Electric Meter and Transformer Testing in an AMI World

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for Aclara Connect
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Objective – understand the need and best practices for meter and instrument transformer testing in an AMI world

- Acceptance and Functional Testing during and after AMI
- Certification
- Accuracy Testing in the shop and field
- Blondel's theorem and why this matters to us in metering
- Site Verification and not just meter testing
- Instrument Transformer Testing (in shop and in field)
- AMI meter population management

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Questions to Answer

- Why do we test?
- How do we test?
- What types of meter tests are there?
- How do utility tests differ from customer request tests?
- What is In-Service Testing?
- How do we know meter tests are good?
- What do we do with the test data?
- What else should we test besides the meter?
- What range of tests/checks should be done in the shop?
- What range of tests/checks should be done in the field?
- Where is the biggest pay back for our limited meter service resources (field and shop)?

Why Do We Test?

- Our regulatory commissions require us to test meters.
- But only for accuracy. State regulatory commissions want electric utilities to ensure that no customer is being billed unfairly and that no subset of customers is being unfairly subsidized by the rest of the rate payers. Some states mandate only accuracy tests and others require demand and time of use accuracy tests.
- Any tests beyond accuracy tests are tests that are simply good business practice.
- And no tests are mandated for functional or accuracy testing of the instrument transformers that are an integral part of the metering circuit.

Complaint Testing

- Customers always have the right to request a meter test.
- Some utilities and some jurisdictions allow for testing at the customer site, others require a test in a laboratory environment.
- Some allow the customer to witness the test and others require the utility commission to witness the test.
- Utilities must show that the meter tests well and must demonstrate that they have a test program in place to ensure the meters in service are performing well.

General Meter Testing Requirements

- New Meters
  - Manufacturers tests
  - In-house tests on new shipments
- Return to Service Testing
- In-Service Meters
  - Periodic Tests
  - Selective, random, or statistical testing
- Retirement tests
- Testing of related metering equipment

New Meter Testing Programs

- Accept the Manufacturer’s Test results
- Perform a Statistical Test of an incoming shipment
- Perform a 100% test of an incoming shipment

Return to Service Testing

- Meters to be returned to service must always (virtually every utility commission requires this) be accuracy tested before being returned to service.
- Best business practices also require that the meter is functionally tested as well.

In Service Testing

- Meter Testing for new and in-service meters is specified in ANSI C12.1-2015, *American National Standard for Electric Meters, Code for Electricity Metering*. Most utility commissions use this Standard a reference or the basis for their meter testing requirements.

Best Practices

- Residential vs Commercial
- Self-Contained vs Transformer Rated
- Follow the money and be as proactive as possible

Using AMI Data

- **AMI data can provide actual usage**
- **Site Verification data can provide a correlation to the Transformers installed at the installation**
- **Not a very difficult analysis to determine how often any one particular installation is operating outside of the operationg parallelogram for the installed transformers**
- **This allows the utility to replace these transformers with transformers that operate more accurately over a larger range of operating conditions. This is especially true as no utility can ever know who the next tenant in a building will be or how they will utilize the service or even how an existing company's needs will change over time.**
- **Look for missing current on a single leg or intermittent data**

Self Contained

- Use AMI analytics on self-contained services to determine where there are problems
- Look for technical and non-technical losses through these analytics
- Minimize the use of field resources in checking these services
- Free up as many field and shop resources as possible to check on and be as proactive as possible with your Transformer Rated services

Why?

Because the Transformer Rated Services are where the money is!!!!

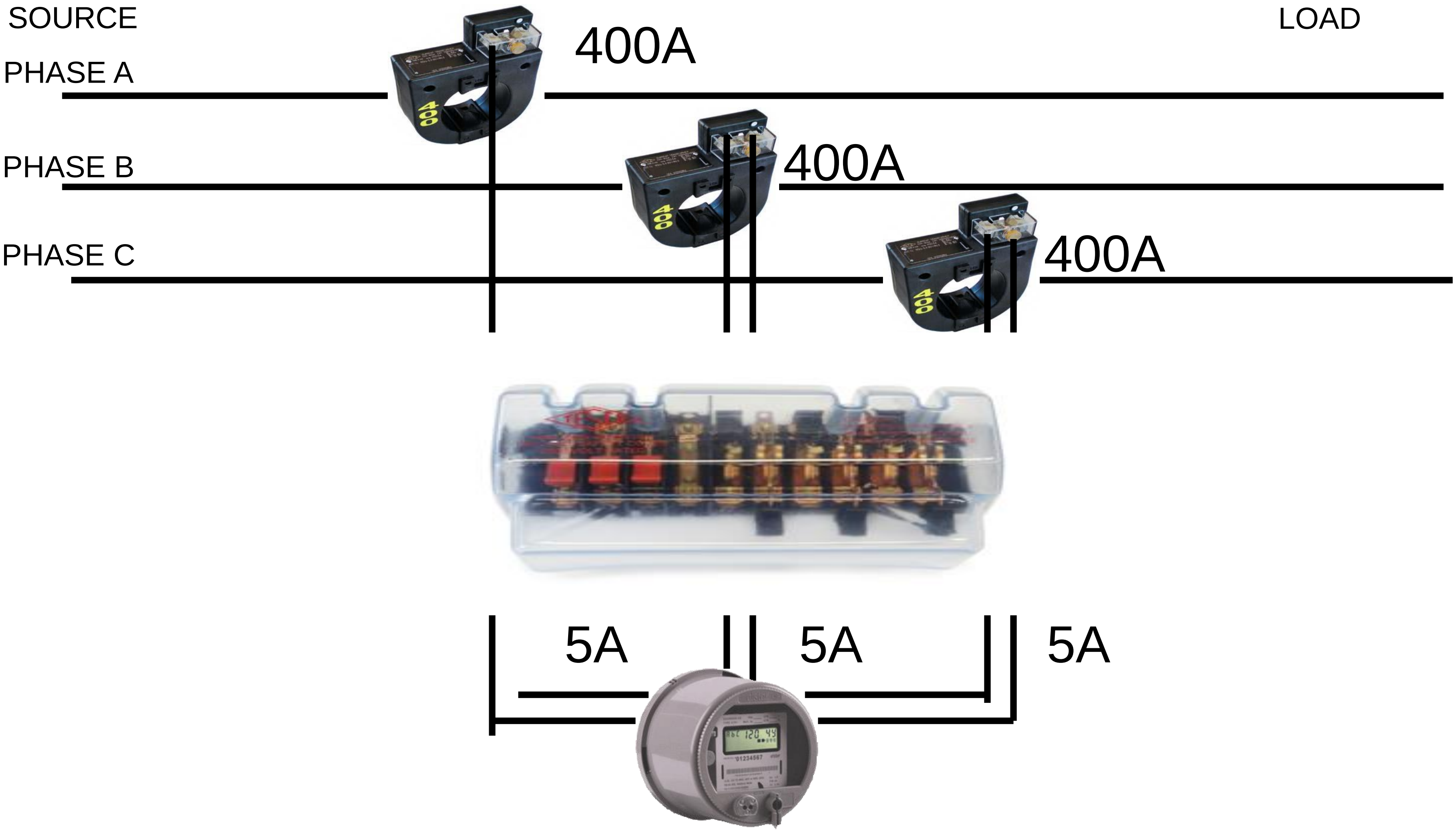
Site Verification: Why should we invest our limited meter service resources here

