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Current Transformer Theory & Testing

Hands On Relay School 2016

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Agenda

- Introduction
- Current Transformer Basics
- Construction & Types
- Industry Standards
- Applications
- Testing

Current Transformer Basics

Function of Current Transformers

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- Convert Primary Power Signals to Manageable Values for
  - Indicating Meters
  - Revenue Metering
  - Protective Relay Systems
  - Power Generation
  - Plant Monitoring Systems
  - Fault Recorders
  - SCADA
  - Overall Electric Grid Monitoring (Local Dispatch & ISO Level)
  - Building (Energy) Management Systems (HVAC,refrigeration...)
  - Load Control

Current Transformers

- Insulation from High Voltages and Currents
- Isolation from other systems
- Safety
- Standardization
- Accuracy (Ratio & Phase)
- Typically Low Power Rating
- Thermal Considerations
- Burden Considerations

Current Transformers

- Insulation Consistent With Voltage Use
- Wide Range of Current to Replicate (Unlike VTs)
- Metering or Protective Class Ratings
- Typically Unprotected
- Dangerous When Open Circuited

Compliance & Standards

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Instrument Transformers Are Expected to Perform & Conform

IEEE

ANSI

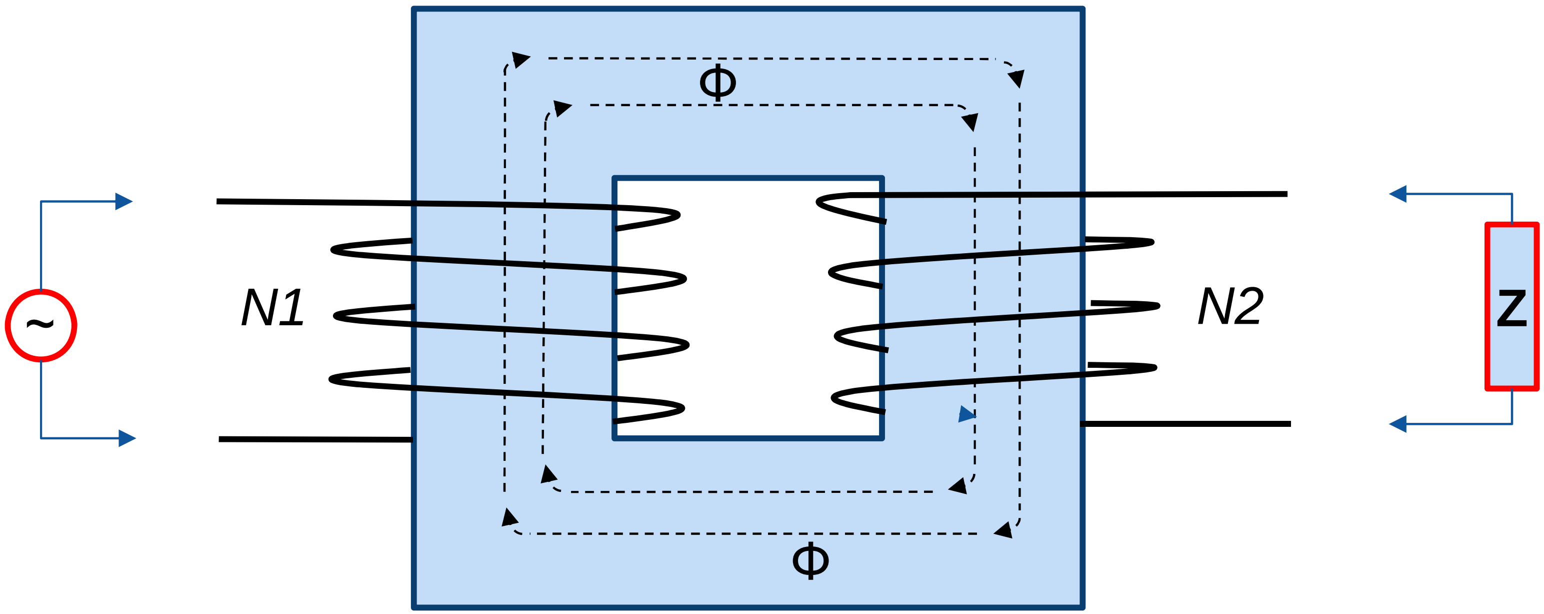
IEC in Europe & Asia

NERC Reliability Standards in US

Supported standards

- IEEE C57.13
  standard requirements for instrument transformers
- IEEE C57.13.6
  standard for high-accuracy instrument transformers
- IEC 60044-1
  current transformers
- IEC 60044-6
  requirements for protective current transformers for transient performance
- IEC 61869-2
  additional requirements for current transformers

