current reaching the meter terminals.
- If these are not correct, then the billing will not be correct.



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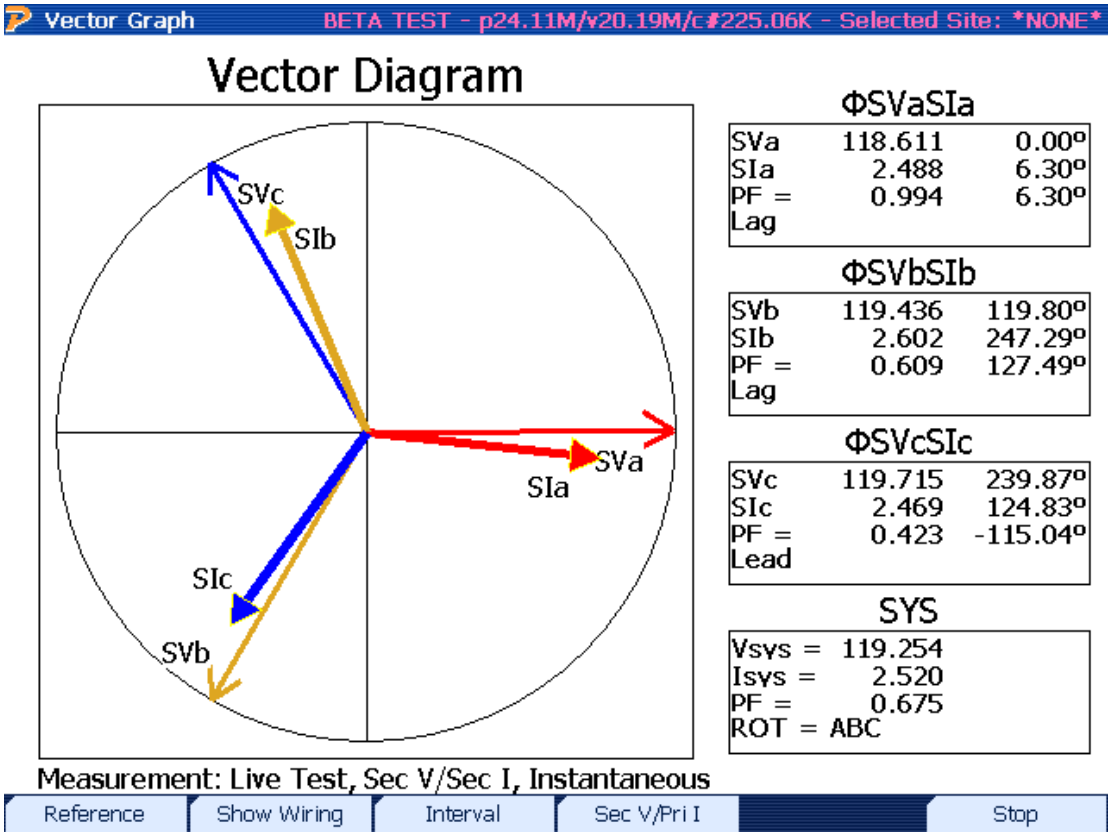
Integrated Site Test Philosophy

Vector Diagram

Site Analysis



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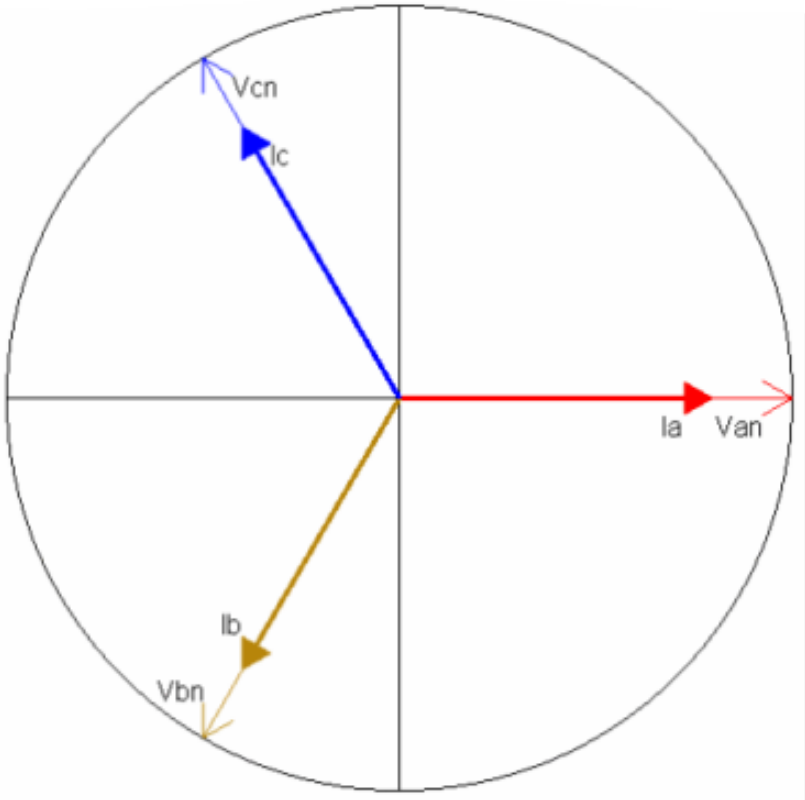
Vector Diagrams are a Powerful Tool

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



Site Analysis

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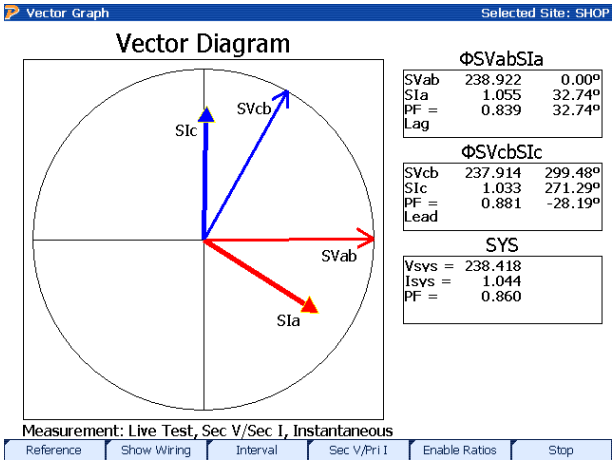
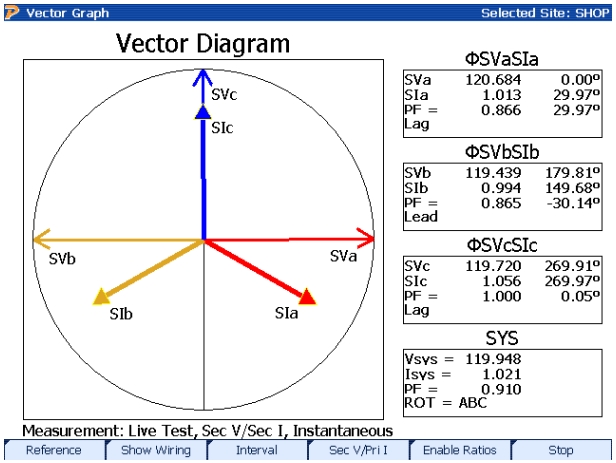
What should the vector diagram look like?

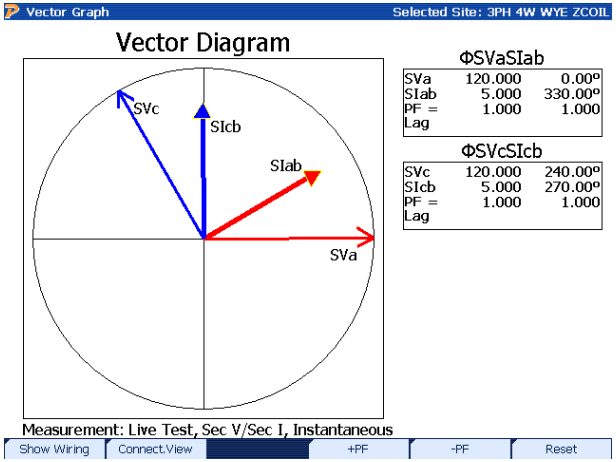
3-Wire Delta Form 5S 2CT 2V



4-Wire Delta Form 9S 3CT 3V



4-Wire Wye Form 6S 3CT 2V



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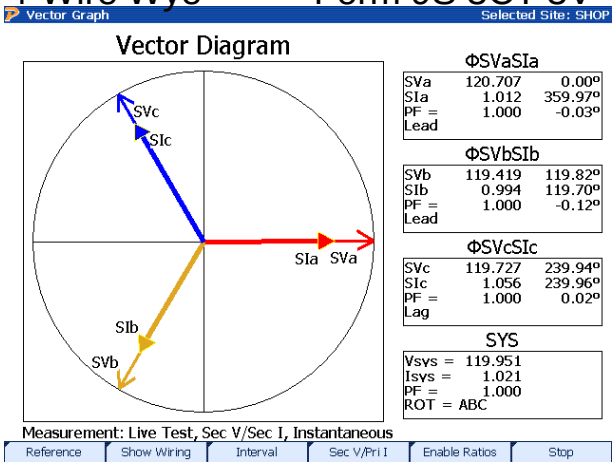
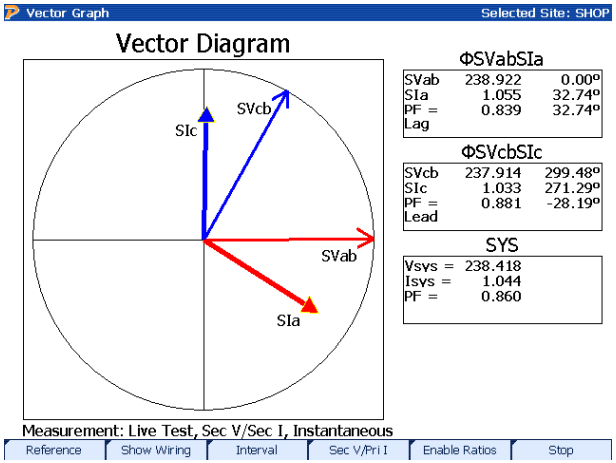


Connect View

What should the vector diagram look like?