- These customers represent a disproportionately large amount of the overall revenue for every utility in North America.
- For some utilities the ten percent of their customers who have transformer rated metering services can represent over 70% of their overall revenue.
- While these numbers will vary from utility to utility the basic premise should be the same for all utilities regarding where Meter Services should focus their efforts
- This is perhaps one of the larger benefits that AMI can provide for our Utilities – more time to spend on C&I metering and less on residential

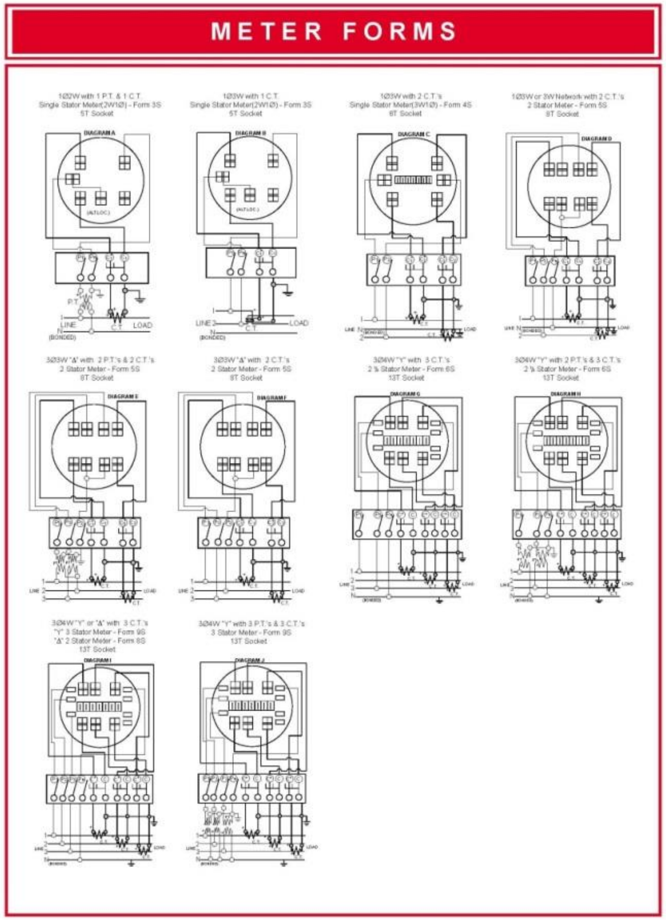
Easy Answer: Money.

The Basic Components

9S Meter Installation with 400:5 CT's



Typical Connections



Typical Connections for Common Transformer (Instrument) Rated Meter Forms

Meter Accuracy Testing

Meter Accuracy Testing in a Nutshell

- ✓ Full Load
- ✓ Light Load
- ✓ Power Factor

Three Phase Power
Blondel's Theorem

The theory of polyphase watthour metering was first set forth on a scientific basis in 1893 by Andre E. Blondel, engineer and mathematician. His theorem applies to the measurement of real power in a polyphase system of any number of wires. The theorem is as follows:

- *If energy is supplied to any system of conductors through N wires, the total power in the system is given by the algebraic sum of the readings of N wattmeters, so arranged that each of the N wires contains one current coil, the corresponding voltage coil being connected between that wire and some common point. If this common point is on one of the N wires, the measurement may be made by the use of N-1 wattmeters.*

