Current & Voltage Transformer Basics

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Agenda

Current Transformers

- Transformer Ratio
- Polarity
- IEEE Metering Accuracy
- IEEE Relaying Accuracy
- Accuracy Influencing factors
- Burden Calculation
- Rating Factor

Voltage Transformers

- IEEE Accuracy Classes
- Installation Guidelines

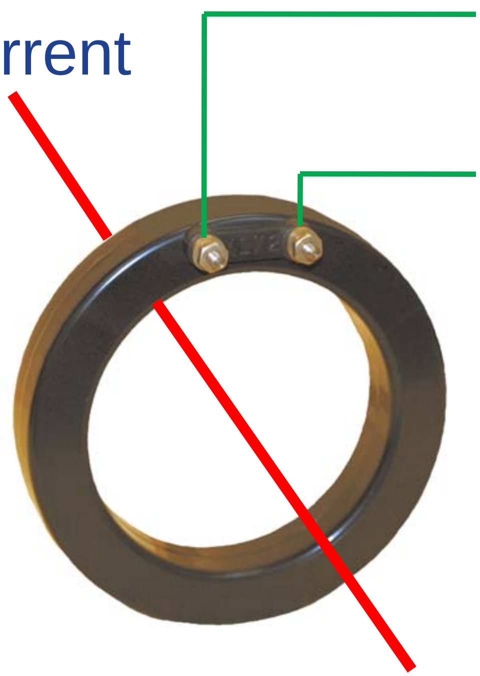
Required Information for Specifying CTs & VTs

"Take Home Rules" for CTs & VTs

Transformer ratio (TR)

$$\text{Transformer Ratio} = \frac{\text{Primary Current}}{\text{Secondary Current}}$$

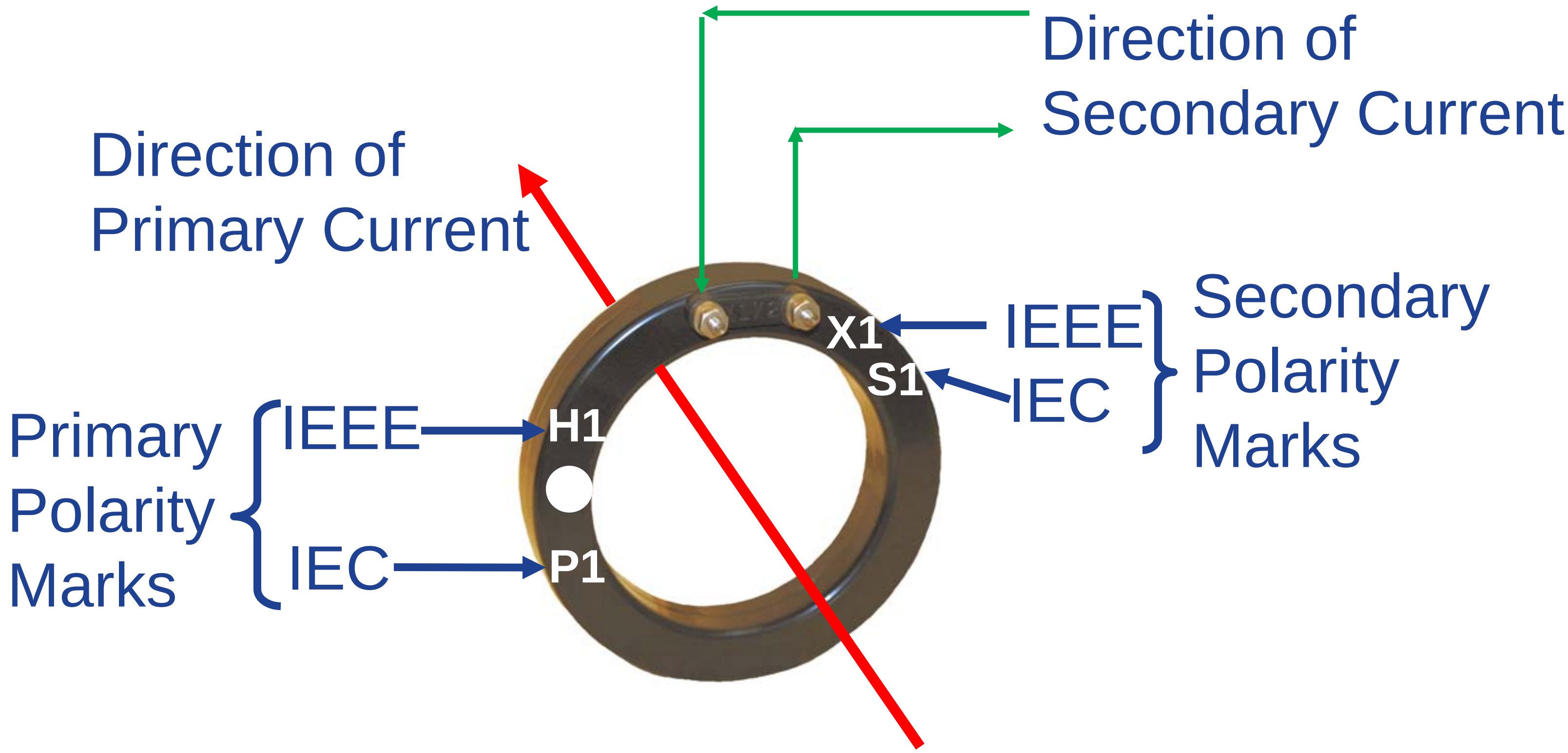
Primary Current
(100 amps)



Secondary
Current
(5 amps)

$$\frac{100}{5} = 100:5 \text{ or } 20:1$$

Polarity

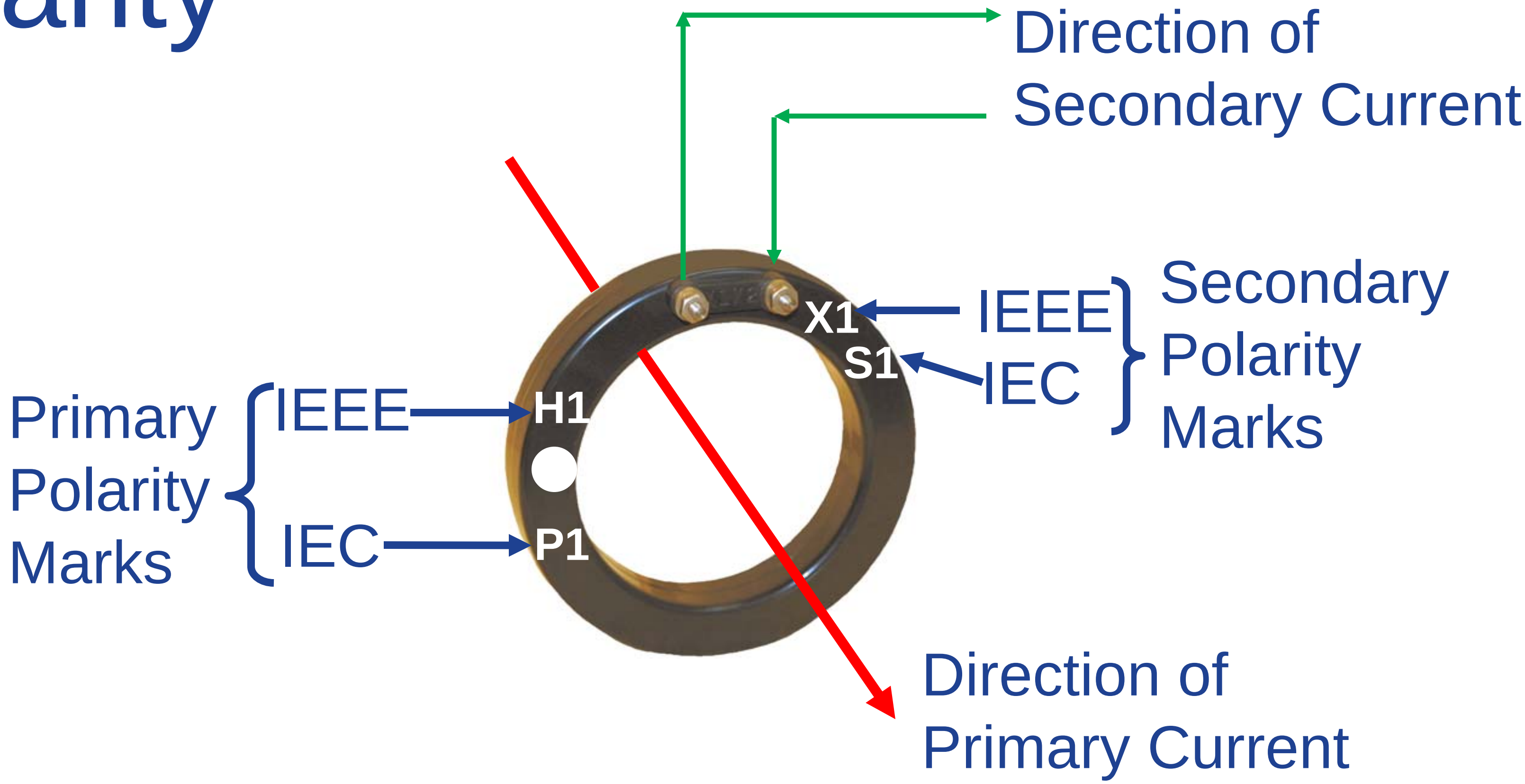


Remember:

Primary current <u>into</u> "polarity" =

Secondary current <u>out of</u> "polarity"

Polarity



Remember:

Primary current into "non-polarity" =

Secondary current out of "non-polarity"

CT Metering Accuracy

Actual secondary current ≠ **Rated** secondary current

Difference in % is known as the **"Accuracy"** of the CT

IEEE CT Metering Accuracy

Accuracy Class (*)	Application
0.15	High Accuracy Metering
0.15S	"Special" High Accuracy Metering
0.3	Revenue Metering
0.6	Indicating Instruments
1.2	Indicating Instruments

* All accuracy classes defined by IEEE C57.13 or C57.13.6

* Accuracy classes include both ratio & phase angle error

IEEE CT Metering Accuracy

Burden

- Load connected to CT secondary
- Includes devices & connecting leads
- Expressed in ohms
- Standard values = B0.1, B0.2, B0.5, B0.9, B1.8

  E0.04, E0.2

All burdens defined by IEEE C57.13 or C57.13.6 for 60 Hz only

;

IEEE CT Metering Accuracy

Standard IEEE CT Burdens (5 Amp) (Per IEEE Std. C57.13-1993 & C57.13.6)

