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Advanced protection and control IEDs from ABB

Relion. Thinking beyond the box.

Designed to seamlessly consolidate functions, Relion relays are smarter, more flexible and more adaptable. Easy to integrate and with an extensive function library, the Relion family of protection and control delivers advanced functionality and improved performance.



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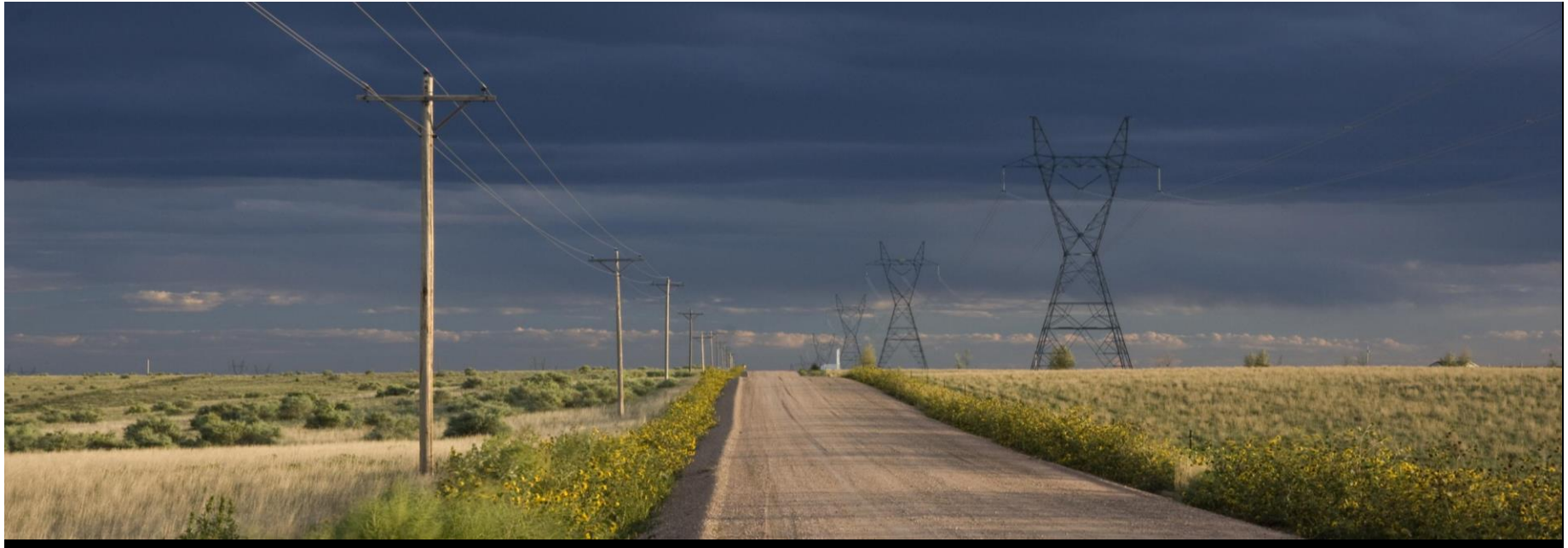


ABB Protective Relay School Webinar Series

Input sources for protective relays

Bharadwaj Vasudevan

June 21, 2016

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Power and productivity
for a better world™

Presenter



Bharadwaj Vasudevan

Bharadwaj graduated from North Carolina State University with a Master of Science degree in Electrical Engineering. During his school days, he worked as a Research Assistant in the FREEDM Systems Center, designing and maintaining the labs' automation infrastructure.

He began his career with Areva T&D Ltd in New Delhi, India as a Power Systems Engineer. He has worked on various EHV substation design projects throughout India.
Bharadwaj started at ABB as a consulting engineer for the Power systems group. With a strong background in real time power system modelling, he got to work on developing transient system models for a couple of transmission planning projects under the group.

He is currently working as an application engineer with the Power Systems Automation group for North America market. He supports all transmission level Relion relay products from Raleigh, NC. He is a member of the IEEE power system relay committee and contributes to various working groups in the relay communications subcommittees.

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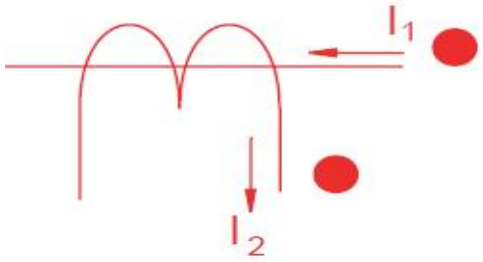
Learning objectives

- What are Instrument Transformers ?
- What are the application issues with voltage transformers ?
- What are the application issues with CCVT's ?
- What are the application issues with current transformers ?
- How to select a CT?
- What are non conventional instrument transformers ?
- Emerging Technologies

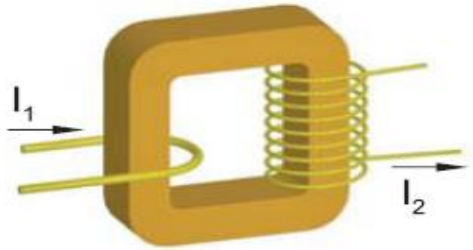
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Instrument transformer symbols

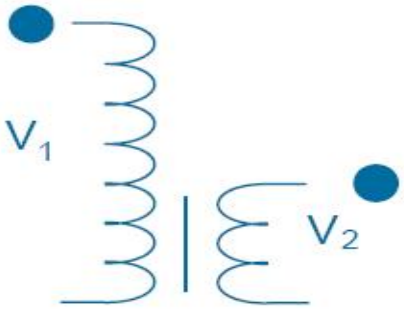
Symbol of a
Current Transformer



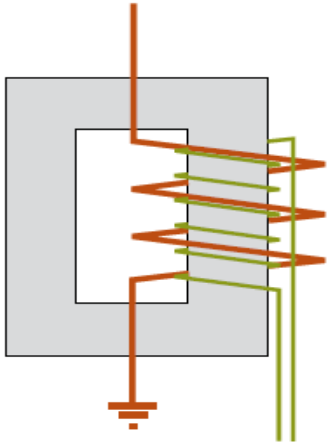
Conceptual picture of
a Current Transformer



Symbol of a
Voltage Transformer



Conceptual picture of
a Voltage Transformer



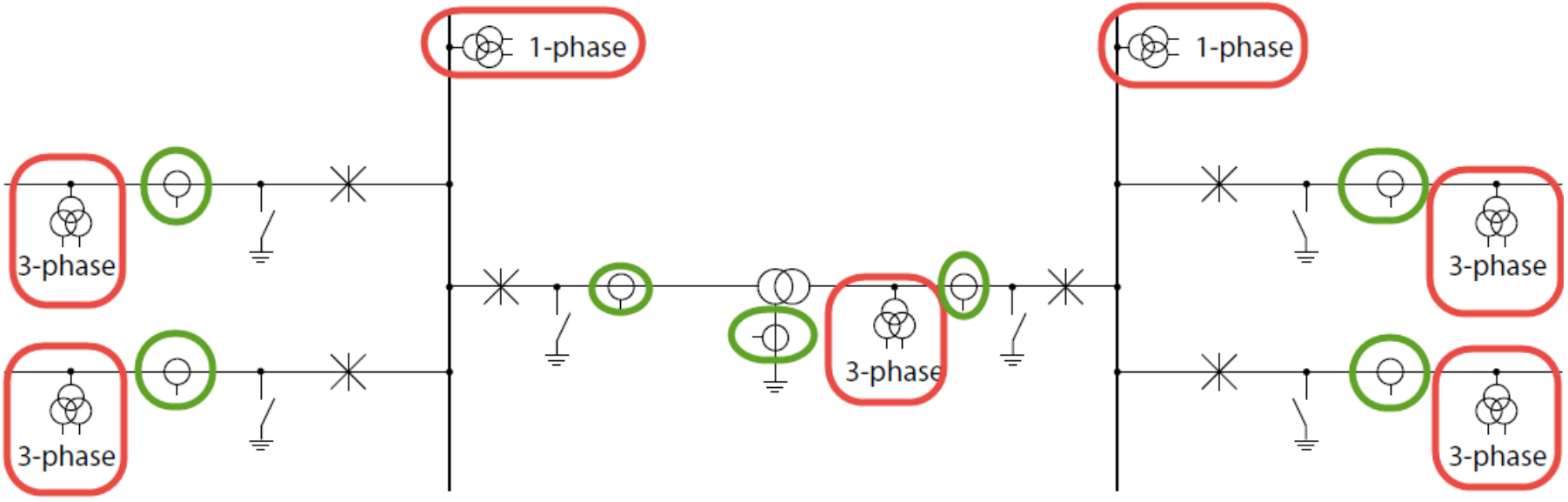
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Purpose

- Accurately reproduce primary voltage and current signals at secondary levels suitable for protective relays, meters, etc.
- Provide secondary circuit isolation
  - High voltage transients occurring on the primary system
  - Secondary circuit isolation
- Design
  - VTs are designed to minimize voltage magnitude and phase angle error. Series leakage [and lead] losses are minimized
  - CTs are designed to minimize current magnitude and phase angle error. Magnetizing impedance is maximized.

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Instrument transformer connections



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Types of instrument transformers

- Voltage transformation
  - Electromagnetic voltage transformer
  - Coupling capacitance voltage transformer
  - Optical voltage transformer
- Current transformation
  - Electromagnetic current transformer
  - Optical current transformer
  - Rogowski coil

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Voltage Transformers

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Voltage transformer (VT/PT)

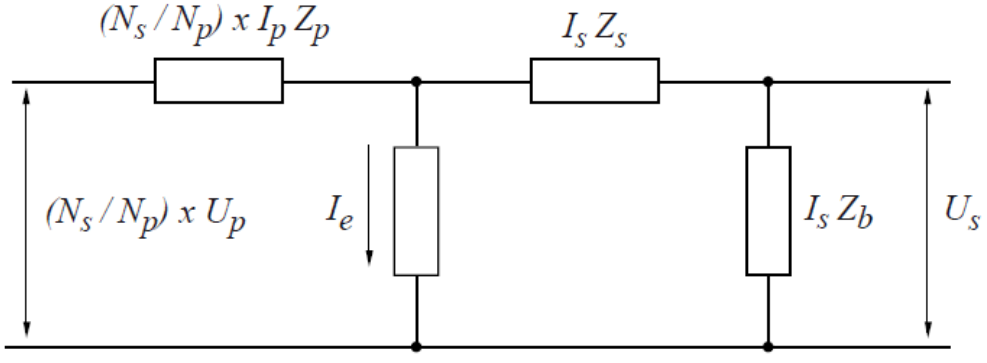


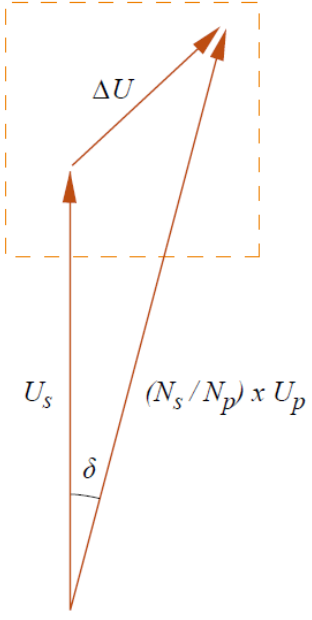
Inductive Voltage Transformer

- Do not differ materially from constant-potential power transformers except
  - Power rating is small
  - Designed for minimum ratio & phase angle error
- Application limited to lower transmission and distribution voltages due to cost
  - Full winding
  - Cascade