3-Wire Delta Form 5S 2CT 2V



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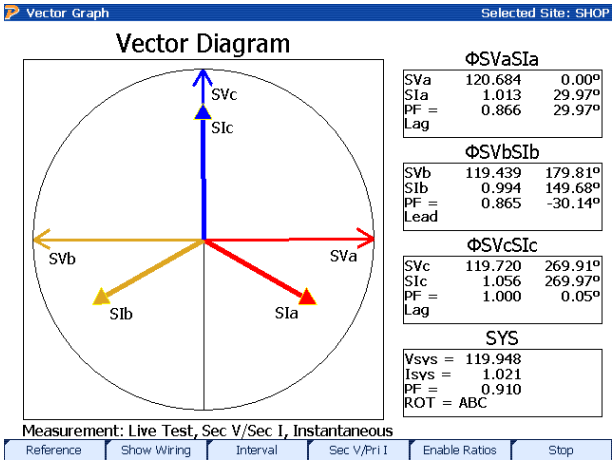

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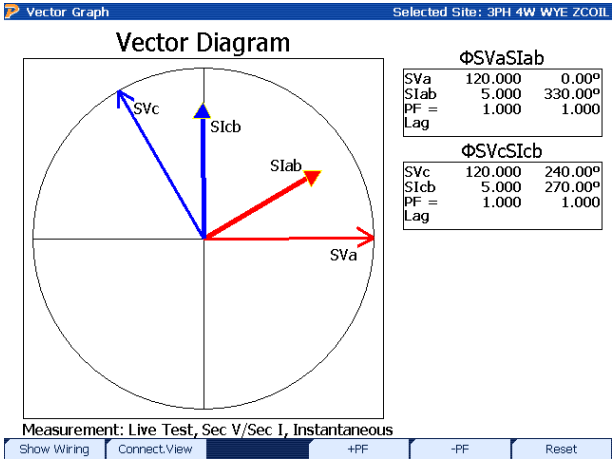

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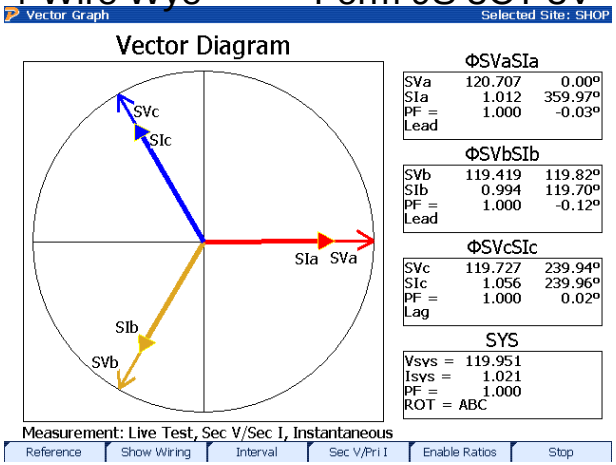
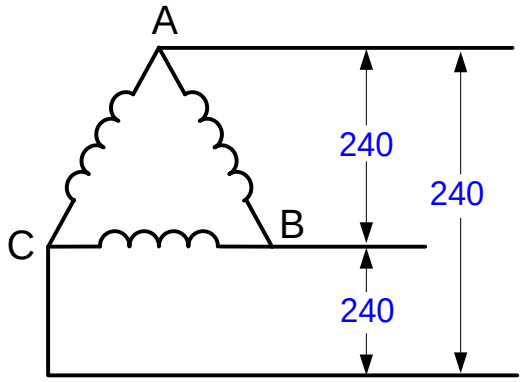


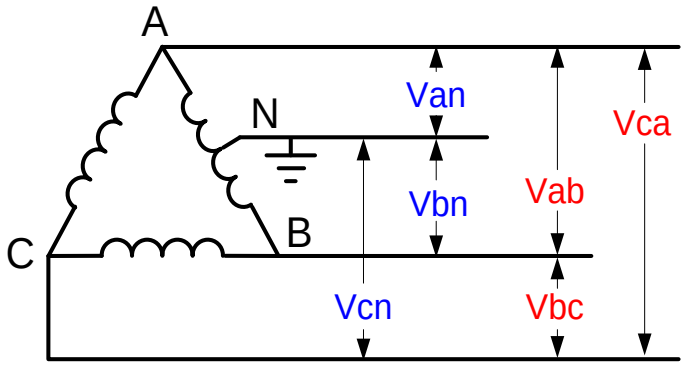
Connect View

Services are Generally Simple

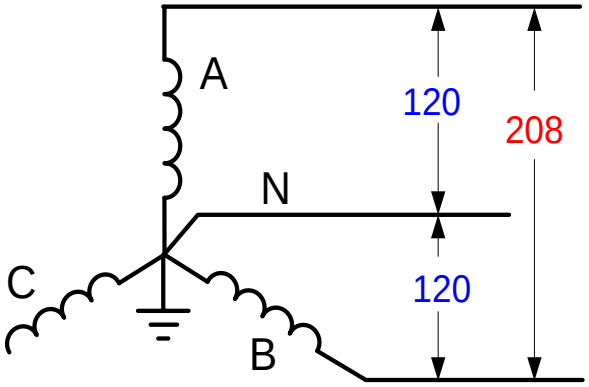
3-Wire Delta



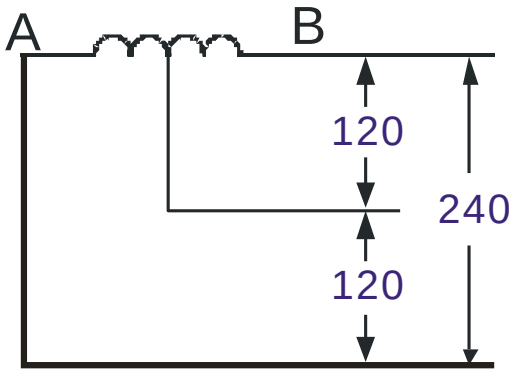
4-Wire Delta



4-Wire Wye



Single Phase



Our metering choices make them complex.

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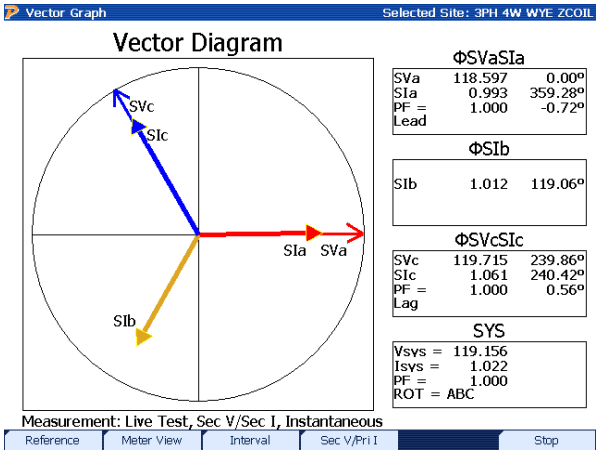
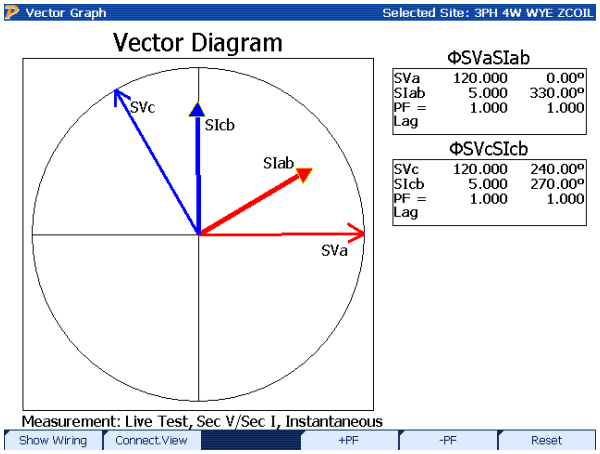
Vector Diagrams Tell You Everything
1 Form, 1 Service Type – Two Views

3 PH 4-Wire Wye 3CT 2V - Form 6S

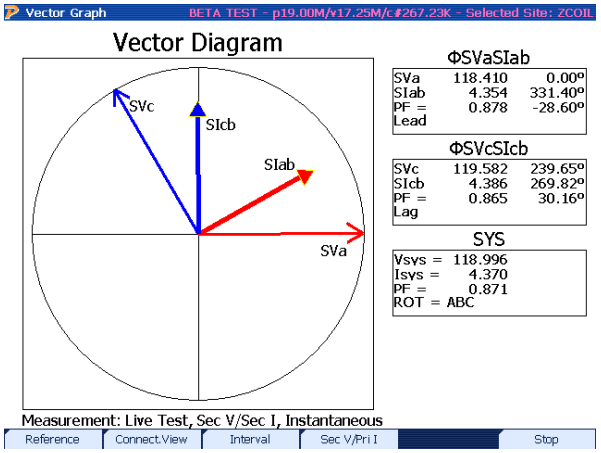


Connect View

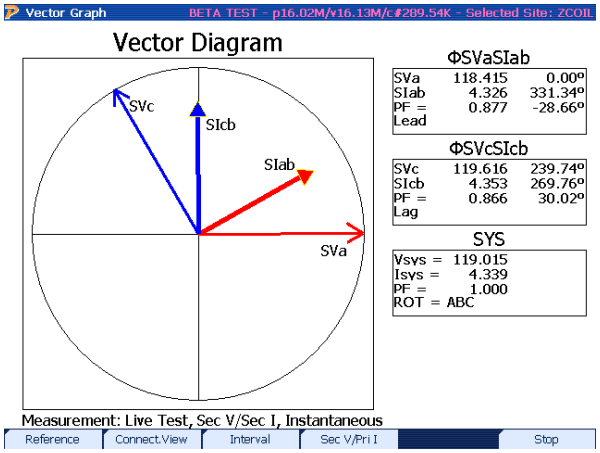
3PH 4-Wire Wye 3CT 2V - Form 6S



Meter View



Arithmetic



Vector

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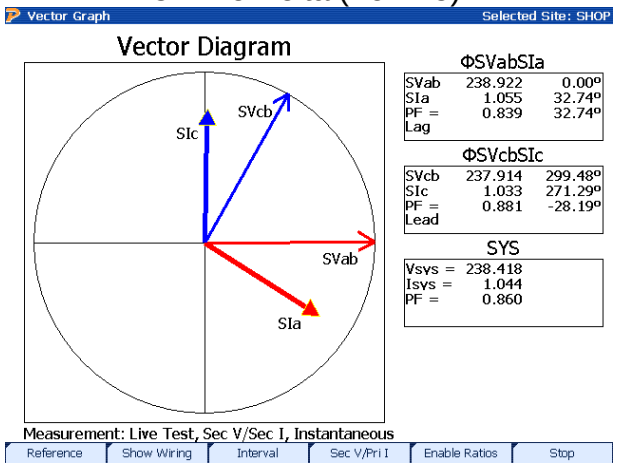
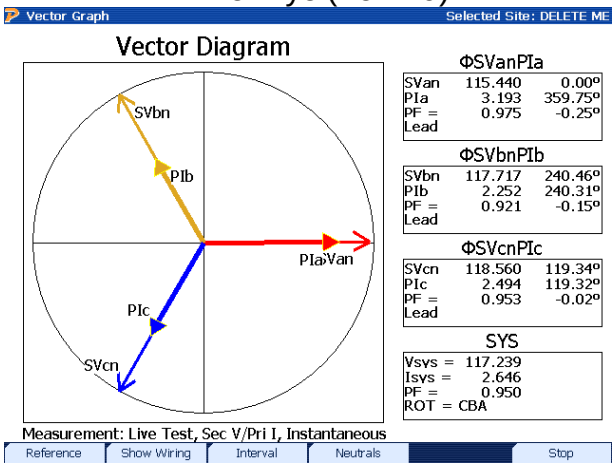
Vector Diagrams are a Powerful Tool

They show everything you need

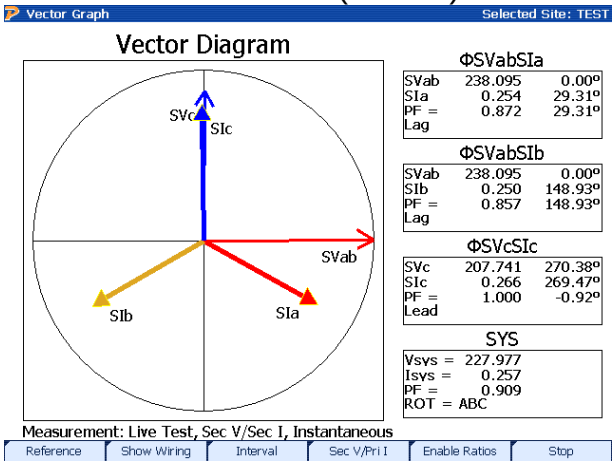
3-Wire Delta (Form 5)



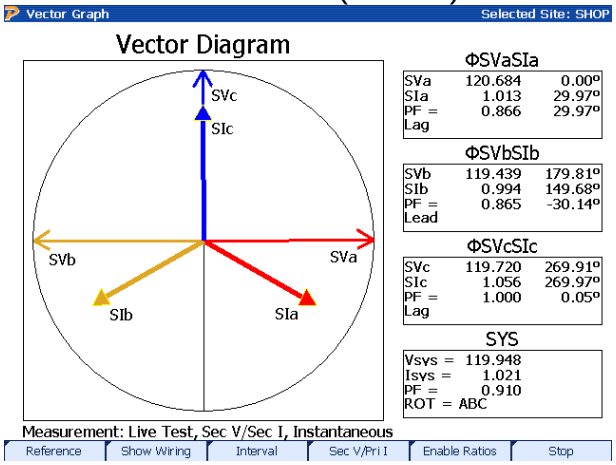
4-Wire Wye (Form 9)



