TESCO METERING

ANSI Meter Forms

TESCO's Meter School
TESCOOL
July 20-23, 2025

Monday, July 21, 2025

3:15 PM-4:30 PM

Mike Parker, NV Energy

Agenda

Meters 101 - Electro-Mechanical vs Solid-State

Meter Forms

Self-Contained vs Transformer Rated

Blondel's Theorem

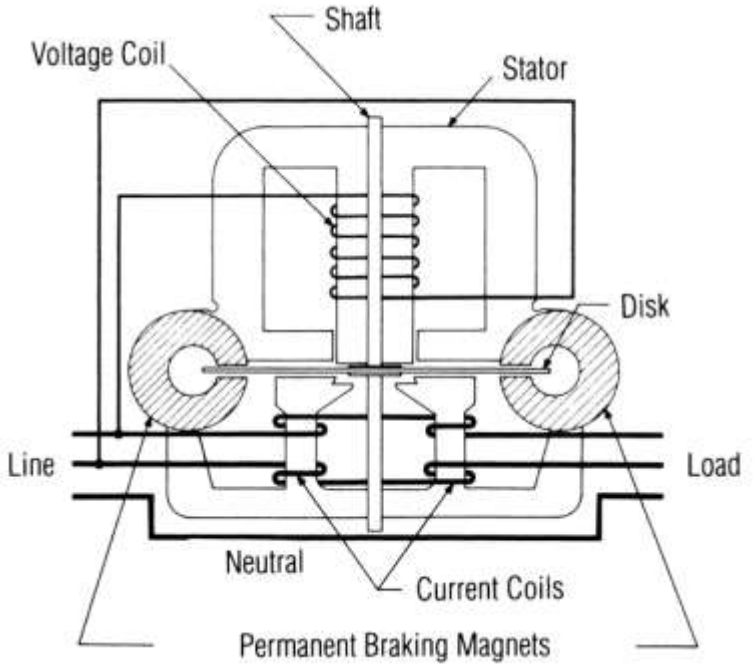
Available References (Hardy's Power Measurement Handbook, UGLY's Elect Ref)

Examples

1S, 2S, 3S, 4S, 5/35S, 8/9S, 16S

Induction Meters

- Two coils and a conducting (usually aluminum) disk.
  A braking magnet.
- Magnetic field from the first coil generates *eddy currents* in the disk.
- Magnetic field from the second coil interacts with the eddy currents to cause motion.
- Disk would accelerate without bound except for eddy currents caused by motion through fixed magnetic field which slows the disk.
- The end result is that each revolution of the disk measures a constant amount of energy.



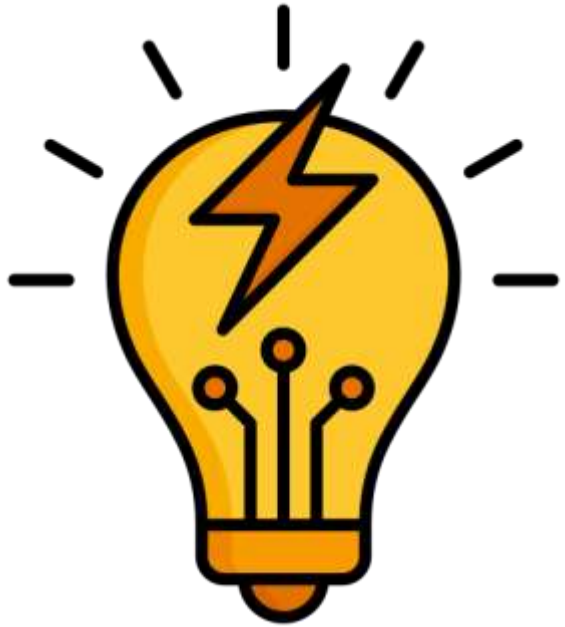
Basic Energy Formula

- The essential specification of a watthour meter's measurement is given by the value
  K_h [Watthours per disk revolution]

- A Kh of 7.2 is typical. In this example, each full rotation of the disk is equivalent to 7.2Wh of energy.

- The watthour meter formula is as follows:

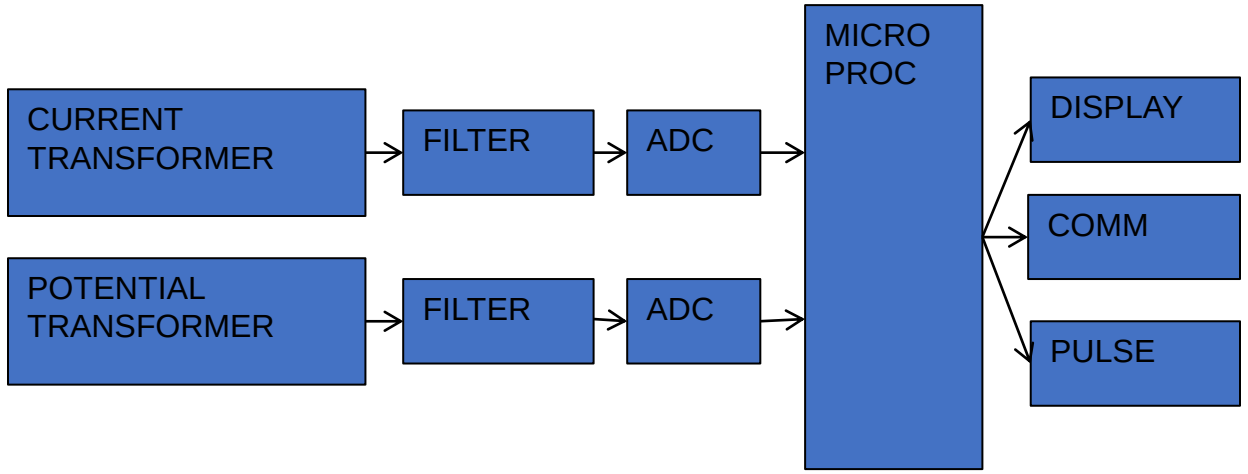
$$E\left[\textbf{Watthours}\right] = K_h\left[\frac{\textbf{watthours}}{\textbf{disk revolution}}\right] * n\left[\textbf{disk revolutions}\right]$$



Meters 101 – Solid-state

Overview of Functionality

- Potential and Current is scaled down and conditioned with transformers and filters.
- ADC's (analog to digital converters) digitize the signals.
- A micro-processor or DSP executes the calculations.
- Resulting data is displayed, sent externally via the communication circuits, and used for the calibrated pulse output.