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Equivalent circuit of a VT





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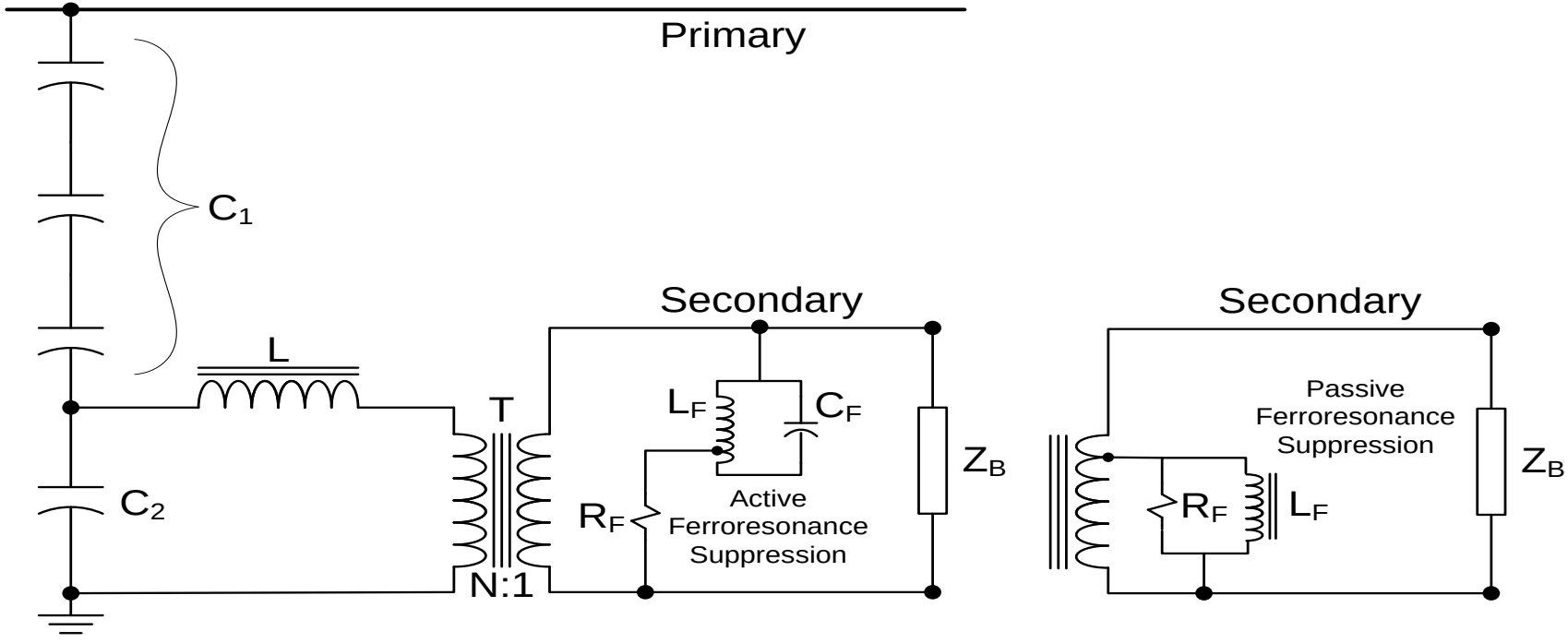
CCVT (CVT) - Coupling Capacitance Voltage Transformer



- CCVTs are less expensive than inductive VTs at higher voltage level
- Bases on capacitive coupling with low voltage inductive transformer
- Subsidence transient issues due to capacitive and inductive response to system transient voltages (Zone–1 Overreach)

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Simplified schematic of a CCVT



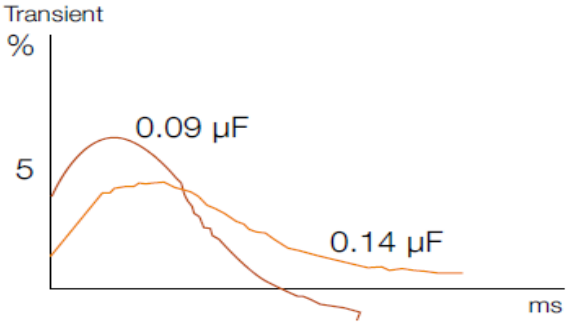
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Parameters that affect CCVT performance

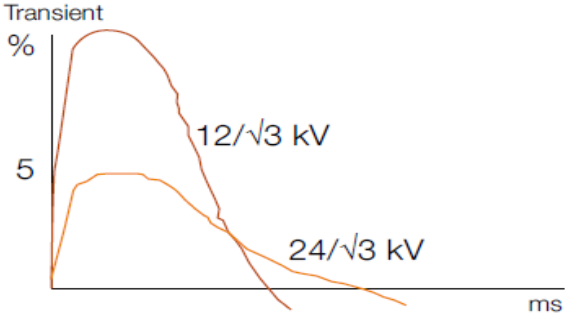
- Controlled by CCVT design
  - Magnitude of tap and stack capacitance C_1 and C_2
  - Turns ratio of the intermediate transformer T
  - Type of ferroresonant suppression system
- Controlled by user
  - Magnitude and p.f. of the burden
- At power system's mercy
  - Voltage transient characteristics
    - Point on voltage wave where the fault occurs
    - Magnitude of voltage dip (fault inception voltage)

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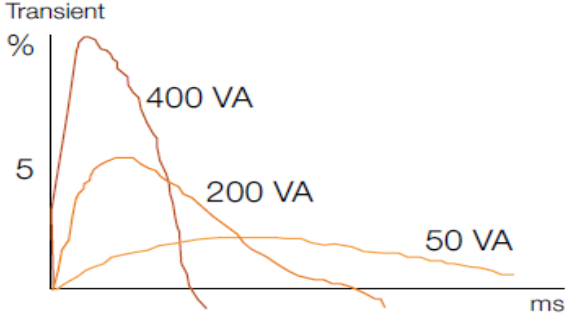
Transient response for today’s design



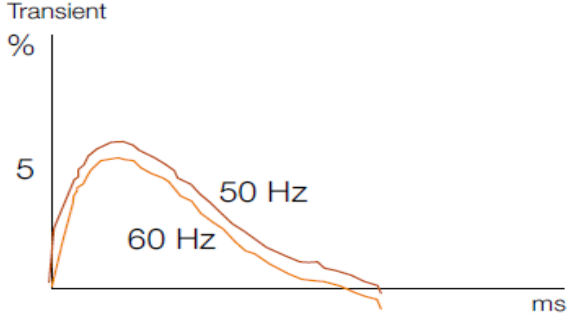
Equivalent capacitance



Intermediate voltage



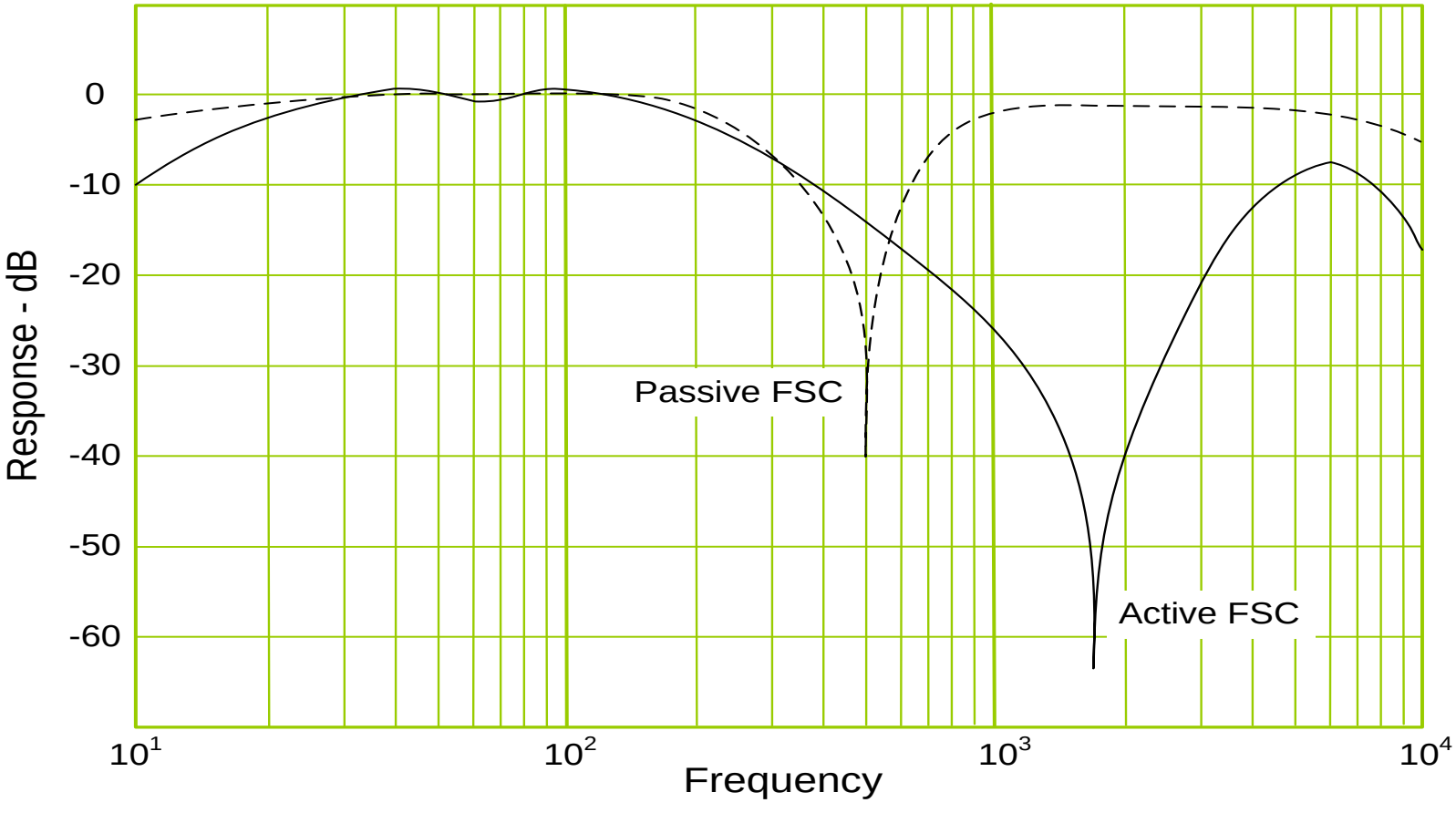
Burden



Frequency

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CCVT frequency response



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Parameters that affect CCVT Performance

Parameter	Small Transient	Large Transient
Magnitude of tap and stack capacitance C_1 and C_2	High	Low
Turns ratio of the intermediate transformer T	High	Low
Type of ferroresonant suppression system	Passive	Active
Magnitude and p.f. of the burden	Resistive	Inductive

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IEEE C57.13 accuracy class

Class	Range		Power error at metered load PF 0.6-1.0 %	Application
	Burden %	Voltage %		
0.15	0-100	90-110	0.15	High-accuracy metering
0.3	0-100	90-110	0.3	Revenue metering
0.6	0-100	90-110	0.6	Standard metering
1.2	0-100	90-110	1.2	Relaying
1.2R	0-100	90	1.2	
		25	3	Relaying CCVT
		5	5	

Standard burdens	VA	PF
M	35	0.20
W	12.5	0.10
X	25	0.70
Y	75	0.85
Z	200	0.85
ZZ	400	0.85