Application	Burden Designation	Impedance (Ohms)	VA @ 5 amps	Power Factor
Metering	B0.1	0.1	2.5	0.9
	B0.2	0.2	5	0.9
	B0.5	0.5	12.5	0.9
	B0.9	0.9	22.5	0.9
	B1.8	1.8	45	0.9
	E0.2	0.2	5	1.0
	E0.04	0.04	1	1.0

<

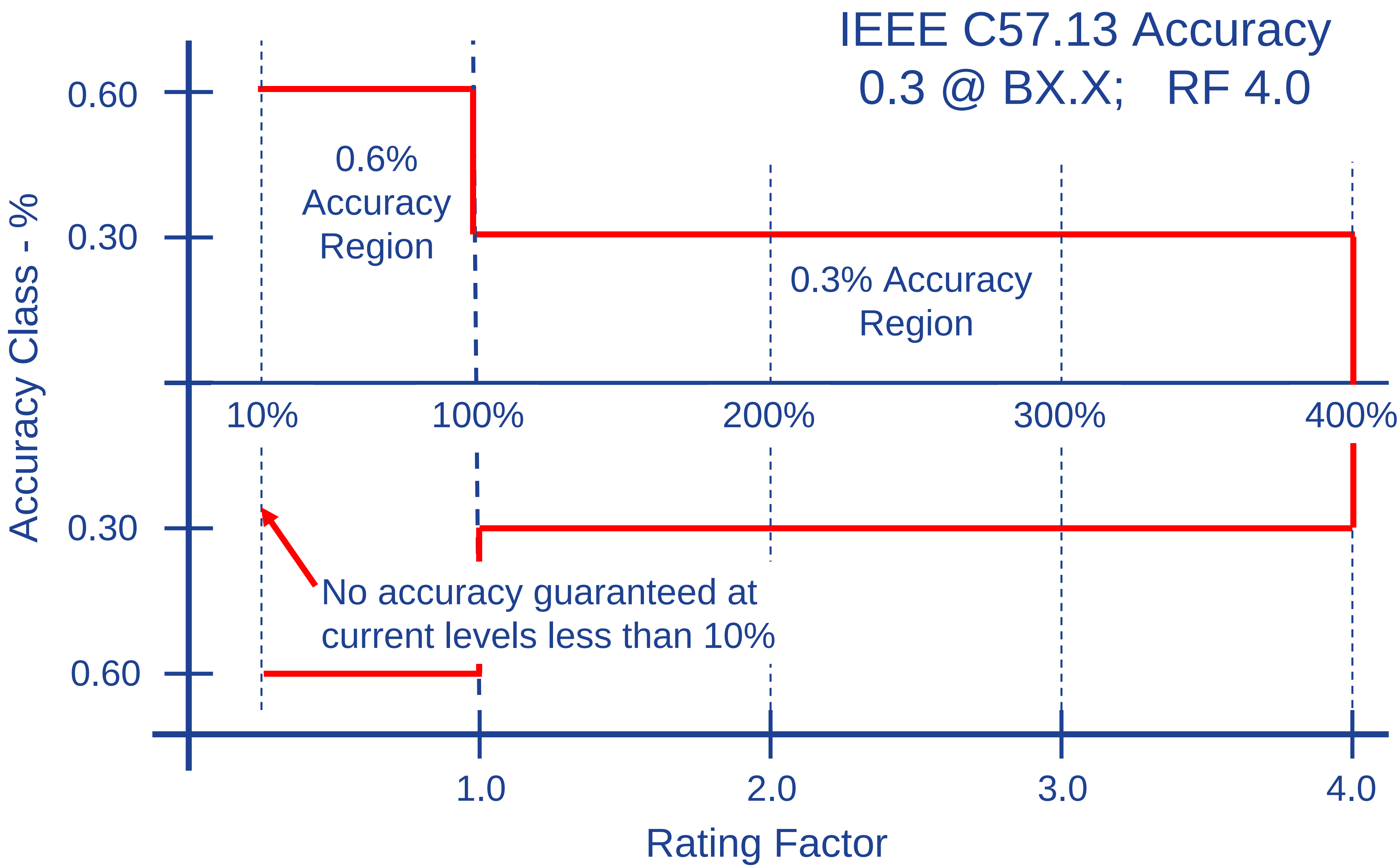
IEEE CT Metering Accuracy

"Accuracy" expressed as:

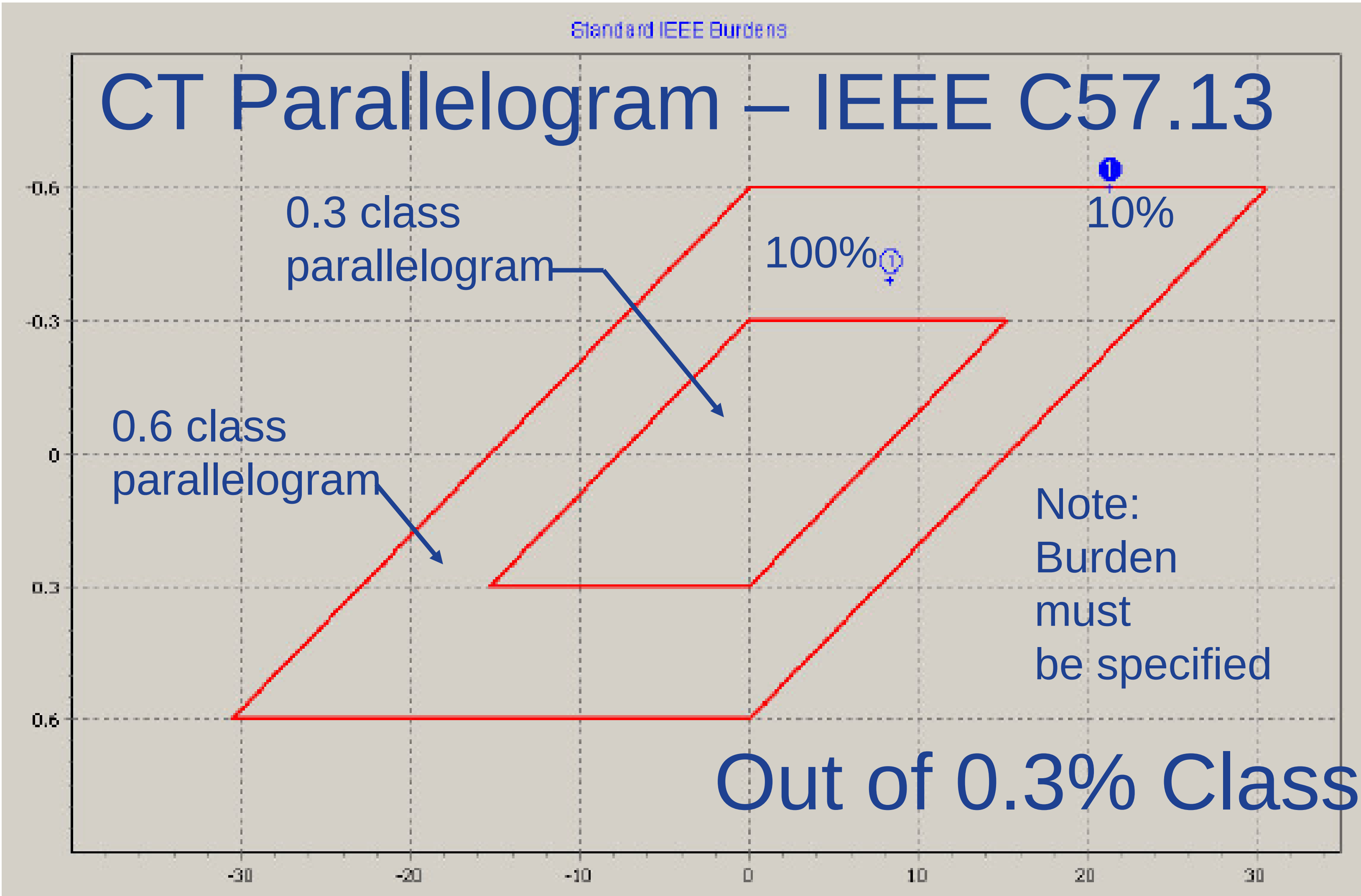
					Typical Examples
Accuracy Class	+	Burden (Ohms)	=		0.3B0.2
(0.3, 0.6, 1.2) (*)		(B0.1, B0.2, B0.5, B0.9, B1.8)			0.6B0.9
					1.2B1.8
(0.15*, 0.15S^)		E0.2, E0.04)			0.15E0.2

* Accuracy class is stated at 100% rated current
* At 10% rated current, twice the error is allowed (5% for 0.15 class)
^ Accuracy class is stated at 100% to 5% rated current