Basic Transformer

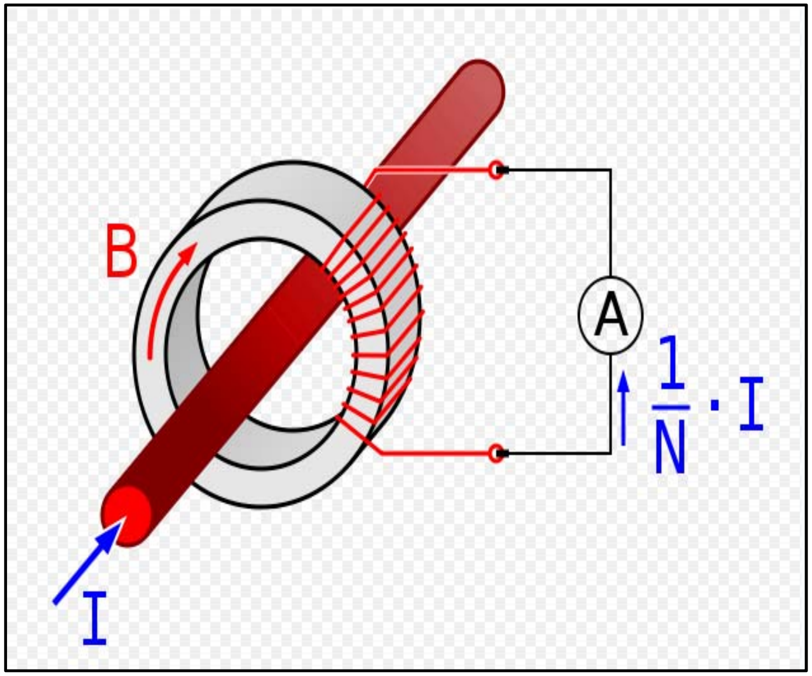


How it Works

In An Ideal CT

$$\Phi_1 = \Phi_2$$

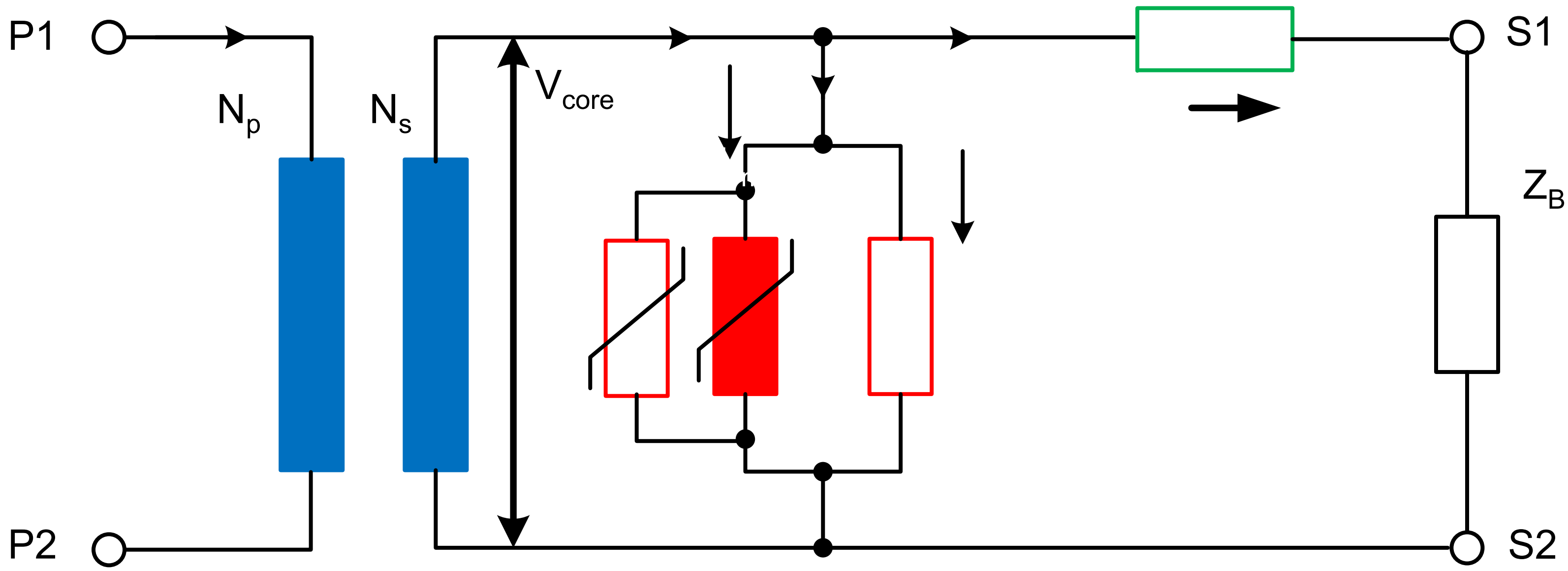
$$\Rightarrow \ddot{u} = \frac{n_1}{n_2} = \frac{I_2}{I_1}$$



Ignoring Magnetic and Resistive losses for the moment:

- The Current in the Seconday is Directly Proportional to the Primary Current by the Factor of the Turns Ratio

In a Real CT - CT Analyzer Model



The 3 parts of the CTA model:

- Winding Ratio (Purely the Ratio of Turns)
- Magnetic & Core Losses from Hysteresis, Gaps, Inductance, Eddy Currents
- Winding Resistance Losses

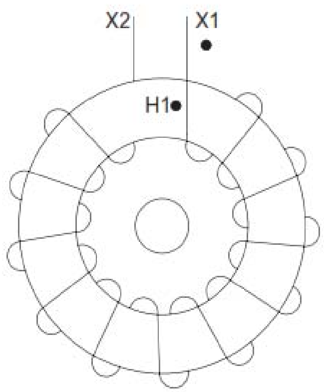
CT Construction Types

- Window or Bus Type
- Split Core
- Freestanding
- Outdoor versus Indoor

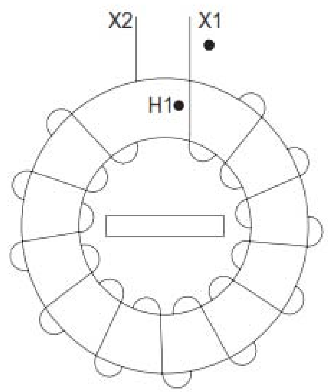
Construction Types

Window or Bus Bar

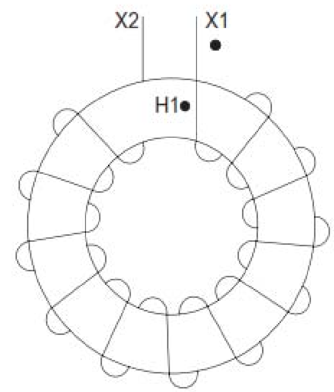
Window-type



Bar-type



Wound



Construction Types

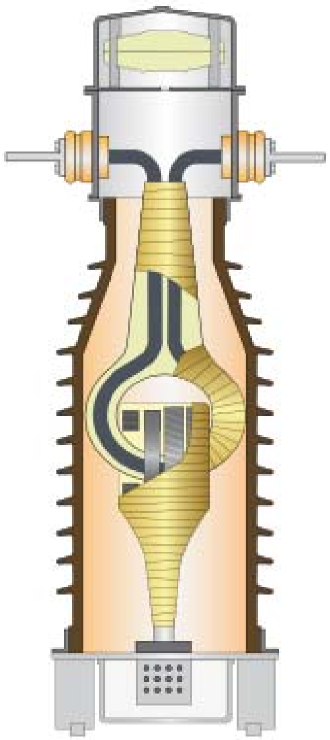
Split Core

Construction Types

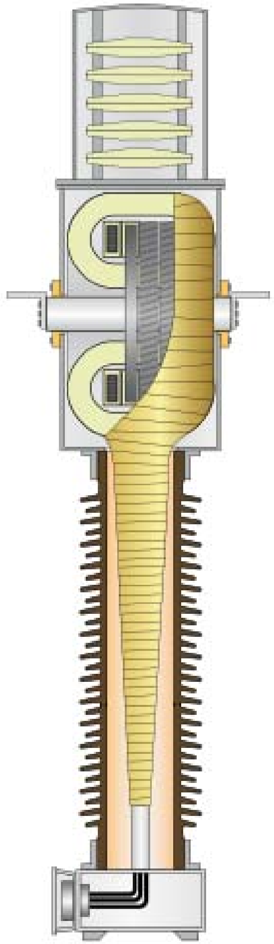
- Wound or Inductive
- Could be GIS Encapsulated
- HV Outdoor Freestanding Shown