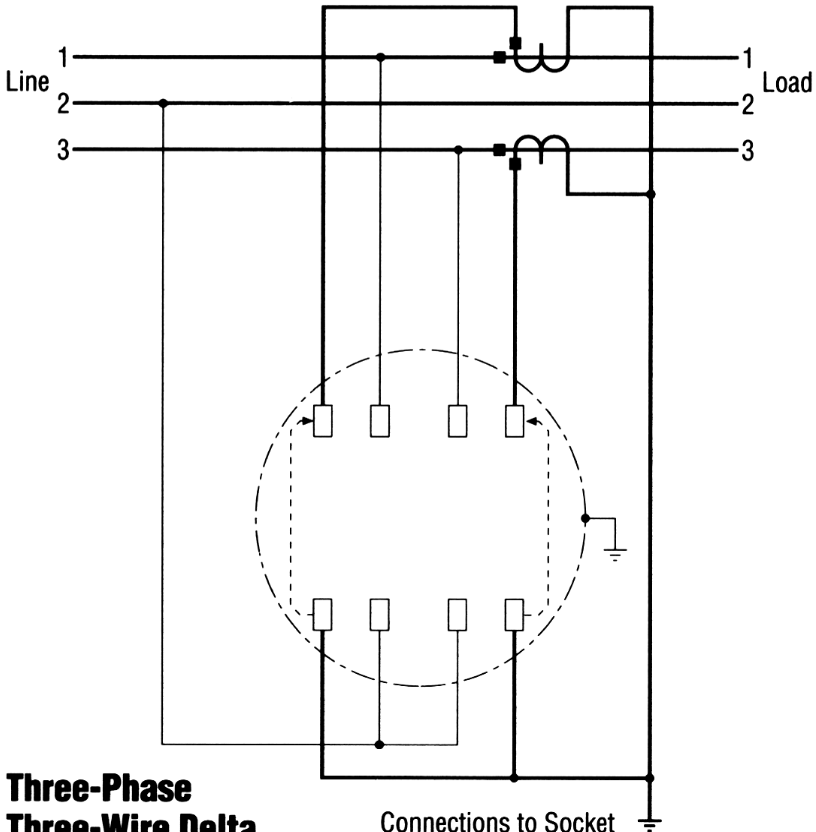
Three Phase Power
Blondel's Theorem

- Simply – We can measure the power in a N wire system by measuring the power in N-1 conductors.
- For example, in a 4-wire, 3-phase system we need to measure the power in 3 circuits.

Three Phase Power
Blondel's Theorem

- If a meter installation meets Blondel's Theorem then we will get accurate power measurements <u>under all circumstances</u>.
- If a metering system does not meet Blondel's Theorem then we will only get accurate measurements if certain <u>assumptions are met</u>.

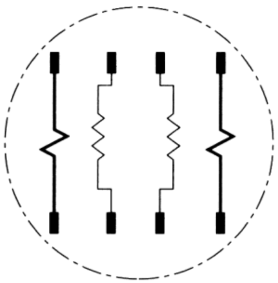
Blondel's Theorem



Three-Phase Three-Wire Delta With Two CTs

Connections to Socket Front View

Form 5S

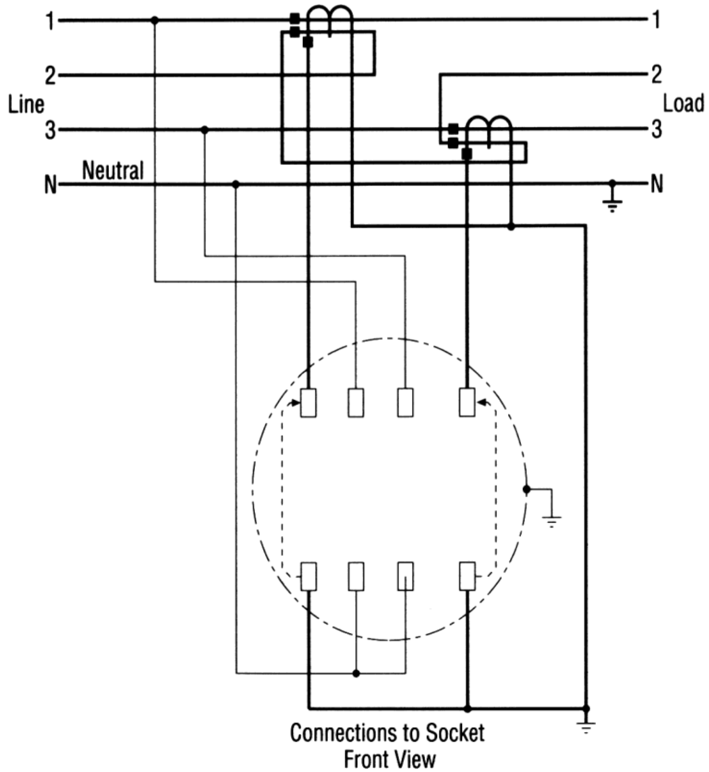


Meter Internal Wiring Front View

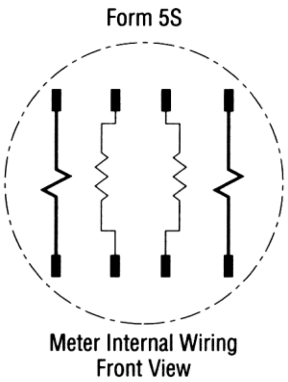
- Three wires
- Two voltage measurements with one side common to Line 2
- Current measurements on lines 1 & 3.

This satisfies Blondel's Theorem.

Blondel's Theorem



Three-Phase
Four-Wire Wye
With Two Equal-Ratio CTs



- Four wires
- Two voltage measurements to neutral
- Current measurements on lines 1 & 3. How about line 2?

This DOES NOT satisfy Blondel's Theorem.

Blondel's Theorem

- In the previous example:
  - What are the "ASSUMPTIONS"?
  - When do we get errors?
- What would the "Right Answer" be?

$$P_{sys} = V_a I_a \cos(\theta_a) + V_b I_b \cos(\theta_b) + V_c I_c \cos(\theta_c)$$

- What did we measure?

$$P_{sys} = V_a [I_a \cos(\theta_a) - I_b \cos(\theta_b)] + V_c [I_c \cos(\theta_c) - I_b \cos(\theta_b)]$$