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Current Transformers

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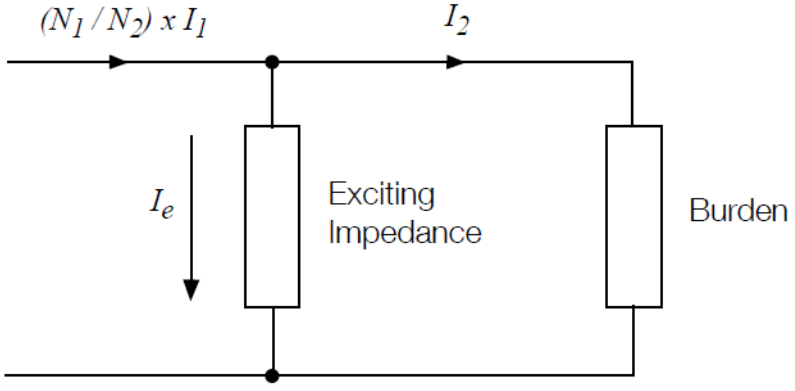
Current transformers

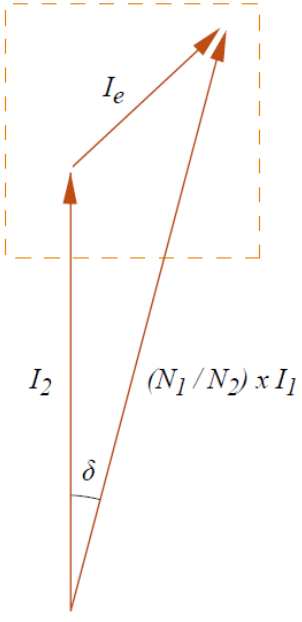


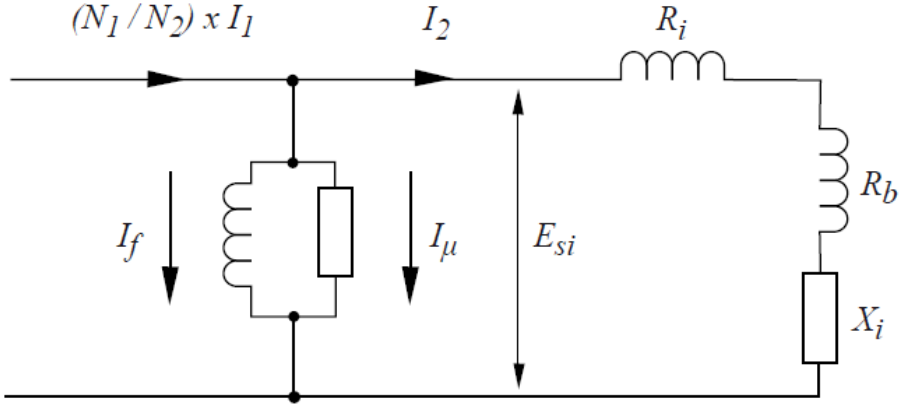
- Current transformer primary connected in series with the line
  - Primary current is determined entirely by system load and not by CT secondary load
- Free-standing
- BCT - bushing mounted
  - Internal
  - External
- Bus and cable
- Ratio of transformation is approximately inverse ratio of turns

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Equivalent circuit of a CT







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Current transformer

- Secondary winding should never be open-circuited
  - Flux in the core, instead of being the difference of the primary & secondary ampere-turns, will now be due to the total primary ampere-turns acting alone
  - This causes a large increase in flux, producing excessive core loss & heating, as well as high voltage across the secondary terminals
  - At zero crossing of ac (60 Hz) flux large voltage spikes occur

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How to choose a CT

Important main factors when selecting current transformers are:

- Standard (IEC, IEEE or national)
- Rated insulation level (service voltage)
- Altitude above sea level (if >1000 m)
- Ambient temperature (daily temperature or average over 24 hours)
- Rated primary current
- Rating factor (maximum continuous current)
- Rated secondary current
- Short-time current (Transients)
- Dynamic current
- Number of cores
- Burdens (outputs) and accuracies for each core
- Pollution level (creepage distance)

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Selection of CTs

- Evaluating steady state performance
  - Formulas (for error calculation)
  - ANSI accuracy classes (for applications)
  - Excitation curves (for saturation limits)
- Transient performance

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Steady state performance of CT

- Formulas used for calculating errors
  - 1. Secondary Induced Voltage(E_{si})

$$E_{si} = I_2 \times Z \ [V]$$

$$Z = \sqrt{(R_i + R_b)^2 + X_b{}^2}$$

  - 2. Flux density needed for inducing this voltage E_{si}

$$B = \frac{E_{si}}{\pi \times \sqrt{2} \times f \times A_j \times N_2}$$

f	Frequency in Hz
A_j	Core area in mm^2
N_2	Number of secondary turns
B	Magnetic flux Tesla (T)

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Steady state performance of CT

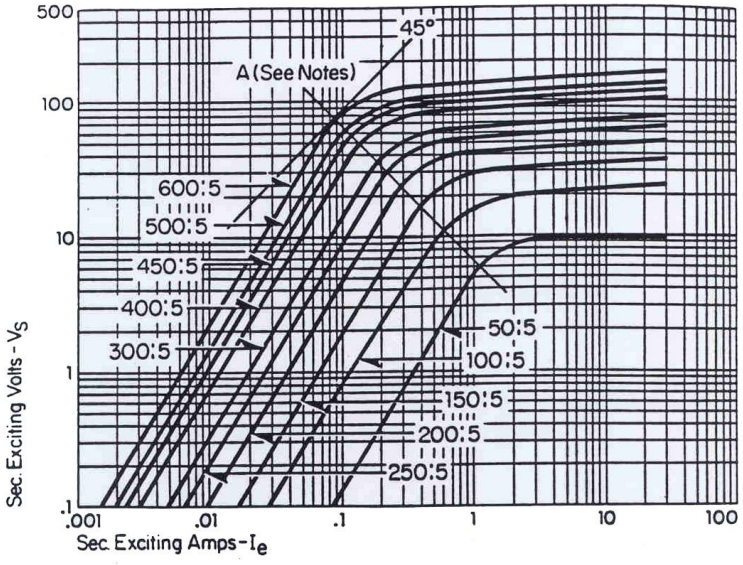
- 3. The exciting current(I_H and I_μ) required to produce the magnetic flux B.

$$I_\mu = H_\mu \times \frac{L_j}{N_2}[A]$$

$$I_f = H_f \times \frac{L_j}{N_2}[A]$$

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Steady state performance of CT



Current Ratio	Turn Ratio	Sec. Res. 1
50:5	10:1	.061
100:5	20:1	.082
150:5	30:1	.104
200:5	40:1	.125
250:5	50:1	.146
300:5	60:1	.168
400:5	80:1	.211
450:5	90:1	.230
500:5	100:1	.242
600:5	120:1	.296

Notes:

1) Above The Line, The Voltage for a Given Exciting Current Will Not be Less Than 95% of The Curve Value.

2) Below The Line, The Exciting Current for a Given Voltage Will Not Exceed The Curve Value by More Than 25%.

Excitation curves method

- Exciting current requirements for a given secondary voltage
- Current obtained by applying voltage to secondary terminals
- Knee point
  - Log-log plot
  - Square decades
  - I.e. (.01,1) – (.1,10)
  - Tangent 45º line

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ANSI accuracy class

- Relaying accuracy classes for CTs are defined with a “C” or “T” classification
  - Class C indicates that the transformer ratio can be calculated
    - leakage flux is negligible
    - The CT ratio error can thus be calculated
    - The excitation characteristic can be used directly to determine performance
  - Class T indicates that the transformer ratio can only be determined by test
    - Leakage impedance is NOT negligible

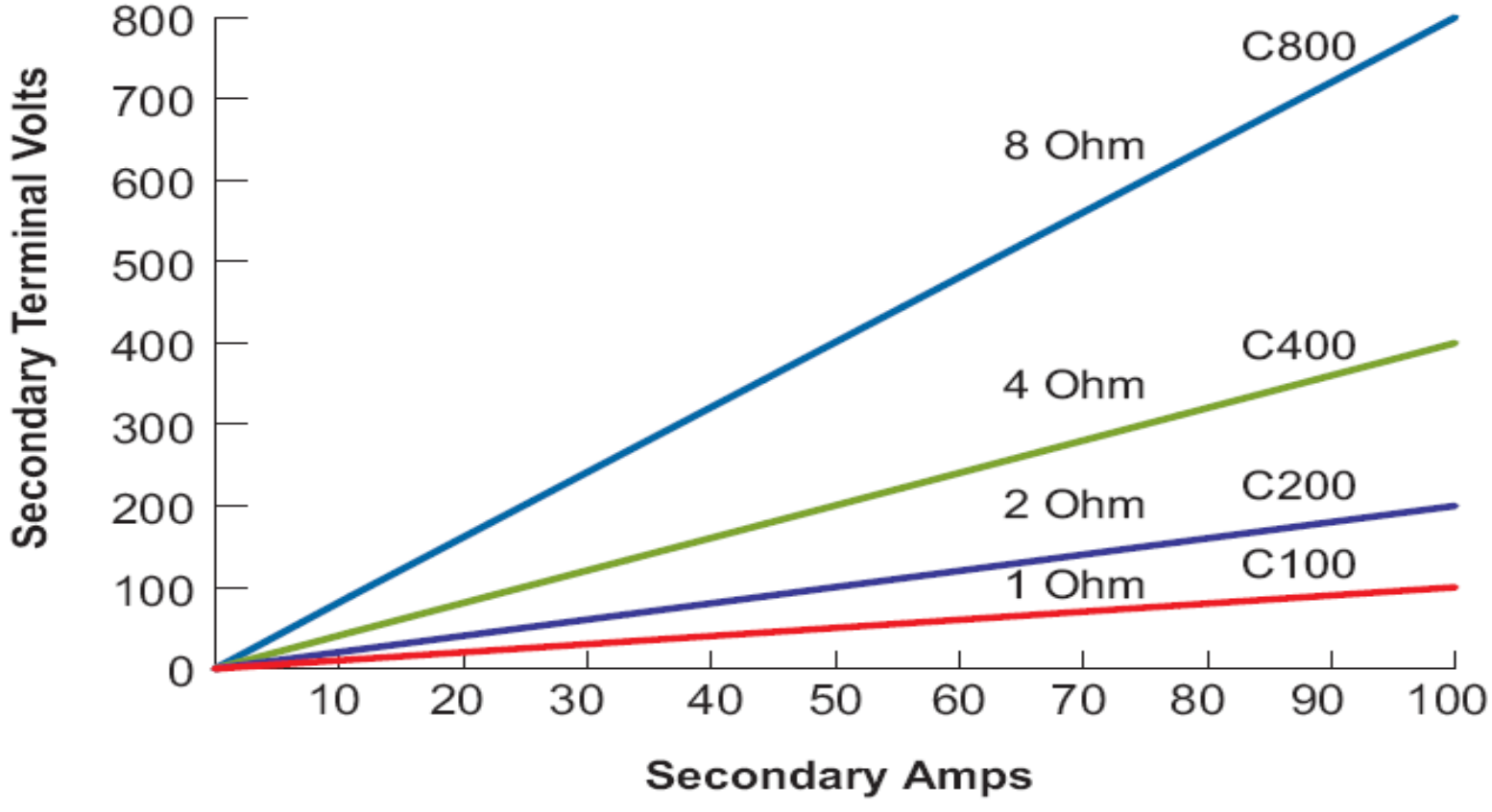
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ANSI accuracy class

- Basis for classification
  - Error ≤ 10%
  - Current range 1 – 20 times normal
- The classification defines how much voltage the CT can supply to the output (burden) without the CT core going into saturation
- Standard accuracy classes, which may be assigned for a relaying CT, are 50, 100, 200, 400 and 800