Meter Forms

1S
14S
39S
17S
2S
3S
12S
35S
4S
25S
10S
76S
46S
66S
45S
11S
32S
6S
5S
26S
16S
9S
13S
15S
24S
56S

Meter Forms

SELF-CONTAINED

1S
14S
12S
2S
25S
16S
17S
13S
15S
32S

TRANSFORMER-RATED

39S
3S
36S
7S
29S
76S
5S
35S
4S
46S
8S
11S
26S
66S
9S
45S
6S
24S
56S
10S

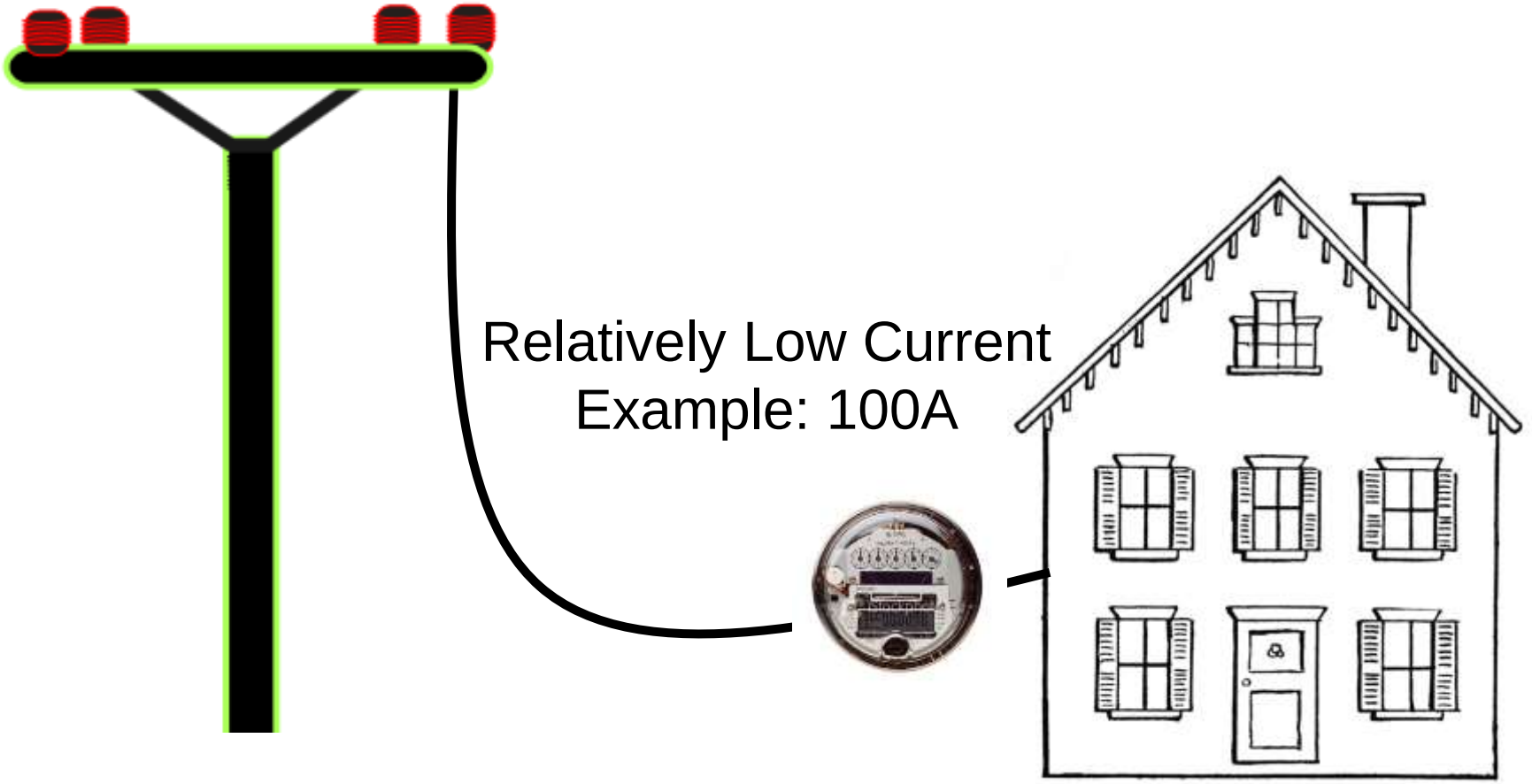
Meter Forms


GENERAL ELECTRIC
KILOWATTHOURS
37 472 065
LINE
LOAD


FlexNet
CL200 240V 3W 60Hz FM 2S Kh 1.0 TA 30A
sensus
Stratus
31 955 277
TYPE SSA4

Self-Contained Meters

Primarily Residential



Self-Contained

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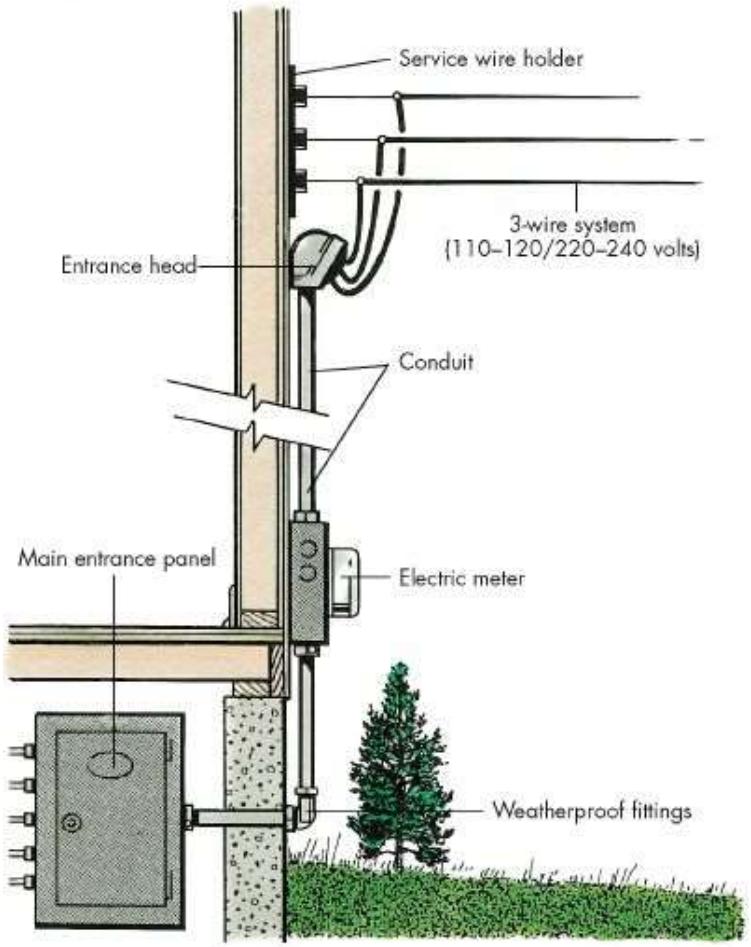
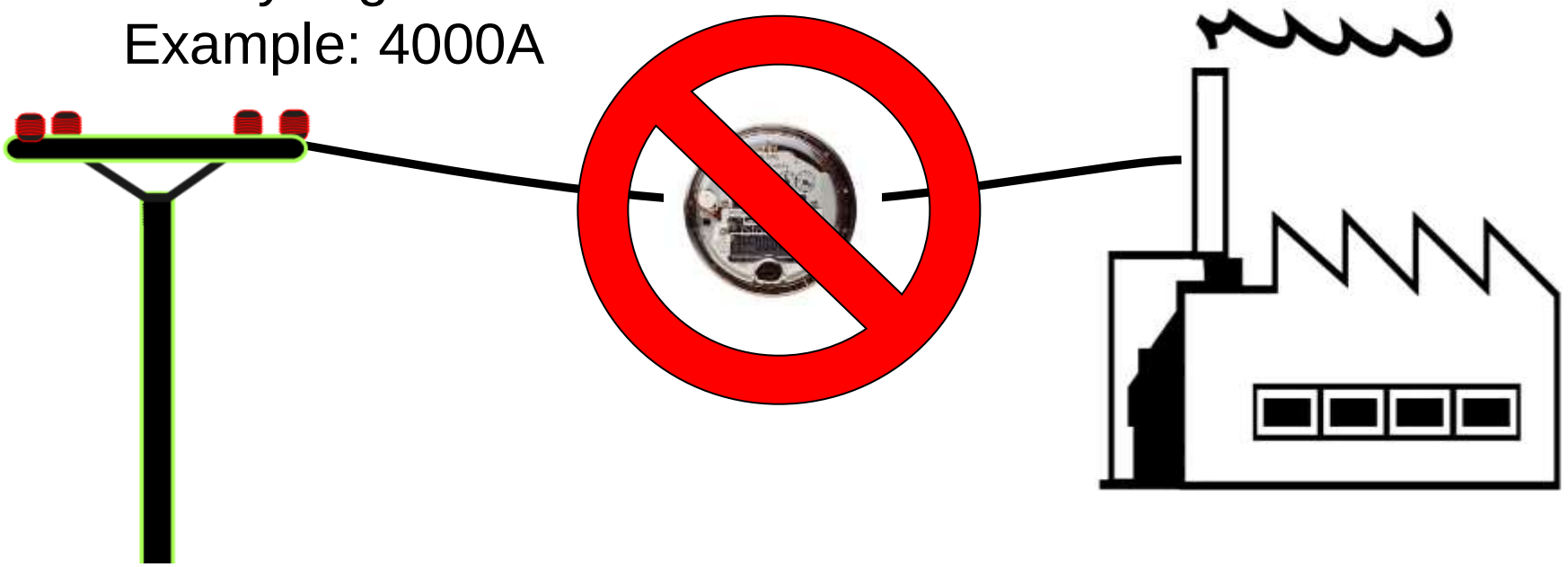