Blondel's Theorem

Power Measurements Handbook

Condition	% V	% I	Phase A				Phase B				non-Blondel
	Imb	Imb	V	ϕvan	I	ϕian	V	ϕvbn	I	ϕibn	% Err
All balanced	0	0	120	0	100	0	120	180	100	180	0.00%
Unbalanced voltages PF=1	18%	0%	108	0	100	0	132	180	100	180	0.00%
Unbalanced current PF=1	0%	18%	120	0	90	0	120	180	110	180	0.00%
Unbalanced V&I PF=1	5%	18%	117	0	90	0	123	180	110	180	-0.25%
Unbalanced V&I PF=1	8%	18%	110	0	90	0	120	180	110	180	-0.43%
Unbalanced V&I PF=1	8%	50%	110	0	50	0	120	180	100	180	-1.43%
Unbalanced V&I PF=1	18%	40%	108	0	75	0	132	180	125	180	-2.44%
Unbalanced voltages PF≠1 PFa = PFb	18%	0%	108	0	100	30	132	180	100	210	0.00%
Unbalanced current PF≠1 PFa = PFb	0%	18%	120	0	90	30	120	180	110	210	0.00%
Unbalanced V&I PF≠1 PFa = PFb	18%	18%	108	0	90	30	132	180	110	210	-0.99%
Unbalanced V&I PF≠1 PFa = PFb	18%	40%	108	0	75	30	132	180	125	210	-2.44%
Unbalanced voltages PF≠1 PFa ≠ PFb	18%	0%	108	0	100	60	132	180	100	210	-2.61%
Unbalanced current PF≠1 PFa ≠ PFb	0%	18%	120	0	90	60	120	180	110	210	0.00%
Unbalanced V&I PF≠1 PFa ≠ PFb	18%	18%	108	0	90	60	132	180	110	210	-3.46%
Unbalanced V&I PF≠1 PFa ≠ PFb	18%	40%	108	0	75	60	132	180	125	210	-4.63%

The Importance of CT Testing in the Field

- One transformer in three wired backwards will give the customer a bill of 1/3rd the actual bill.
- One broken wire to a single transformer will give the customer a bill of 2/3rd the actual bill
- One dual ratio transformer inappropriately marked in the billing system as 400:5 instead of 800:5 provides a bill that is ½ of the actual bill. And the inverse will give a bill double of what should have been sent. Both are lose-lose situations for the utility.

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The Importance of CT Testing in the Field (cont)

- Cross Phasing (wiring errors)
- Loose or Corroded Connections
- CT Mounted Backwards
- CT’s with Shorted Turns
- Wrong Selection of Dual Ratio CT
- Detect Magnetized CT’s
- Burden Failure in Secondary Circuit
- Open or Shorted Secondary
- Mislabeled CT’s
- Ensures all Shorting Blocks have been Removed

Testing at Transformer Rated Sites

- ✓Meter Accuracy
- ✓Full Load
- ✓Light Load
- ✓Power Factor
- ✓CT Health
- ✓Burden Testing
- ✓Ratio Testing
- ✓Admittance Testing
- ✓Site Verification

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Poperly sizing Conventional and Extended Range CT’s

- CT Ratings/Parameters
- Standard Accuracy Classes
- Extended-Range Ratings/Types
- Applying ERCTs
- Advantages of ERCT
- The historic revenue metering class is 0.3, with 0.15 being used with increasing frequency.
- 0.15 “high accuracy” classes were introduced under IEEE C57.13.6.

Fundamentals of Polyphase Field Meter Testing and Site Verification

Functionality with Burden Present on the Secondary Loop

PHASE A

- Some burden will always be present – junctions, meter coils, test switches, cables, etc.
- CT's must be able to maintain an accurate ratio with burden on the secondary.

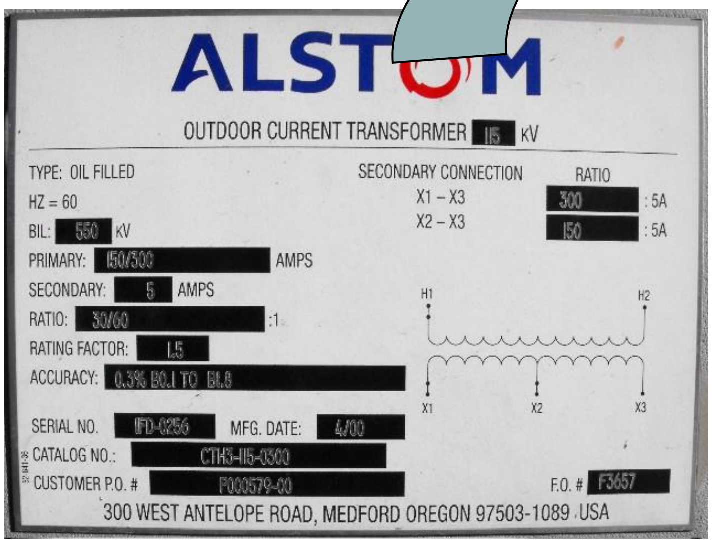
METERING ACCURACY RATING

0.3B1.8

Accuracy Class	Burden Designation
0.15S (High Accuracy)	B0.1
0.15 (High Accuracy)	B0.2
0.3 (Metering Accuracy)	B0.5
0.6 (Indication Accuracy)	B0.9
1.2 (Indication Accuracy)	B1.8