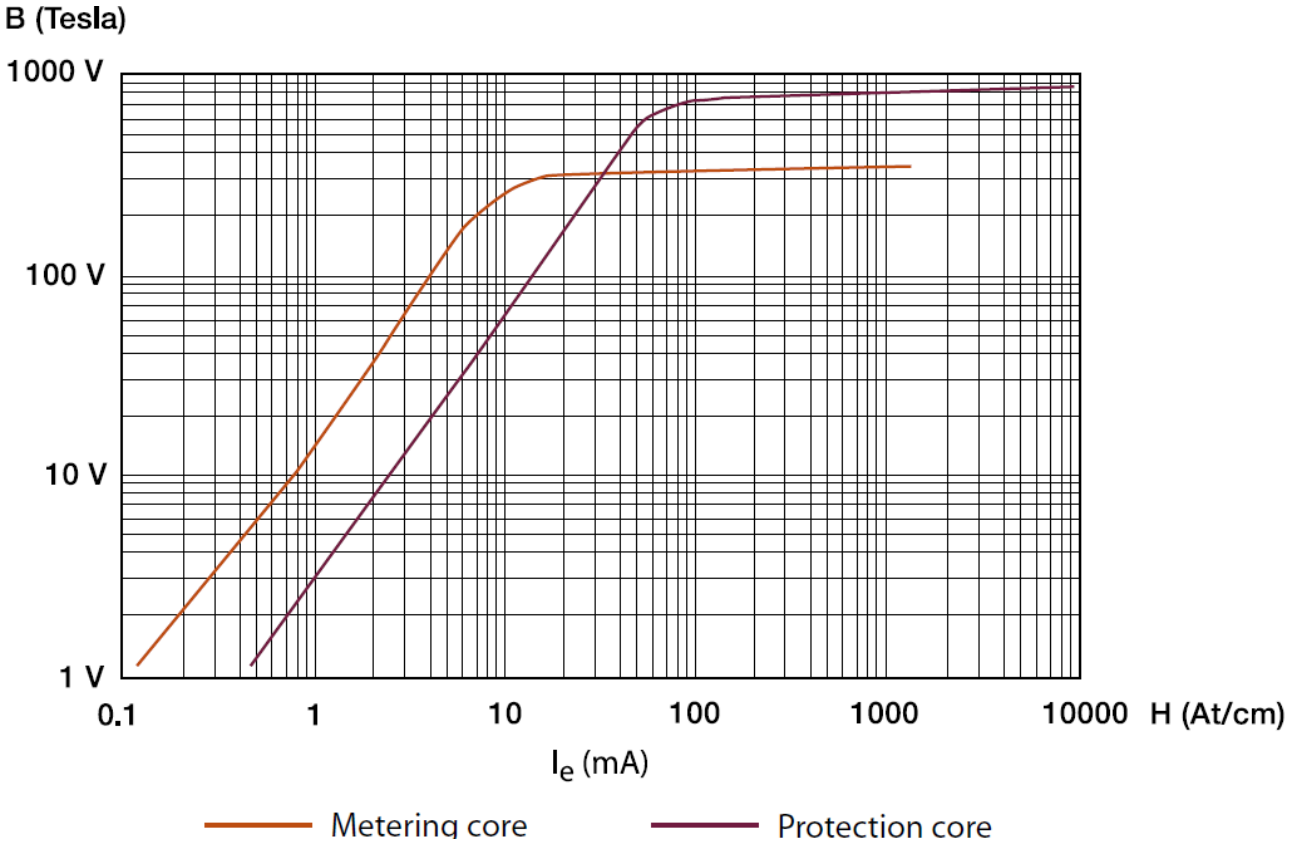
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ANSI accuracy class
Standard chart for class C current transformers



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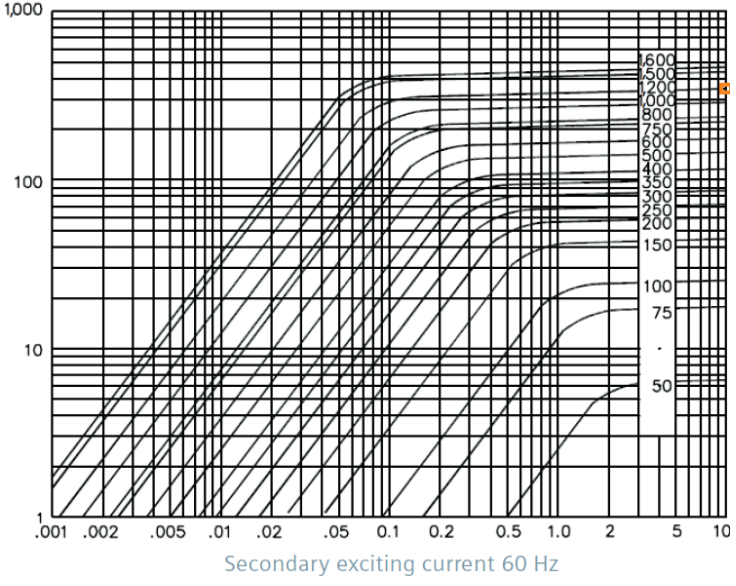
Steady state performance of CT



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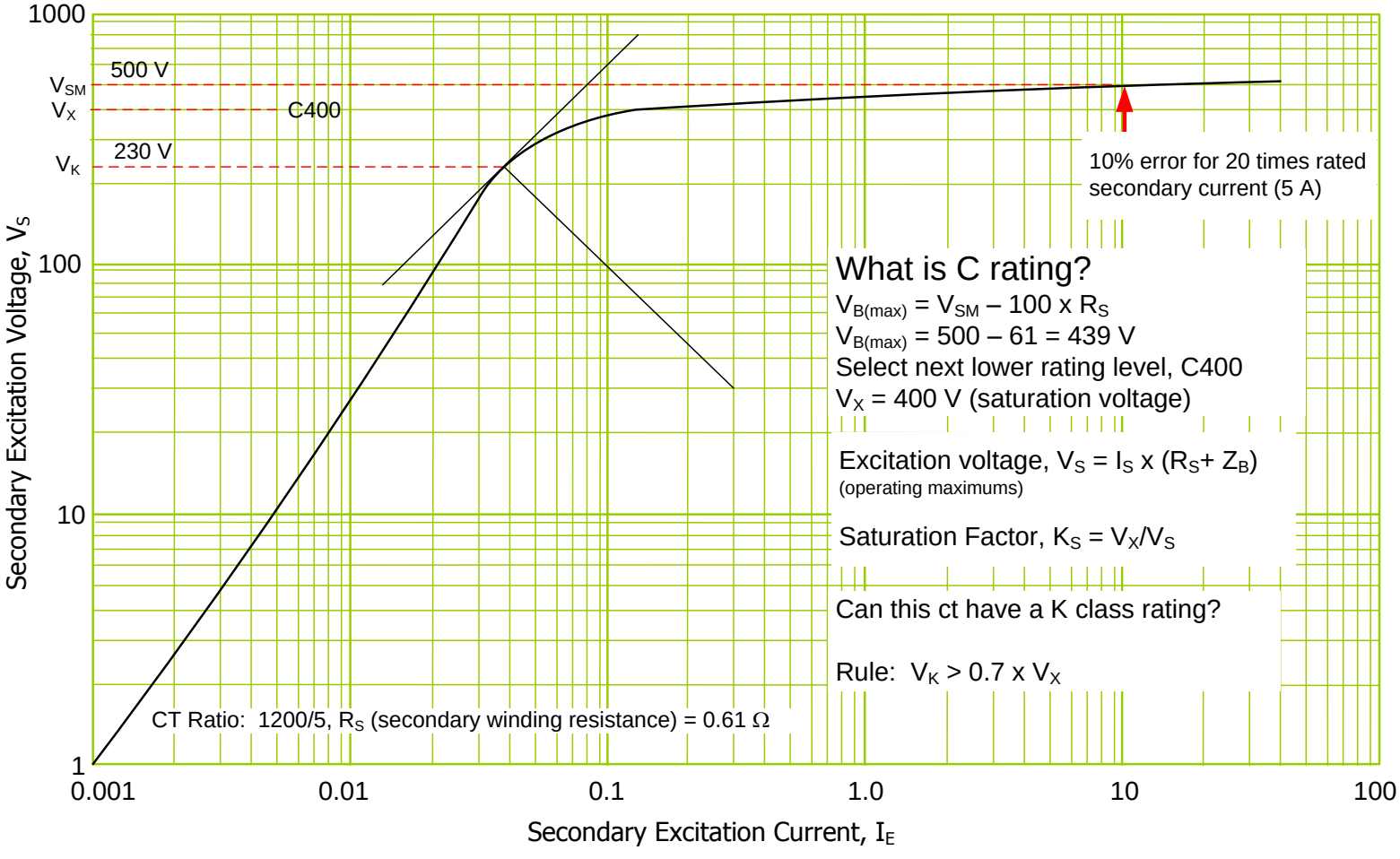
Steady State Performance of CT

- Consider a 1200:5 CT.
- AT 10A the excitation voltage is 340V (from curve)
- For this CT its Rsec is 0.418 ohms(vendor specific)
- So the voltage lost in the CT itself is 41.8V
- So the relay accuracy class should be 340-41.8=298V



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Steady State Performance of CT



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IEEE C57.13 accuracy class

Class	Error limits (the limits are valid for any of the standard burdens below)					
	Times rated current	Power error %	Designation	Ohm	PF	Application
0.15	1.0	0.15	B-0.1 B-0.2 B-0.5 B-0.9 B-1.8	0.1 0.2 0.5 0.9 1.8	0.9	High-accuracy metering
	0.05	0.30				
0.15S	1.0	0.15				
	0.05	0.15				
0.3	1.0	0.3				Metering
	0.1	0.6				
0.6	1.0	0.6				
	0.1	1.2				
1.2	1.0	1.2				
	0.1	2.5				

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IEEE C57.13 accuracy class

Class	For burdens [1]	Limits of errors			Application
		at % rated current	Ratio error %	Phase displacement minutes	
1.0	25-100% of rated burden	5	3.0	180	Industrial grade meters
		20	1.5	90	
		100	1.0	60	
		120	1.0	60	
3.0	50-100%	50	3.0	-	Instruments
		120	3.0	-	
5.0	50-100%	50	5.0	-	Instruments
		120	5.0	-	
5P and 5PR [3]	100%	100	1.0	60	Protection
		$ALF \times I_n$	5 [2]	-	
10P and 10PR [3]	100%	100	3.0	-	Protection
		$ALF \times I_n$	10 [2]	-	
PX [4]	E_k, I_e, R_{ct} [5]	-	-	-	Protection

Class	Times rated current	Ratio error %		Secondary terminal voltage	Designation	PF	Application
		Rated current	Low rated current				
C100 [1] T100	20	3	10	100	B-1.0	0.5	Protection
C200 T200	20	3	10	200	B-2.0		
C400 T400	20	3	10	400	B-4.0		
C800 T800	20	3	10	800	B-8.0		
X	-	1	-	E_s, I_e, R_{ct} [2]			

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CT Transients

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Transients in power system

- Faults on power system are sudden
- Faults are accompanied by transients
- These transients may last only for a few cycles of system frequency
- Transients may effect the performance of fast- acting devices: protective relays, circuit breakers