High Voltage Current Transformer

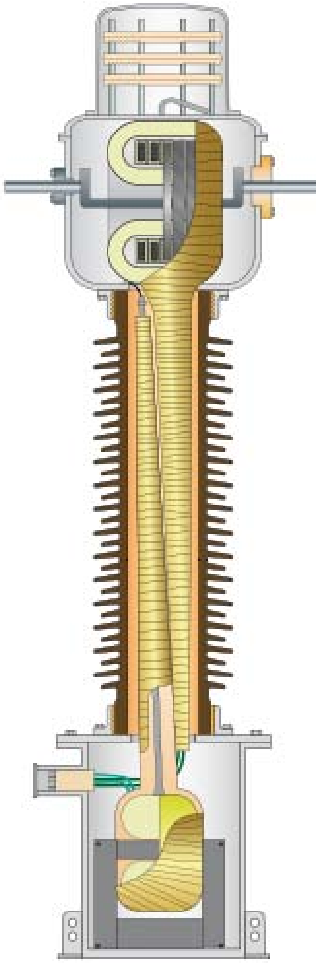
Hair-pin/Tank type



Cascade/Eye-bolt



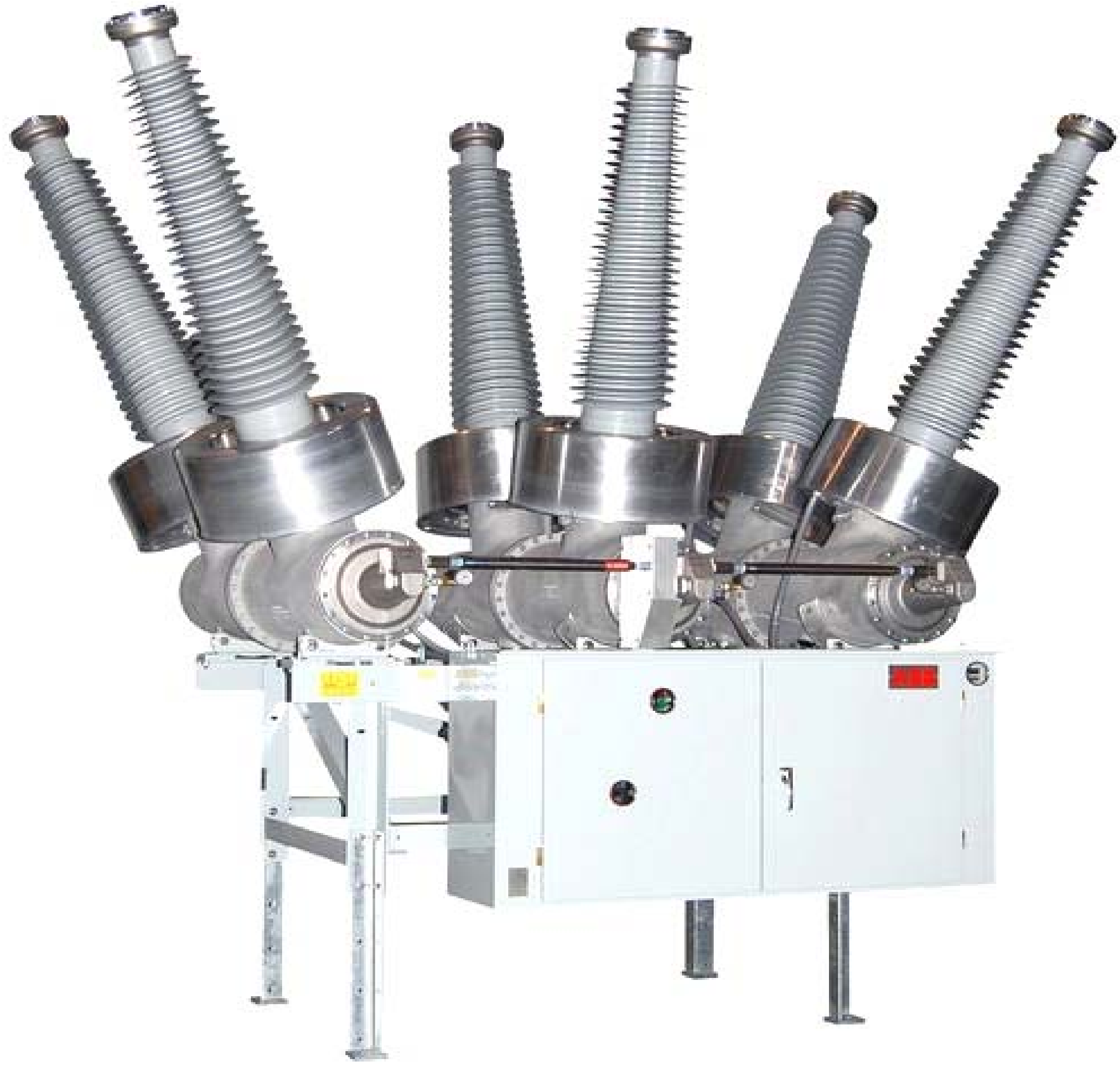
Top-core



Combined current-voltage type

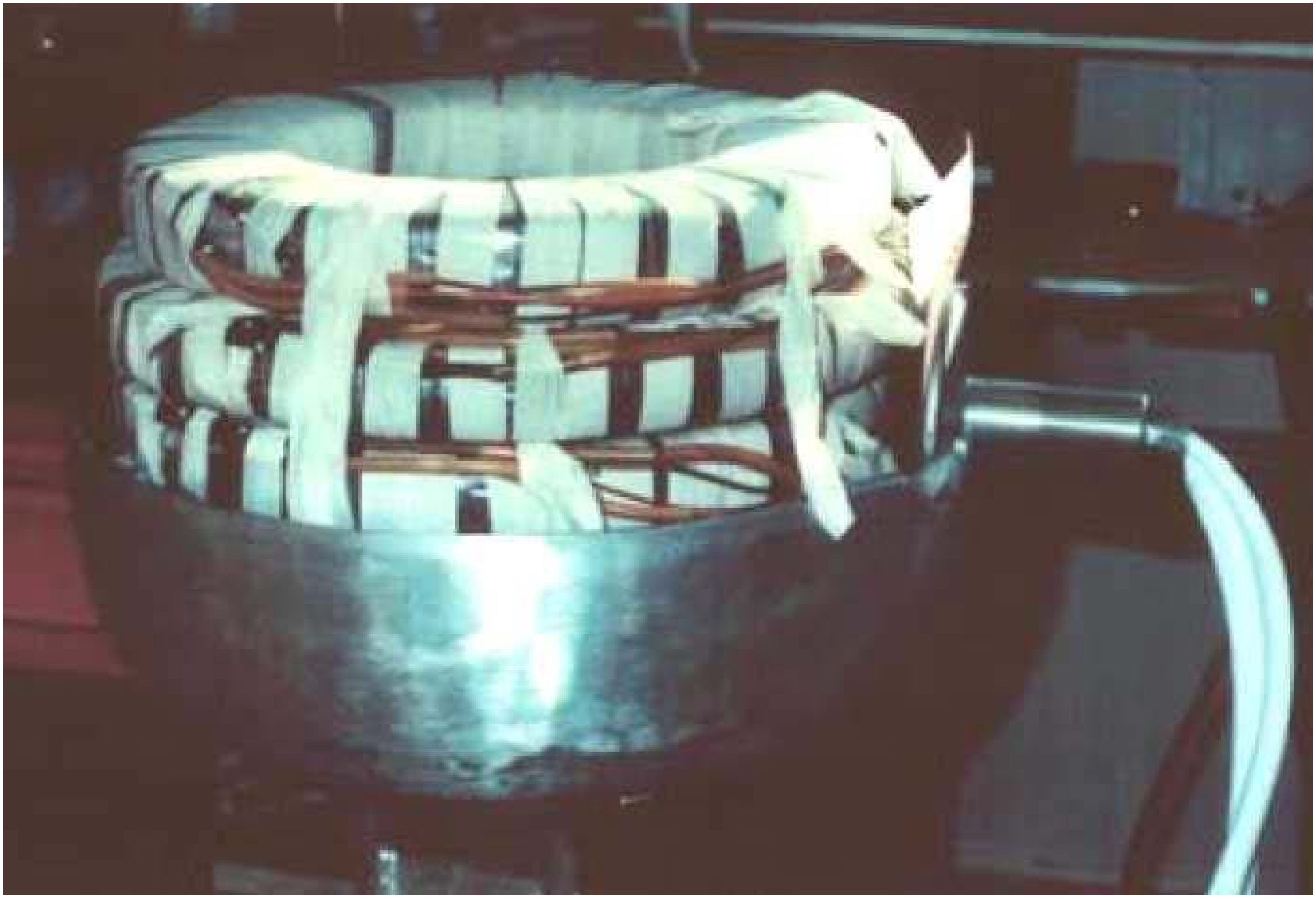
Construction Types

- Wound or Inductive
- Bushing Mounted
- External
- GIS Breaker



CT Cores

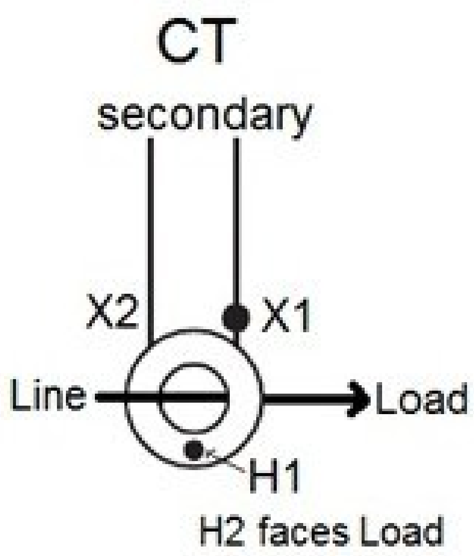
CT with Multiple Cores



Insulation of a Core Pile

Polarity and Terminal Marking

- H1 on HV side
- X1 on LV Side



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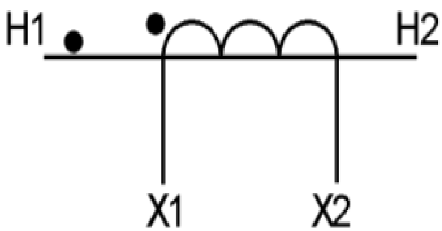
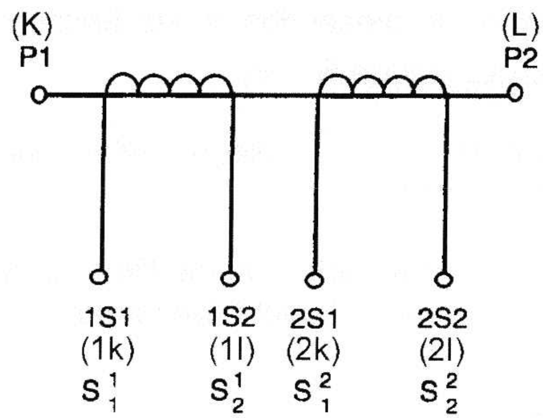
Current Transformer Secondary Types

- Can be Expressed in 5 Amp or 1 Amp Ratio
- Example 2000:5 or 200/1

IEEE C57.13



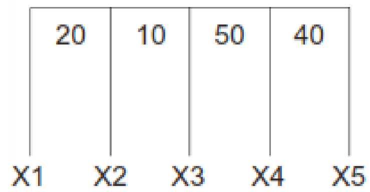
IEC 60044-1



Current Transformer Secondary Types

- **Multi-Ratio Example**

600:5 Multi-Ratio
Secondary Winding



600:5 Multi-Ratio

Primary Ampreres	Secondary terminals to get 5 Amps
50	X2-X3
100	X1-X2
150	X1-X3
200	X4-X5
250	X3-X4
300	X2-X4
400	X1-X4
450	X3-X5
500	X2-X5
600	X1-X5

CTs for Protection and Metering Applications

- A distinction has to be made between a metering class and a protection class current transformer.
- The designs of the magnetic cores are different.
- This insures that they perform according to the needs of the particular connected device.

Metering vs Protection Classes

Metering core

- A metering core is designed to work more accurately within the rated current range designated. When current flow exceeds that rating, the metering core will become saturated, thereby limiting the amount of current level within the device. This protects connected metering devices from overloading in the presence of fault level current flows. It buffers the meter from experiencing excessive torques that might be created during those faults.

- High accuracy in a smaller range.

- Less core material is needed

- Leads to Lower Saturation Voltages

Metering vs Protection Classes

Protection core

- A protection core is designed to transform a distortion-free signal even well into the overcurrent range. This enables the protective relays to measure the fault current value accurately, even in very high current conditions.