Fundamentals of Polyphase Field Meter Testing and Site Verification

Functionality with Burden Present on the Secondary Loop



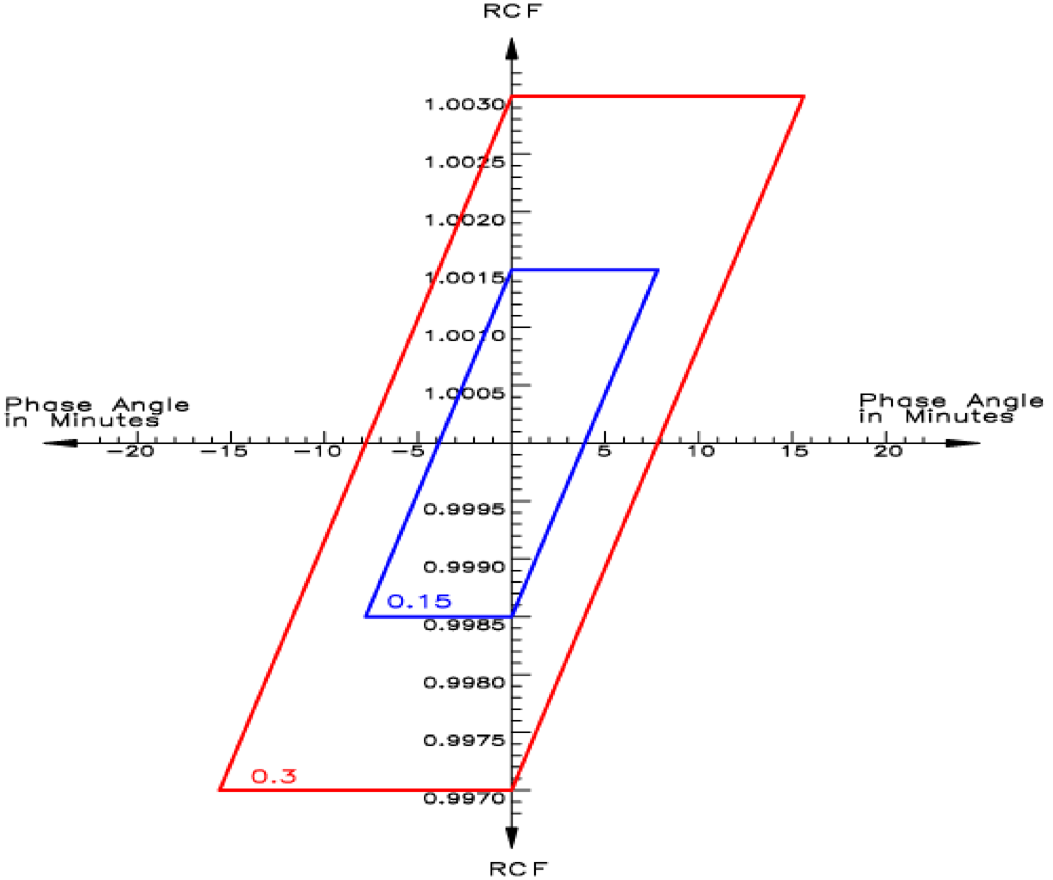
Example Burden Spec:

0.3% @ B0.1, B0.2, B0.5

or

There should be less than the 0.3% change in secondary current from initial ("0" burden) reading, when up to 0.5 Ohms of burden is applied

Current Transformer Accuracy Classes



CT Error

CT error is typically negative…meaning less current in the secondary than there "should" be by the defined ratio.

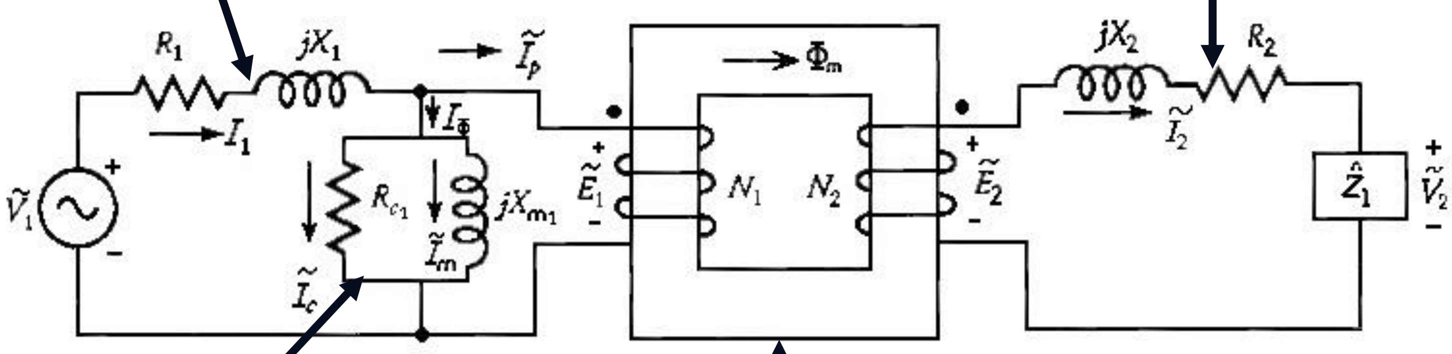
CT error becomes increasingly negative as the primary current level decreases.