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D.C. saturation of a CT

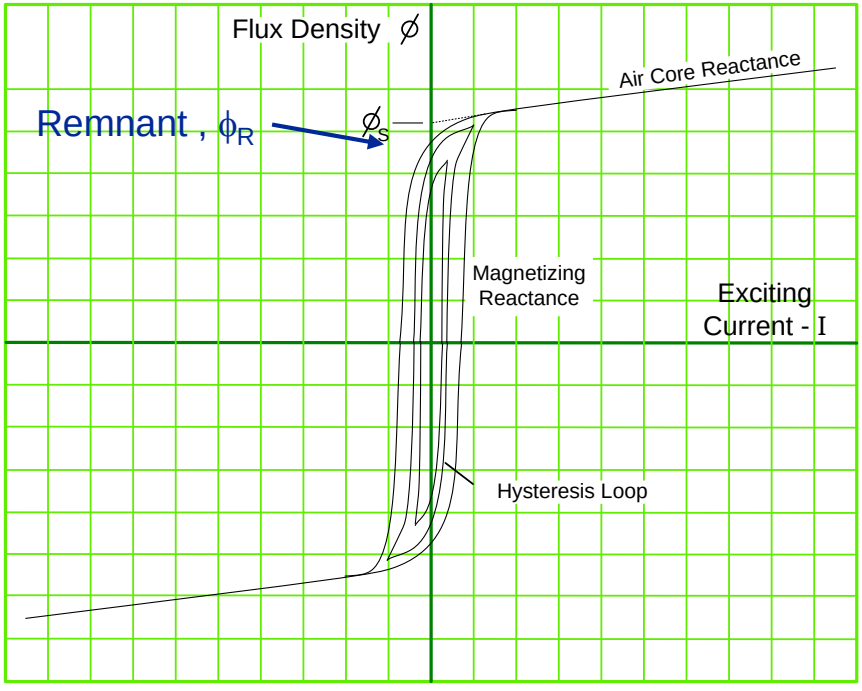
Saturation of a CT may occur as a result of any one or combination of:

- Remnant (residual) flux in the core
- Off-set fault currents (dc component)

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Remnant Flux

- Results from hysteresis
- Depends largely on the instantaneous flux in the core immediately prior to primary fault current (source of flux field) interruption
- The remnant flux is also developed due to dc polarity test
- Normal load current may reduce the amount of remnant flux, but not eliminate it.
- Requires demagnetization



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Remnant flux

- To avoid saturation during a fault with the most unfavorable remnant flux requires about 3 times the core area otherwise needed when using a closed iron core
- The remnant flux is also developed due to polarity test using battery (CT should be demagnetized following the test)

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Remnant Flux and DC Offset

- Avoiding Saturation
  - Steady state

$$V_X > I_S \cdot Z_S$$

  - Effect of primary DC offset

$$V_X > I_S \cdot Z_S \left(1 + \frac{X}{R}\right)$$

  - Effect of worst case saturation

$$V_X > \frac{I_S \cdot Z_S \left(1 + \frac{X}{R}\right)}{1 - \varphi_R / \varphi_S}$$

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Analyzing Transient Response of CT

- Possibly sufficient time for relay operation prior to ct saturation
- Time to Saturation
  - Possible maximum remnant flux
  - Level of fault current
  - System time constant
  - Parameters of ct and burden

$$t_S = -\frac{X}{\omega R} \cdot \ln\left(1 - \frac{\frac{K_S - 1}{X}}{R}\right)$$

$t_S = time\ to\ saturate$

$\omega = 2\pi f$ - f is system frequency

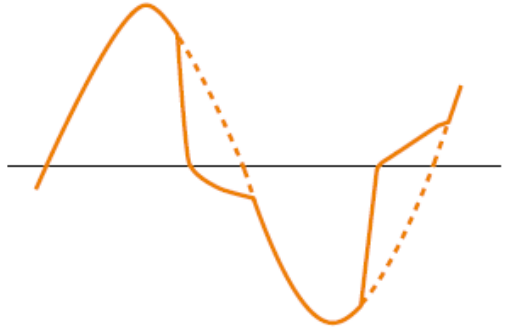
X = primary reactance to point of fault

R = primary resistance to point of fault

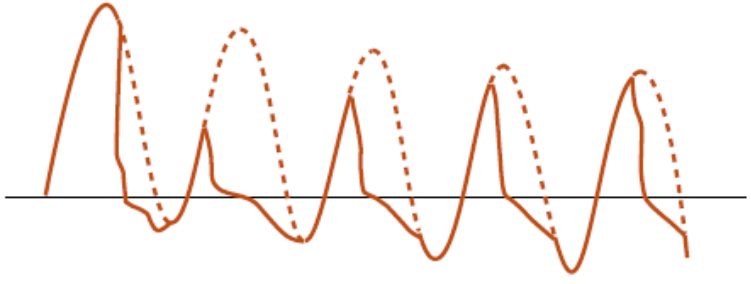
K_S = saturation factor

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Core saturation effect in current



AC-saturation



DC-saturation

CT_Saturation_Curve.xls

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Protective relay designs to address CT issues

- Most common issues
  - CT saturation
  - Open CT
- Can be addressed in modern microprocessor relays

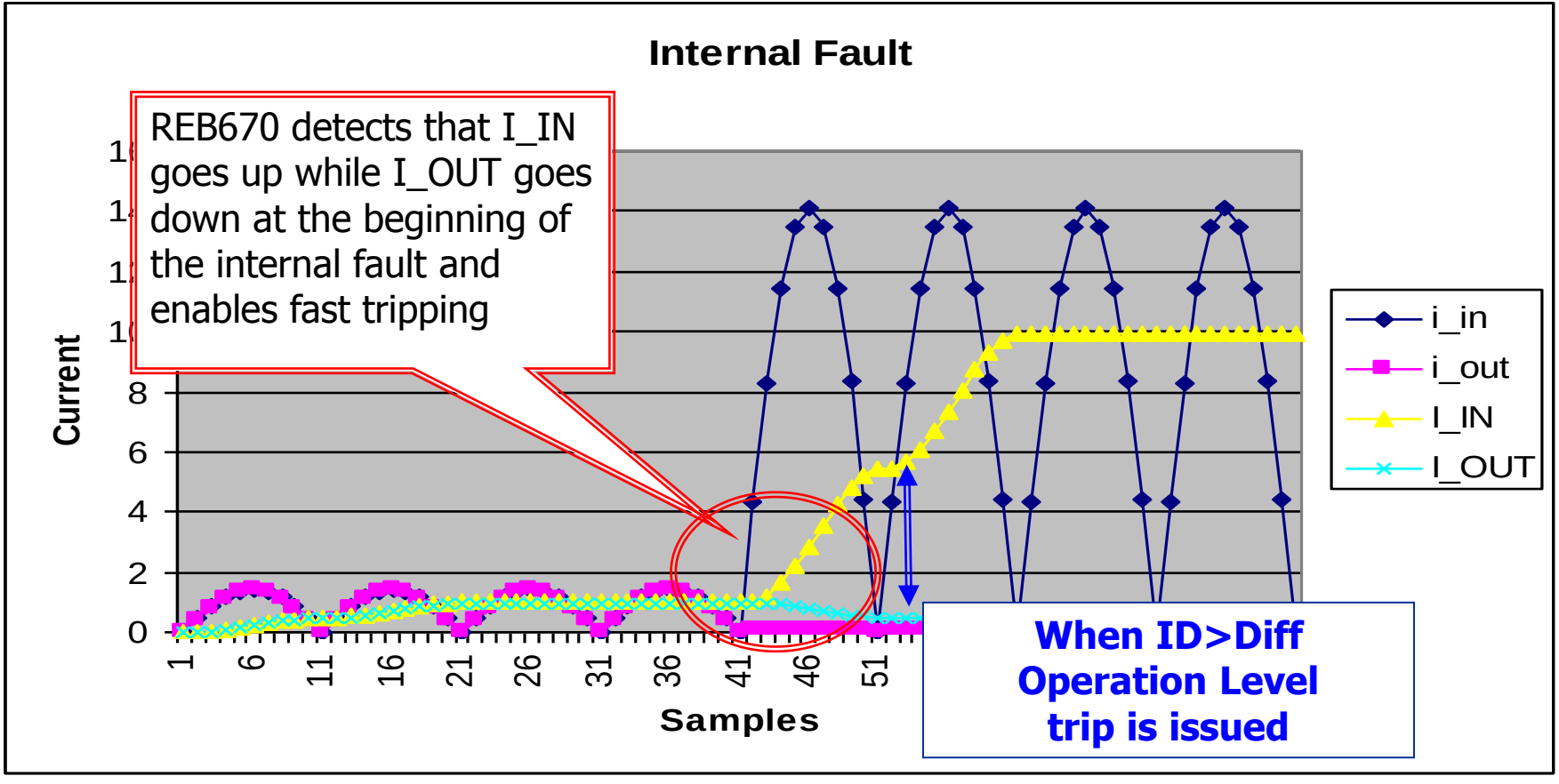
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REB670 operating principles

- Next slides will visualize the behavior of REB670 terminal during:
  - Internal fault
  - External fault with CT saturation
  - Open CT condition
- Disturbance occurs at sample No 41 on all of the following slides

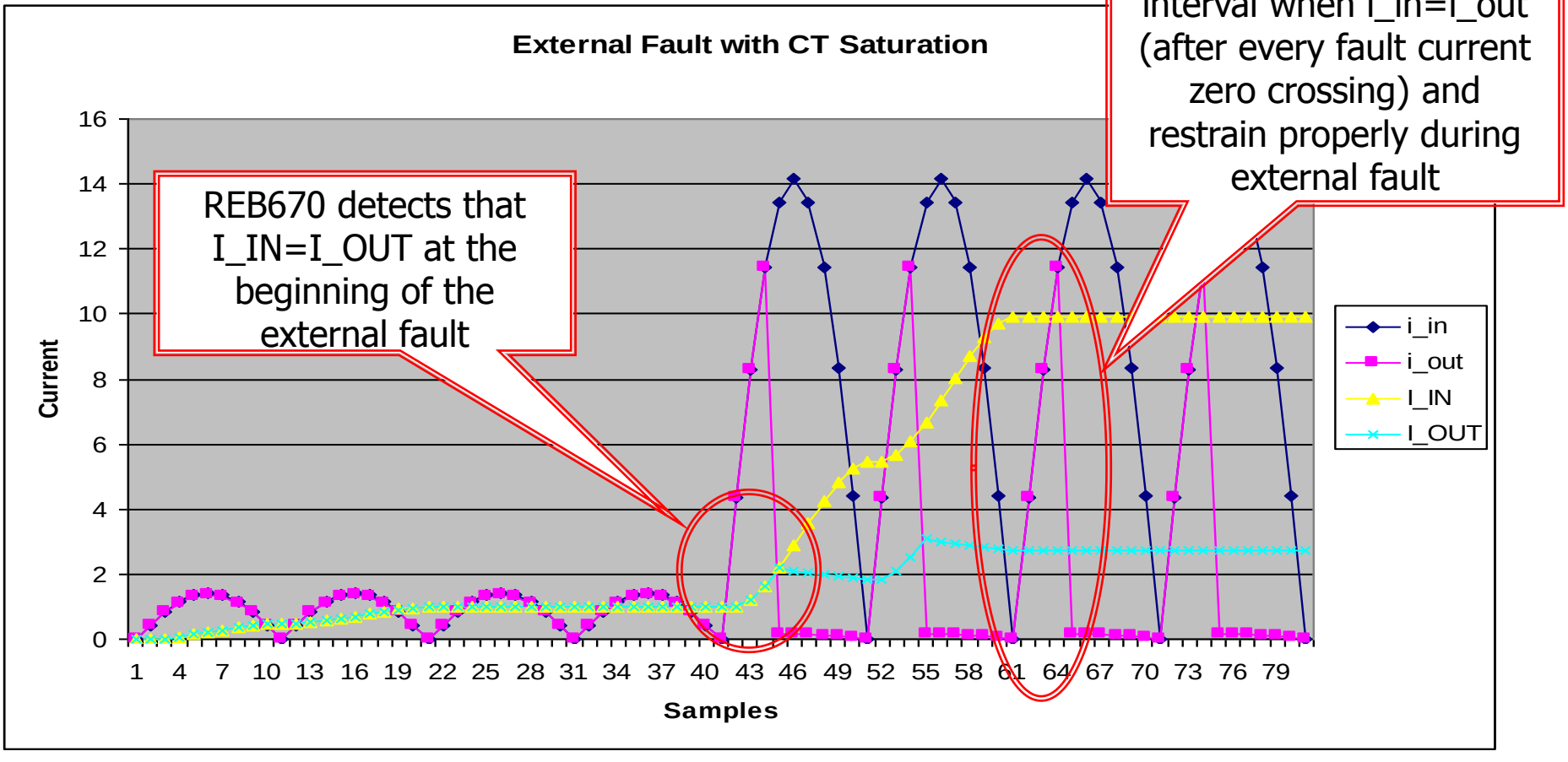
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Quick operation for internal fault