4-Wire Delta (Form 8)



4-Wire Delta (Form 9)



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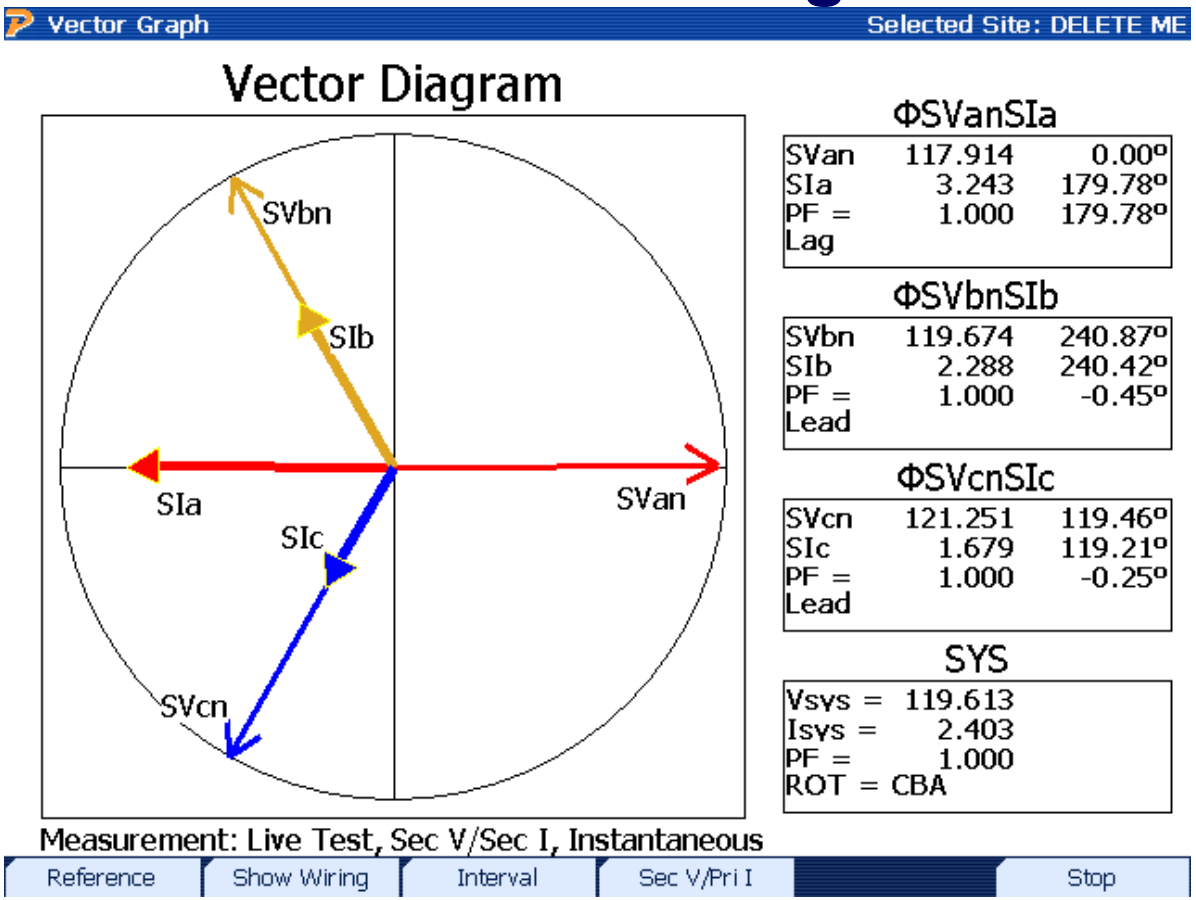
Testing Current Transformers

What's Wrong?



Phase A CT reversed.

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Backwards CT = ??? $$$

- kW = Va * Ia * Cos θ + Vb * Ib * Cos θ + Vc * Ic * Cos θ
- Cos 180 on phase A makes this NEGATIVE power!
- Reading will be 33% low assuming a balanced current load!

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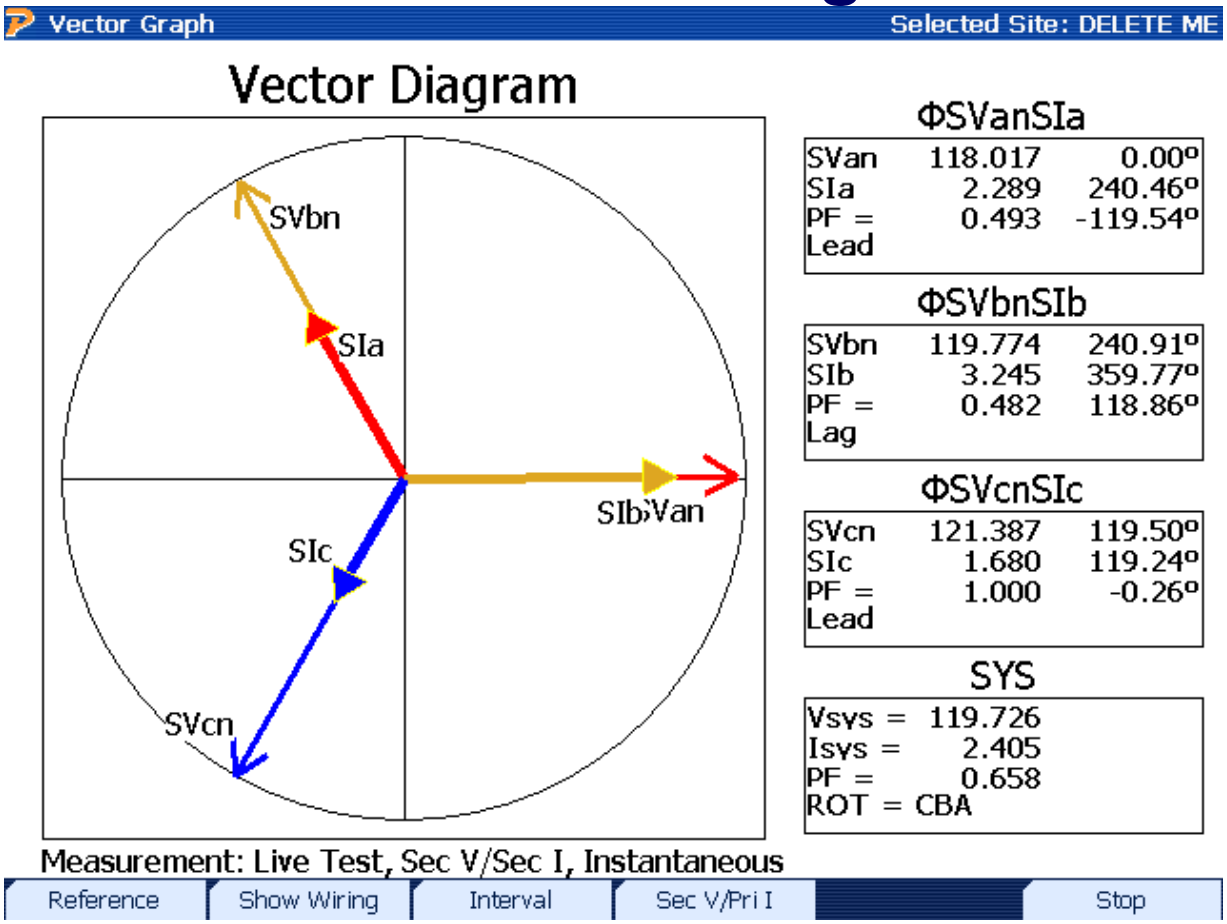
Testing Current Transformers

What's Wrong?



Phase A & B CTs swapped.

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Swapped Wire = ??? $$$

- kW = Va * Ia * Cos θ + Vb * Ib * Cos θ + Vc * Ic * Cos θ
- Cos 120 on phase A and B makes this NEGATIVE power!
- Reading will be 0W assuming a balanced current load!

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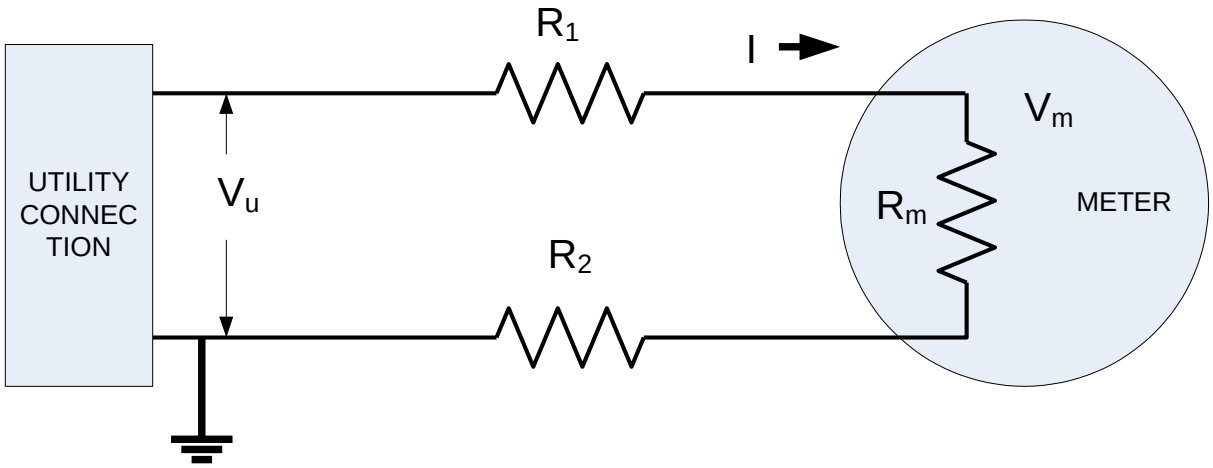
Bad Wiring on Voltage Circuit

- **Can reduce available current to meter so it doesn't have VA to operate properly**
- **Current drawn by meter reduces voltage seen at meter**



$$V_m = V_u - I * (R_1 + R_2)$$

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Bad Wiring on Voltage Circuit

- **For 50 ft of #14 wire to the meter, normally we would have:**
  - Vu = 120V, I = 0.2A, R1+R2 = 0.036Ω => 0.0075V =>0.006% Error
- **Consider a bad connection with resistance 4.0 Ω, then**
  - Vu = 120V, I = 0.2A, R1+R2 = 4.036Ω => 0.843V =>0.7% Error
- **A significant error**

$$V_m = V_u - I * (R_1 + R_2)$$

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Bad Wiring on Current Circuit

- **A faulty connection can easily add a few tenths of an Ohm burden**
- **Improper wiring**
- **Missing commons**
- **Multiple Grounds**

- **Almost all wiring errors result in reduced billing.**

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Bad Wiring on Current Circuit

- **Using too small a gauge wire can result in over burden**
  - 50 ft of #14 wire is 0.14Ω this is more burden than is allowable for a 0.1B class CT.
  - 50 ft of #12 wire is 0.09Ω this is almost the total burden allowable for a 0.1B class CT.
- **Without any bad connections or other problems using too small a wire size can insure you get the worst performance from your CTs.**

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CTs

- **One of lowest accuracy items in chain**
  - 0.3 percent FL to RF x FL
  - 0.6 percent 10% FL to FL
  - Not specified < 10%
- **Accuracy decreases rapidly with burden**
- **IF RF exceeded accuracy decreases rapidly**