Transformer-Rated Meters

Primarily Commercial/Industrial

Relatively High Current
Example: 4000A



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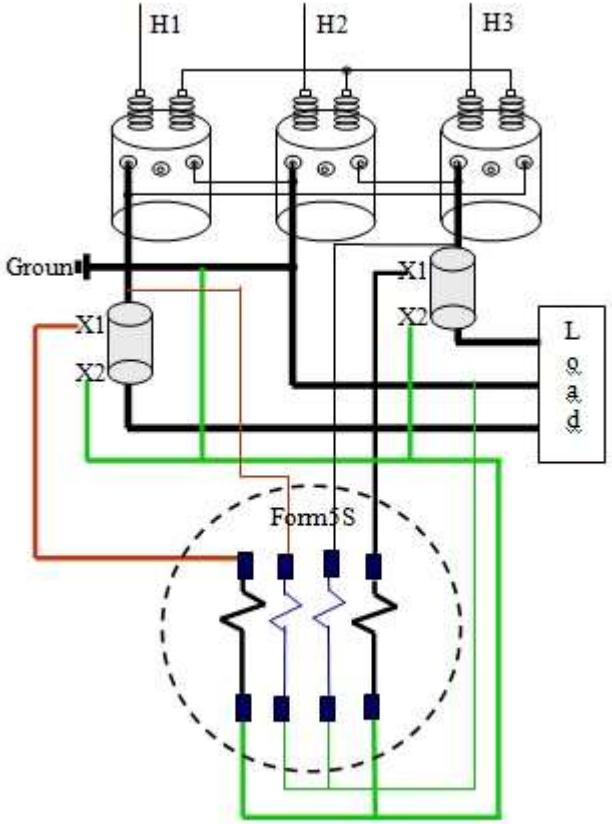
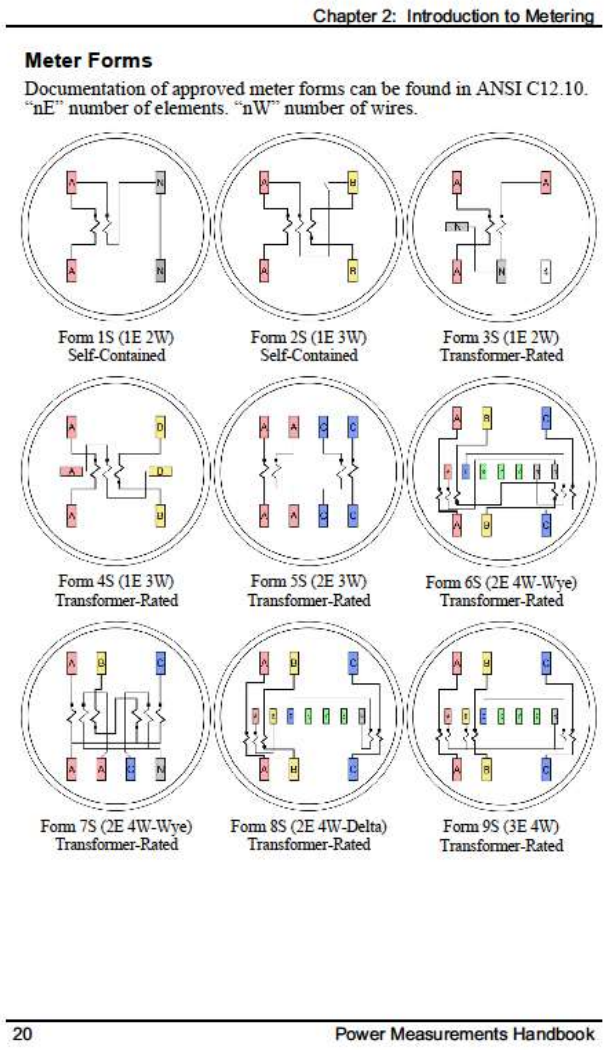


Diagram Example



Chapter 2: Introduction to Metering

Meter Forms

Documentation of approved meter forms can be found in ANSI C12.10. "nE" number of elements. "nW" number of wires.

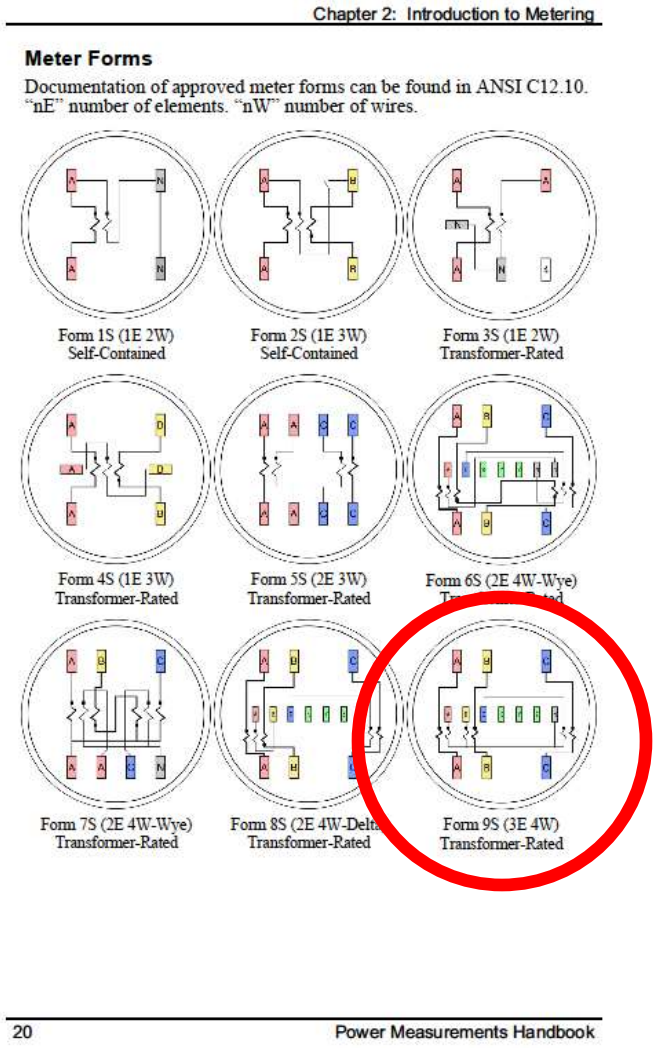
Form 1S (1E 2W) Self-Contained
Form 2S (1E 3W) Self-Contained
Form 3S (1E 2W) Transformer-Rated
Form 4S (1E 3W) Transformer-Rated
Form 5S (2E 3W) Transformer-Rated
Form 6S (2E 4W-Wye) Transformer-Rated
Form 7S (2E 4W-Wye) Transformer-Rated
Form 8S (2E 4W-Delta) Transformer-Rated
Form 9S (3E 4W) Transformer-Rated

20 Power Measurements Handbook

References

- Power Measurements Handbook, Dr. Bill Hardy
- UGLY's Electrical References
- Meterman's Handbook
- Manufacturer's websites