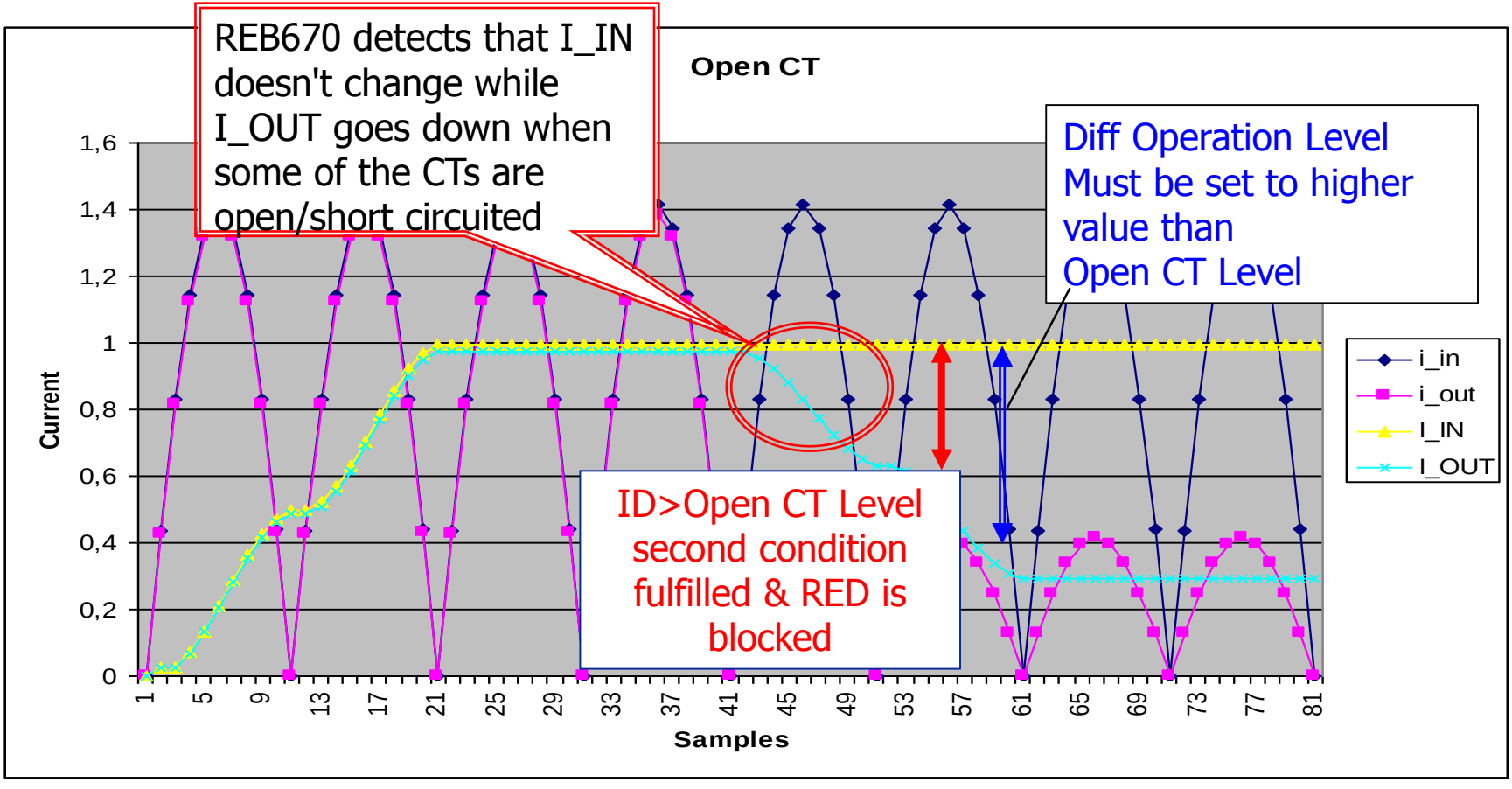
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Proper and secure restraint



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Fast open CT algorithm



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New Sensor Technology

Non-traditional
Instrument Transformers

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New sensor technology

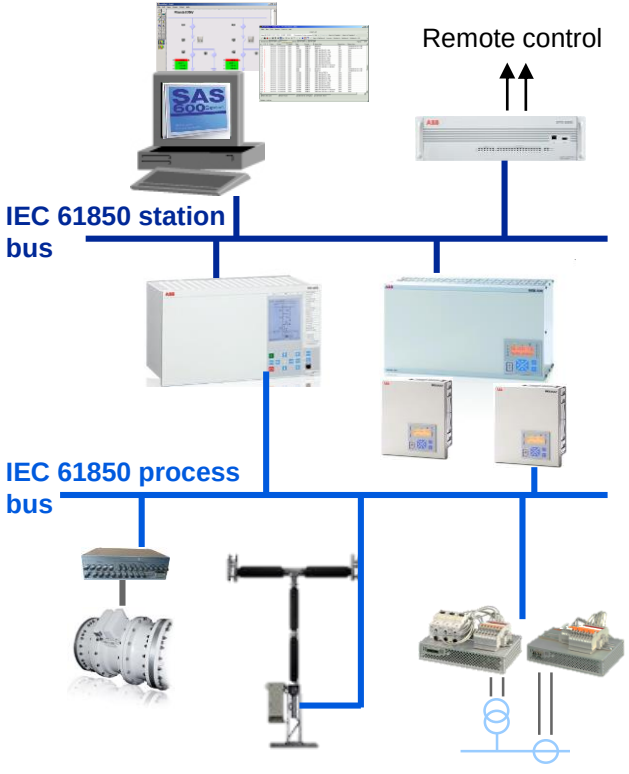
- Traditional instrument transformers were required to meet the high power output requirements for electromechanical protection and control apparatus
- Today’s modern digital IEDs and process bus communications do not require high power sensors
- New sensor technologies are based on “old” proven concepts applied in new ways
- New sensor technology offers:
  - Reduced wiring costs
  - Reduced weight
  - Designed integration with primary system apparatus
  - Immunity to electromagnetic interference
  - Greatly improved accuracy

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New sensor technology enables the digital substation

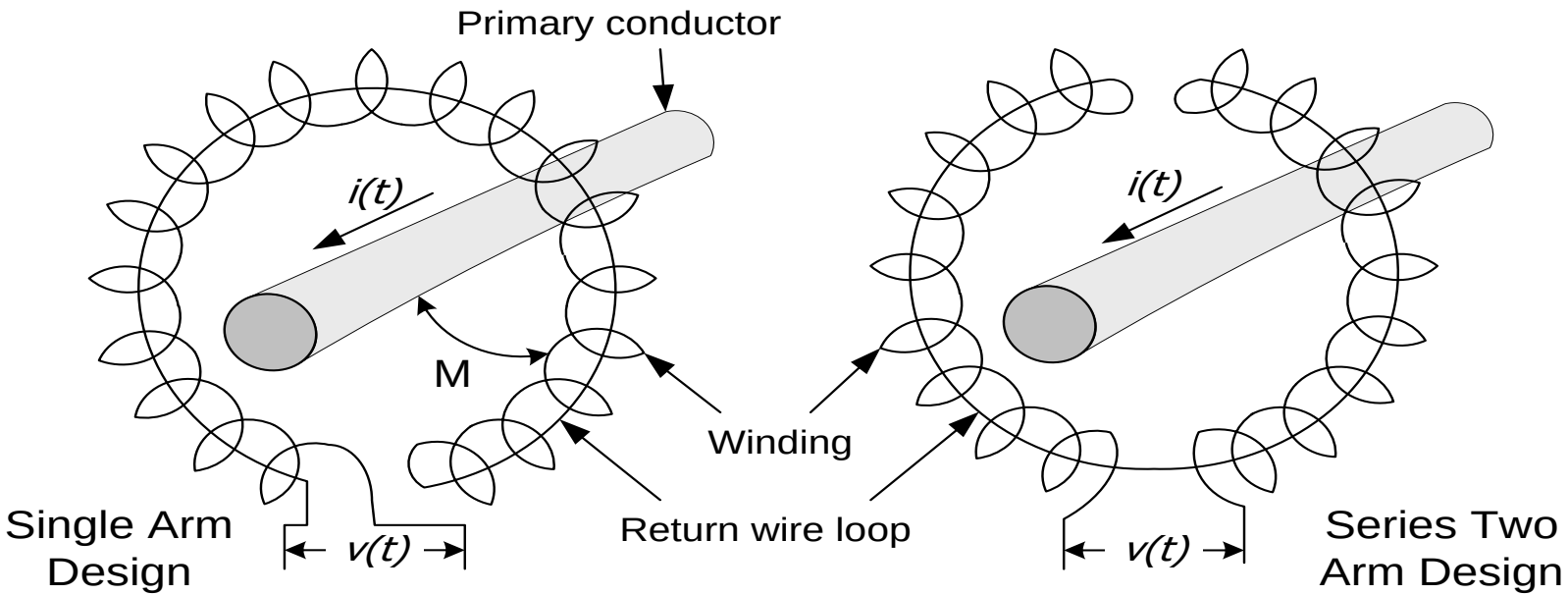
- Types of new sensor technologies
  - Rogowski coils for current measurement
  - Fiber-optic current sensors
- Provides digital signals to relays using IEC 61850-9-2LE

- Supporting the digital substation architecture

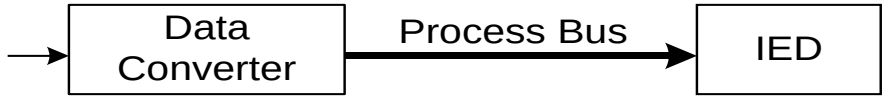


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Rogowski coils



$$v(t) = -M\frac{di(t)}{dt}$$



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Rogowski coils

- Advantages
  - High measurement accuracy, from less than 1% to 3%
  - Wide measurement range, up to 100s of kA
  - Wide frequency range, typically 0.1 Hz to 1.0 MHz
  - Can withstand unlimited short circuit current
  - Can be physically small or large for application flexibility
  - Applicable at all voltage levels

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FOCS
Operating Principle of Optical Current Sensor