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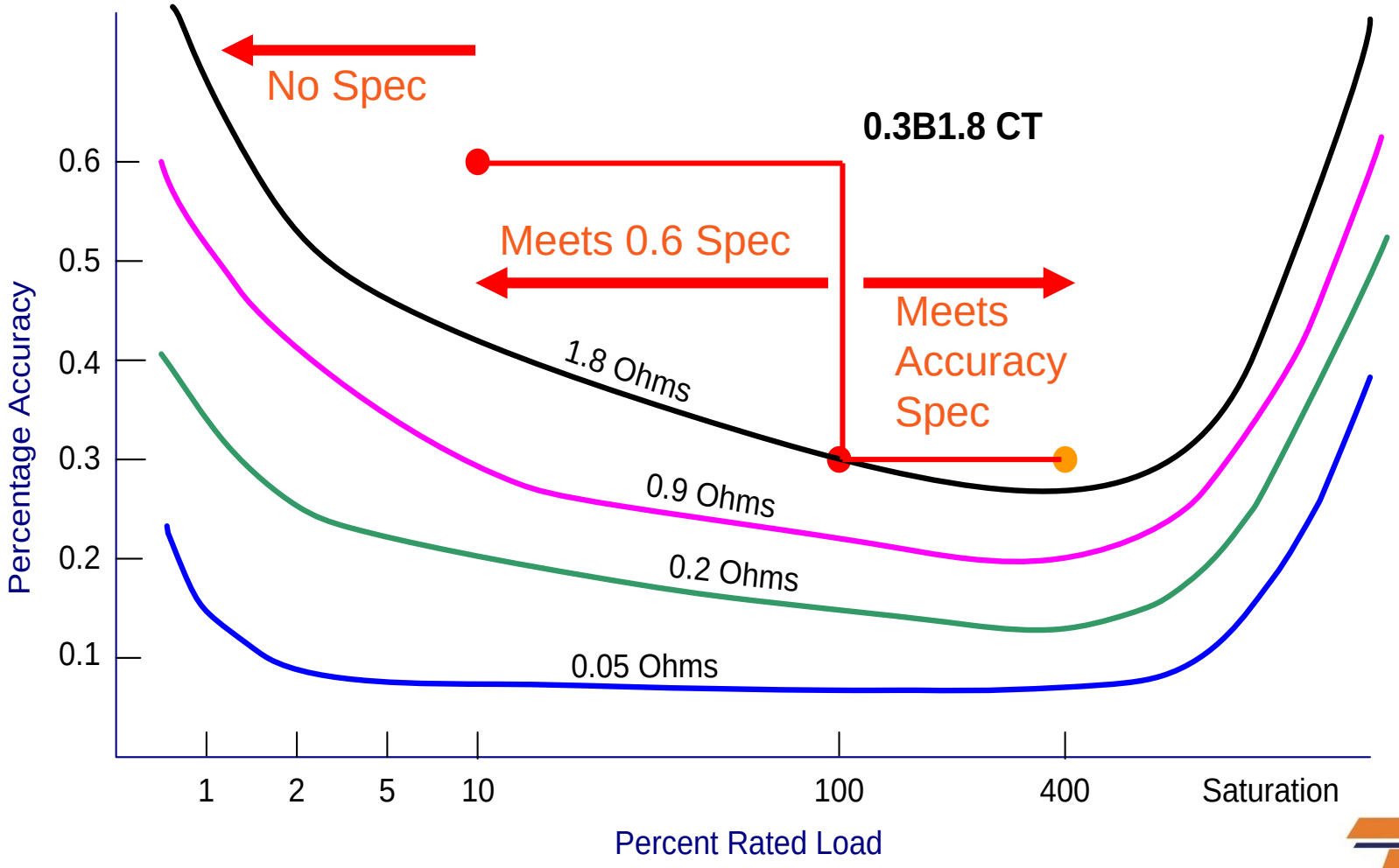
CT – Accuracy - Burden - Load



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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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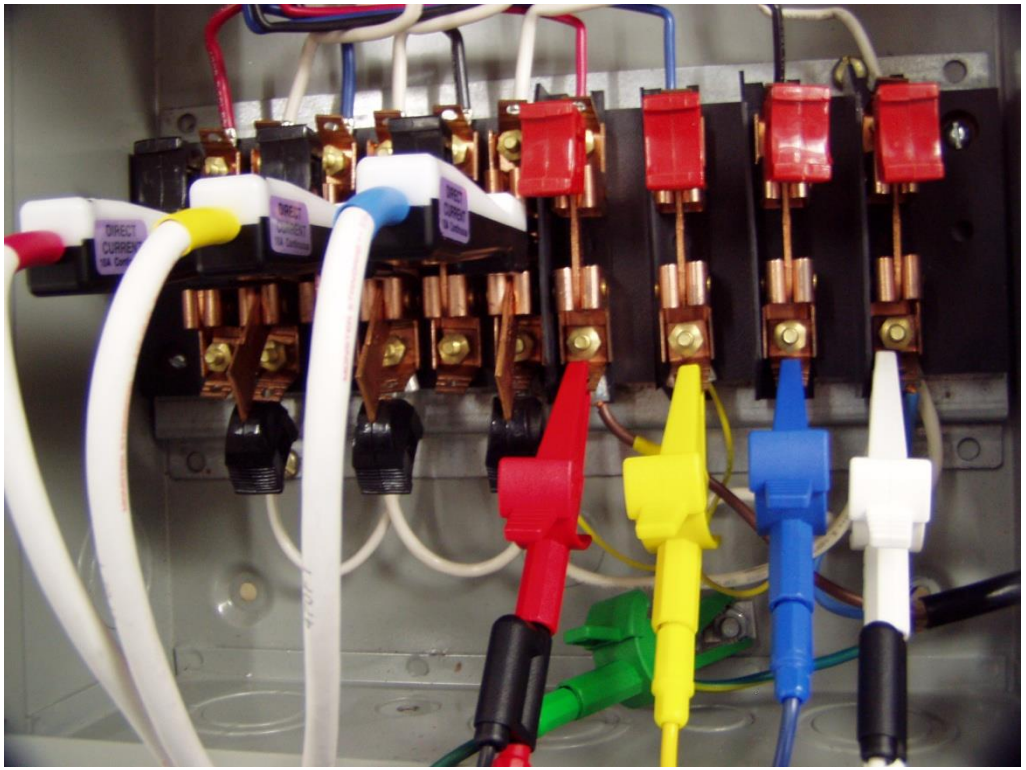
CT Ratio with Burden Testing



- 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.

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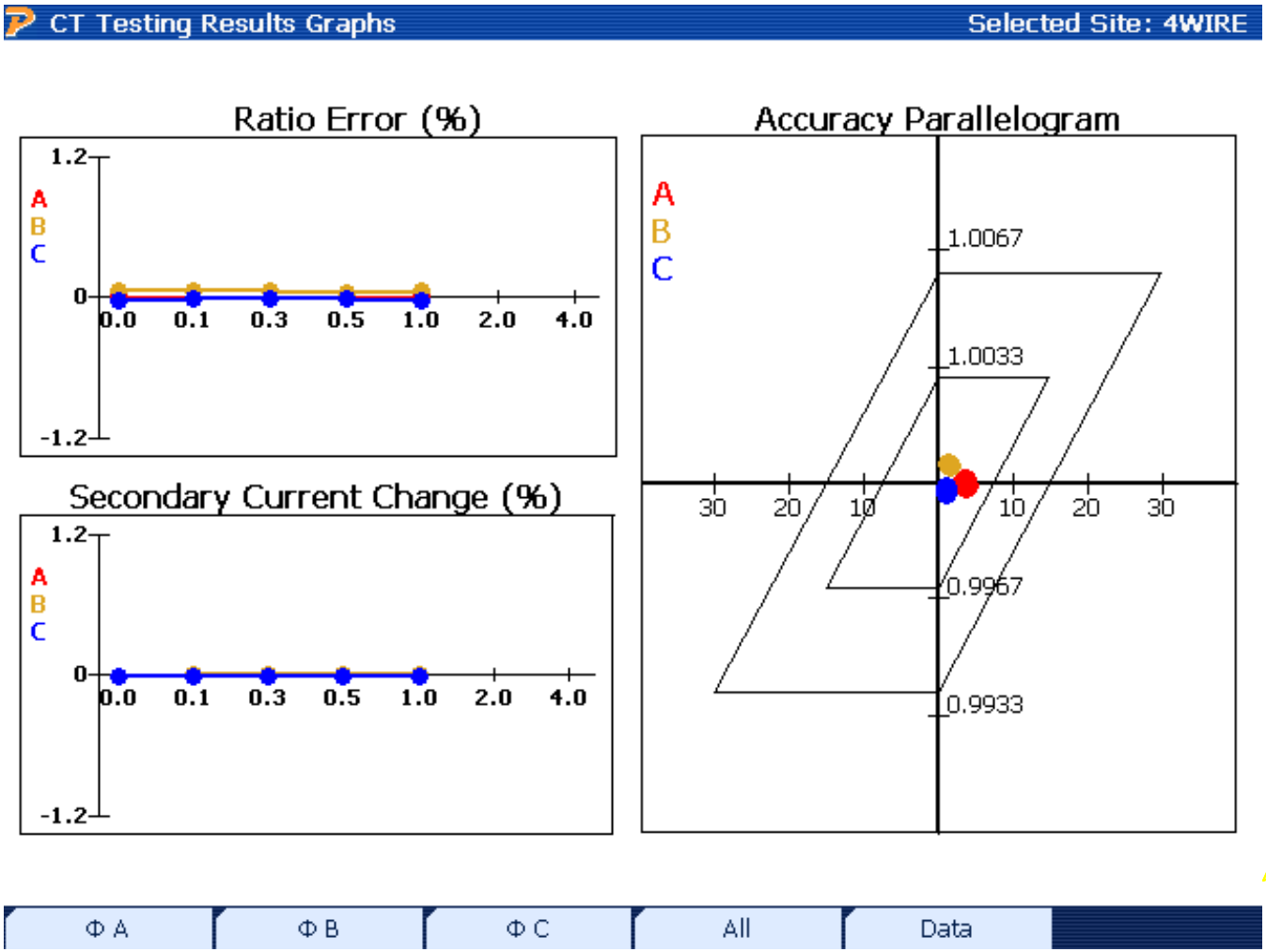
Integrated Site Test Philosophy



Reference CTs measured using Powermaster

CT Testing

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Direct Burden Measurement

- DBM measures voltage and current at the CT secondary and uses Ohm's law to get a specific burden reading