Diagram Example



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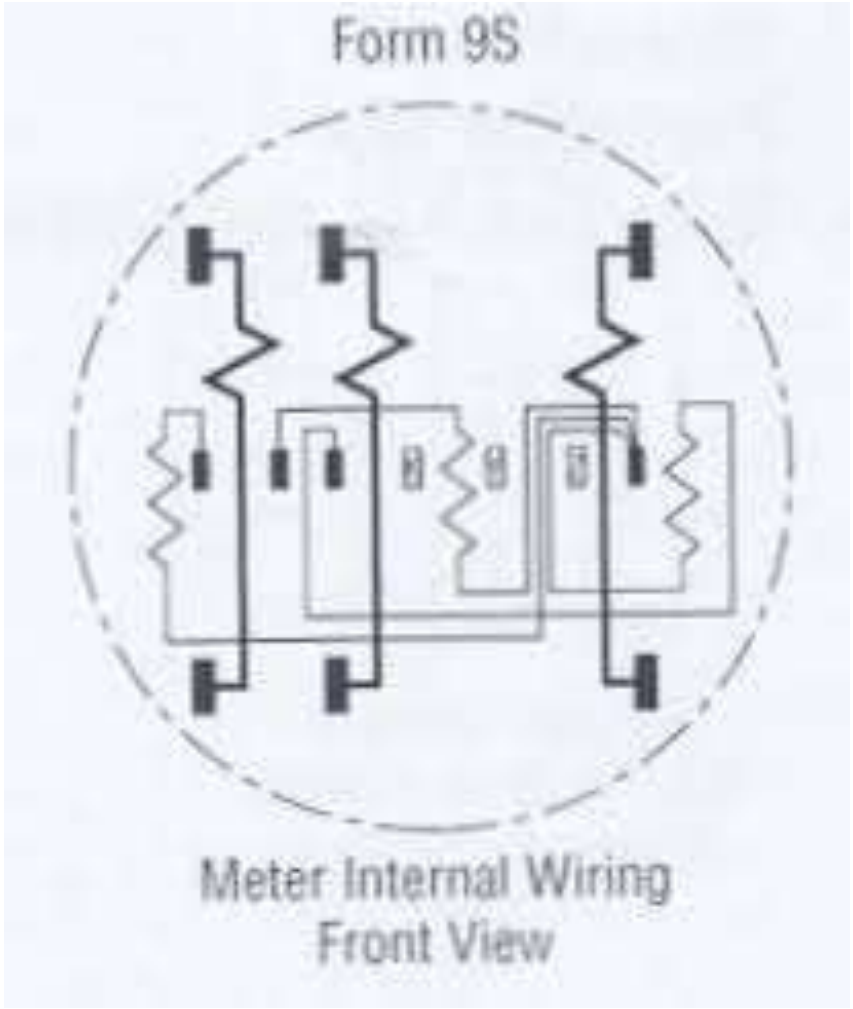


- 3 Current Coils
- 3 Potential Coils

Blondel's Theorem

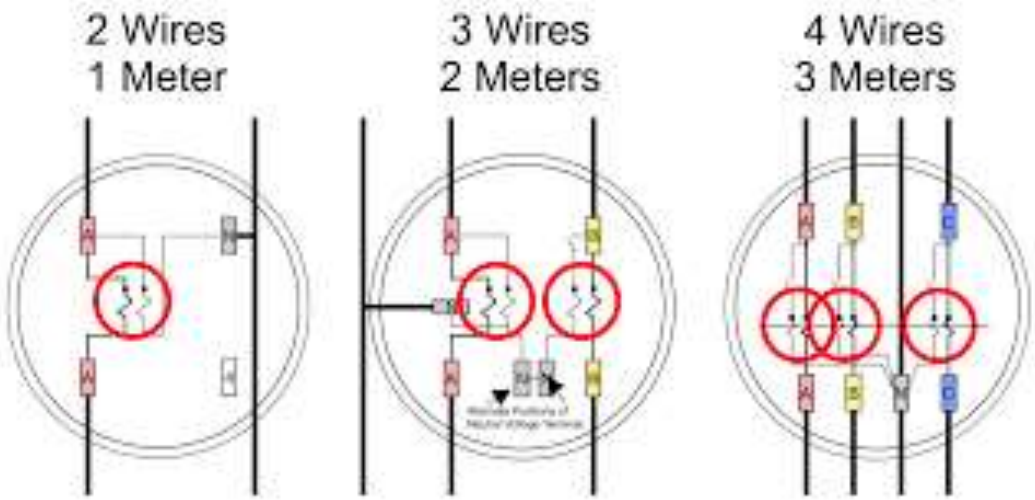
- French Electrical Engineer Andre Blondel
- Attempt to simplify electrical measurements and validation of the results
- Paper submitted to the International Electric Congress in Chicago in 1893.

$$E = n - 1$$

The theorem states that the power provided to a system of N conductors is equal to the algebraic sum of the power measured by N watt-meters. The N watt-meters are separately connected such that each one measures the current level in one of the N conductors and the potential level between that conductor and a common point. In a further simplification, if that common point is located on one of the conductors, that conductor's meter can be removed and only N-1 meters are required.

Blondel's Theorem

Blondel Compliant



1S 12S 9S

$$E = n - 1$$

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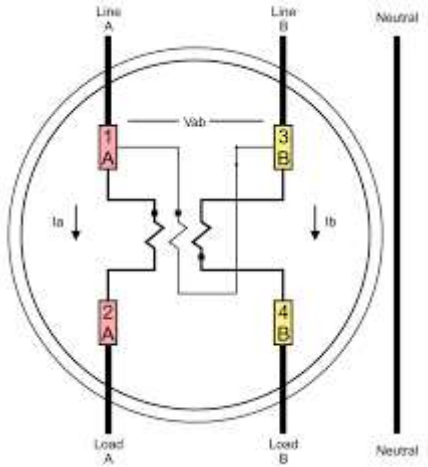
Blondel's Theorem

Non-Blondel Compliant



2S

$$E = n - 1$$

The theorem states that the power provided to a system of N conductors is equal to the algebraic sum of the power measured by N watt-meters. The N watt-meters are separately connected such that each one measures the current level in one of the N conductors and the potential level between that conductor and a common point. In a further simplification, if that common point is located on one of the conductors, that conductor's meter can be removed and only N-1 meters are required.

Blondel's Theorem

Why is non-Blondel metering bad?

- Makes assumptions about the service
- Example: balanced voltages
- Assumptions might not be true
- When these assumptions are not true, then there are power measurement errors even if the meter is working perfectly.

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Blondel's Theorem

Why are non-Blondel meters used?

- Fewer elements (meters) = lower cost
- Especially true for electro-mechanical meters
- Fewer CT's and PT's = lower cost
- Less wiring and cheaper sockets

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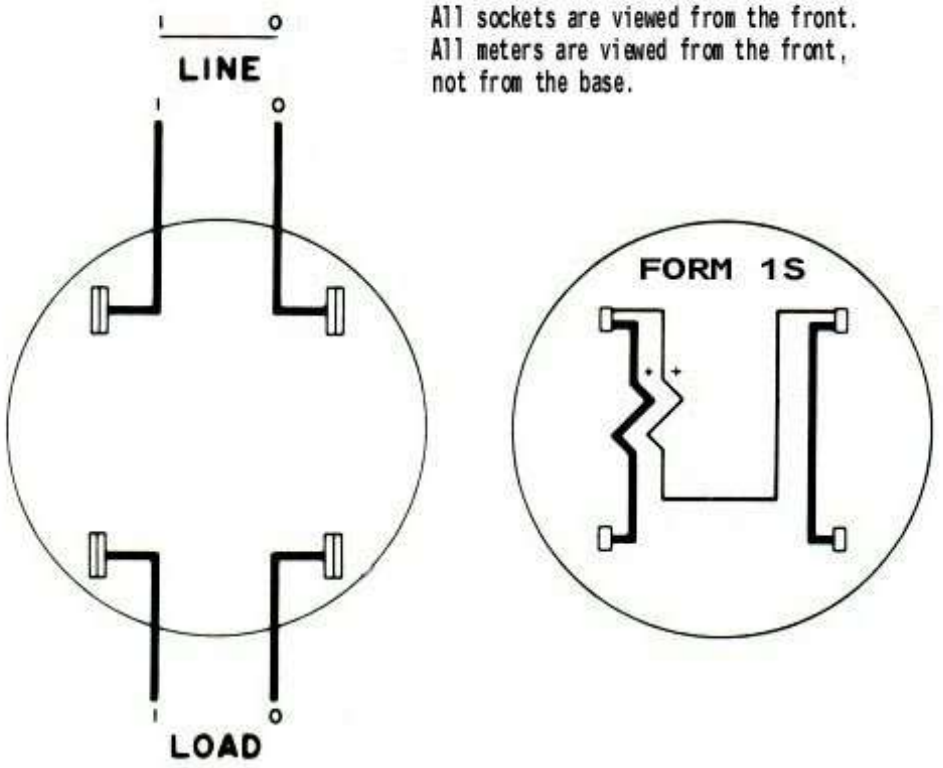
Metering Examples