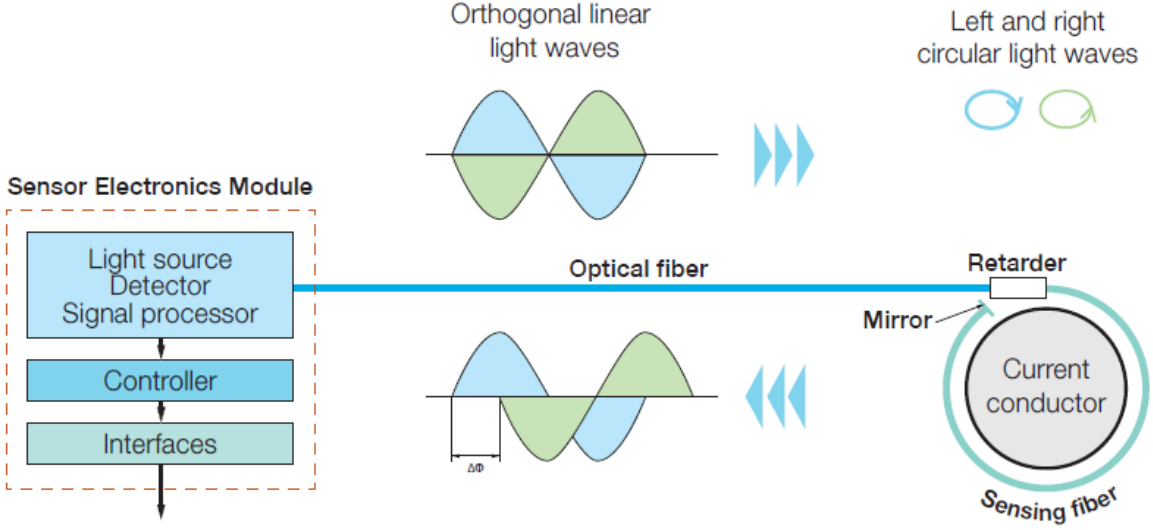
Michael Faraday
ca. 1842



André-Marie Ampère

$$\oint_C \boldsymbol{B} \cdot d\boldsymbol{l} = \mu_0 I_{enc}$$

- Faraday Effect: Left and right circular light waves travel at different speed through optical material if magnetic field is present
- Primary current produces magnetic field which induces a phase shift $\Delta\Phi_R$ of circularly polarized light
- Optical phase shift is proportional to <u>any instantaneous value</u> of primary current

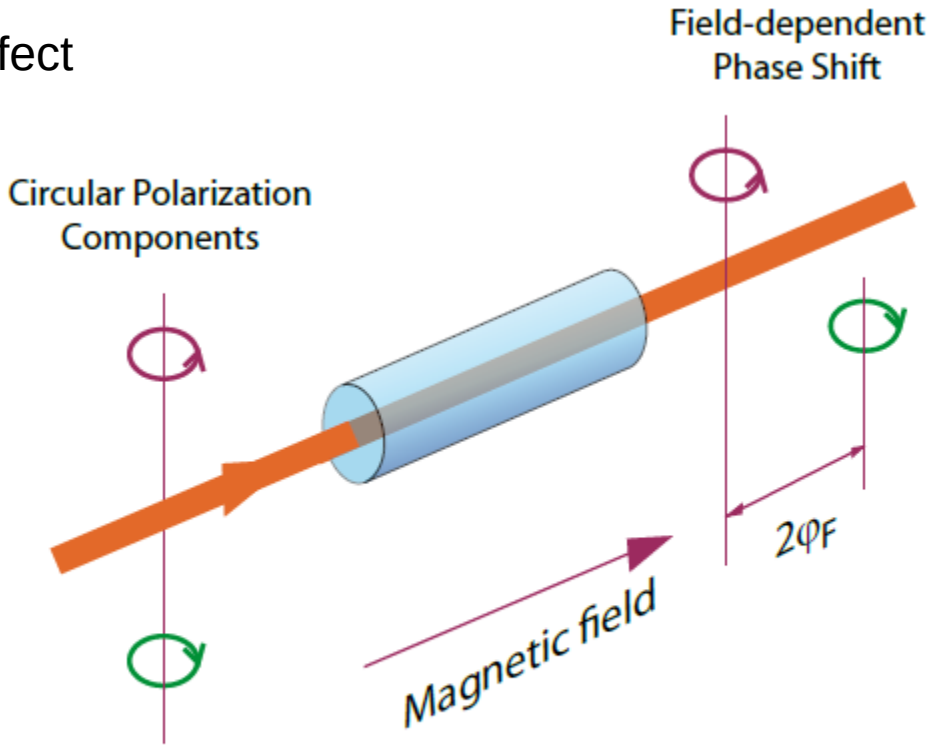


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Current-induced phase shift: $\Delta\phi_R = 4\ V\ N\ I$

Fiber-optic current sensor

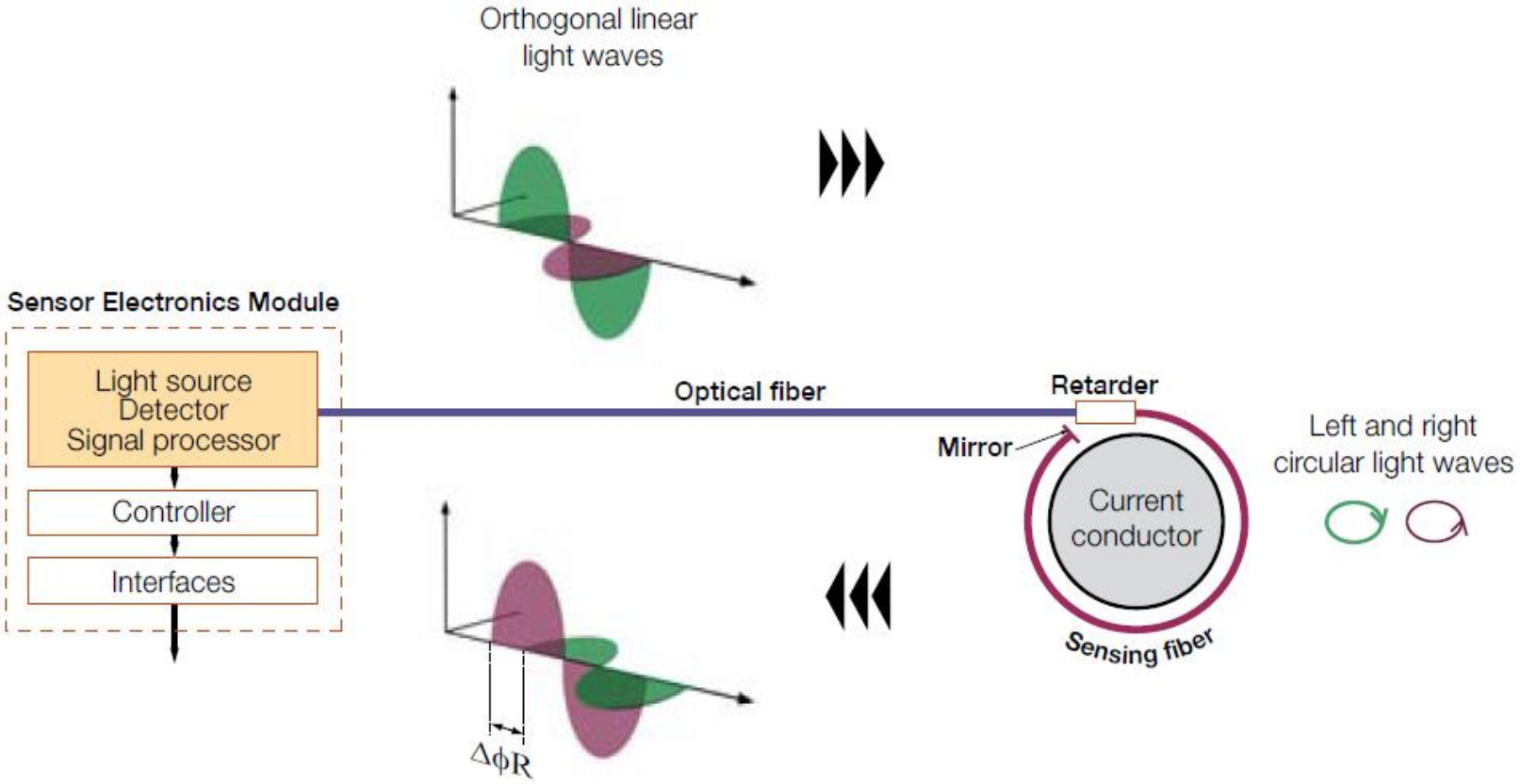
Faraday Effect



Phase shift due to Magnetic field

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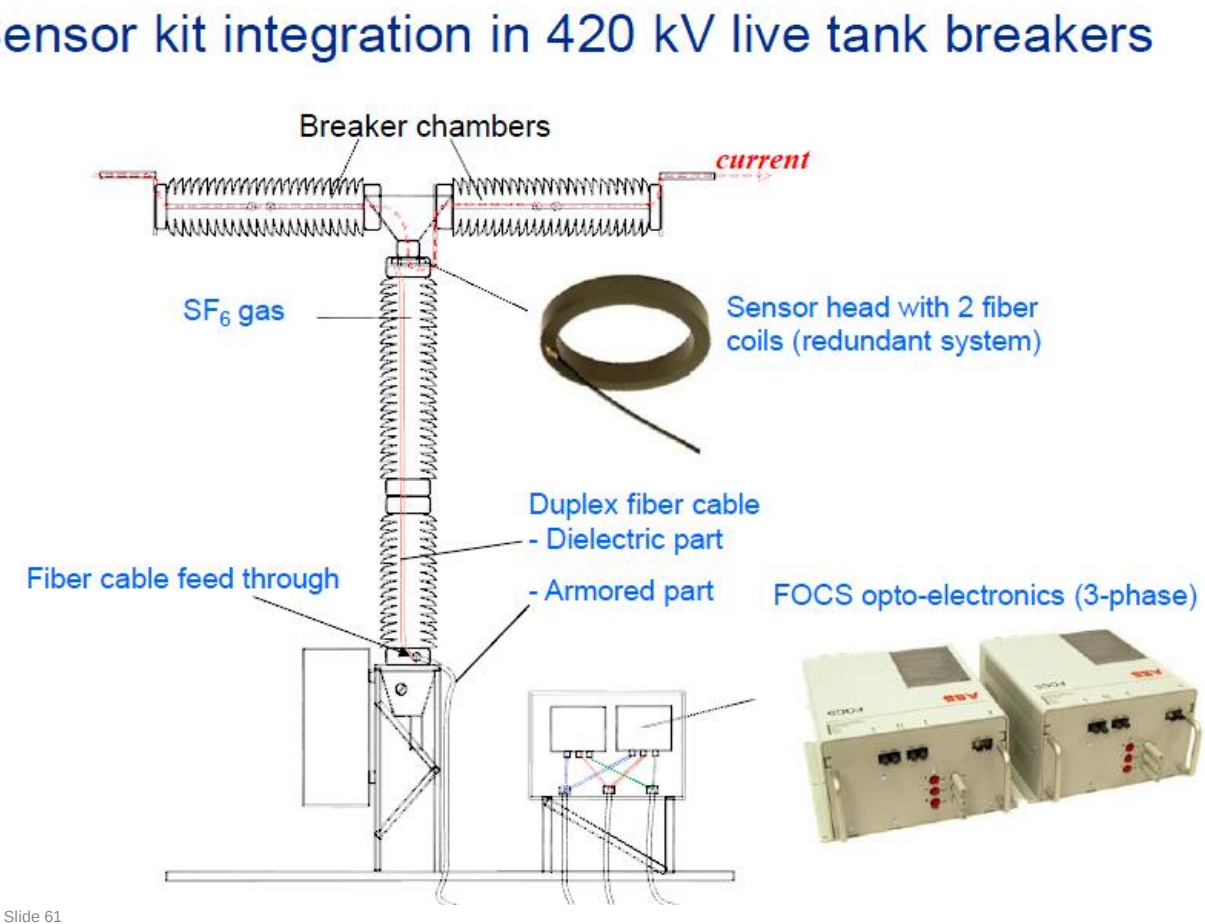
Fiber-optic current sensor measuring principle