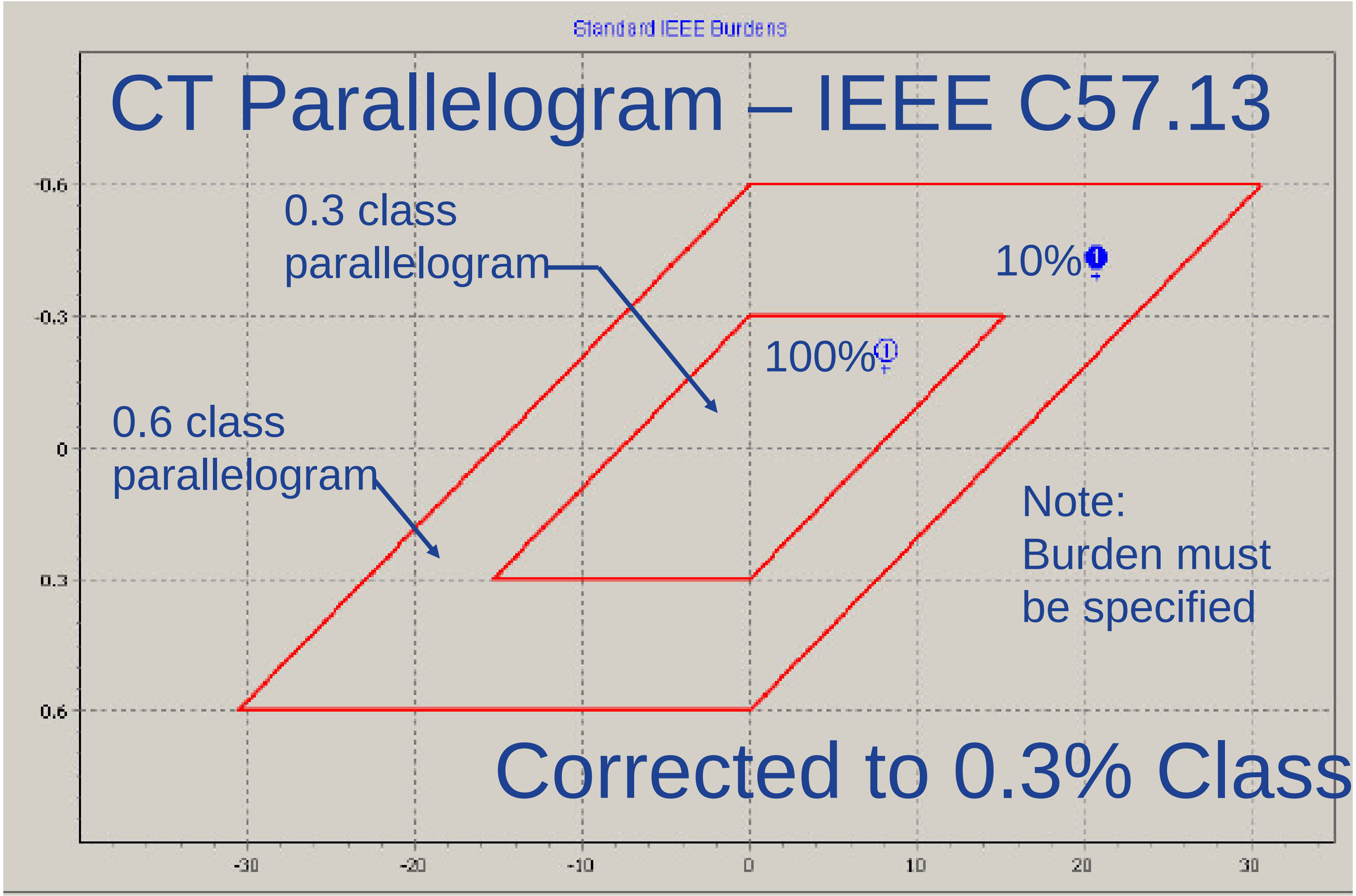
IEEE CT Metering Accuracy



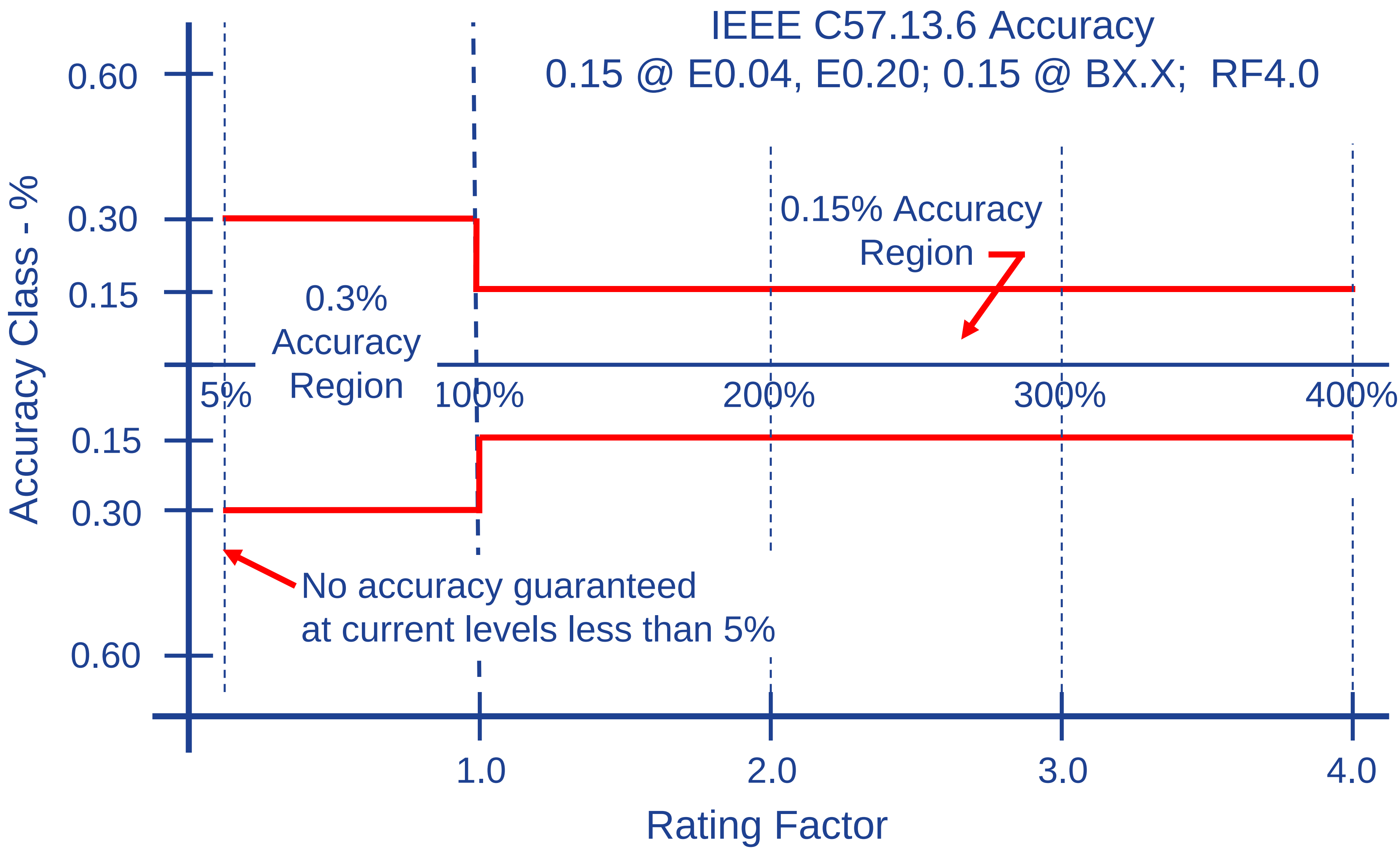
IEEE CT Metering Accuracy



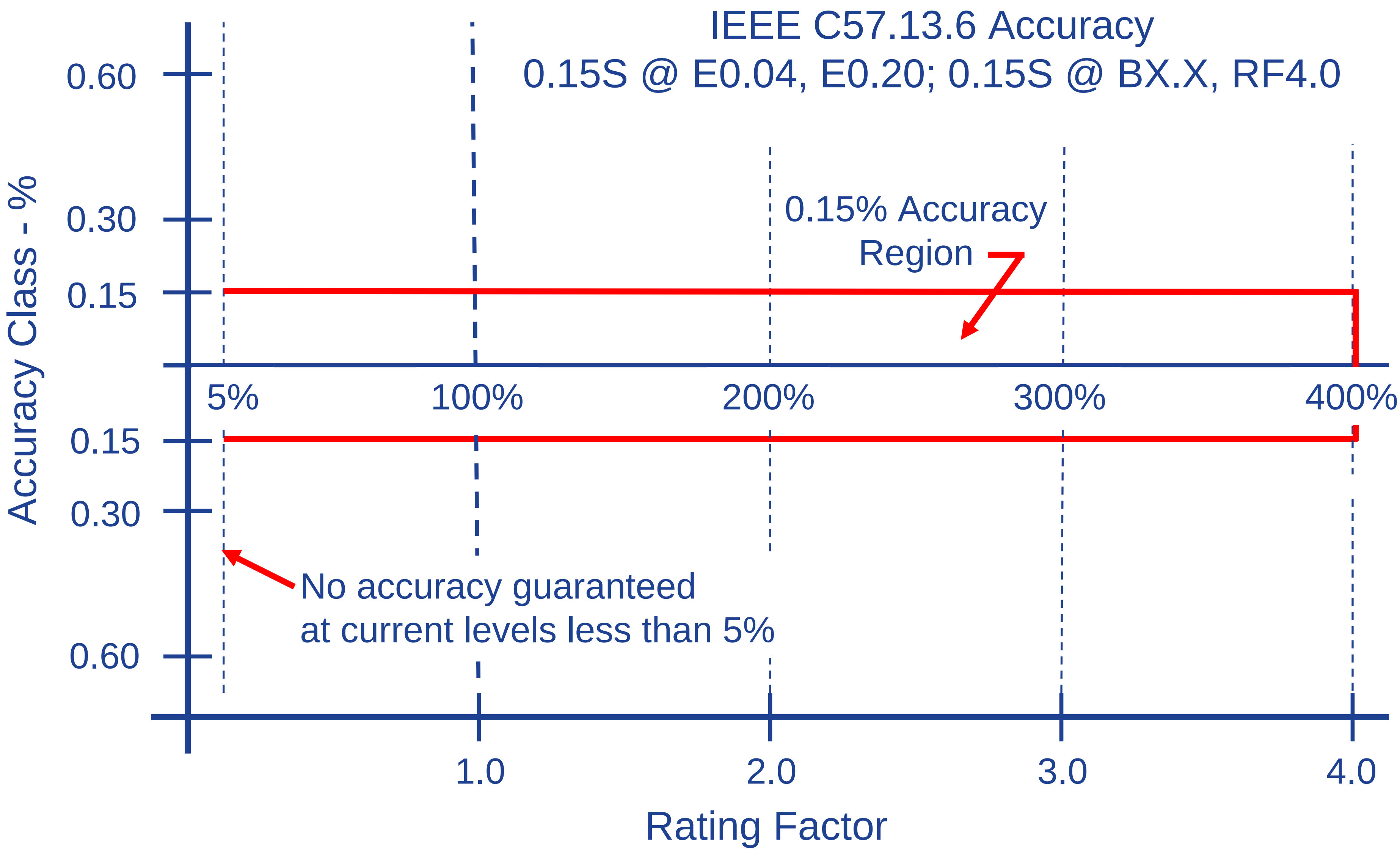
IEEE CT Metering Accuracy



IEEE CT Metering Accuracy



IEEE CT Metering Accuracy



IEEE CT Relay Accuracy

Standard Relay Accuracy Classes

C or T100

C or T200

C or T400

C or T800

What do these mean?