- V = I * R

  becomes

- R (burden) = V / I

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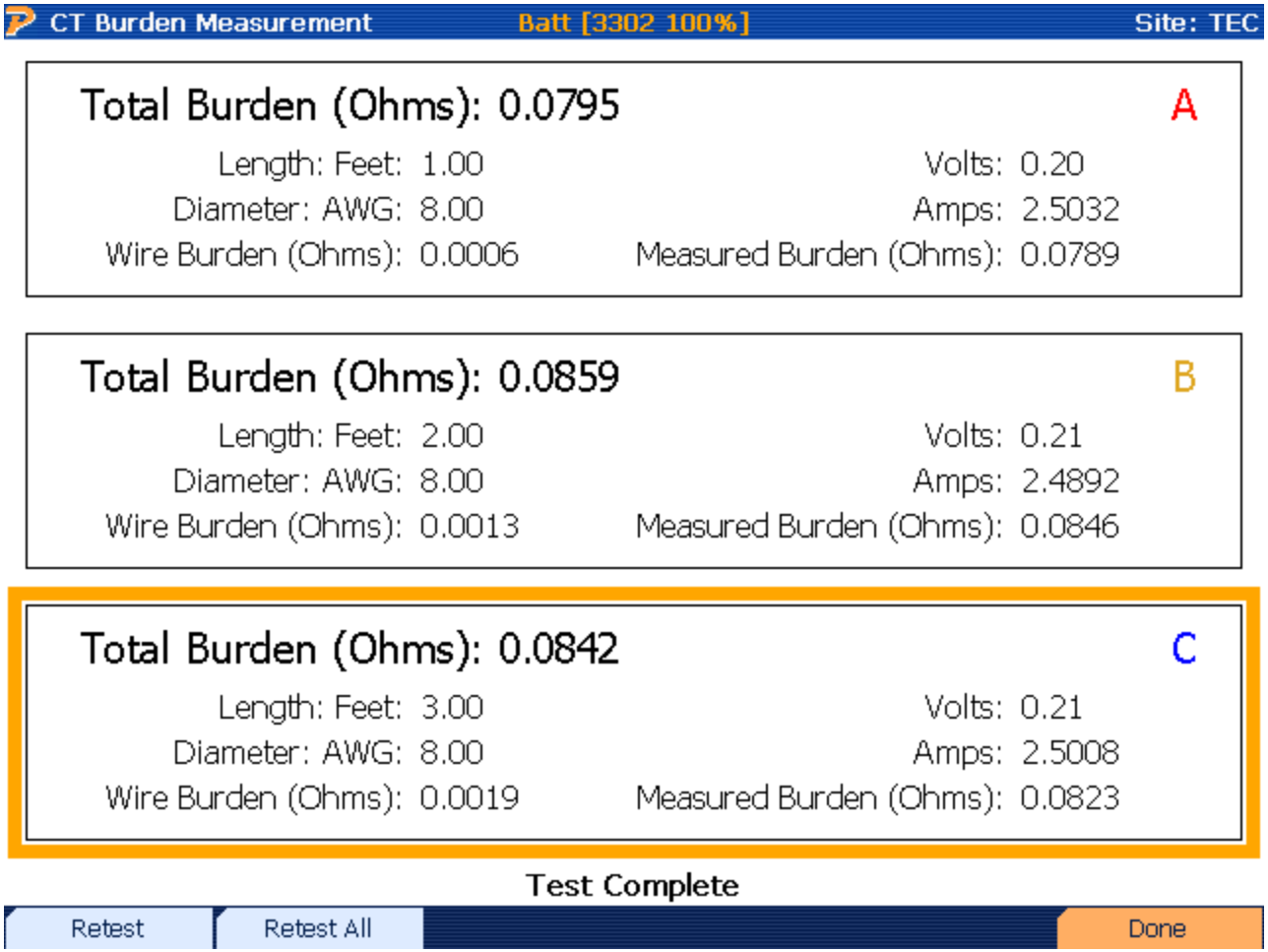
Direct Burden Measurement



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Direct Burden Measurement

- Can be used on sites with as low as 1mA on the secondary
- This is the preferred technique over added burden as it gives a direct answer rather than a burden range
- DBM can also be used to help troubleshoot loose and intermittent connections

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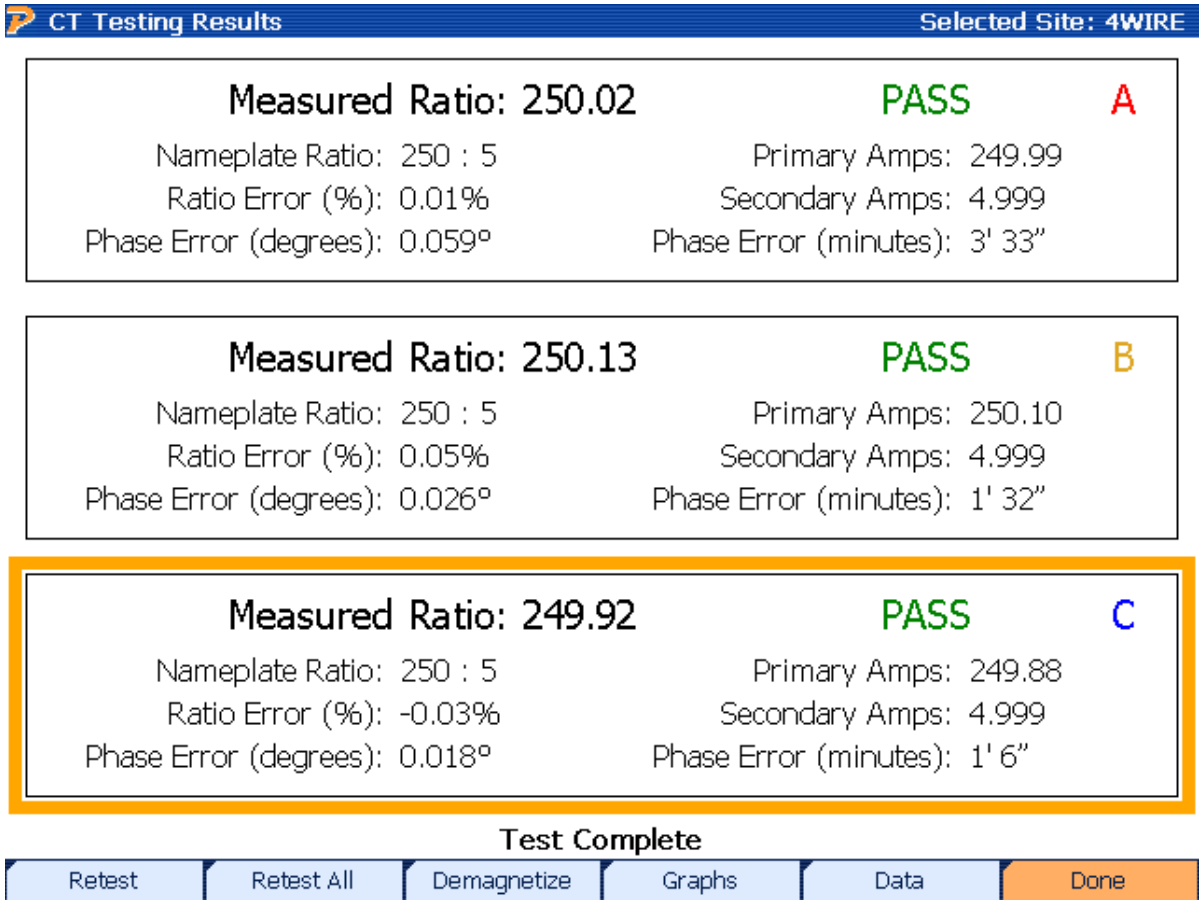
Testing Current Transformers

Ratio vs Applied Burden

- CT testing can be done with very high accuracy



Reference CT measured using PowerMaster with 752 clamp-on probes. Essentially NO ratio error, phase shift, or change in secondary current versus applied burden.

POWERMETRIX

Testing Current Transformers

Ratio vs Applied Burden

- CT testing can be done with very high accuracy

CT Testing Results — Selected Site: 4WIRE

% Change in Secondary Amps

Phase	Ref	0.0Ω	0.1Ω	0.3Ω	0.5Ω	1.0Ω	2.0Ω	4.0Ω
A		0.000	0.000	0.000	0.000	0.000	N/A	N/A
B		0.000	0.001	0.001	0.001	0.001	N/A	N/A
C		0.000	-0.001	-0.001	0.000	0.000	N/A	N/A

Ratio Data

Phase	Ref	0.0Ω	0.1Ω	0.3Ω	0.5Ω	1.0Ω	2.0Ω	4.0Ω
A	250:5	250.02	249.98	249.96	249.98	250.02	N/A	N/A
B	250:5	250.13	250.13	250.13	250.12	250.13	N/A	N/A
C	250:5	249.92	249.97	249.96	249.96	249.96	N/A	N/A

Ratio Error (%)

Phase	Ref	0.0Ω	0.1Ω	0.3Ω	0.5Ω	1.0Ω	2.0Ω	4.0Ω
A		0.01	-0.01	-0.02	-0.01	0.01	N/A	N/A
B		0.05	0.05	0.05	0.05	0.05	N/A	N/A
C		-0.03	-0.01	-0.02	-0.02	-0.02	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		0.06	0.07	0.06	0.07	0.06	N/A	N/A
B		0.03	0.03	0.02	0.03	0.02	N/A	N/A
C		0.02	0.02	0.02	0.02	0.02	N/A	N/A

Graphs

Reference CT measured using PowerMaster with 752 clamp-on probes. Essentially NO ratio error, phase shift, or change in secondary current versus applied burden.

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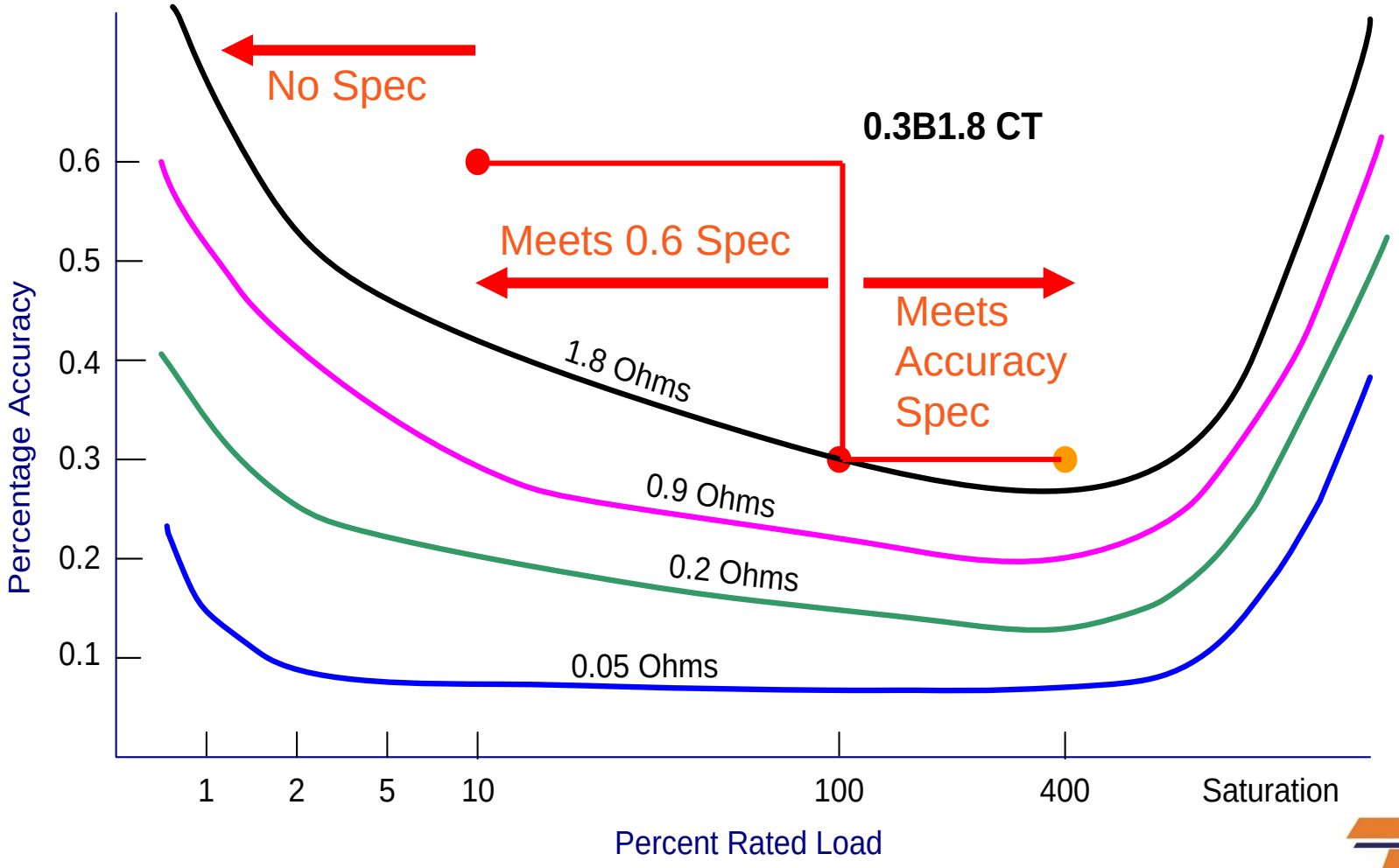
CT – Accuracy – Burden - Load