- Relays are required to perform in fault current type situations

- Moderate accuracy over a wider range

- More core material is needed

Protection CT Classes (IEEE C57.13-2008)

CT Classes defines the Performance of a CT

C 200

C Rating:

- Less than 3% ratio error at rated current
- Less than 10% ratio error at 20 times rated current
- Standard burden 200V/ (5A x 20) = 2Ω

200:

- Secondary terminal voltage which the CT must maintain within the C Rating which is 200V in this example.

- In CTAnalyzer – This is known as Vb

Actual Transformer Label (Protection Class)

FLEX-CORE
CURRENT TRANSFORMER
RATIO 3000:5A. CAT 781-302MR
RF 1.5 ACC CLASS C200
50-400 HZ 600V INS CLASS 10kV BIL

1. Manufacturer's name or trademark
2. Manufacturer's type
3. Rated primary and secondary current
4. Continuous thermal current rating factor (RF)
5. Accuracy classes
6. Rated frequency (Hz)
7. Insulation and Basic impulse insulation level (BIL kV)

Other Protection CT Classes (IEEE C57.13-2008)

- **C** – Ratio error can be determined by **Calculation** from the Excitation Curve
- **K** – Same as C class, except the **Knee-point** must be greater than 70% of the V_B rating
- **T** – Ratio error must be determined by **Test** due to significant leakage flux
- **PX** – User defined CT performance (e.g. V_k, I_k, R_{ct})

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Metering CT Classes (IEEE C57.13-2008)

0.3 B 0.9

Metering Class CT

- At 100% rated current, the error limit is 0.3%
- At 10% rated current, the error limit is 0.6% (doubled)

Maximum Burden (e.g. 0.9Ω)

Burdens	**Burden designation**[b]
Metering burdens	B-0.1
	B-0.2
	B-0.5
	B-0.9
	B-1.8

Ratio Error

Metering accuracy class[b]	Current transformers			
	At 100% rated current[a]		At 10% rated current	
	Minimum	Maximum	Minimum	Maximum
0.3	0.997	1.003	0.994	1.006
0.6	0.994	1.006	0.988	1.012
1.2	0.988	1.012	0.976	1.024

Rating Factor (RF)

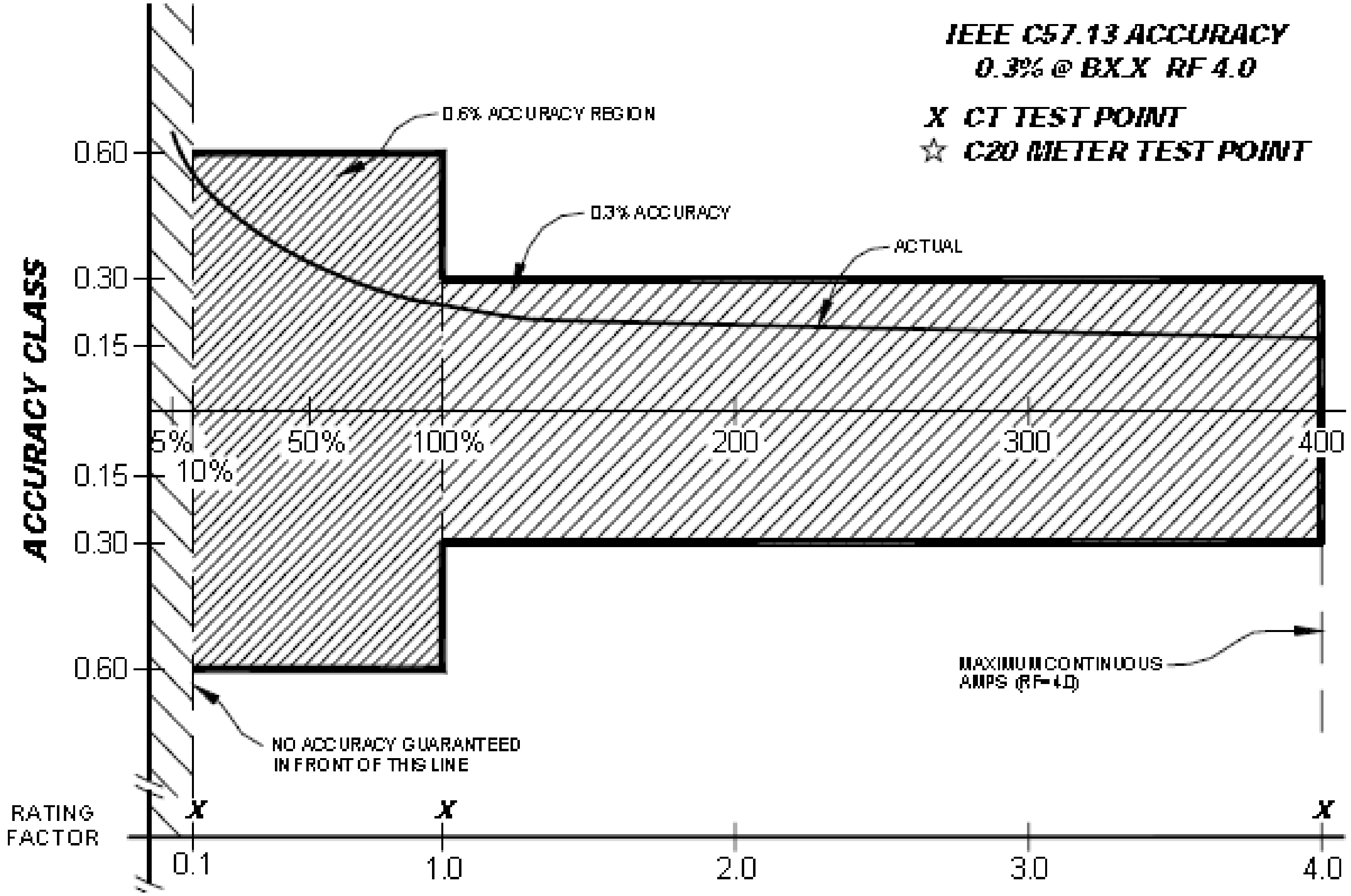
Multiples of Rated Current to which the CT can maintain its accuracy