IEEE CT Relay Accuracy

Relay class (C or T___) designates minimum secondary terminal volts…

At 20 times rated current

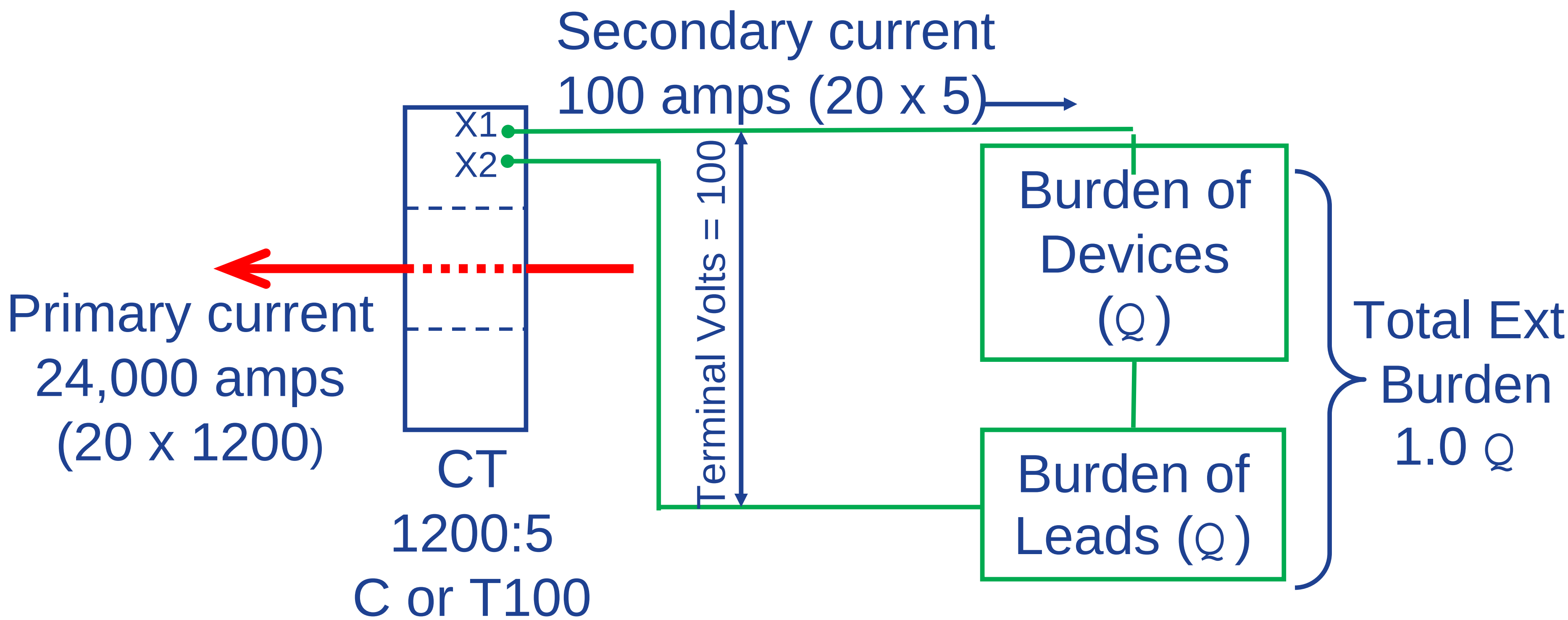
Without exceeding 10% ratio error

Into a maximum specified burden

Now that everyone is totally confused let's look at some simple examples …

IEEE CT Relay Accuracy

C or T100 example

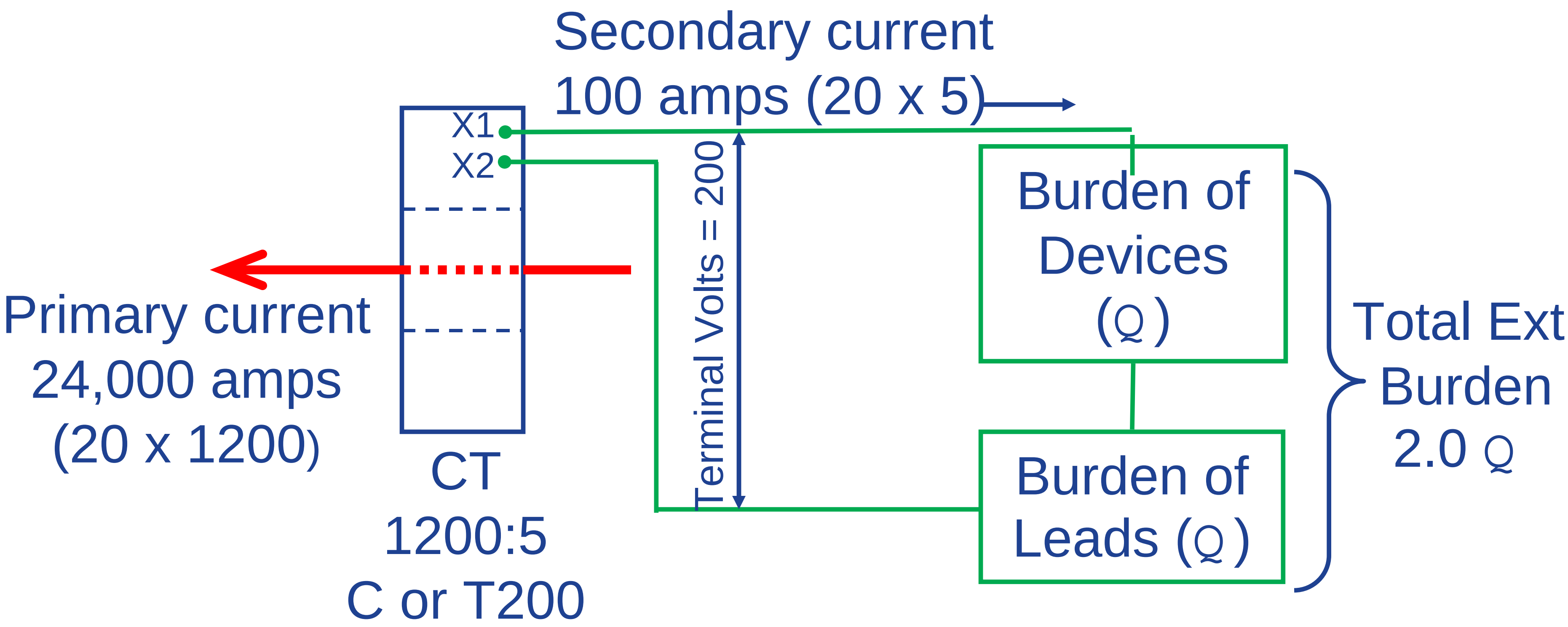


Terminal Volts = (20 times rated) (Total external burden)

100 Volts = (100 amps) (1.0 Ω)

IEEE CT Relay Accuracy

C or T200 example



Terminal volts = (20 times rated) (Total external burden)

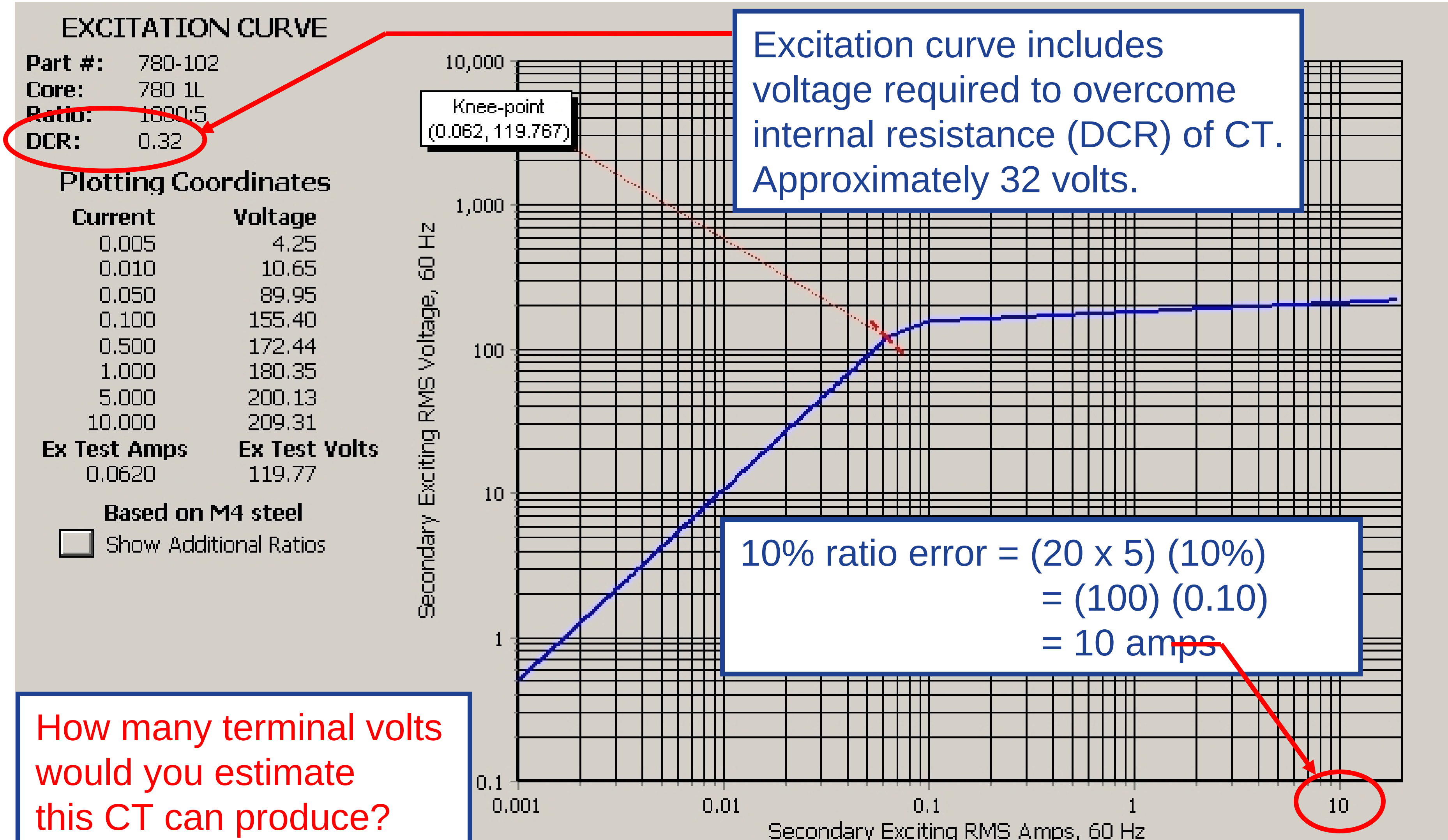
200 Volts = (100 amps) (2.0 Ω)

IEEE CT Relay Accuracy

Standard IEEE CT Burdens (5 Amp)
(Per IEEE Std. C57.13-1993)

Application	Burden Designation	Impedance (Ohms)	VA @ 5 amps	Power Factor
Relaying	B1	1	25	0.5
	B2	2	50	0.5
	B4	4	100	0.5
	B8	8	200	0.5

IEEE CT Relay Accuracy



Excitation curve includes voltage required to overcome internal resistance (DCR) of CT. Approximately 32 volts.

10% ratio error = (20 x 5) (10%)
= (100) (0.10)
= 10 amps

How many terminal volts would you estimate this CT can produce?

Factors Influencing CT Accuracy

Frequency

"Low frequency" and "High accuracy" are not friends!!