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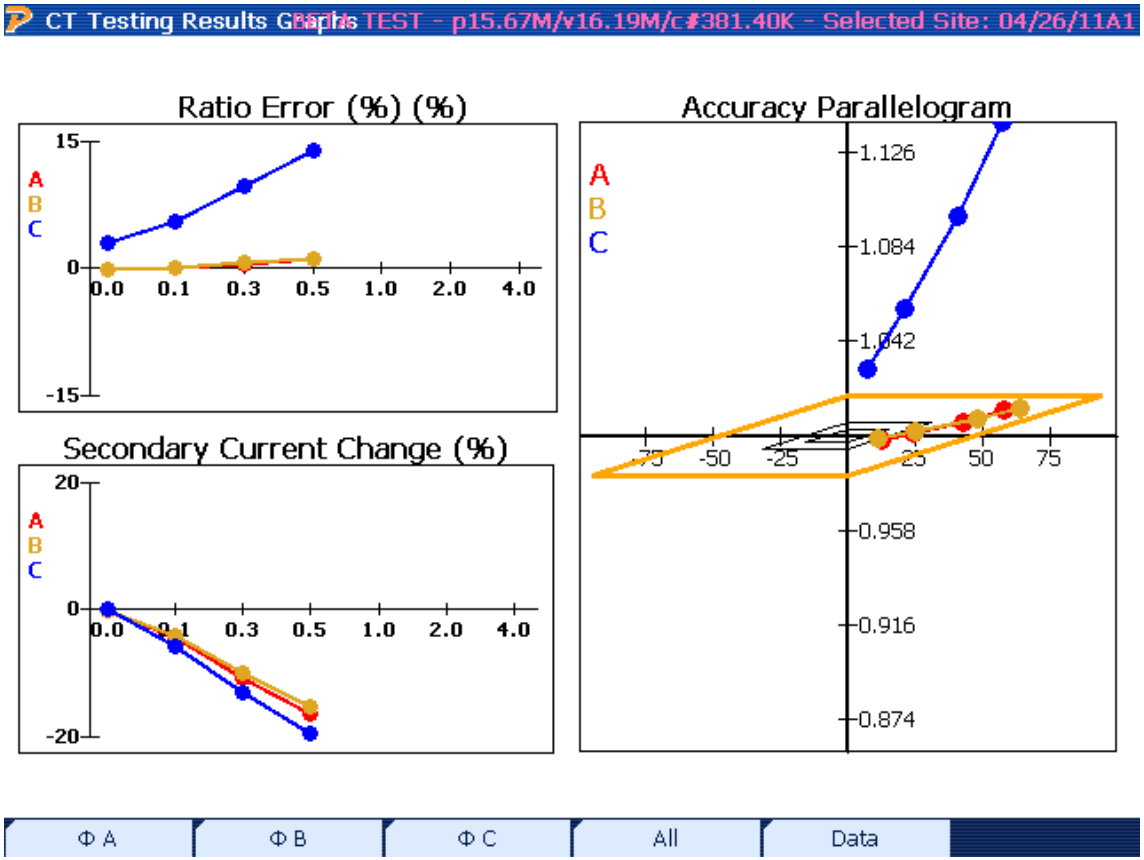
Testing Current Transformers
Ratio vs Applied Burden

- Arrived at site and ran a CT test



- Phase C looked really bad.

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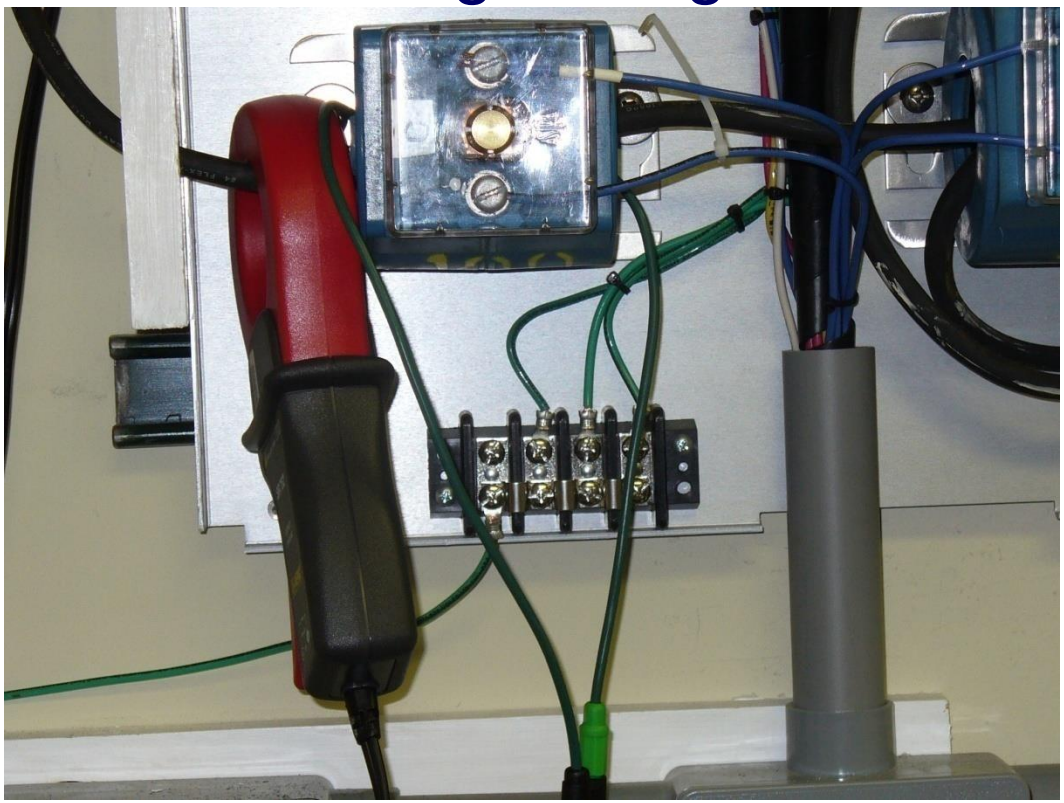
Testing Current Transformers

Ratio vs Applied Burden

- Saw wire running through CT.



- Shouldn't be there.

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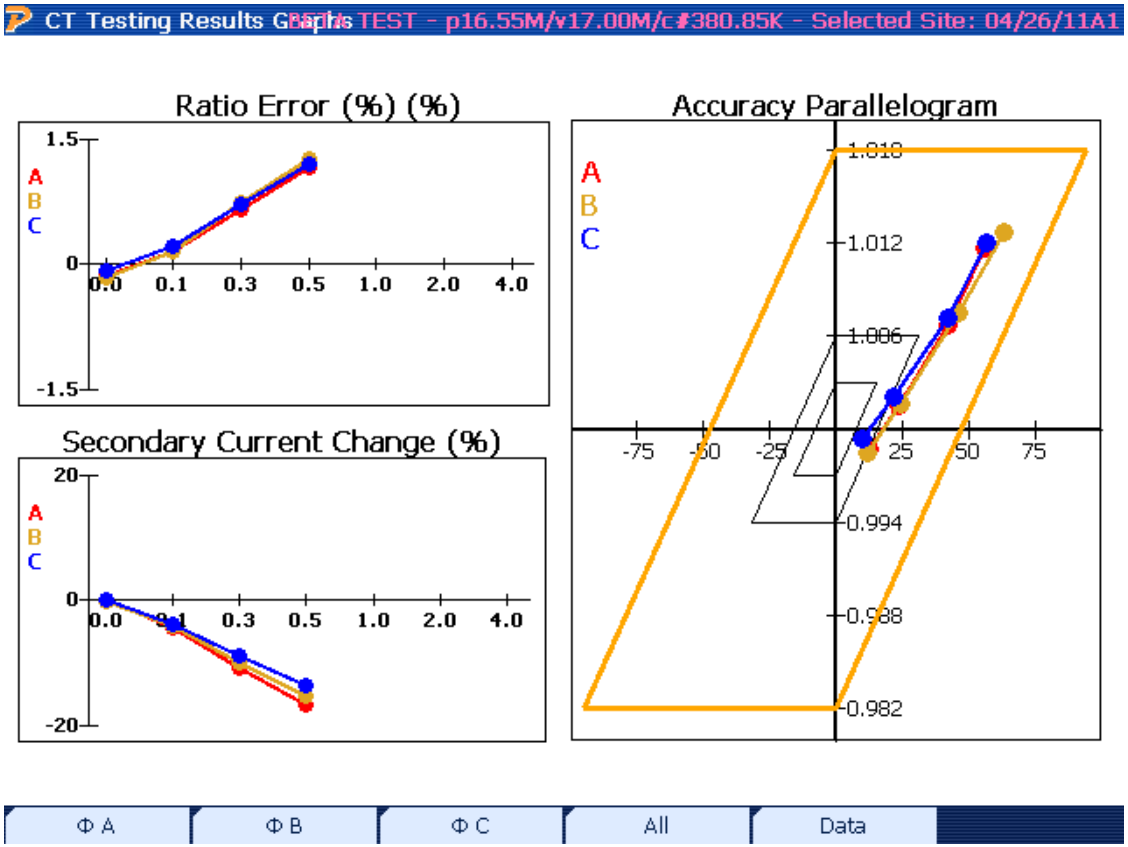
Testing Current Transformers
Ratio vs Applied Burden

- Removed wire.



- Everything tests OK.

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PTs

- **Another low accuracy item in chain**
  - 0.3 percent basic accuracy
- **Accuracy decreases rapidly with burden**