Negative Error = Lost Revenue

Idealized Transformer Circuit

Primary Winding Impedance

Secondary Winding Impedance



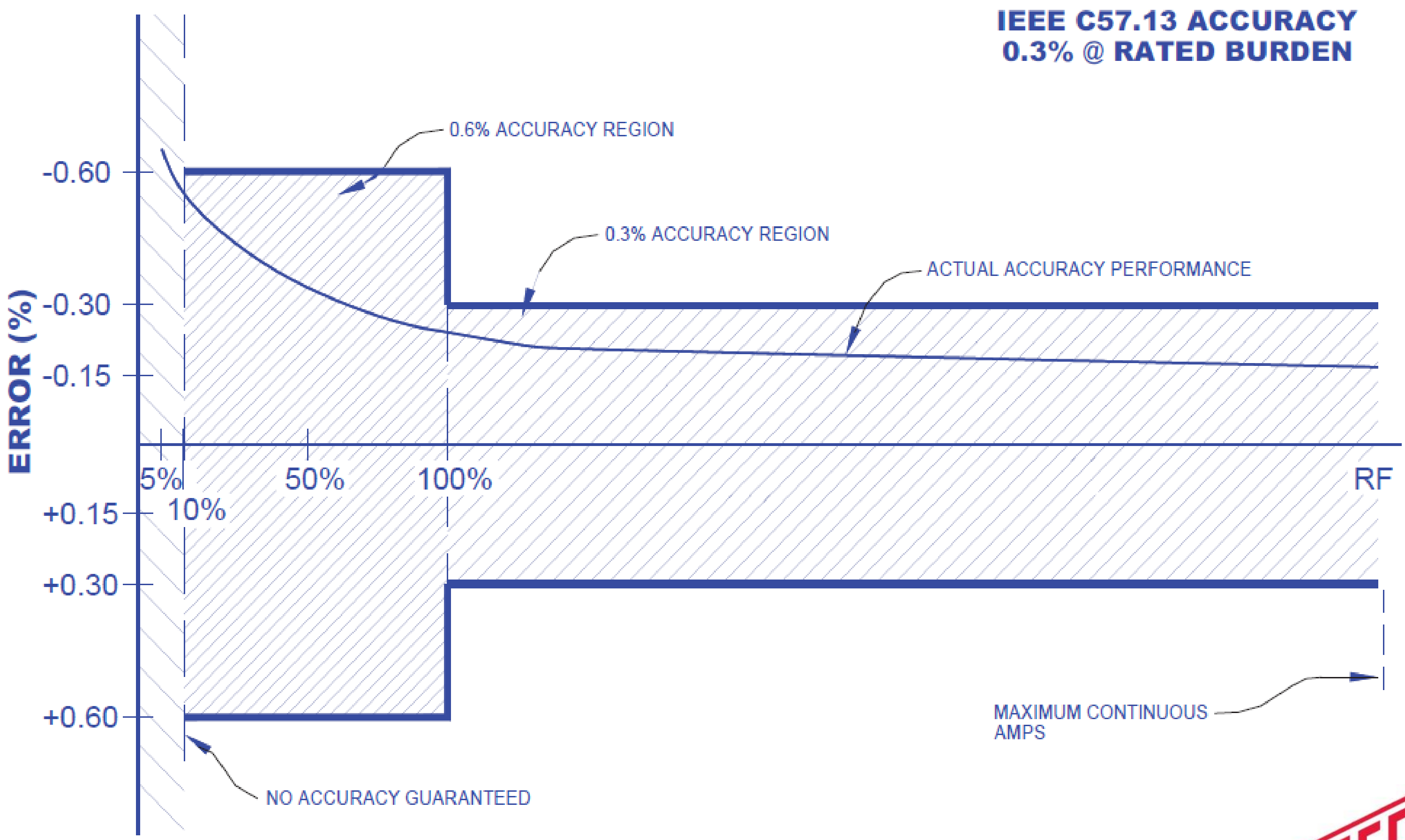
Core Loss Branch

(function of core mat'l, core size, number of sec turns)

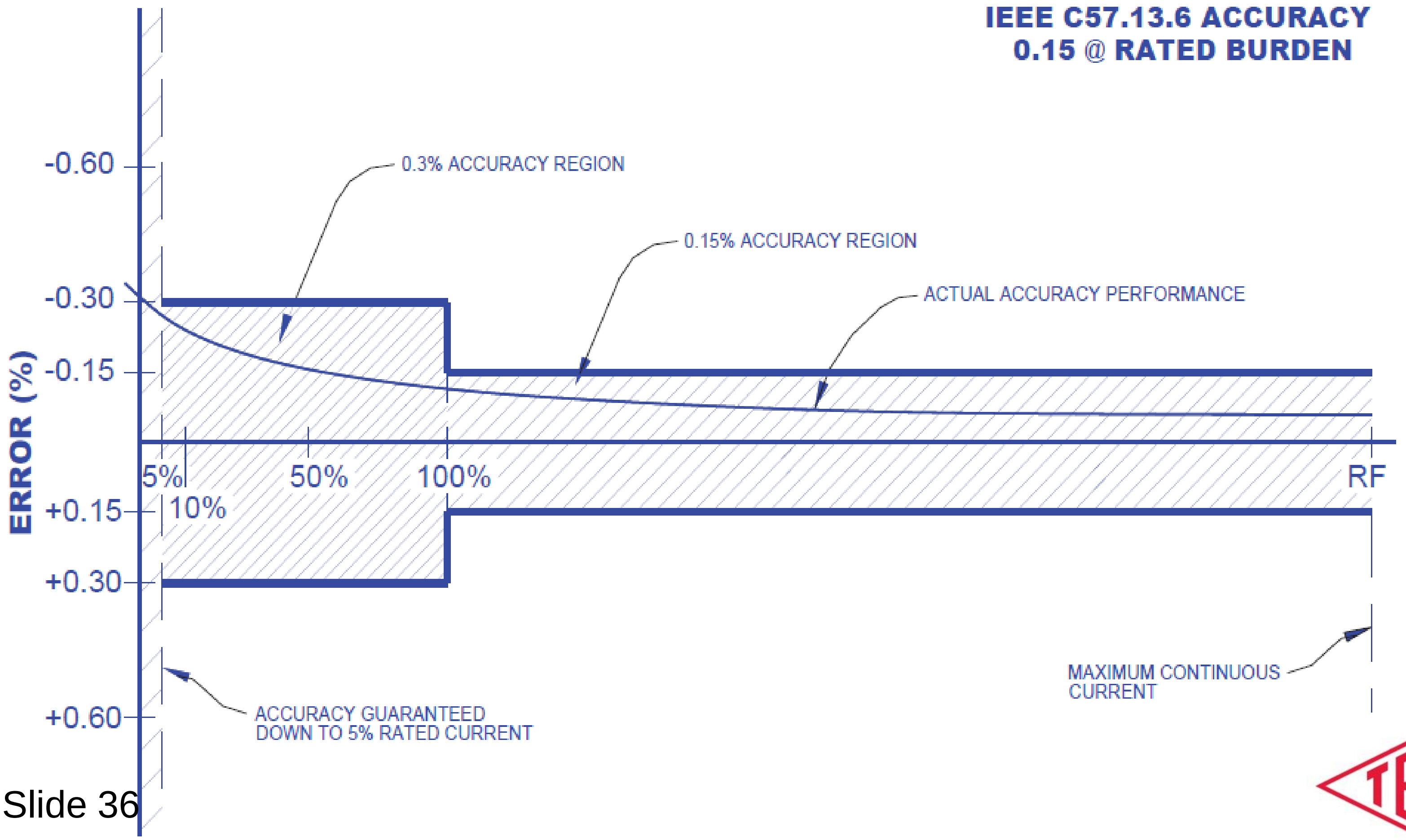
Ideal Transformer

This is an illustration that the excitation current is the current lost from the primary current that does not get to the meter. Accuracy is largely a function of minimizing this excitation current and why transformer accuracy is typically negative.