Current Ratio

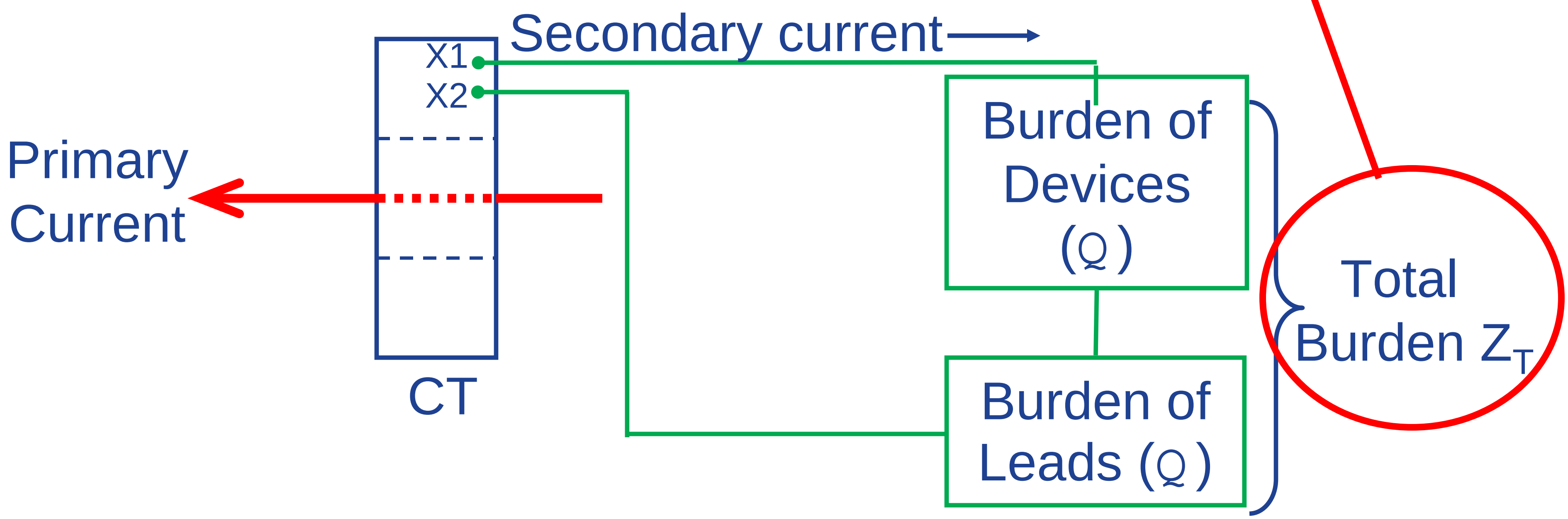
"Low ratio" and "high accuracy" are not friends!!

Burden

"High burden" and "High Accuracy" are not friends!!

CT Burden Calculation

How do we calculate this?



CT Burden Calculation

$$Z_T = R_{CT} + R_L + Z_B$$

Z_T = Total burden in ohms (vector summation of resistance and inductance components)

R_{CT} = CT secondary resistance in ohms @75 deg C (DCR)

R_L = Resistance of leads in ohms (Total loop distance)

Z_B = Device impedance in ohms

Assumption: 3 phase CTs are “Y” connected

CT Rating Factor (RF) -- IEEE

Rated current x (RF) =

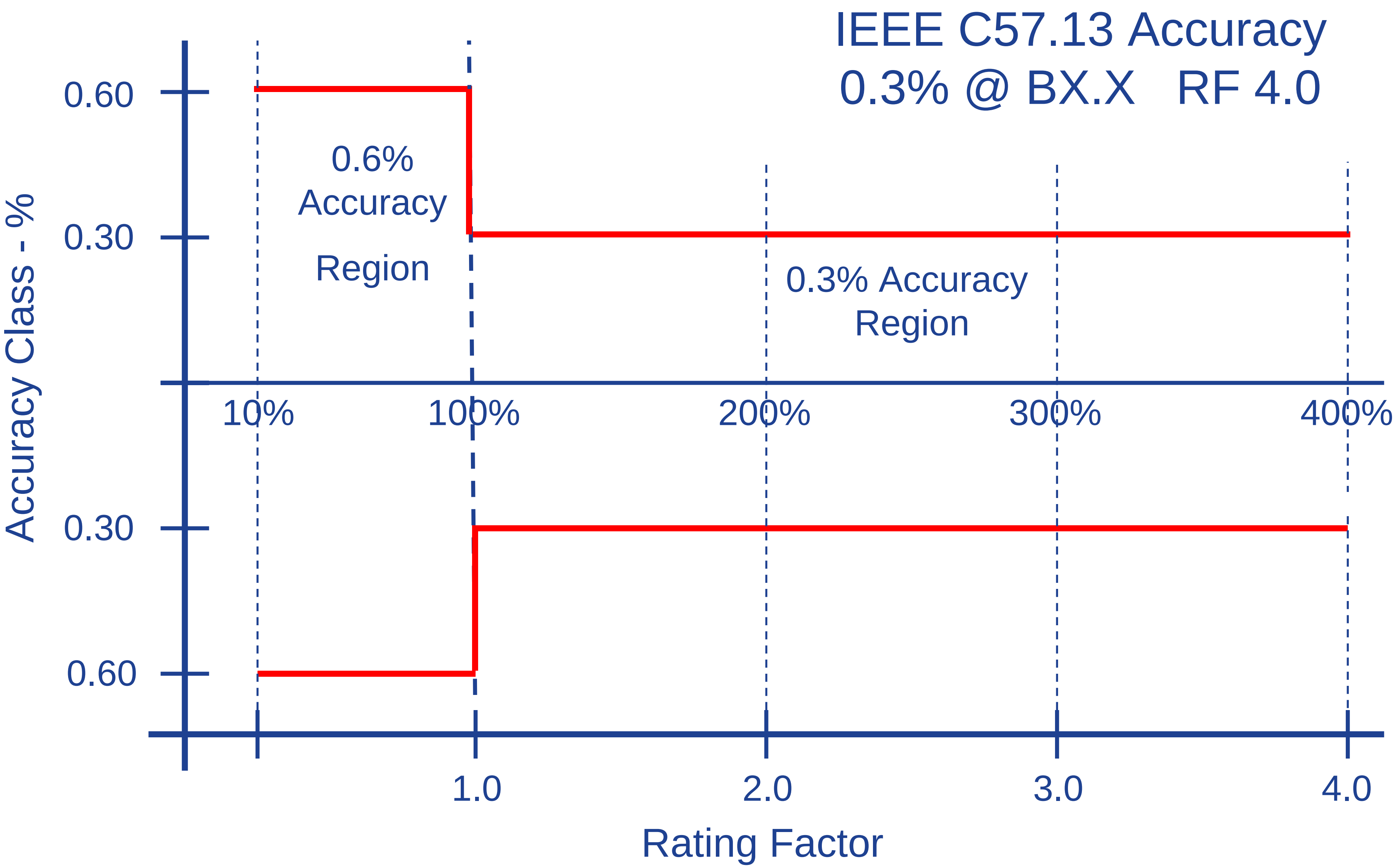
Maximum continuous current carrying capability:

Without exceeding temperature limits

Without loss of published accuracy class

Typical rating factors -- 1.0, 1.33, 1.5, 2.0, 3.0, 4.0

CT Rating Factor (RF) -- IEEE



IEEE VT Accuracy Class

Metering Accuracy Classes (% error)

0.3, 0.6, 1.2 — Defined by IEEE C57.13

Applicable from 90% to 110% rated voltage

0.15 — Defined by IEEE C57.13.6

IEEE VT Accuracy Class

Metering Accuracy Class Burdens	VA	PF
W	12.5	0.10
X	25	0.70
M	35	0.20
Y	75	0.85
Z	200	0.85
ZZ	400	0.85

These standard burden designations have no significance at frequencies other than 60 Hz.

IEEE VT Accuracy Class

Expressed as:

Accuracy Class + Burden Code

0.3 W,X,Y
0.6 Z
1.2 ZZ

These standard designations have no significance
at frequencies other than 60 Hz.

VT Installation Guidelines

Caution:

Rated voltage: Do not operate above 110%

Line to ground rated:

Do not connect line to line

Do not use on ungrounded systems w/o consulting factory

Rated Frequency: Do not operate below rated frequency w/o consulting factory

Required Information for Specifying CTs

Current Transformer RFQ Specification Sheet

Environment: ___ Indoor ___ Outdoor

Insulation Level Required: ____kV

System Voltage (kV) _____ Power Frequency (kV) ____ BIL (kV) ____ IEEE ___ IEC __

CT application: ____Metering ____ Protection

Max. Outside dimensions: ____________________ Max. Depth: ________________

Transformer window size (If applicable): ___ inches ___ mm

Round: __________ Diameter
Rectangular: _______ Height x _______ Width
Primary Bar : Yes ____ No ____

Current ratio: _______ : 5 _______ : 1 _______ : _______ other

Indicating only application: _____ % at _____VA (skip metering and protection selections)

Metering class:
IEEE - _____0.3 _____0.6 _____ 1.2 _____ 2.4 ________ other
IEC - _____0.2 _____0.5 _____ 1.0 __________other

Metering burden:
IEEE - _____B0.1 _____B0.2 _____ B0.5 _____ B0.9 _____ B1.8 ________ other
IEC - _____2.5VA _____5.0VA _____ 10VA _____ 15 VA _____ 30VA __________other

Protection Class: C _______ for IEEE _____VA, ____ P ______ for IEC

Operating Frequency: _____50 HZ _____ 60 HZ

Rating Factor: _____ 1.0 _____ 1.33 _____ 1.5 _____ 2.0 __________ other

Secondary Connections: _____ terminals _____ 24" leads _____ Other (Specify below)

Outer Insulation: _____ Standard _____ Cotton Tape and Varnish _____ Polyester Tape

Insulation Class: _____ 105 °C (standard) _____ Other

Other Special Requirements (dimensional constraints, mounting requirements, other performance requirements, etc):

Required Information for Specifying VTs

Voltage Transformer (VT) RFQ Specification

Environment: ☐ Indoor ☐ Outdoor

System Voltage (kV)	Power Frequency (kV)	BIL (kV)	Standard (check one)	
0.6	4	10	IEEE	☐
0.72	3	--	IEC	☐
3.6	10	40	IEC	☐
5.0	19	60	IEEE	☐
7.2	20	60	IEC	☐
8.7	26	75	IEEE	☐
12	28	75	IEC	☐
15	34	110	IEEE	☐
24	50	125	IEC	☐
25	40	125	IEEE	☐
34.5	70	150	IEEE	☐
34.5	70	200	IEEE	☐

Frequency: 50 HZ ☐ 60 HZ: ☐

Accuracy: IEEE: W X M Y Z ZZ
Enter 0.3, 0.6, 1.2 or leave blank.

IEC: 10VA 25VA 50VA 100VA 200VA
500VA other
Enter 0.2, 0.5, 1.0 or leave blank.