FORM 1S

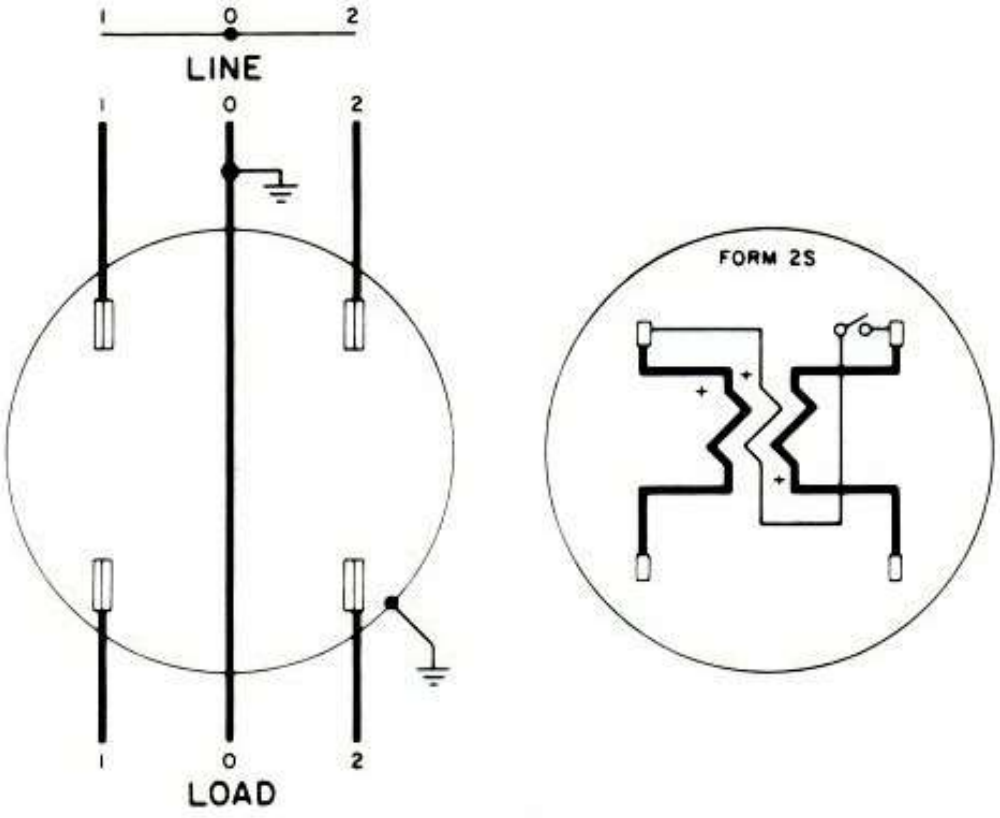
1ø, 2 W CIRCUIT

1 Stator, 2 W Meter, Self-Contained

BCM Bay City Metering

P: 212-575-0785

Metering Examples



1ø, 3 W CIRCUIT
1 Stator, 1ø, 3 W Meter, Self-Contained

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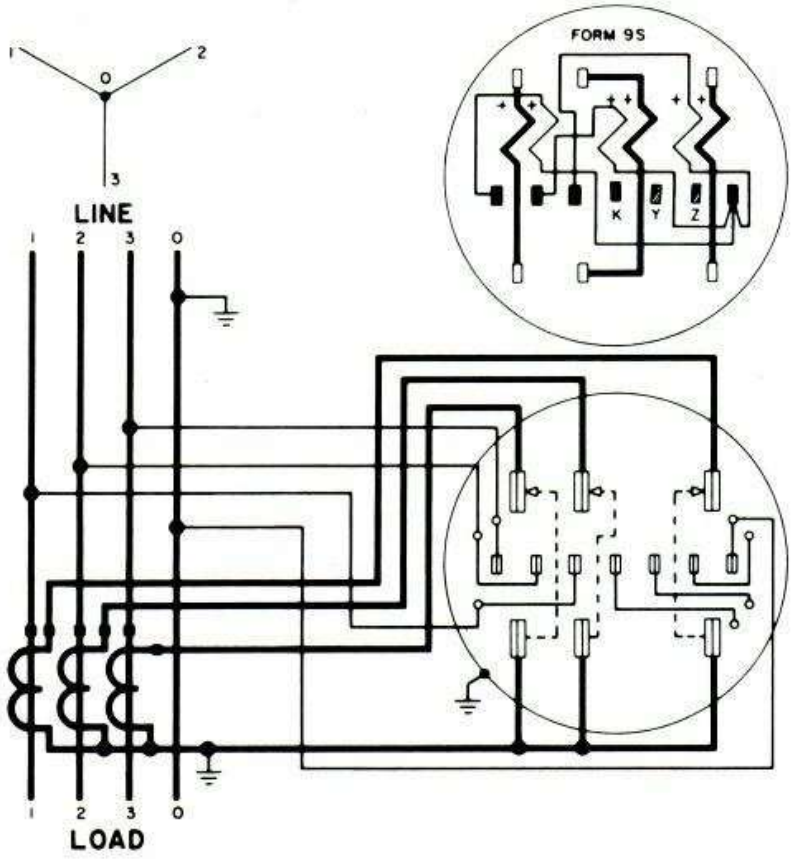
Metering Examples



3ø, 4 W, Y CIRCUIT
3 Stator, 3ø, 4 W, Y Meter with 3-2 W CT's

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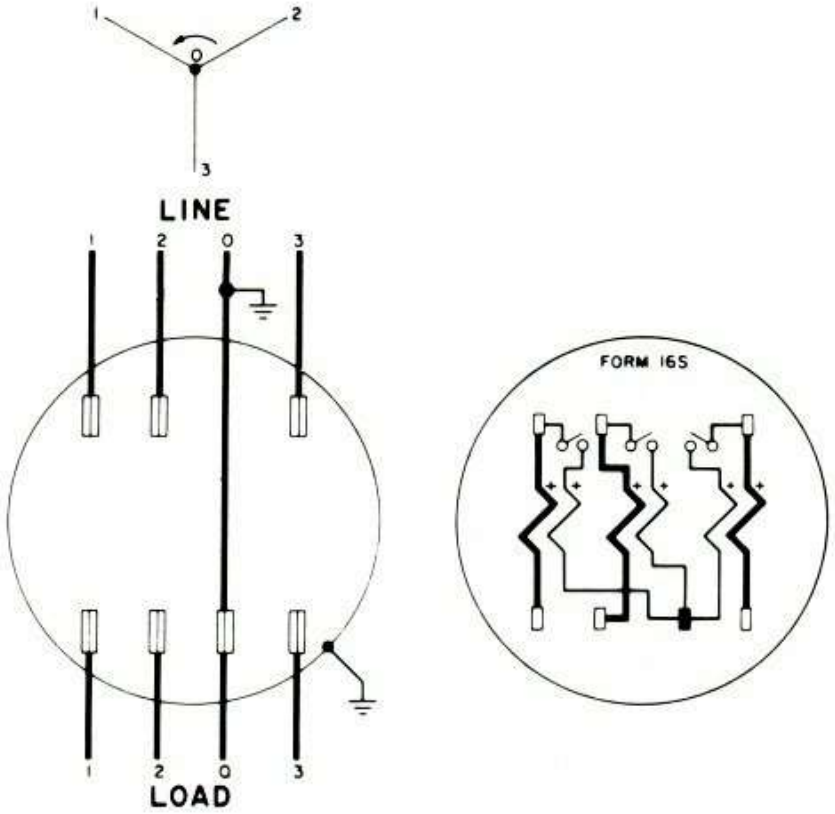
Metering Examples