Typical RF: 1, 1.5, 2, 3, 4

Example: 200/5A CT with RF 2

CT will maintain it's accuracy certification up to 400A

Metering CT Accuracy



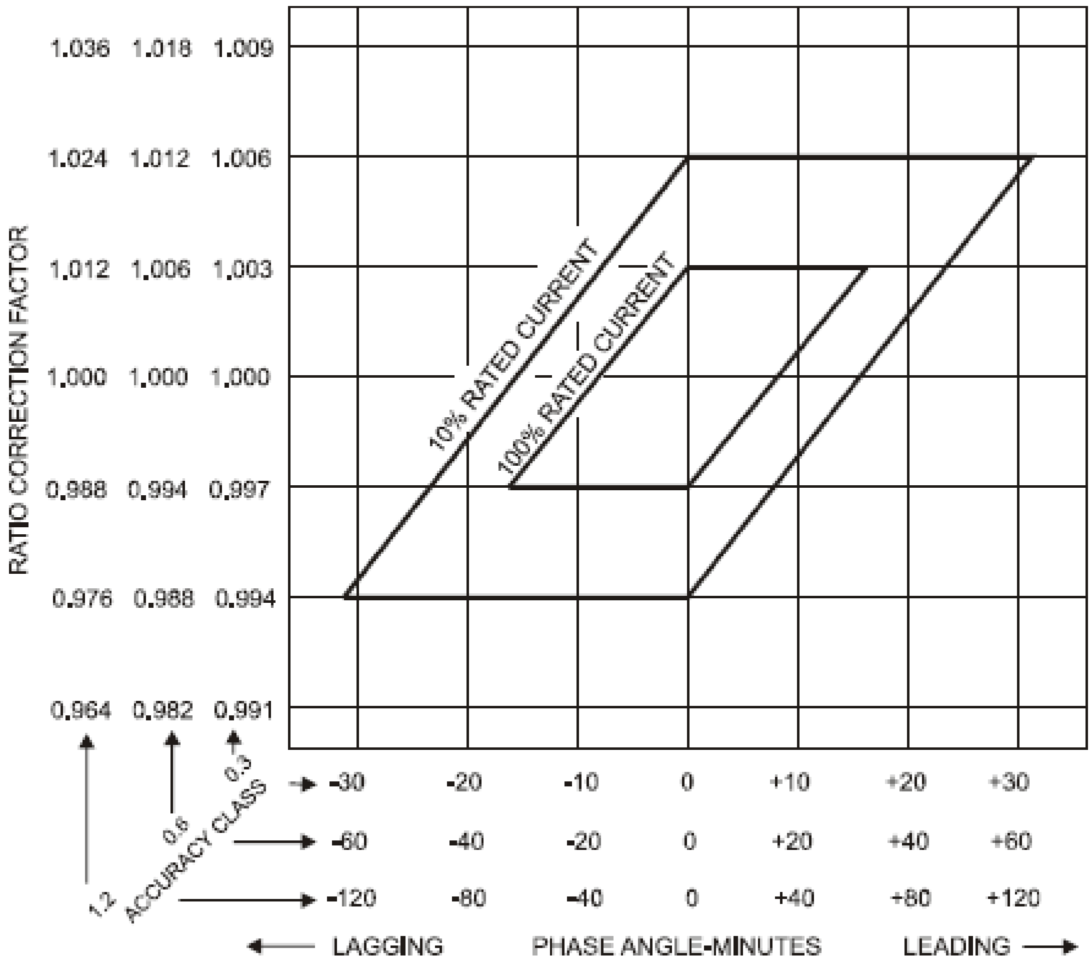
Actual Transformer Label (Metering)

INSTRUMENT TRANSFOMERS,INC.
CURRENT TRANSFORMER
RATIO 400:5 A. CAT 115-401
RF 2.0 ACC CLASS 0.3B0.9 C50
50-400 HZ 600V INS CLASS 10kV BIL

1. Manufacturer's name or trademark
2. Manufacturer's type
3. Rated primary and secondary current
4. Continuous thermal current rating factor (RF)
5. Accuracy classes
6. Rated frequency (Hz)
7. Insulation and Basic impulse insulation level (BIL kV)

Actual Transformer Label (Meter Class)

Error Parallelogram: Metering CTs



Source: IEEE C57.13-2008

CT Selection

CURRENT TRANSFORMER TYPE:: GIF 36-68

Current Ratio (A)	Catalog Number	IEEE Accuracy Class 60 Hz		Rating Factor
		Meter	Relay	
500:5	113026068 45893	0.3B-0.9	C100	3.0
600:5	113026068 45894	0.3B-0.9	C100	3.0
800:5	113026068 45895	0.3B-0.9	C100	2.0
1000:5	113026068 45897	0.3B-0.9	C100	1.5
1200:5	113026068 45896	0.3B-0.9	C100	1.5
500/1000:5	113026068 45948	0.3B-1.0/2.0	C200/C400	2.0/1.5
600/1200:5	113026068 45949	0.3B-1.0/2.0	C200/C400	2.0/1.5
800/1600:5	113026068 45950	0.3B-1.0/2.0	C200/C400	2.0/1.5
1000/2000:5	113026068 45951	0.3B-1.0/2.0	C200/C400	2.0/1.5
1500/3000:5	113026068 45952	0.3B-1.0/2.0	C200/C400	2.0/1.0

Residual Magnetism (Remanence flux)

- When excitation is removed from the CT, some of the magnetic domains retain a degree of orientation relative to the magnetic field that was applied to the core
- Residual magnetism in CTs can be described by amount of flux left in the core