Thermal Rating: VA (optional)

Primary Voltage: 1 bushing V_{AC} – phase to neutral
2 bushing V_{AC} – phase to phase

Secondary Voltage: ☐ 120V ☐ 115V ☐ 110V ☐ 100V
☐ $120/\sqrt{3}$ ☐ $115/\sqrt{3}$ ☐ $110/\sqrt{3}$ ☐ $100/\sqrt{3}$
☐ other

Rated Voltage Factor (1 bushing only): ☐ 1.9 for 30s ☐ 1.9 for 8 hours
☐ other

Fuses:

Primary	Secondary	None	Voltage
☐	☐	☐	600 – 720 V
☐	N/A	☐	2.5 kV - 15 k V

Note: Integral fusing not available above 15 kV

Take Home Rule # 1

Never open circuit a current transformer secondary while the primary is energized

CTs are intended to be proportional current devices. Very high voltages can result from open circuiting the secondary circuit of an energized CT. Even very small primary currents can cause damage… Consult the factory if you have questions.

Take Home Rule # 2

<u>Never short circuit the secondary of an energized VT</u>

VTs are intended to be used as proportional voltage devices. Damaging current will result from short circuiting the secondary circuit of an energized VT.

Take Home Rule # 3

Metering applications
do not require a "C" class CT

"C" class ratings are specified for protection purposes only. With some exceptions metering class CTs are typically smaller and less expensive.

Take Home Rule # 4

CT secondary leads must be added to the CT burden

Electronic relays usually represent very little burden to the CT secondary circuit. In many cases the major burden is caused by the CT secondary leads.

Take Home Rule # 5

Never use a 60 Hz rated VT on a 50 Hz System

60 Hz VTs may saturate at lower frequencies and exceed temperature limitations. VT failure is likely…severe equipment damage is possible.

Take Home Rule # 6

Exercise caution when connecting grounded VTs to ungrounded systems

Line to ground voltage on any VT may exceed the primary voltage rating during a fault condition… VT must be designed for application.

QUESTIONS?

Backup Data

CT Burden Calculation

1. For single phase or zero sequence applications:

   Total burden: Zt=Rct+2•Rl+Zb

2. For three phase connections:

   The burden on individual CTs varies with the type of connection, fault and applications:

Connection method and CT location	Type of Fault/Application	
	3 Phase, Ph. to Ph. or Metering	Phase to ground
Y (connected at CT)	Zt=Rct+Rl+Zb	Zt=Rct+2•Rl+Zb
Y (connected at relay or meter)	Zt=Rct+2•Rl+Zb	Zt=Rct+2•Rl+Zb
Delta (connected at relay or meter)	Zt=Rct+2•Rl+3•Zb	Zt=Rct+2•Rl+2• Zb
Delta (connected at CT)	Zt=Rct+3•Rl+3•Zb	Zt=Rct+2•Rl+2• Zb

Zt: Total burden seen by the CT in Ω used for calculating required CT excitation voltage (Es).
Zte=Zt-Rct: Total CT external burden in Ω used for calculating required CT relay class.
Rct: CT's secondary winding resistance in Ω. Also include any relay impedance that is inside the delta connection.
Rl: One way leads burden in Ω.
Zb: Relay impedance in Ω.

So, optimum CT performance (lowest burden) will therefore be obtained if Y connected CTs are interconnected at the CT location and delta connected CTs are interconnected at the relay location.

CT Burden Calculation -- Auxiliary CT (ACT)

1 Calculate ACT primary impedance (Z_{pri}) converted from ACT secondary burden (Z_{sec})

$$(I_{pri})^2 \bullet Z_{pri} = (I_{sec})^2 \bullet Z_{sec}$$

$$Z_{pri} = (I_{sec}/I_{pri})^2 \bullet Z_{sec}$$

I_{sec} = ACT secondary current (A)

I_{pri} = ACT primary current (A)

2 Calculate total burden (Z_{tmct}) on main CT

$$Z_{tmct} = Z_{bm} + Z_{pri} + Z_{act}$$

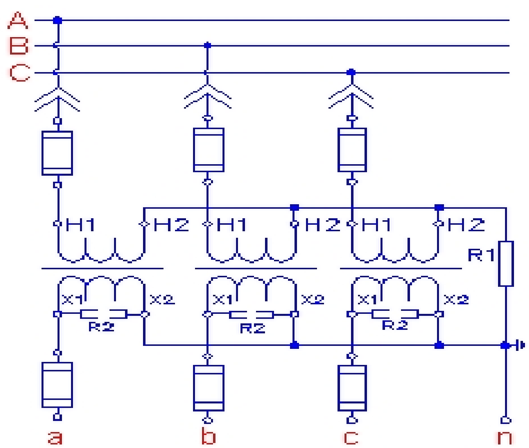
$$Z_{tmct} = Z_{bm} + [(I_{sec}/I_{pri})^2 \bullet Z_{sec}] + Z_{act}$$

Z_{bm} = Burden on the main CT (including leads) w/o ACT (Ω)

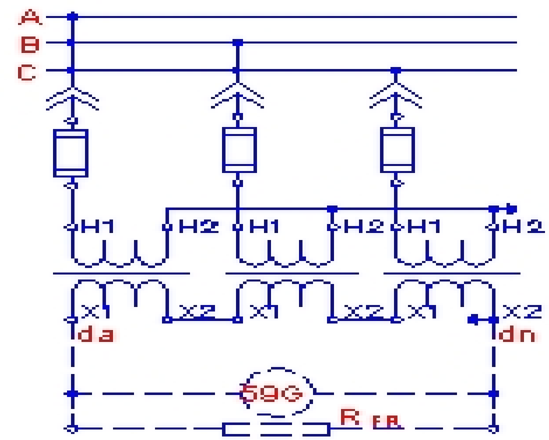
Z_{sec} = Burden on the ACT, including leads burden (Ω)

Z_{act} = Burden of the ACT itself (Ω)

Comparison of Different VT Connections for GF Detection & Ferroresonance Damping



Y-Y with damping resistor connected between the VT primary neutral and the ground or connected parallel with the VT secondary windings



Y-Broken Delta Δ with damping resistor and 59G relay connected across the VT secondary broken corner delta

- ❑Resistor connected in primary
  It has to use high voltage resistor that involves high cost and more space.
- ❑Use 3 resistors connected in Y connected secondary
  3 resistors are needed and power loss occurs at system normal condition
- ➢ Y-Broken Corner Delta is a preferred method

IEC CT Metering Accuracy Class

(Per IEC 60044-1)

Class	± Percentage current (ratio) error at percentage current shown below				± Phase displacement at percentage of rated current shown below							
					Minutes				Centiradians			
	5	10	100	120	5	20	100	120	5	20	100	120
0.1	0.4	0.2	0.1	0.1	15	8	5	5	0.45	0.24	0.15	0.15
0.2	0.75	0.35	0.2	0.2	30	15	10	10	0.90	0.45	0.30	0.30
0.5	1.5	0.75	0.5	0.5	90	45	30	30	2.70	1.35	0.90	0.90
1.0	3.0	1.5	1.0	1.0	180	90	60	60	5.40	2.70	1.80	1.80

Class	± Percentage current (ratio) error at percentage current shown below	
	50 % Current Rating	120% Current Rating
3.0	3	3
5.0	5	5

Conditions: 1. PF = 0.8 lagging
2. Burden = 25%-100% of rated burden for Classes 0.1-1.0
3. Burden = 50%-100% of rated burden for Classes 3.0-5.0

IEC CT Metering Accuracy Class

(Per IEC 60044-1)

Standard IEC
Metering /Relaying Burdens (VA)
50 / 60 Hz

2.5
5
10
15
30
40

IEC CT <u>Metering</u> Accuracy Class

(Per IEC 60044-1)

“Accuracy” expressed as:

Burden (VA)   Accuracy Class

Typical Examples:

2.5 VA class 0.2
10 VA class 1.0
15 VA class 0.5

IEC CT Relay Accuracy

(Per IEC 60044-1)

Protection Class

__VA class __P__

Standard IEC Burdens (VA) 50/60 Hz	Standard Accuracy Class (% Composite Error)	Standard Accuracy Limit Factor (# of Times Rated Current)
2.5	5P	5
5	10P	10
10		15
15		20
30		30
40		

Examples: 20VA class 10P20
15VA class 5P10

Extended Current Rating
IEC 60044-1

Similar to IEEE CT Rating Factor (RF)

Expressed as a percentage of the rated primary current

Standard values are 120%, 150% & 200%

For example: IEC extended current rating = 200%

Is very similar to

IEEE CT rating factor (RF) = 2

Instrument Security Factor (FS)

(Per IEC 60044-1)

Defines the minimum excitation current (Iexc) of the CT (horizontal axis of excitation curve) at the secondary limiting e.m.f. (vertical axis of excitation curve):

$\underline{\text{Iexc}} \geq \text{FS} \bullet \text{Isn} \bullet 10\%$

Isn = Rated secondary current

$\underline{\text{Secondary limiting e.m.f.}} = \text{FS} \bullet \text{Isn} \bullet (\text{Rated Burden} + \text{Rct})$

Rct = Internal resistance of the CT @ 75 deg C usually expressed in ohms

"Rated Burden" usually expressed in VA. Convert to ohms by dividing VA by $(\text{Isn})^2$

Let's look at a typical example

Instrument Security Factor (FS)

(Per IEC 60044-1)

Typical example: 10VA class 0.5 FS 5

Iexc ≥ FS • Isn • 10%

Iexc ≥ 5 • 5 • 10% ≥ 2.5 amps

Secondary limiting e.m.f. = FS • Isn • (Rated Burden + Rct)

Reference excitation curve to verify Iexc ≥ 2.5 amps at the calculated secondary limiting e.m.f.

Note: High accuracy class and low FS requirements may not be possible

IEC VT Accuracy Class

Per IEC 60044-2

Metering VTs

Metering Accuracy Class	± Percentage voltage (ratio) error	± Phase displacement	
		Minutes	Centiradians
0.1	0.1	5	0.15
0.2	0.2	10	0.30
0.5	0.5	20	0.60
1.0	1.0	40	1.20
3.0	3.0	Not specified	Not specified

Conditions:
PF = 0.8 lagging
Voltage range = 80% -120% of rated voltage
Burden range = 25% - 100% of rated burden.