CT 0.3 Accuracy Class



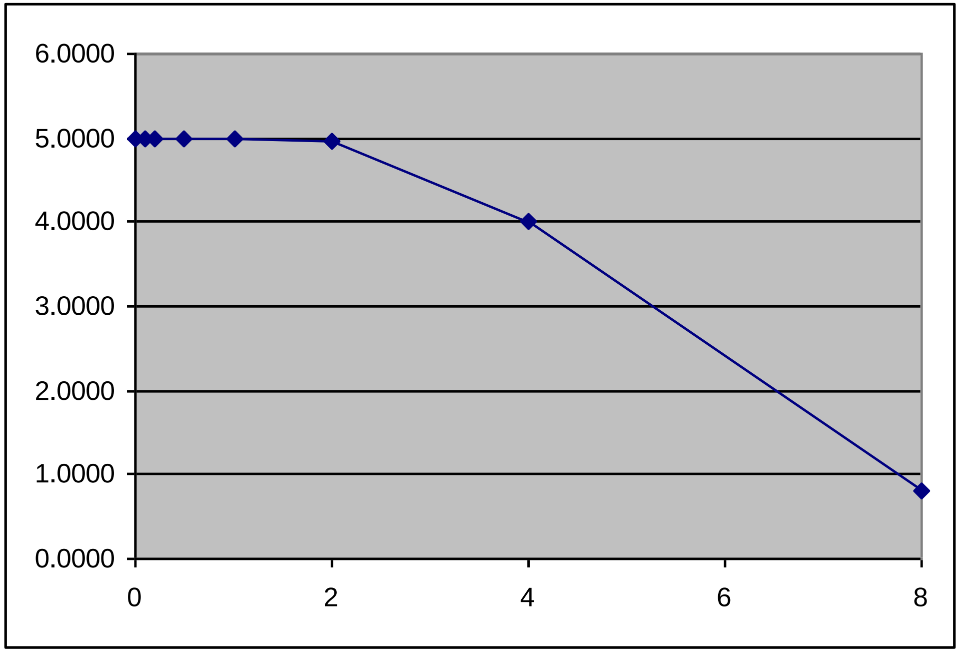
CT 0.15 Accuracy Class



Fundamentals of Polyphase Field Meter Testing and Site Verification

Functionality with Burden Present on the Secondary Loop

0.3% @ B0.1, B0.2, B0.5



Initial Reading = 5Amps

0.3% x 5A = 0.015A

5A – 0.015 = 4.985A

Burden	Reading
0	5.0000
0.1	4.9999
0.2	4.9950
0.5	4.9900
1	4.9800
2	4.9500
4	4.0000
8	0.8000

Site Verification: Potential Site Check List

- Double check the meter number, the location the test result and the meter record.
- Perform a visual safety inspection of the site. This includes utility and customer equipment. Things to look for include intact down ground on pole, properly attached enclosure, unwanted voltage on enclosure, proper trimming and site tidiness (absence of discarded seals, etc.).
- Visually inspect for energy diversions (intentional and not). This includes broken or missing wires, jumpers, open test switch, unconnected wires and foreign objects on meters or other metering equipment. Broken or missing wires can seriously cause the under measurement of energy. A simple broken wire on a CT or VT can cause the loss of 1/3 to 1/2 of the registration on either 3 element or 2 element metering, respectively.
- Visually check lightning arrestors and transformers for damage or leaks.
- Check for proper grounding and bonding of metering equipment. Poor grounding and bonding practices may result in inaccurate measurements that go undetected for long periods of time. Implementing a single point ground policy and practice can reduce or eliminate this type of issue.
- Burden test CTs and voltage check PTs.

Potential Site Check List (con't)

- Verify service voltage. Stuck regulator or seasonal capacitor can impact service voltage.
- Verify condition of metering control wire. This includes looking for cracks in insulation, broken wires, loose connections, etc.
- Compare the test switch wiring with the wiring at the CTs and VTs. Verify CTs and VTs not cross wired. Be sure CTs are grounded in one location (test switch) only.
- Check for bad test switch by examining voltage at the top and bottom of the switch. Also verify amps using amp probe on both sides of the test switch. Verify neutral connection to cabinet (voltage).
- Check rotation by closing in one phase at a time at the test switch and observing the phase meter for forward rotation. If forward rotation is not observed measurements may be significantly impacted as the phases are most likely cancelling each other out.
- Test meter for accuracy. Verify demand if applicable with observed load. If meter is performing compensation (line and/or transformer losses) the compensation should be verified either through direct testing at the site or by examining recorded pulse data.
- Loss compensation is generally a very small percentage of the overall measurement and would not be caught under utilities normal high/low checks. However, the small percentages when applied to large loads or generation can really add up overtime. Billing adjustments can easily be in the $million range if not caught early.

Potential Site Check List (con’t)

- Verify metering vectors. Traditionally this has been done using instruments such as a circuit analyzer. Many solid state meters today can provide vector diagrams along with volt/amp/pf and values using meter manufacturer software or meter displays. Many of these desired values are programmed into the meters Alternate/Utility display. Examining these values can provide much information about the metering integrity. It may also assist in determining if unbalanced loads are present and if CTs are sized properly. The vendor software generally has the ability to capture both diagnostic and vector information electronically. These electronic records should be kept in the meter shop for future comparisons.