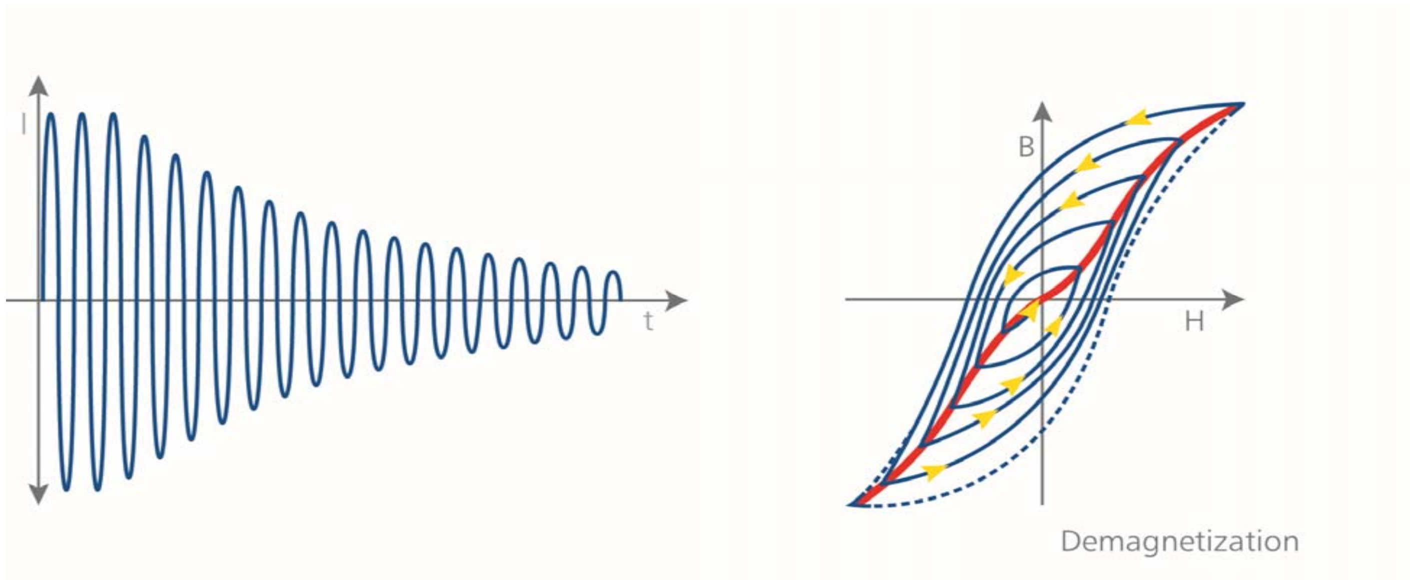
Causes of Residual Magnetism

Residual Magnetism Can Occur Due To:

- High Transient Fault Currents
- Circuit Breaker Arc During Trip Operations
- DC Currents Due to Winding Resistance Measurement
- Other Tests

Residual Magnetism – How to get rid of?

Demagnetization process



Done automatically by the CTAnalyzer at the very end of the measurement

Testing CTs

- When ?
  - Initial Commissioning
  - Investigation
  - Scheduled

- Why ?
  - Verify Factory Tests
  - Ordered/Delivered Correctly
  - Insure no damage

Test Methods

- Primary Injection
- Secondary Injection – Fixed Frequency
- Secondary Injection – Variable Frequency

$$\hat{B} = \frac{V_C}{n \cdot 2\pi f \cdot A}$$

Test Requirements

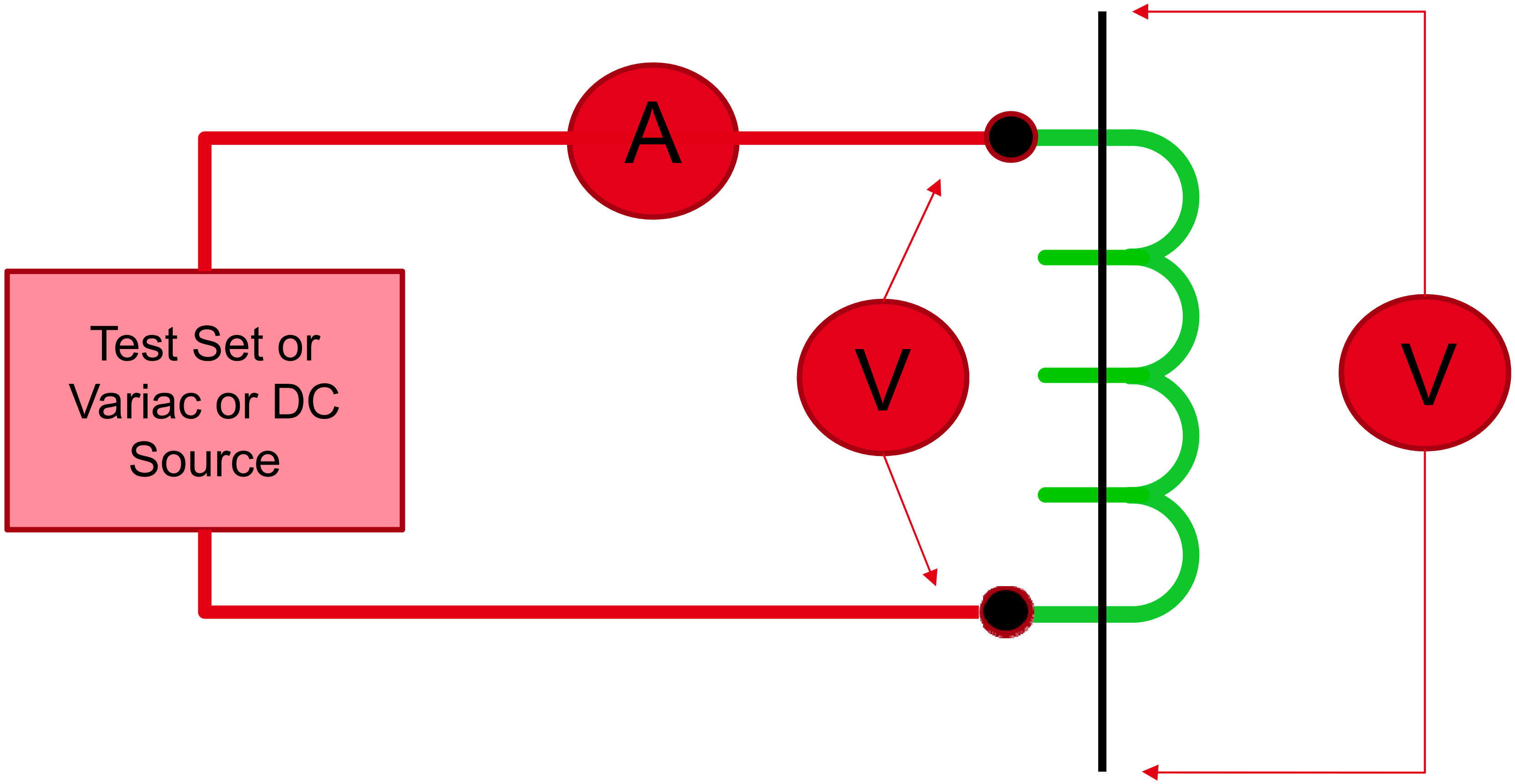
- Excitation to Determine Knee/Saturation Point
- Insulation
- Polarity
- Winding Resistance
- Primary Ratio
- Secondary Ratio
- Burden Check
- Documentation

Why So Many Tests?