3ø, 4 W, Y CIRCUIT
3 Stator, 3ø, 4 W, Y Meter, Self-Contained

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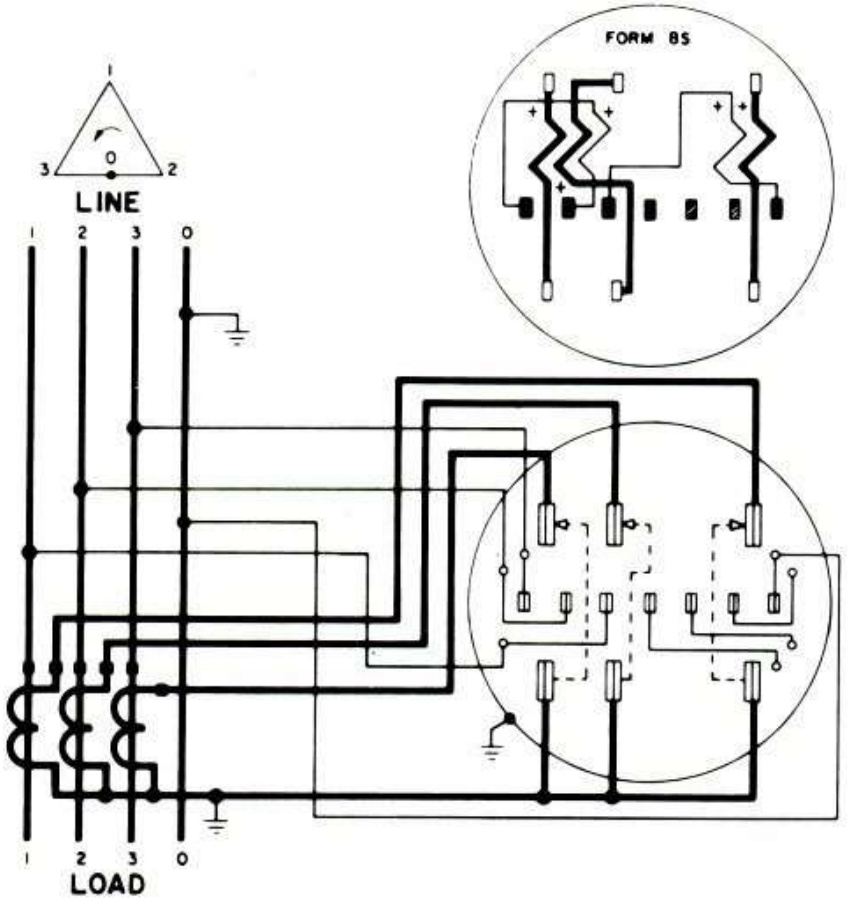
Metering Examples



3ø, 4 W, Δ CIRCUIT

2 Stator, 3ø, 4 W, Δ Meter with 3-2 W CT's

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References

- Wikipedia – of course
- https://en.wikipedia.org/wiki/Blondel%27s_theorem

- Power Measurement Handbook – Dr. Bill Hardy – TESCO CTO Emeritus
- http://www.powermeasurements.org/library/Presentations/NCMS%202013%20-%20Non-Blondel%20Metering.pdf

- Third Party meter sites
- https://www.baycitymetering.com/

Agenda

Meters 101 - Electro-Mechanical vs Solid-State

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Available References

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Introduction to Watthour Meter Testing

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John Pollard

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 vs Periodic Testing?
- What are regulatory tests?
- How do we know meter tests are good?
- What do we do with the test data?

Why Do We Test?

- The meter is the “cash register” of the utility company and serves as a junction / interface between the utility and the customer
- Meter accuracy establishes “fair” transactions / billing between the utility company and customer
- Meter testing guidelines are taken from ANSI C12.1-2014 American National Standard for Electric Meters – Code for Electricity Metering
- Section 5 of C12.1 covers “Standards for New and In-Service Performance”
- ANSI provides guidance rather than enforces standards
- Final testing guidelines are established by the governing commission, local government, or the utility

Why Do We Test?

- Our regulatory commissions typically require us to test meters for accuracy
  - Regulatory commissions typically take their lead from ANSI C12.1 American National Standard for Electricity Metering

- State regulatory commissions focus on accuracy because they 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
  - With the advent of AMI, functional testing has taken a high priority for the utility as well

ANSI
American National Standards Institute

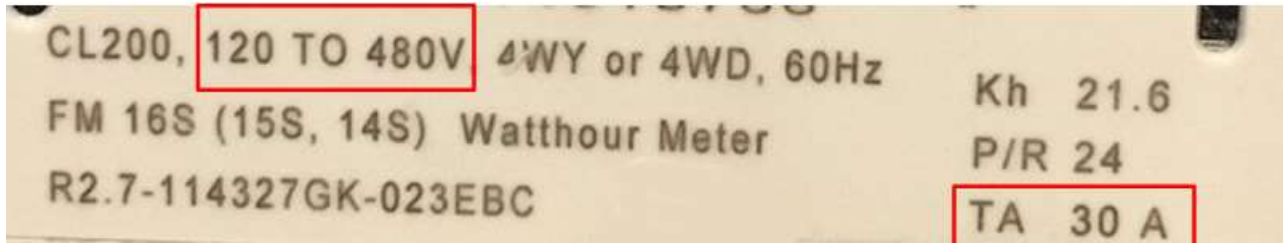
Basics of meter testing

- Equipment Needed for Testing
  - Reference Standard
  - Test Kit or Load Box
  - Test Jack or Test Switch
  - Multi-Meter
  - PPE & Safety Equipment

- Tests Performed

Test	Voltage	Current	PF
Full Load	Rated V	Rated Test Amps (TA)	1.0
Power Factor	Rated V	Rated TA	0.5
Light Load	Rated V	10% of TA	1.0

- Meter Characteristics - Test Amps, Class, Form, and Voltage are shown on the face of the meter as well as Kh (energy per pulse).



Shop Testing

- Shop or lab testing is considered to be done under ideal conditions.
- The test machine contains the reference standard, meter socket interface, load circuit, and electronics.
- The test machine is often connected to a PC and data management system.
- The test machine may have an optical probe and other pickups to be able to sense a physical disc rotation, IR output, etc.
- Test machines are designed to test single phase and three phase meter forms as well as solid state and electro-mechanical meters.

Field Testing

- Field testing can be performed with an adapter and site voltage from the meter socket or by removing the meter and testing in a piece of field equipment that may be contained in a utility vehicle nearby.

- Voltage and current may by synthesized through electronics or the customer's meter socket may be used as a source.

- Some commissions may require complaint & witness tests to be done in the field while others may allow to meter to be removed, secured(bagged), and tested in the shop with a witness.

- Field testing and shop testing have various benefits to a utility.
  - Quicker field procedure vs more back-office work.
  - Longer field procedure vs less back-office work.

Compliant Testing

- Customers always have the right to request a meter test.
  - There may be limits to how often a test can be requested and there may be a cost to the end customer as well.
- Some utilities and some jurisdictions allow for testing at the customer site(field), others require a test in a laboratory (shop) 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 within acceptable limits 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 Purchase Meters
  - Manufacturers tests
  - In-house tests on new shipments
- Recycled Meters
  - Return to Service Testing
- In-Service Meters
  - Periodic Tests
  - Selective, random, or statistical testing
- End of Life Meters
  - Retirement tests
- Testing of related metering equipment

New Meter Testing Programs

- Utilities generally accept the manufacturer's test results then perform some type of test on their own
  - Statistical Sample Test of an incoming shipment
  - 100% test of an incoming shipment
- Utilities may opt for sample testing for residential and 100% testing for commercial shipments
- With consistent performance and accuracy of newer solid-state meters many utilities have moved to statistical sampling for all new purchases
- A utility may have more stringent guidelines than the commission
  - 98-102% vs 99.5-100.5% or even 99.7-100.3%

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.

- With advances in AMI technology, many utilities may identify meters as End of Life (EOL) and simply “test and retire” OR they may perform accuracy testing, functional testing, and programming to return service and use in the field.

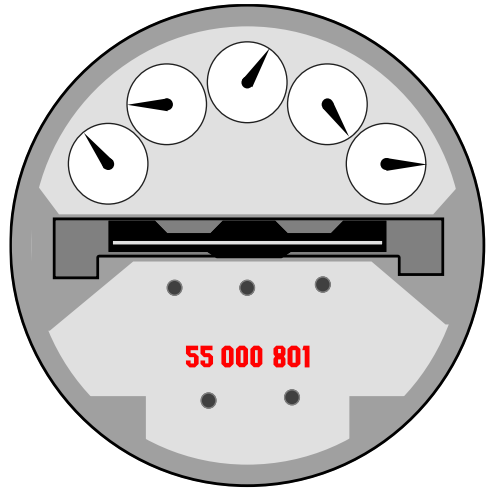
In-Service Testing

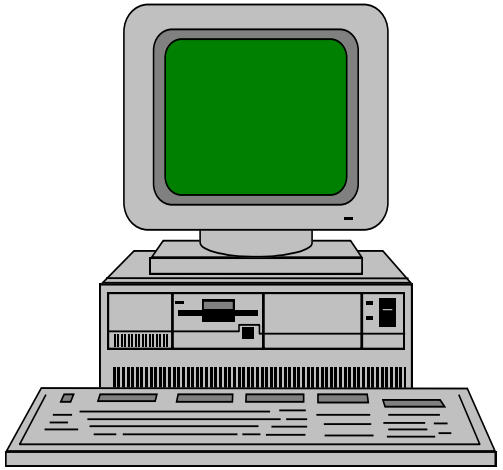
- Meter Testing for new and in-service meters is specified in ANSI C12.1-2015, *American National Standard for Electric Meters, Code for Electricity Metering.*

- Most utility commissions use this Standard a reference or the basis for their meter testing requirements.