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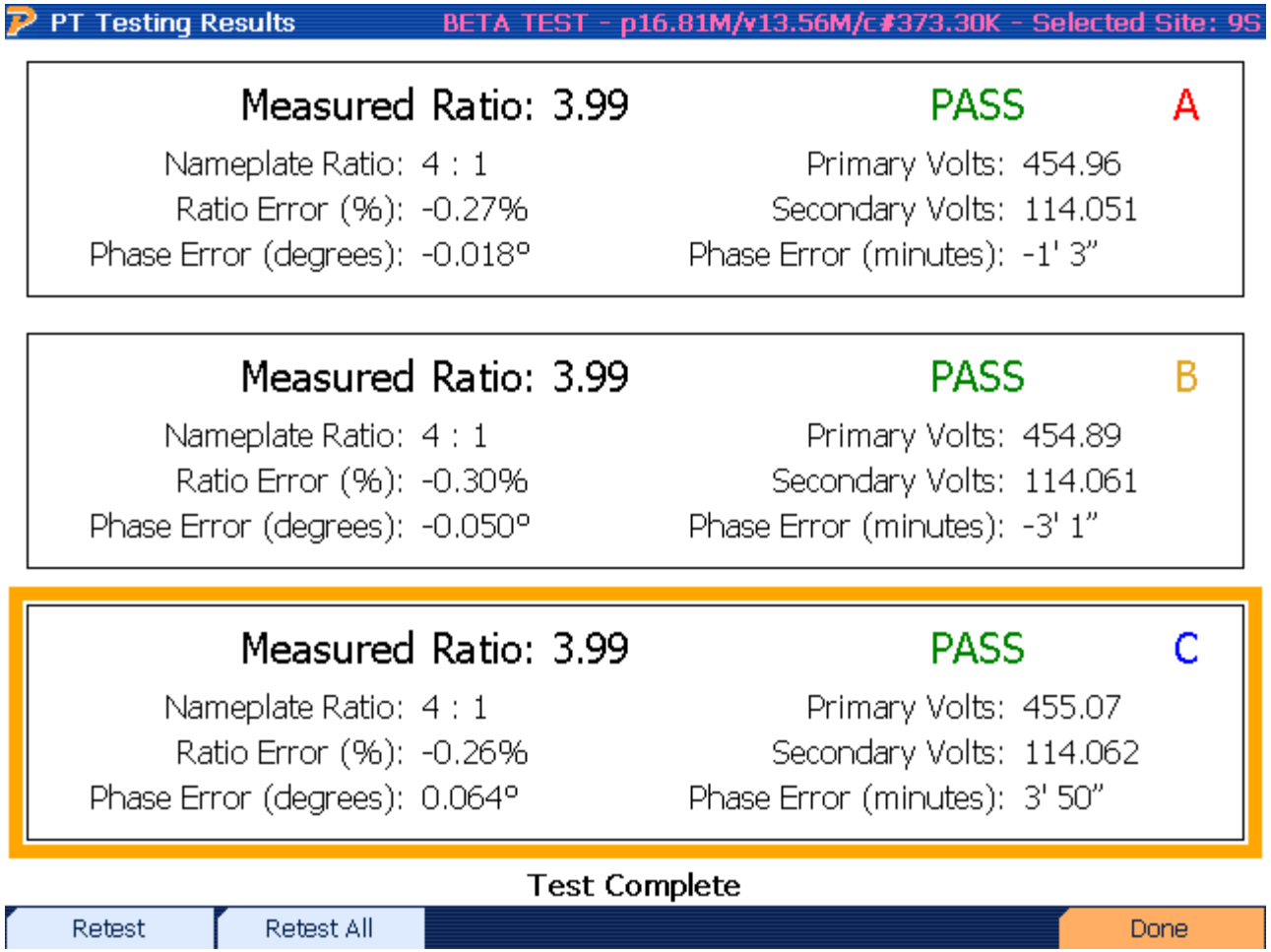
Testing Potential Transformers

Ratio Test



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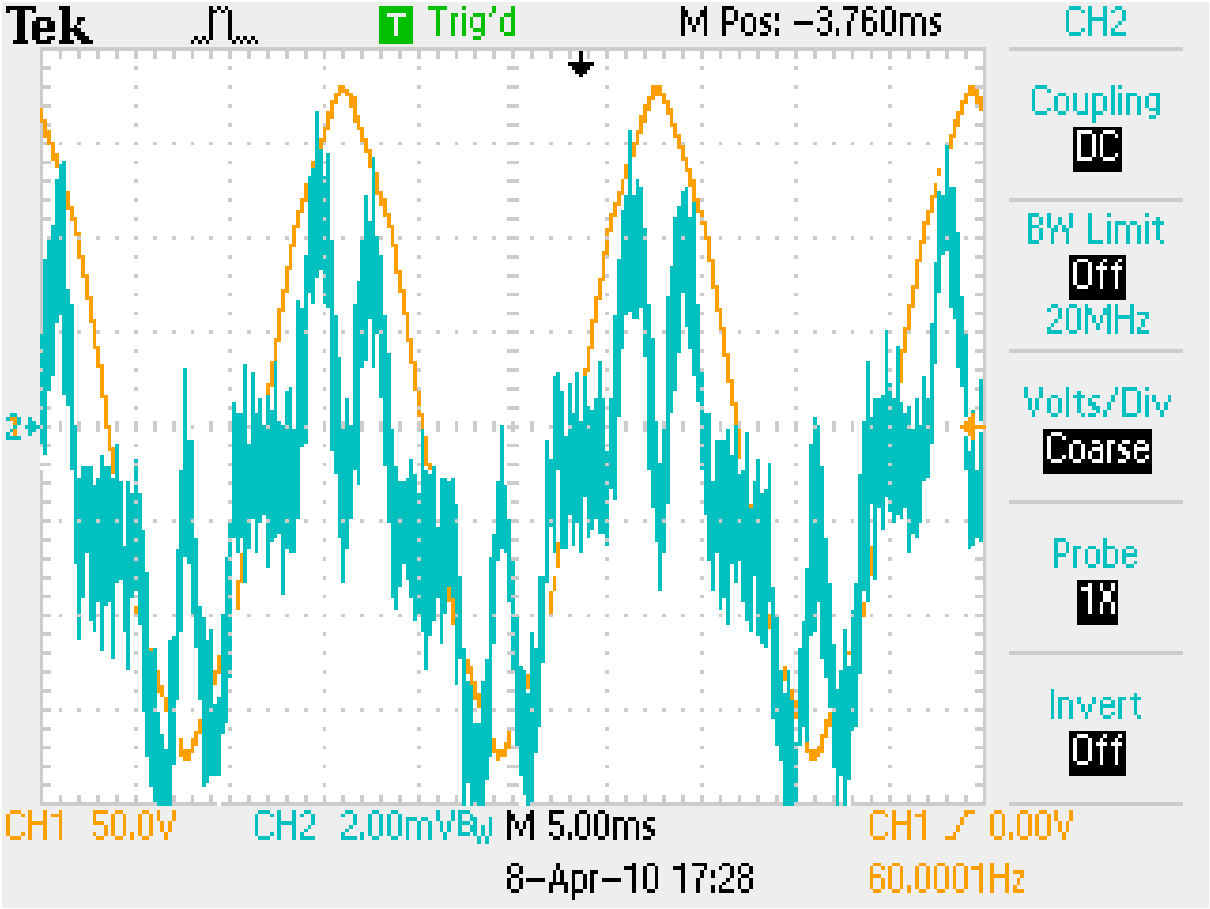
Overloaded PT

- **Under sized PT can lead to overburden situation and waveform distortion. Especially with high end meters.**



Yellow — PT output

Blue – Current being drawn by meter from this phase

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Meter Performance under Real World Conditions

- **The fact that a meter is accurate in the lab does not mean it is accurate in the field**
  - Harmonics
  - Rapidly changing loads
  - Power factor variations
- **Can all affect accuracy**

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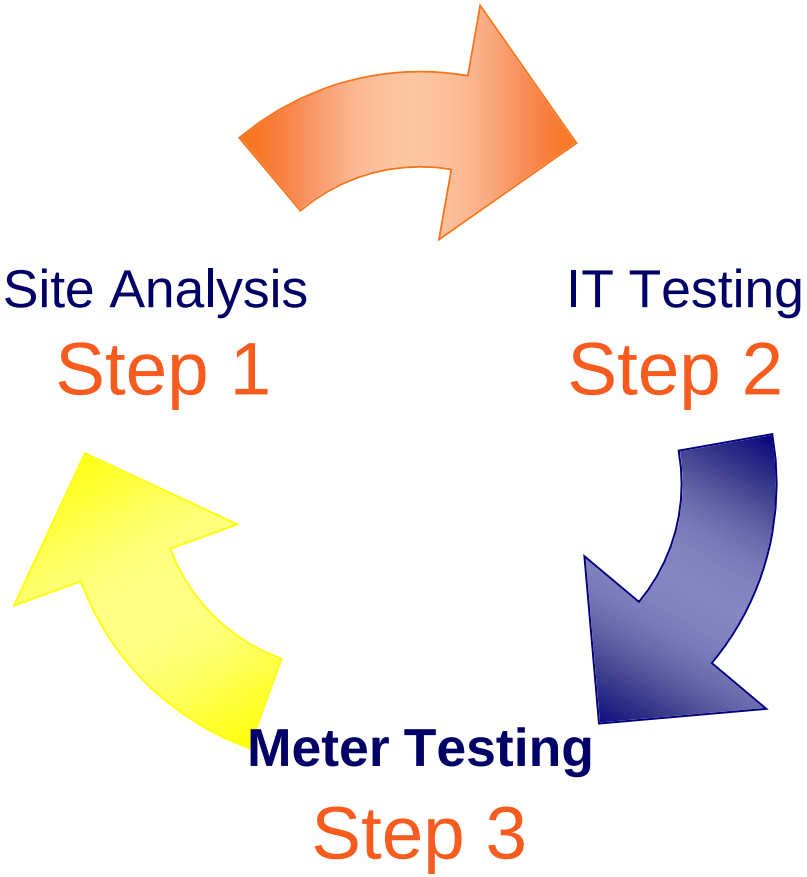
Integrated Site Test Philosophy



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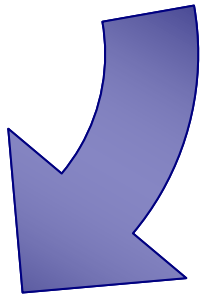
Integrated Site Test Philosophy

Meter Testing



Customer Load Test

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

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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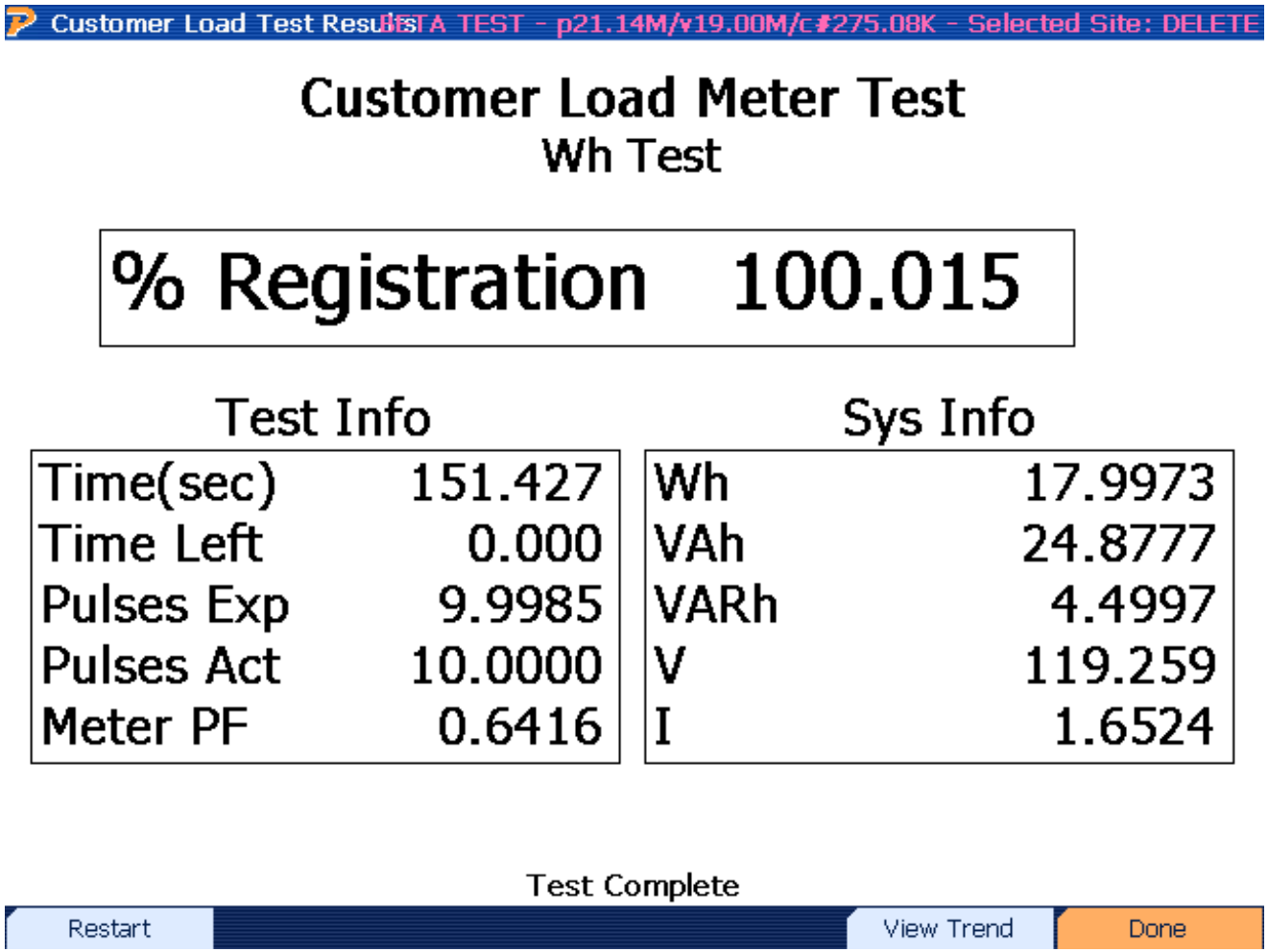
Integrated Site Test Philosophy