IEC VT Accuracy Class

Per IEC 60044-2

Relaying VTs

Relaying Accuracy Class	± Percentage voltage (ratio) error	± Phase displacement	
		Minutes	Centiradians
3P	3.0	120	3.5
6P	6.0	240	7.0

Conditions:

PF = 0.8 lagging

Voltage range = 5% rated voltage to RVF*rated voltage

Burden range= 25% - 100% rated burden

IEEE/ANSI does not have VT relaying classes. It uses metering classes for relay applications

IEC VT Accuracy Burdens

Per IEC 60044-2

Standard Burdens (VA)		Preferred Burdens (VA)
10	100	10
15	150	25
25	200	50
30	300	100
50	400	200
75	500	500

IEC VT Accuracy Class

Per IEC 60044-2

Expressed as:

Frequency + Burden + Accuracy Class

50 Hz, 25 VA, class 0.5

50 Hz, 30 VA, class 3P

The accuracy designation may also include the RVF (Rated Voltage Factor) specifying the maximum allowable operating voltage level

IEC VT Rated Voltage Factor (RVF)

Per IEC 60044-2

Multiplying factor applied to primary voltage rating

Specifies maximum voltage and associated time period

Must be specified for line to ground applications involving non effectively grounded systems and line to ground rated primary voltages

IEC VT Rated Voltage Factor (RVF)

Per IEC 60044-2

RVF	Rated Time	Method of connecting the primary winding and system grounding conditions
1.2	Continuous	Between phases in any network Between transformers star-point and ground in any network
1.2	Continuous	Between phase and ground in an effectively grounded neutral system
1.5	30 seconds	
1.2	Continuous	Between phase and ground in a non-effectively grounded neutral system with automatic ground-fault tripping
1.9	30 seconds	
1.2	Continuous	Between phase and ground in an isolated system without automatic ground-fault tripping or in a resonant grounded system without automatic ground-fault tripping
1.9	8 hours	
Notes: Reduced rated times are permissible by agreement between manufacturer and user. All standard designs meet 1.2 continuous.		

VT Thermal Ratings

Typical ratings @ 30 deg C ambient

Low voltage	Med Voltage
150 VA	600 VA
300 VA	750 VA
750 VA	1500 VA

Note these values are typically much higher than the rated accuracy burdens

IEC products not required to refer to thermal ratings

Current Transformer (CT) RFQ Specification

Environment: ___Indoor ___Outdoor

System Voltage (kV)	Power Frequency (kV)	BIL (kV)	Standard (Check one)
0.6	4	10	IEEE __
0.72	3		IEC __
3.6	10	40	IEC __
5.0	19	60	IEEE __
7.2	20	60	IEC __
8.7	26	75	IEEE __
12	28	75	IEC __
15	34	110	IEEE __
24	50	125	IEC __
25	40	125	IEEE __
34.5	70	150	IEEE __
34.5	70	200	IEEE __

CT Application: ___Metering ___Protection

Dimensions: ___ Inches ___ mm

Max. Outside: L ______ x W ______ x D ______

CT Window: Round: ______ Diameter; Rectangular: L ______ x W ______ ; Primary Bar: _____

Current Ratio: _______ : 5 _______ : 1

Continued next slide

Current Transformer (CT) RFQ Specification (Continued)

Accuracy:

Indication Only: _____ %, _____VA (Skip metering & protection selections)

Metering Class:

IEEE: ___0.3 ___0.6 ___1.2 ___2.4 ________Other

IEC: ___0.2 ___0.5 ___1.0 ________Other

Metering Burden:

IEEE (Ohms): ___B0.1 ___B0.2 ___B0.5 ___B0.9 ___B1.8 ______Other

IEC (VA): ___2.5 ___5.0 ___10 ___15 ___30 ______Other

Protection Class: C______(IEEE) ___VA, ___P___(IEC)

Operating Frequency: ___60HZ ___50HZ

Rating Factor: ___1.0 ___1.33 ___1.5 ___2.0 ______Other

Secondary Connections: ___Terminals ___24 inch leads

Outer Insulation: ___Standard ___Cotton tape & varnish ___Polyester tape

Insulation Class: ___105 ^{0}C (Standard) _____Other

Other Special Requirements (dimensional constraints, mounting requirements, …etc):

____

____

Voltage Transformer (VT) RFQ Specification

Environment: ___Indoor ___Outdoor

System Voltage (kV)	Power Frequency (kV)	BIL (kV)	Standard (Check one)
0.6	4	10	IEEE __
0.72	3		IEC __
3.6	10	40	IEC __
5.0	19	60	IEEE __
7.2	20	60	IEC __
8.7	26	75	IEEE __
12	28	75	IEC __
15	34	110	IEEE __
24	50	125	IEC __
25	40	125	IEEE __
34.5	70	150	IEEE __
34.5	70	200	IEEE __

Operating Frequency: ___60HZ ___50HZ

Accuracy:

IEEE: ___W___X ___M___Y ___Z ___ZZ ________Other
(Enter 0.3, 0.6, 1.2, or leave blank)

IEC: ___10VA ___25VA ___50VA ___100VA ___200VA ___500VA ______Other
(Enter 0.2, 0.5, 1.0, or leave blank)

Continued next slide

Voltage Transformer (VT) RFQ Specification (Continued)

Thermal Rating: _______VA (Optional)

Primary Voltage: ___1 bushing _________V_{AC} - Phase to neutral

___2 bushing _________V_{AC} - Phase to phase

Secondary Voltage: ___120V ___115V ___110V ___100V

___120/√3 ___115/√3 ___110/√3 ___100/√3

___Other _________________

Rated Voltage Factor (RVF) (1 bushing only): ___1.9 for 30s ___1.9 for 8 hours ___Other____________

Fuses:

___Primary ___Secondary ___None (600 – 720 V)

___Primary ___Live parts only ___Switchgear Style ___Unfused (2.5kV – 15kV)

Note integral fusing not available above 15kV

Ferroresonance

Possible with *Y connected grounded VTs* on *ungrounded power systems*

A VT is an inductive component

Capacitance to ground exists in the system

When they match ferroresonance may occur

May cause higher VT voltages & saturation

Possible results -- High VT currents
Overheating
VT failure

Ferroresonance

Recommended reading:

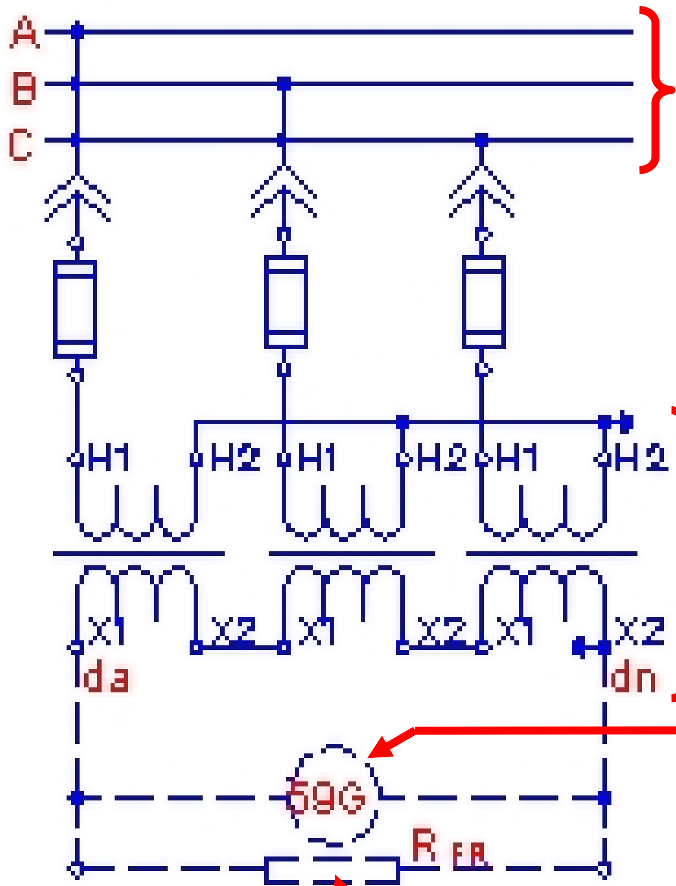
"Ferroresonance of Grounded Potential Transformers on Ungrounded Power Systems"

AIEE Power Apparatus & Systems,

Aug 1959, pg 607-618, by Karlicek and Taylor

Ferroresonance Damping

Preferred method



Non effectively grounded system

Y – Broken Corner Δ VT connection

Voltage relay to detect ground fault

0 volts @ normal condition

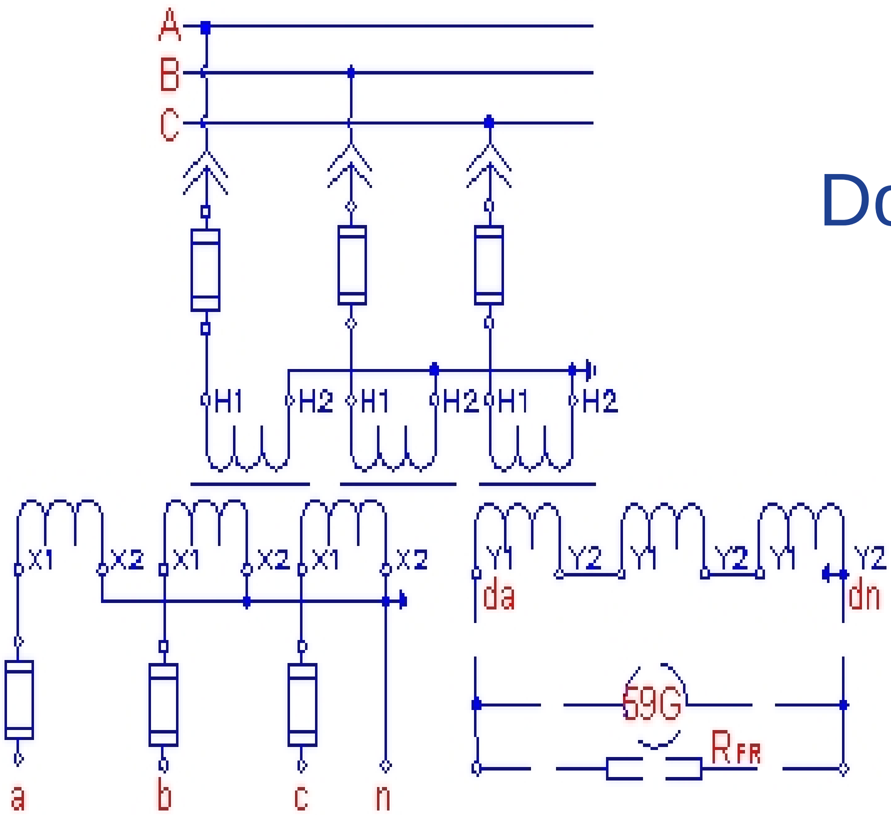
3 times normal L-N phase voltage @ ground fault