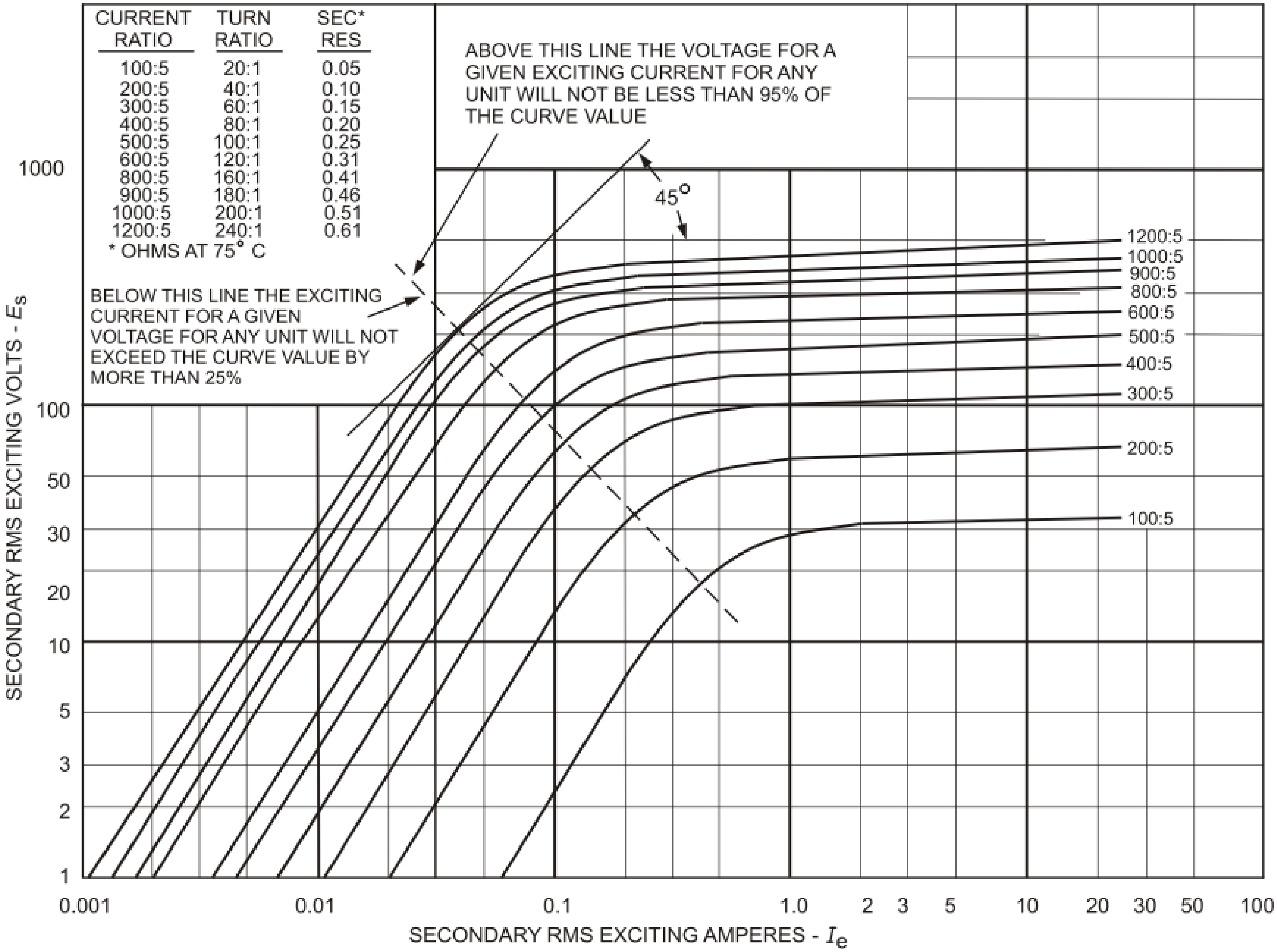
- Ensure proper Relay Operation
- Certify Billing Accuracy
- Reduce Possibility of Failure when Energized
- Reduce Possibility of Injury Due to Failure
- Manufacturing Defects Do Happen
- Installation Errors Do Happen

What is This Relic ???

Test Setup



Excitation curves for multi-ratio C class CT



Relay Class Test Result

TEST RESULTS:

Operating Burden (VA): 50.0VA
Operating Burden (Ω): 2.0Ohm

Taps	Nameplate Ratio	Turns Ratio	Current Ratio	Ratio Error	Phase Error	Polarity	IEEE C57.13 Kneepoint Voltage	IEEE C57.13 Kneepoint Current
X1-X5	1200	239.98	1200.0	-0.1562%	-0.065min	OK	131.99V	0.049479A
X2-X5	1000	199.99	1000.0	-0.213%	-0.474min	OK	110.11V	0.059313A
X3-X5	900	179.99	900.0	-0.1603%	0.648min	OK	99.21V	0.065826A
X4-X5	400	79.99	400.0	-0.6536%	-1.051min	OK	44.17V	0.147855A
X1-X4	800	159.99	800.0	-0.2006%	0.536min	OK	87.82V	0.074366A
X2-X4	600	120.00	600.0	-0.3245%	-0.049min	OK	65.94V	0.099045A
X3-X4	500	99.99	500.0	-0.3874%	6.67min	OK	55.04V	0.11865A
X1-X3	300	60.00	300.0	-0.6147%	10.741min	OK	32.78V	0.199246A
X2-X3	100	20.00	100.0	-2.1099%	33.625min	OK	10.9V	0.599422A
X1-X2	200	40.00	200.0	-0.6594%	14.526min	OK	21.88V	0.29845A

Relay Class Test Result

Taps	ANSI 30 Kneepoint Voltage	ANSI 30 Kneepoint Current	IEEE C57.13 Vb @ rated Burden	IEEE C57.13 Vb @ op. Burden.	Remanence Factor (Kr)	Rct (measured)	Rct (ref)	Class Assessment
X1-X5	167.06V	0.06743A	202.6V	202.6V	83.39%	0.514Ohm	0.614Ohm	OK
X2-X5	139.36V	0.08083A	173.8V	173.8V		0.433Ohm	0.516Ohm	n/a
X3-X5	125.57V	0.089707A	138.4V	158.5V		0.396Ohm	0.473Ohm	n/a
X4-X5	55.91V	0.201494A	66.4V	72.5V		0.2868Ohm	0.3421Ohm	n/a
X1-X4	111.15V	0.101344A	126.3V	142.5V		0.3519Ohm	0.4197Ohm	n/a
X2-X4	83.46V	0.134977A	100.3V	110.0V		0.27Ohm	0.322Ohm	n/a
X3-X4	69.67V	0.161694A	77.8V	92.9V		0.2336Ohm	0.2786Ohm	n/a
X1-X3	41.49V	0.27153A	46.8V	55.4V		0.1244Ohm	0.1484Ohm	n/a
X2-X3	13.79V	0.816883A	15.8V	13.5V		0.0424Ohm	0.0506Ohm	n/a
X1-X2	27.7V	0.406724A	26.3V	35.9V		0.0919Ohm	0.1096Ohm	n/a

Test Results

	Current ratio error in % at % of rated current							
VA/cosPhi	1	5	10	20	50	100	120	400
12.5 VA/ 0.9	-0.872	-0.541	-0.446	-0.365	-0.289	-0.231	-0.214	-0.107
5 VA/ 0.9	-0.283	-0.088	-0.037	0.004	0.049	0.073	0.077	0.123
2.5 VA/ 0.9	-0.036	0.085	0.117	0.143	0.170	0.187	0.191	0.211
VA/								
VA/								
VA/								
VA/								
VA/								