Meter Testing

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Integrated Site Test Philosophy

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

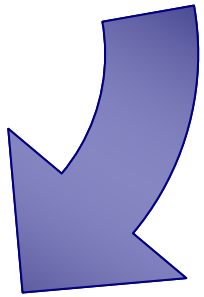
LL 99.966

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

Page 1 / 1

Retest | Retest All | Done

Meter Testing



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Integrated Site Test Philosophy

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

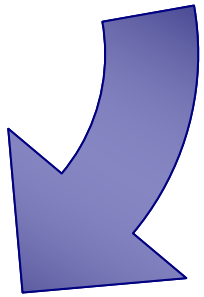
Int	Start Time	Pulses	Voltage	Current	PF	Wh	VAh	mVARh	%REG
1	10:45 AM	35.97	116.580	2.256	0.998	64.77	64.84	-1660.17	99.96
2	10:50 AM	35.95	116.566	2.255	0.998	64.74	64.81	-1639.85	99.96
3	10:55 AM	35.91	116.480	2.255	0.998	64.66	64.73	-1633.58	99.96

Demand Interval	116.542	2.256	0.998	194.16	194.37	-4933.60	99.96
Minimum	116.480	2.255	0.998	64.66	64.73	-1660.17	99.96
Maximum	116.580	2.256	0.998	64.77	64.84	-1633.58	99.96

Test Complete - Data Saved

View Trend | Meter Reg. | Done

Meter Testing



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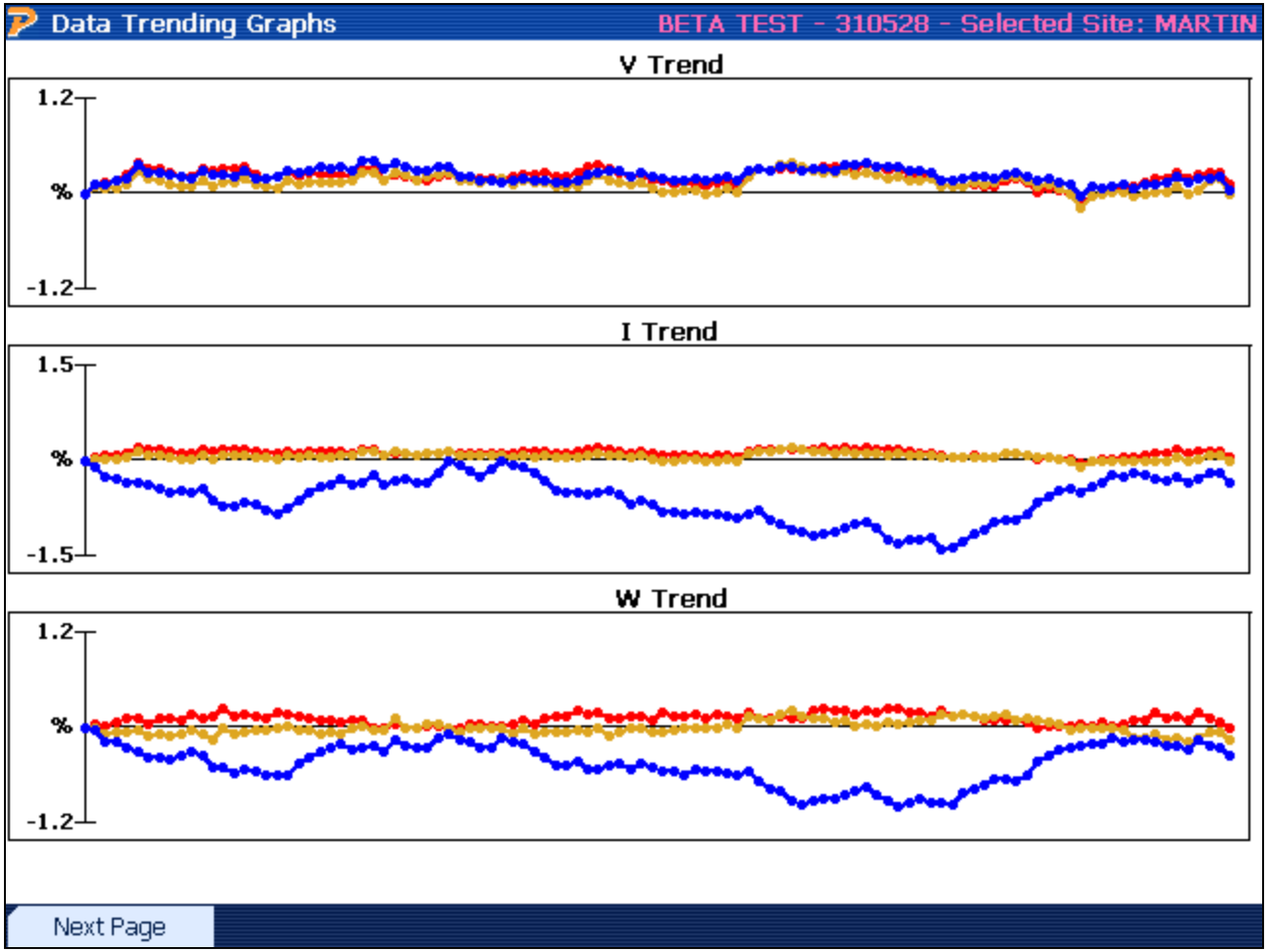
Integrated Site Test Philosophy



Meter Testing

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Meter Performance under Real World Conditions

- **Large “errors” can occur in the calculation of VA and VARS when PF≠1**
  - There is no “official” definition in the presence harmonics.
  - Different meters may implement different definitions
  - Variations can be as large as 15-30 percent between two meters each of which is “working properly”

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Clerical Errors

- **Clerical errors can be the largest of all**
  - No amount of testing will detect them
  - Only care and careful procedures will eliminate these errors

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Not All Problems are Natural

- **The current recession has dramatically increased incidences of revenue theft**
  - Self Contained Services
    - Diversion prior to the meter
    - Meter by-passing
  - Transformer Rated Services
    - Diversion prior to CT
    - Tampering with the CT
    - Tampering with PT
    - Tampering with meter wiring

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The Same Testing

That Finds Revenue Loss

Due to Equipment Problems

Also Finds

Revenue Loss Due to Theft

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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.**

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When Accuracy Really Matters

- **What do you do when 0.5% to 1.1% accuracy is not enough?**
  - Meter – Choose a 0.2% accuracy class
    - Test for accuracy under customer load conditions
  - CT – Use accuracy class 0.15S
    - Or reduce burden well below rated levels
  - PT – Use accuracy class 0.15S
    - Or reduce burden well below rated levels

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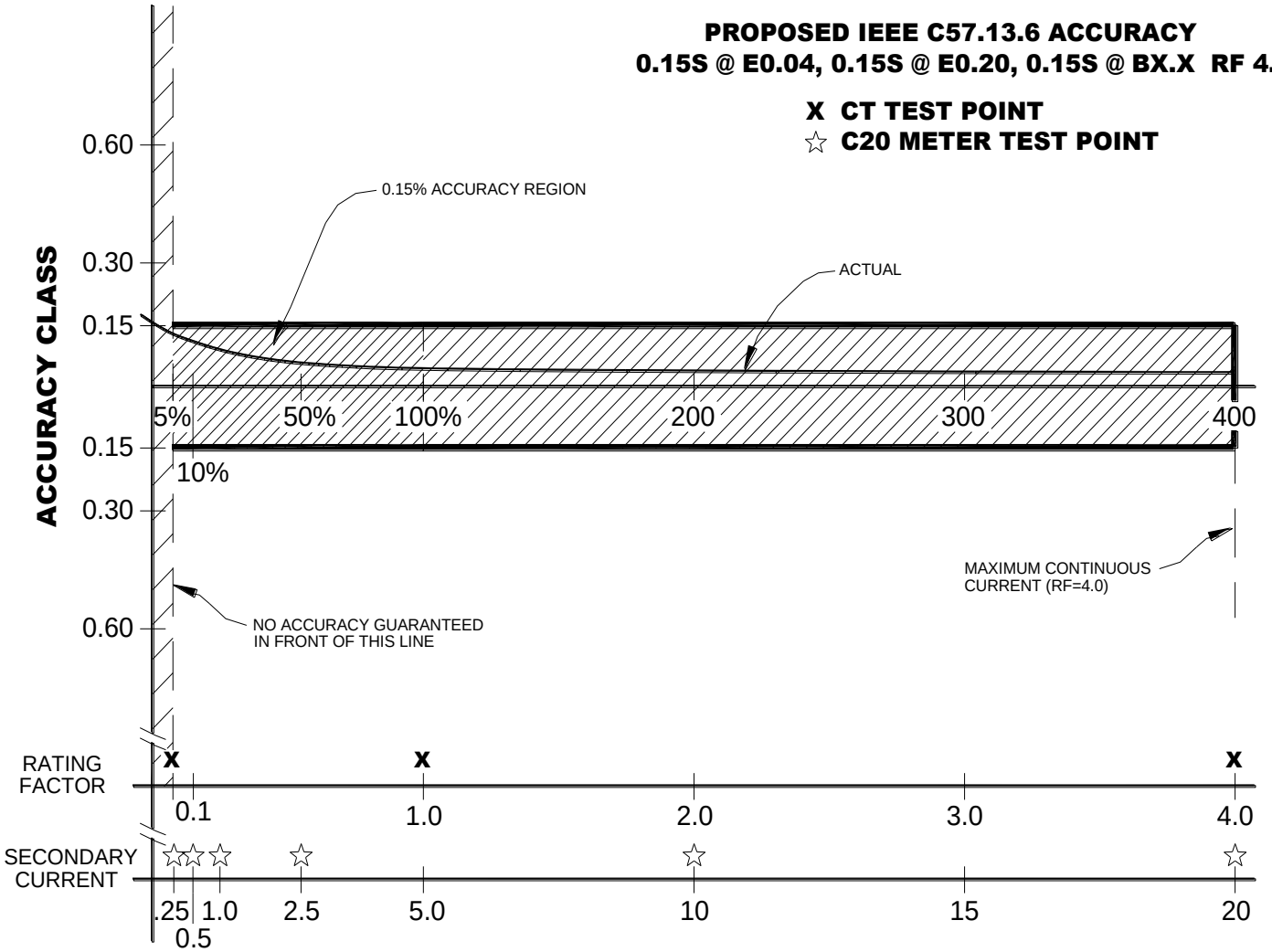
Burden Class 0.15S



Slide Courtesy Kent Jones, GE

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When Accuracy Really Matters

- **We can reasonably obtain:**
  - Meter – 0.2%
  - CT – 0.15%
  - PT – 0.15%
- **Worse Case Error Estimate**
  - 0.2% + 0.15% + 0.15% = 0.5%
- **Expensive to implement but doable.**
- **Reducing the burden can often accomplish nearly as much**

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The Best Accuracy

- **The best we can obtain:**
  - Meter – 0.07%
  - CT – 0.05% 0.15S CT with low burden in optimal range
  - PT – None
- **Worse Case Error Estimate**
  - 0.07% + 0.05% = 0.12%

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