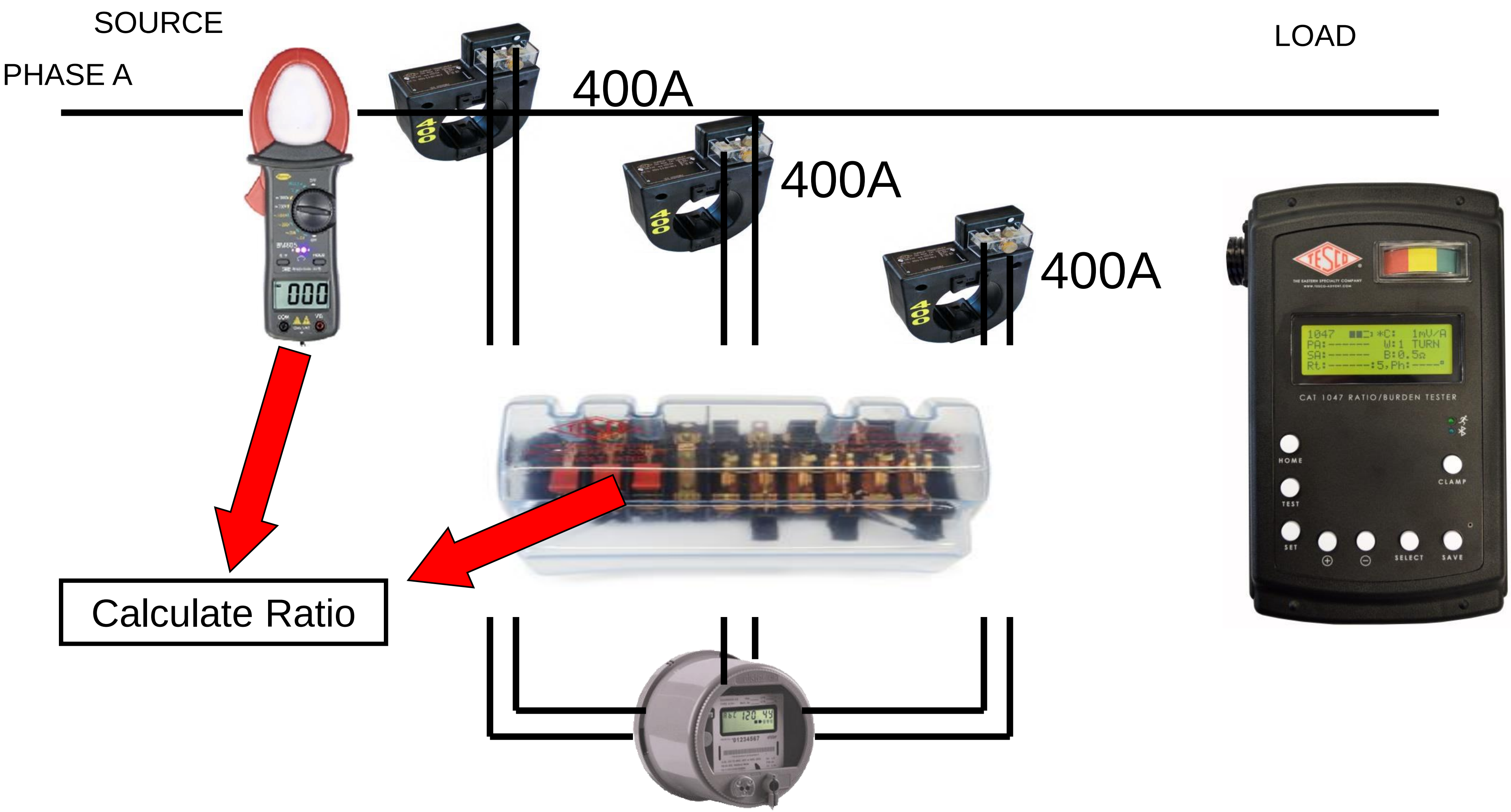
- If metering is providing pulses/EOI pulse to customers, SCADA systems or other meters for totalization they also should be verified vs. the known load on the meter.

- Verify meter information including meter multiplier (rework it), serial number, dials/decimals, Mp, Ke, Primary Kh, Kr and Rate. Errors in this type of information can also cause a adverse impact on measured/reported values.

- Verify CT shunts are all opened.

Fundamentals of Polyphase Field Meter Testing and Site Verification

Ratio of Primary Current to Secondary Current



Periodic Site Inspections…..

….Can Discover or Prevent:

- Billing Errors
- Bad Metering set-up
- Detect Current Diversion
- Identify Potential Safety Issues
- Metering Issues (issues not related to meter accuracy)
- AMR/AMI Communications Issues
- The need for Unscheduled Truck Rolls due to Undetected Field Related Issues
- Discrepancies between what is believed to be at a given site versus the actual setup and equipment at the site

Shop Testing

- Accuracy Testing
- Meter Communications Performance
- Software & Firmware Verification
- Setting Verification
- Functional Testing
- Disconnect/Reconnect Functionality
  and as left setting
- Ratio and accuracy testing
- Polarity checking
- Accuracy class determination

Shop Testing Programs

100% of all Transformers

- If not possible then sample testing of all and 100% of all those over a certain size for CT's and all VT's (generally not a large volume)

Transformer testing should include

- Ratio and accuracy testing
- Polarity checking
- Accuracy class determination

100% of all transformer rated meters

- If not possible then sample testing of all transformer rated meters and 100% of all those going into a certain size service and over

Meter testing should include:

- Software & Firmware Verification
- Setting Verification
- Functional Testing
- Disconnect/Reconnect Functionality and as left setting

AMI Meter Population Management

- A Meter Farm is a representation of your meter population in the field
- The Meter Farm is designed to be a tool to measure base line performance of your meters
- Meter farms are typically located outside so meters are exposed to the same temperatures, sun and elements as your meter population.
- Meter Farms should include a simulation of the entire communication network back to the head end

AMI Meter Population Management

- A Meter Farm needs to have a statistically significant representation of your meter population in the field. This means a minimum of 30 meters regardless of population. Typical farms have 50 to 100 meters for populations up to 50,000 meters and several thousand meters for populations over two million.
- The breakdown of forms should be roughly representative of the breakdown of meters within your population. 2S meters will typically have 85 to 90% of the spots in a meter farm. Every polyphase meter is represented with a minimum of two to three sockets if possible.

Summary

- Perform a shop test of every meter going into a transformer rated service. This includes a functional test as well as an accuracy test.
- Perform a shop test of every CT going into a transformer rated service.
- Perform a shop test of every VT going into a transformer rated service.
- Perform a base line site verification of every transformer rated service in your service territory.
- Use your AMI analytics to determine where there are misses:
  - No draw on one leg
  - Intermittent draw on one leg
  - Performing outside the rated range for the installed transformers
  - Reversed polarity
- Start checking for field issues all over again.
- Reduce the resources spent on self-contained metering by leveraging your AMI data as much as possible and creating new systems and procedures to replace older processes that did not have the availability of this type of data.

Questions and Discussion

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