	Phase displacement in [min] at % rated current							
VA/cosPhi	1	5	10	20	50	100	120	400
12.5 VA/ 0.9	44.696	25.919	21.505	17.884	13.266	9.840	8.925	3.114
5 VA/ 0.9	30.430	15.617	12.650	10.493	8.254	6.637	6.233	3.459
2.5 VA/ 0.9	24.757	11.569	9.207	7.544	5.970	4.982	4.715	3.054
VA/								
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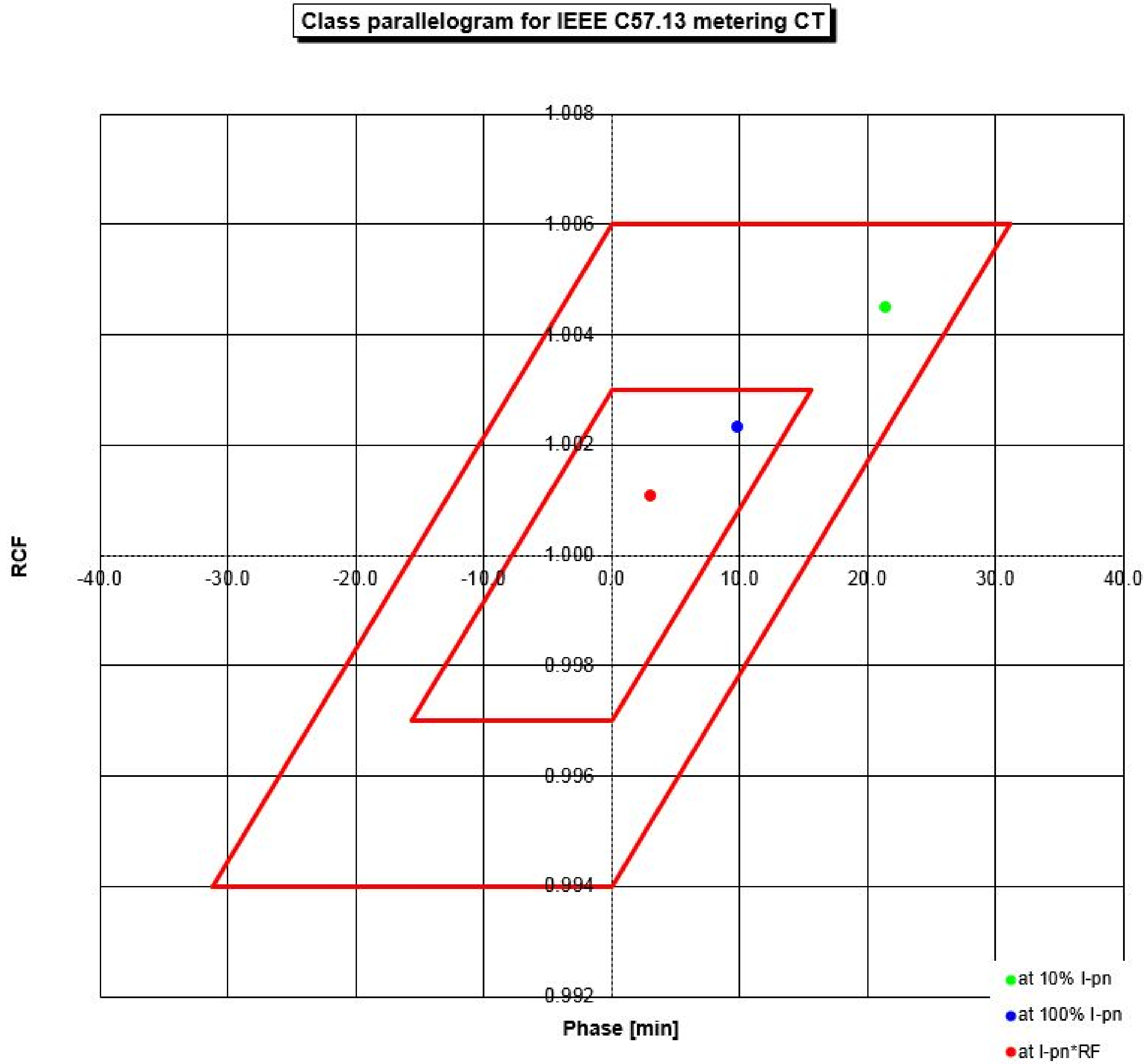
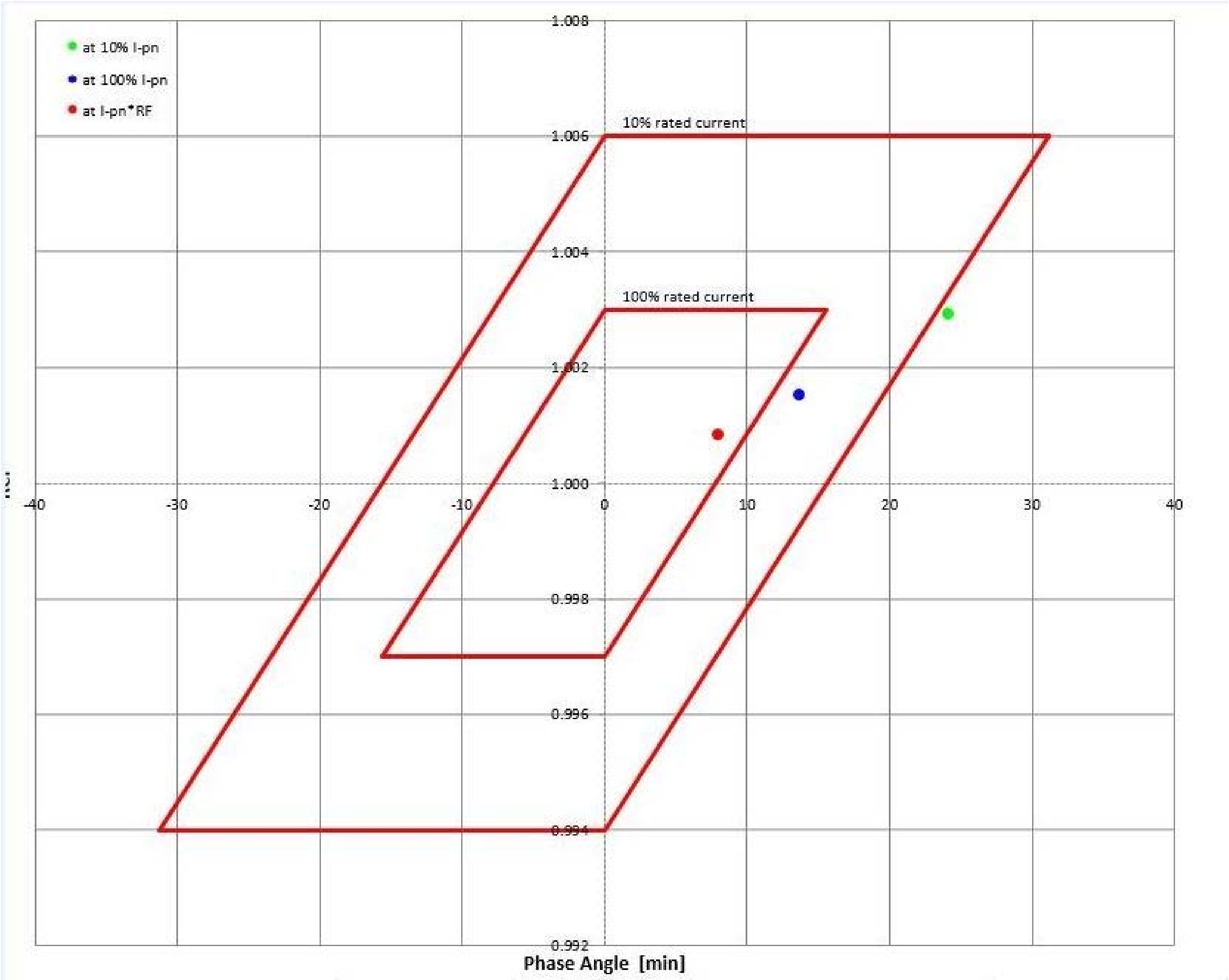
Actual Test Results - Pass



Actual Test Results - Failure



Questions ?

Thank you

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