Test Plans for Meters

- The most common test plans for in-service meters include periodic and statistical plans.
  - Periodic plans may be based on a test every x number of years.
  - This is more common with commercial meters.
  - This may even be annually on interconnect meters and generation meters.
    - Example ISO/RTO - PJM and 1 vs 2 years.
  - Statistical plans generally are based on a subset of the population and broken out by groupings of the population.





Periodic Test Plans

- Periodic
  - Varies by State / Jurisdiction
  - Example provided by ANSI C12.1:
    - Each electromechanical meter is tested once every 8 years.
    - All other meters are tested every 16 years.
    - Appendix D provides details for other meters & devices.
    - No guidance for AMI meters.
  - Generally, an average of 12.5% of the population is tested per year.
  - With AMI data and consistent performance, some utilities have moved their commercial populations to once every 12 or even 16 years.

8 Years

16 Years

Why Use a Statistical Testing Plan

- Focuses testing on the proper meters.
- Minimizes number of meters to be tested; usually requires less than 30% of what a periodic testing plan requires.
- Provides data and analysis tools for use in understanding what is happening with installed meters or for use in the purchasing of new meters.

Homogeneous Population(s)

- The groups or populations being sampled and tested are made up of the same or similar items, items which operate in the same way and were made in the same manner.

- For electric meters, this has traditionally been interpreted as being meters of a specific meter type from a manufacturer (IE AB1, J5S, MX, etc).

- AMR & AMI programs have helped to make the overall populations more homogenous. This makes a utility with AMR & AMI meters better prepared to take advantage of a statistical sampling plan.

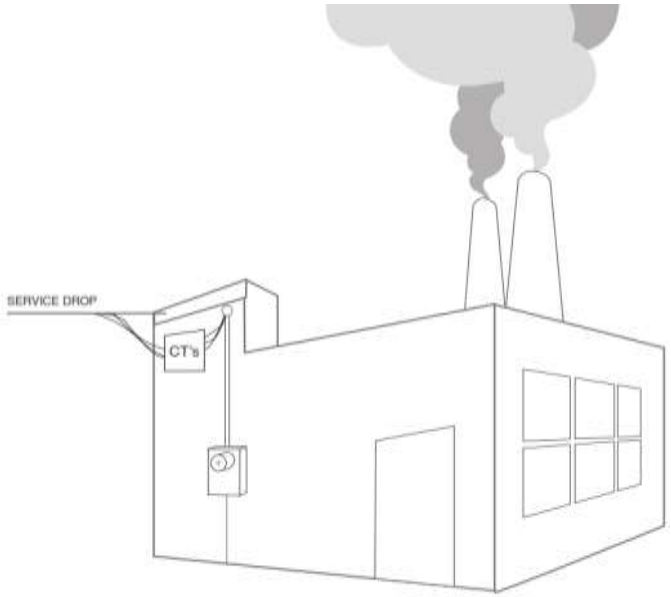
    - Some utilities may only have 4-5 groups now where they used to have 20+ groups to test
    - (IE Focus, i210+c, kv2c, centron, etc).

Sample Test Plans

- ANSI z1.4 and ANSI z1.9 are some of the more commonly accepted sampling plans
  - Z1.4 is more common and may be preferred as it is a sampling procedure based on attributes
    - Meters pass or fail
  - Z1.9 is more granular and may be preferred for aging population as it is a sampling procedure based on variables
    - Meters can fail but there is an average and statistical value calculated for the group
      - One abnormal test (33%) could be enough to fail an entire group
      - Utilities may denote abnormalities as “outliers”

Testing of a Meter vs Testing a Site

- ***Test an installation and site and not just the meter***
  - Test programs may need to involve testing and checking th*e* meter performance as well as checking and testing the installation.
  - This more extensive test check list needs to be done especially for the higher revenue C&I customers.



Testing of a Meter vs Testing a Site

- Testing of CTs, PTs, and associated site equipment is often overlooked but many times is the key to lost revenue
  - Voltage & current checks may show a condition to cause concern
    - IE missing current on phase A or voltage on phase C
      - Site accuracy may be 66%!
  - Phase angle and phasor checks may show concern
    - IE current 180 degrees off – one CT wired in reverse
      - Meter tests at 100% but site accuracy is 33%!

Meter Testing Traceability

- Test equipment to NIST standards
- Tracking number of meters to be tested per State Commission requirements
- Tracking meter test data
  - Meter Records
  - Meter Data Management System (MDMS)

Meter Testing Traceability

- Traceability is defined as the ability to link the results of the calibration and measurement to related standard and/or reference (preferably national or international standard) through an unbroken chain of comparisons.

- Calibration is typically performed by measuring a test unit against a known standard or reference.

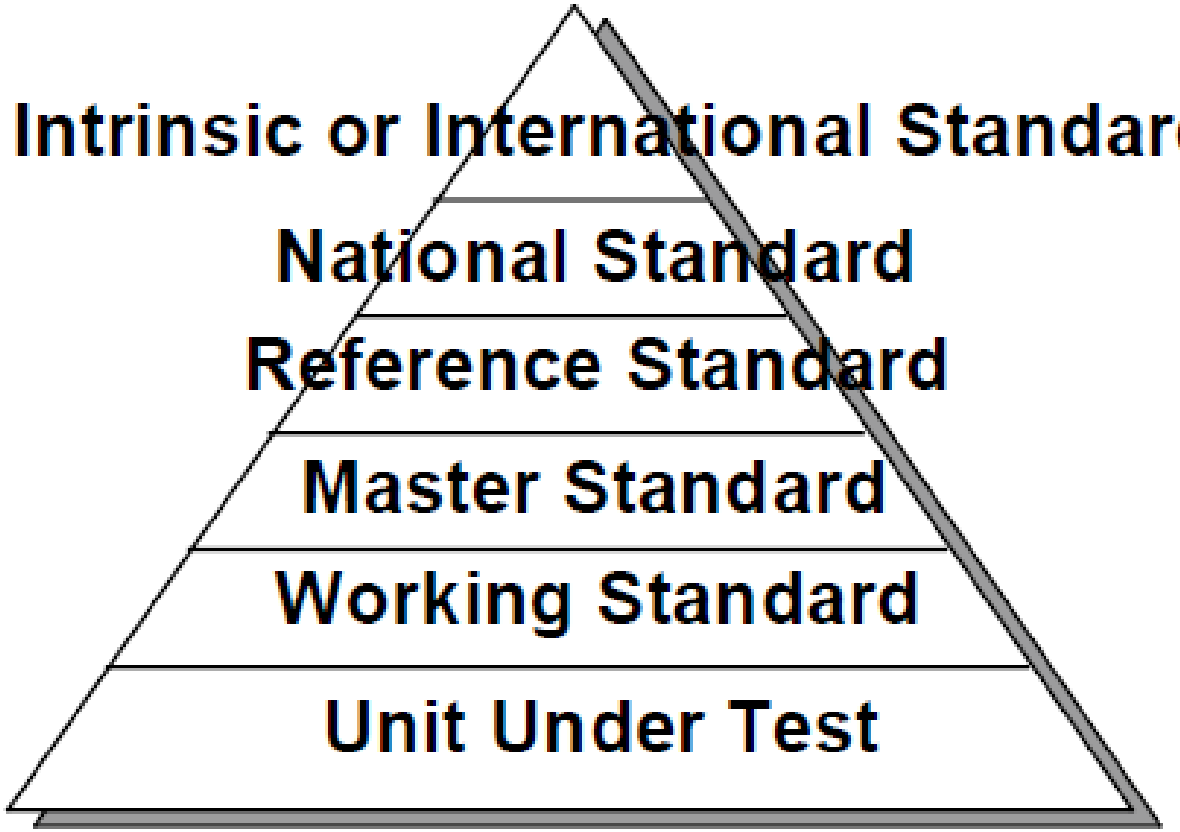
- Master standard (IE gages) are kept by National Measurement Institute (NMI) of each country.