Ferroresonance damping resistor R_{FR}

Ferroresonance Damping

Preferred method

Y-Y/Broken Corner Δ Connection

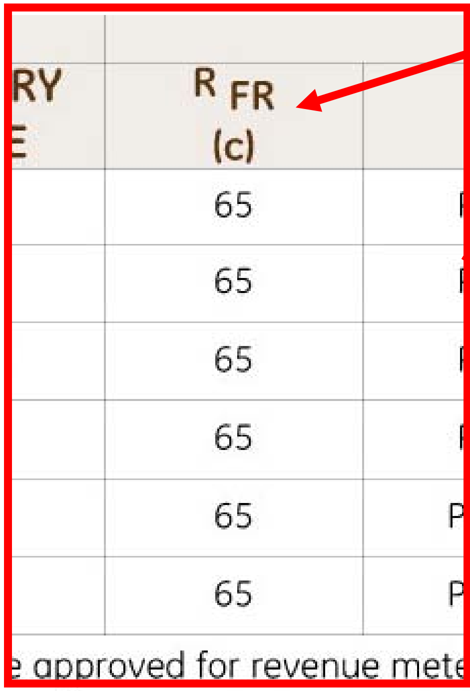


Double secondary VT

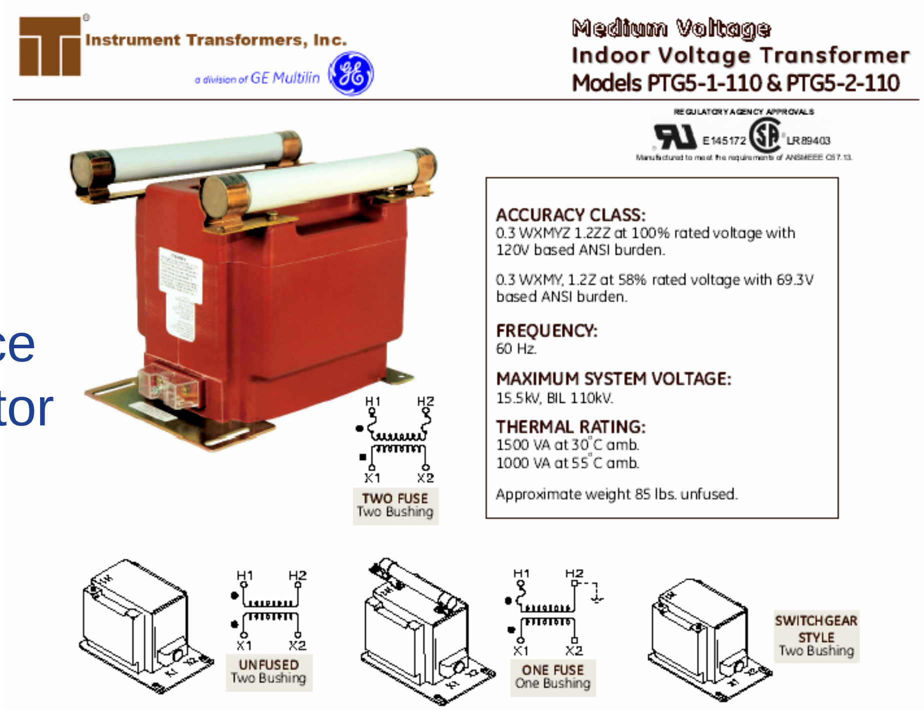
(1) Relaying / Metering

(1) Ground fault detection and *ferroresonance damping*

Ferroresonance Damping



Ferroresonance damping resistor R_{FR} value



TWO BUSHING (a)				CATALOG NUMBERS			
GROUP	PRIMARY VOLTAGE	RATIO	SECONDARY VOLTAGE	UNFUSED	FUSES	FUSE CLIPS ONLY	SWITCHGEAR STYLE
1	*7200	60:1	120	PTG5-2-110-722	PTG5-2-110-722FF	PTG5-2-110-722CC	PTG5-2-110-722SS
1	*8400	70:1	120	PTG5-2-110-842	PTG5-2-110-842FF	PTG5-2-110-842CC	PTG5-2-110-842SS
2	11000	100:1	110-50Hz	PTG5-2-110-113	PTG5-2-110-113FF	PTG5-2-110-113CC	PTG5-2-110-113SS
2	*12000	100:1	120	PTG5-2-110-123	PTG5-2-110-123FF	PTG5-2-110-123CC	PTG5-2-110-123SS
2	13200	110:1	120	PTG5-2-110-1322	PTG5-2-110-1322FF	PTG5-2-110-1322CC	PTG5-2-110-1322SS
[illegible]	*14400	120:1	120	PTG5-2-110-1442	PTG5-2-110-1442FF	PTG5-2-110-1442CC	PTG5-2-110-1442SS

[illegible]NE BUSHING (b)				CATALOG NUMBERS				
GROUP	PRIMARY VOLTAGE	[illegible]ATIO	SECON[illegible]ARY VOLTA[illegible]E	R_{FR} (c)		FUSES	FUSE CLIPS ONLY	SWITCHGEAR STYLE
4A	*7200	60:1	120	65		[illegible]G5-1-110-722FF	PTG5-1-110-722C	PTG5-1-110-722S
4A	*8400	70:1	120	65		[illegible]G5-1-110-842FF	PTG5-1-110-842C	PTG5-1-110-842S
4B	11000	100:1	110-50[illegible]z	65		[illegible]G5-1-110-113FF	PTG5-1-110-113C	PTG5-1-110-113S
4B	*12000	100:1	120	65		[illegible]G5-1-110-123FF	PTG5-1-110-123C	PTG5-1-110-123S
4B	13200	110:1	120	65		[illegible]G5-1-110-1322FF	PTG5-1-110-1322C	PTG5-1-110-1322S
4B	*14000	120:1	120	65		[illegible]G5-1-110-1442FF	PTG5-1-110-1442C	PTG5-1-110-1442S

NOTE: All Primary voltages marked with an asterisk (*) [illegible]re approved for revenue me[illegible]ing in Canada by Industry Canada, Approval No. AE-0431 Rev.01

Based on 2 variables:

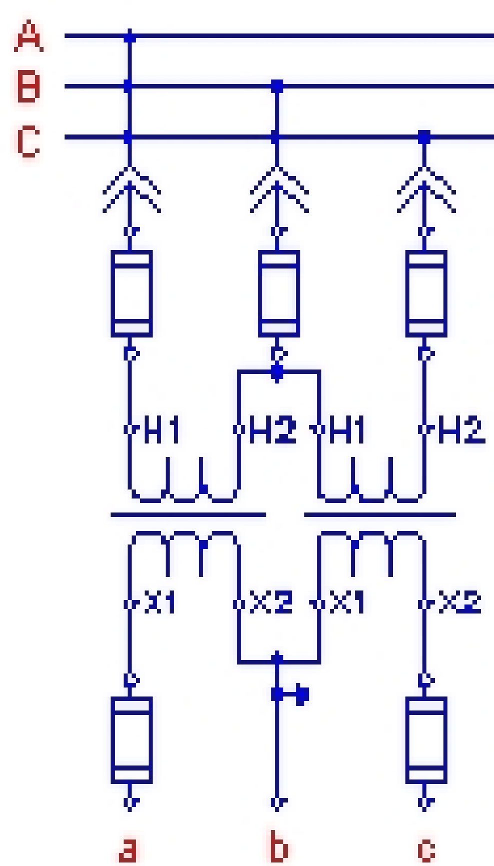
- Air core inductance of primary winding (L_a)
- VT ratio (N)
- $R_{FR} = 100\ L_a / N^2$

Power rating (watts) of the resistor is a system related problem.
Jim Bowen's paper suggests 50% of VA rating of a single VT.

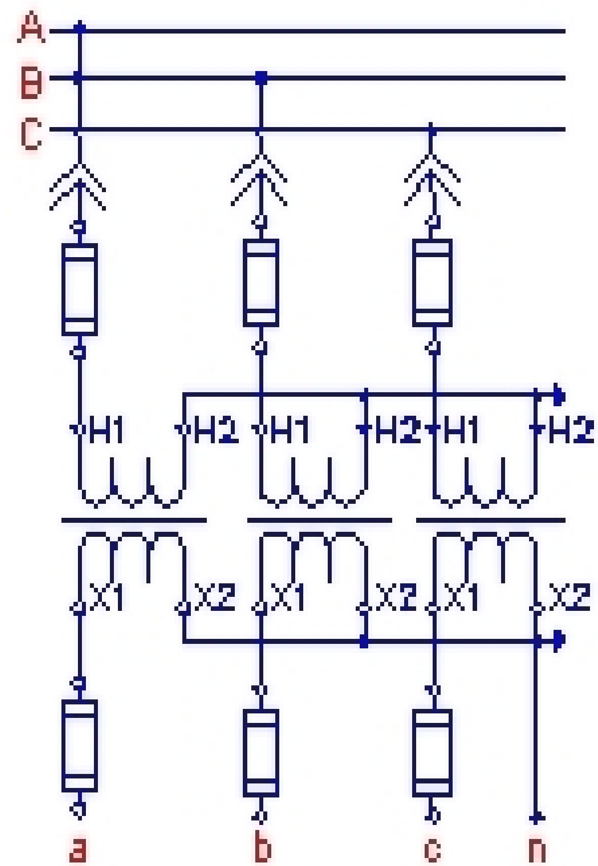
IEEE VT Groups

VT Group	No. of Bushing	Connection Method	Neutral Grounding	Notes
1	2	open Δ Y-Y possible	Any	Withstand 25% over rated voltage on an emergency basis
2	2	open Δ Y-Y possible	Any	Withstand 10% over rated voltage continuously. Primary rated for line to line voltage.
3	1	Y-Y-Y	Any	Outdoor, two secondary windings. Withstand 10% over rated voltage continuously.
4A	1	Y-Y	Effectively	Withstand 10% over rated voltage continuously & 25% on an emergency basis. For operation at 100% rated voltage.
4B	1	Y-Y Y-Broken Corner Δ	Non-effectively	Withstand 10% overvoltage continuously. For operation at 58% rated voltage.
5	1	Y-Y	Effectively	Outdoor. Withstand 40% over rated voltage for 1 minute and 10% over rated voltage continuously

VT Typical Connections



Open Delta Connection
(2) Double Bushing VTs



Y – Y Connection
(3) Single Bushing VTs

Short-Time Thermal Current Rating

One (1) – second thermal rating

Expressed as value of RMS primary current

Main influencing factor:

CT primary & secondary wire size

Can be converted to thermal rating for any time period (t) up to five (5) seconds:

$$\mathbf{I_{1\text{-sec}}}\ 3\ \sqrt{\mathbf{t}}$$

Tips for Avoiding CT Saturation

Use higher ratio CTs

Use separate set of high ratio CTs for high fault current tripping

Reduce secondary burden
- Select low burden relays & meters
- Distribute single phase burdens among phases
- Increase size of secondary leads
- Reduce length of secondary leads

Use “step down” auxiliary CTs