Meter Testing Traceability

- National Institute of Standards and Technology (NIST) provides internal tracking numbers, which are often used as evidence of traceability.

- **WARNING!** NIST does not certify or guarantee that calibration and measurements are correct, nor does it provide any kind of certification of accuracy and calibration.
  - NIST only provides certifications for the work performed by them

Meter Testing Traceability - Standards



Meter Testing Traceability - Standards

- *National Standard*
  In the US, this is maintained by NIST, in Canada by NRC. Not all countries have a National Standards group and even the US does not have a group for every item of interest to a utility (IE voltage transformers).

- *Reference/Master Standard*
  Item of highest metrological quality located at a site where calibration is being conducted.

  Transfer Standard
  Lower level of Reference Standard and used for calibration of lower-level calibration requirements measuring devices.

- *Working Standard*
  Lower level of Reference Standard and used for calibration of lower-level calibration requirements measuring devices. Should be compared to Master Standard or Reference Standard on regular basis; used for daily checks comparisons of the calibrated devices.

Test Equipment Calibration

Primary Requirement: Traceable to NIST Standards

- Meter Test Boards, Field Test Kits calibrated to a known master standard maintained at Meter Shop
  - ✓ Some periodicity such as monthly or quarterly
- Reference or Master standard calibrated by outside vendor traceable to NIST or directly by NIST
  - ✓ Usually annually

Tracking Meter Records

- AMI programs help to update and overhaul meter record systems.

- Having the records for the entire meter population updated allows for a better chance that test data is available to answer questions and that any meter may be selected as part of the sample for testing.

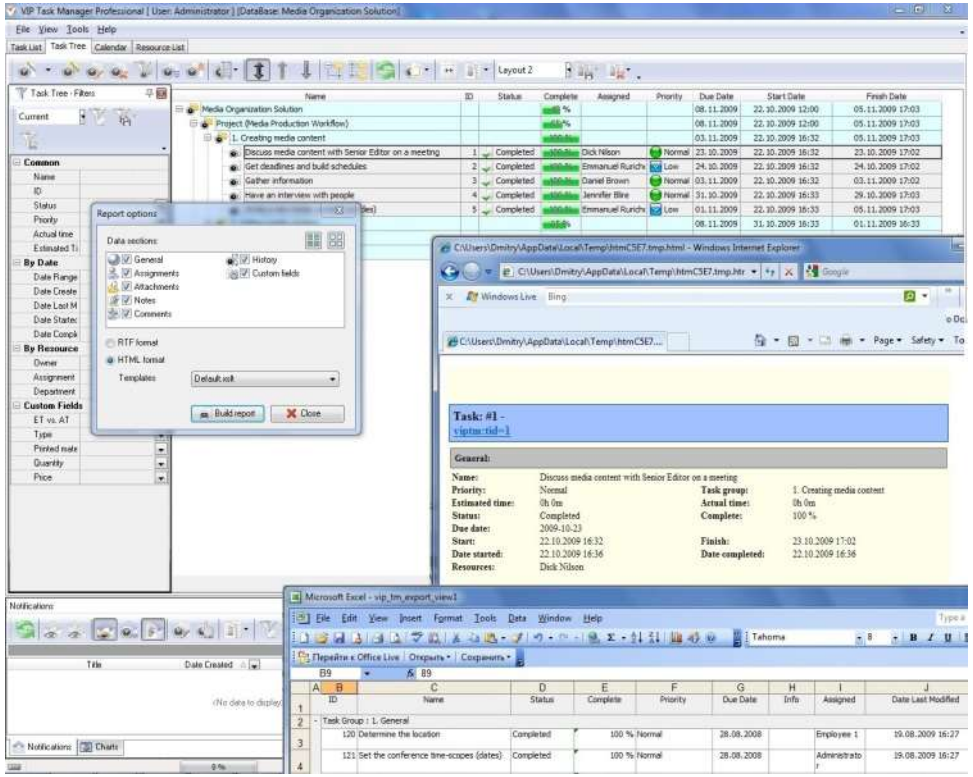
Meter Test Data Tracking

- Test data should be tracked throughout meter life
  – Certification testing, first article, acceptance testing, in-service (field & shop), retirement.

- Meter test data should be linked to meter record data such as meter form, amps, voltage, display type, etc.

- Best time to start to develop the program is before the meters are being installed.

- Accuracy test data is usually collected automatically as new meters are tested in meter shops or cross docks.

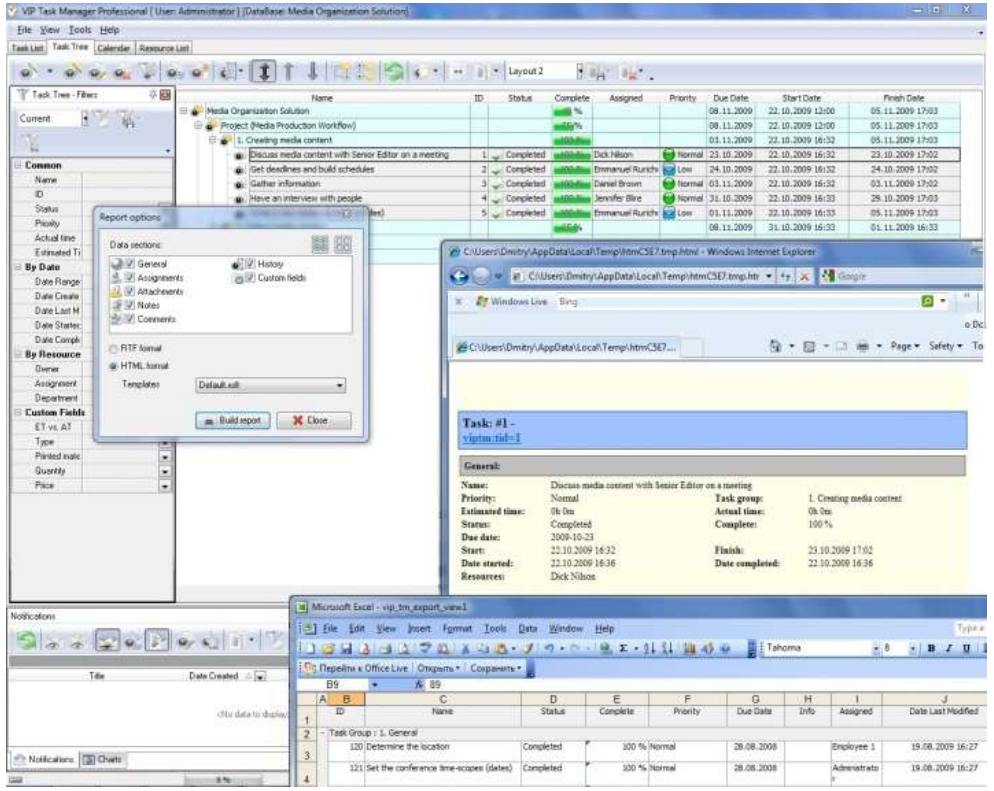


Meter Test Data Tracking

- Need to consider tracking non-accuracy functional testing (meter software configuration, service disconnect testing, voltage, etc.)

- Use installation reports to determine if there is any initial concerns about the meters being installed.

- Typical reports that should be available:
  - Failed Meter Report, Project to Date
  - Electric Meters on Network Report



Meter Test Data Tracking System

- System should track meter test results for ease of future reference or for response to public or utility commission inquiries.
- May be part of Meter Data Management System (MDMS) or a separate Meter Records system.
- Requires discipline in collecting & entering data, especially field tests.

Questions?

- 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?

Course Feedback

Please Take a Few Minutes To Provide Feeback About The Course & Instructor

Questions and Discussion

John Pollard

TSTM

This presentation can also be found under Meter Conferences and Schools on the TESCO website:
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