FOCS Measuring principle

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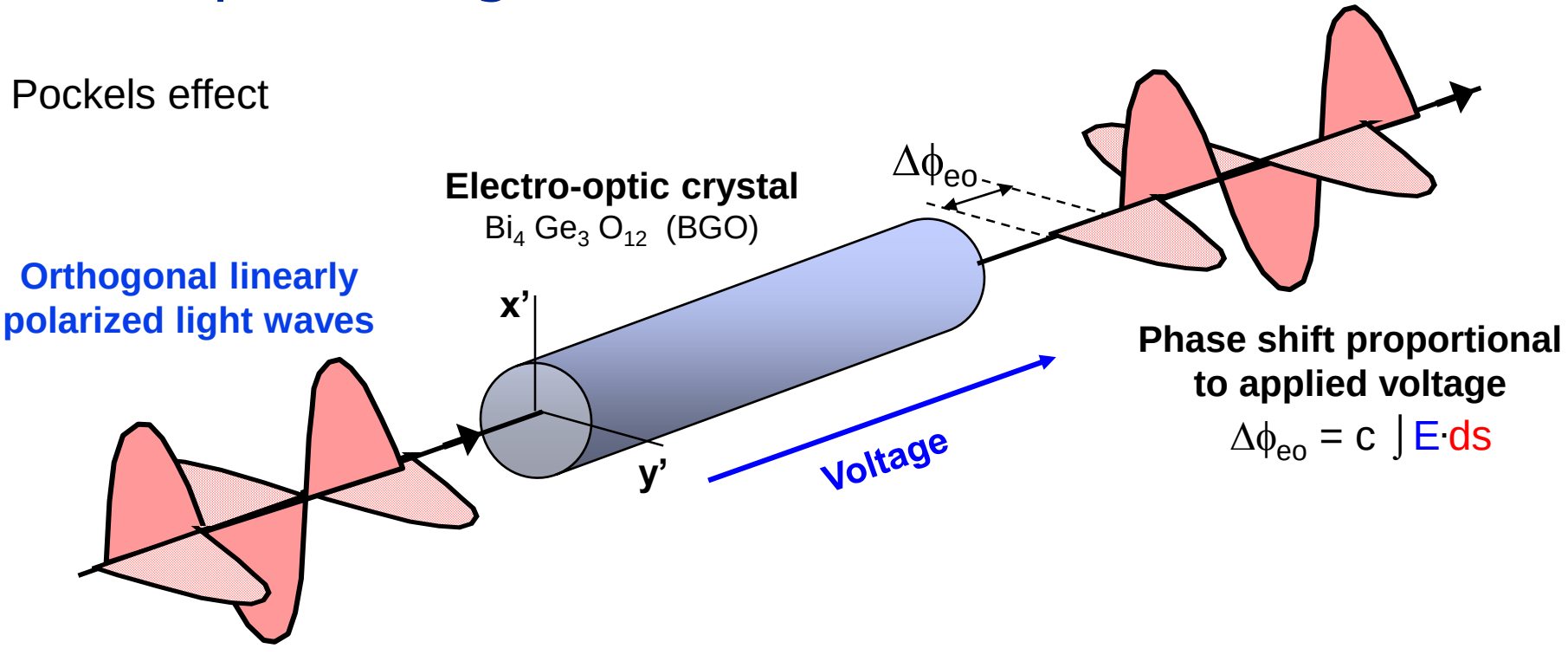
Fiber-optic current sensor
Applied to 400kV live tank circuit breaker



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Electro-Optic Voltage Transducer

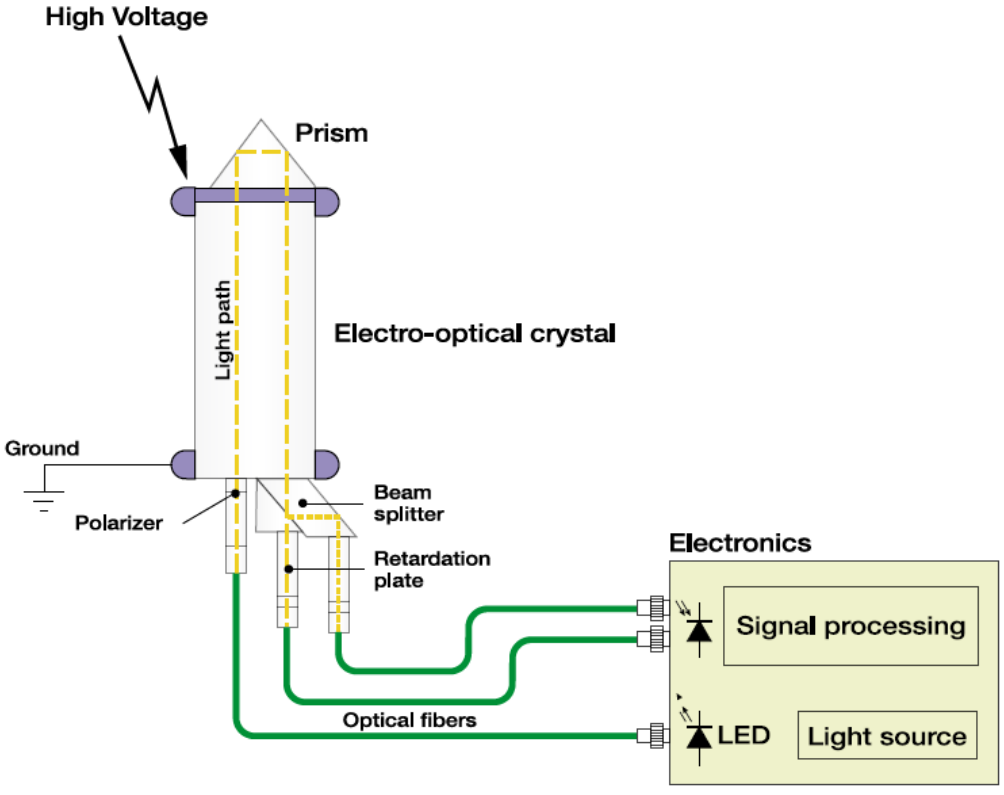
Pockels effect



- Electric field introduces refractive index difference for orthogonal light waves
- Results in different speeds of light and differential phase shift

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Electro-Optic Voltage Transducer measuring principle



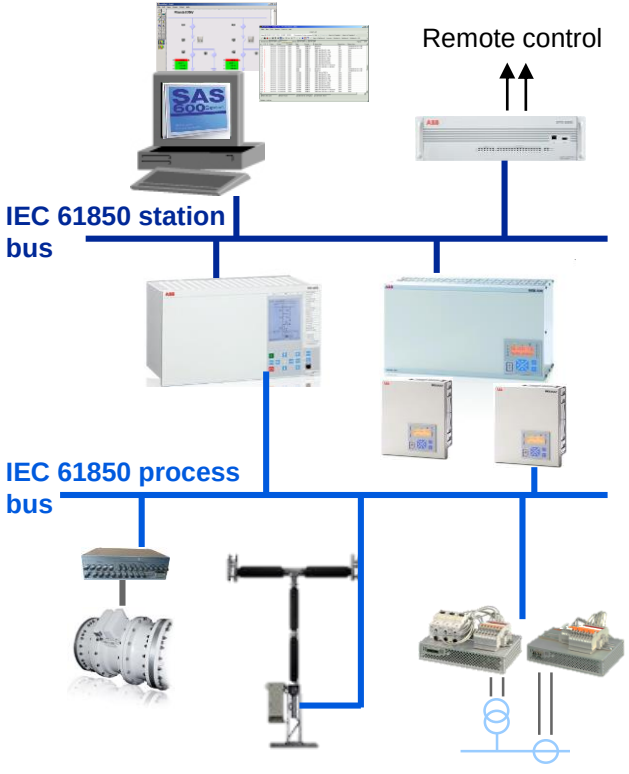
Optical voltage measurement

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New sensor technology enables the digital substation

- Hybrid solution can use conventional ITs and convert to digital process bus
  - Utilize IEC 61850-9-2LE with 80 samples/cycle for protection and operational metering

- Supporting the digital substation architecture



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Hybrid Solution using a Merging Unit (MU)



Analog Signal



SAM600-CT

control house

Low level signals in the control house

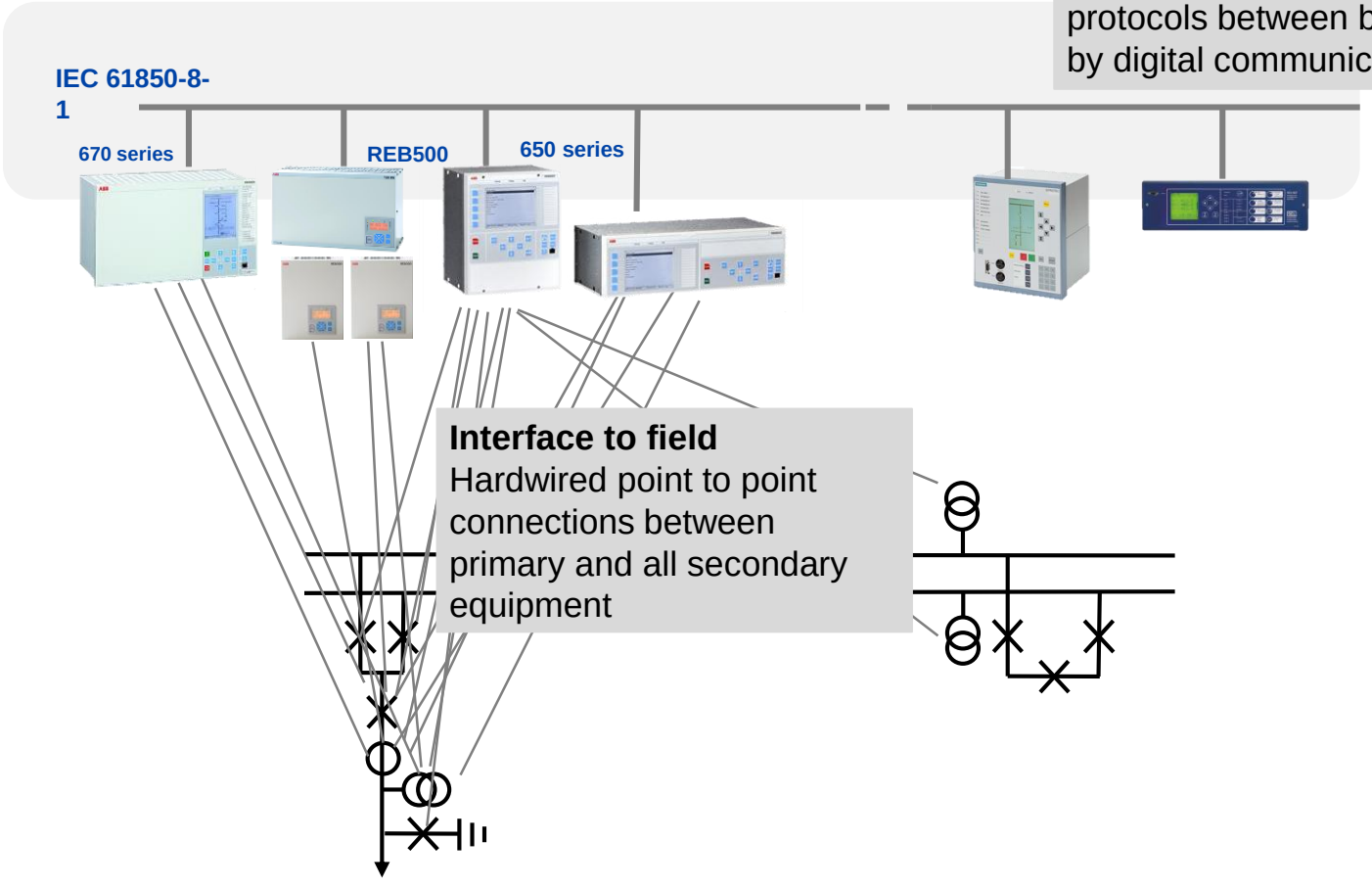
Digital Signal



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Digital Substation and IEC61850 Today

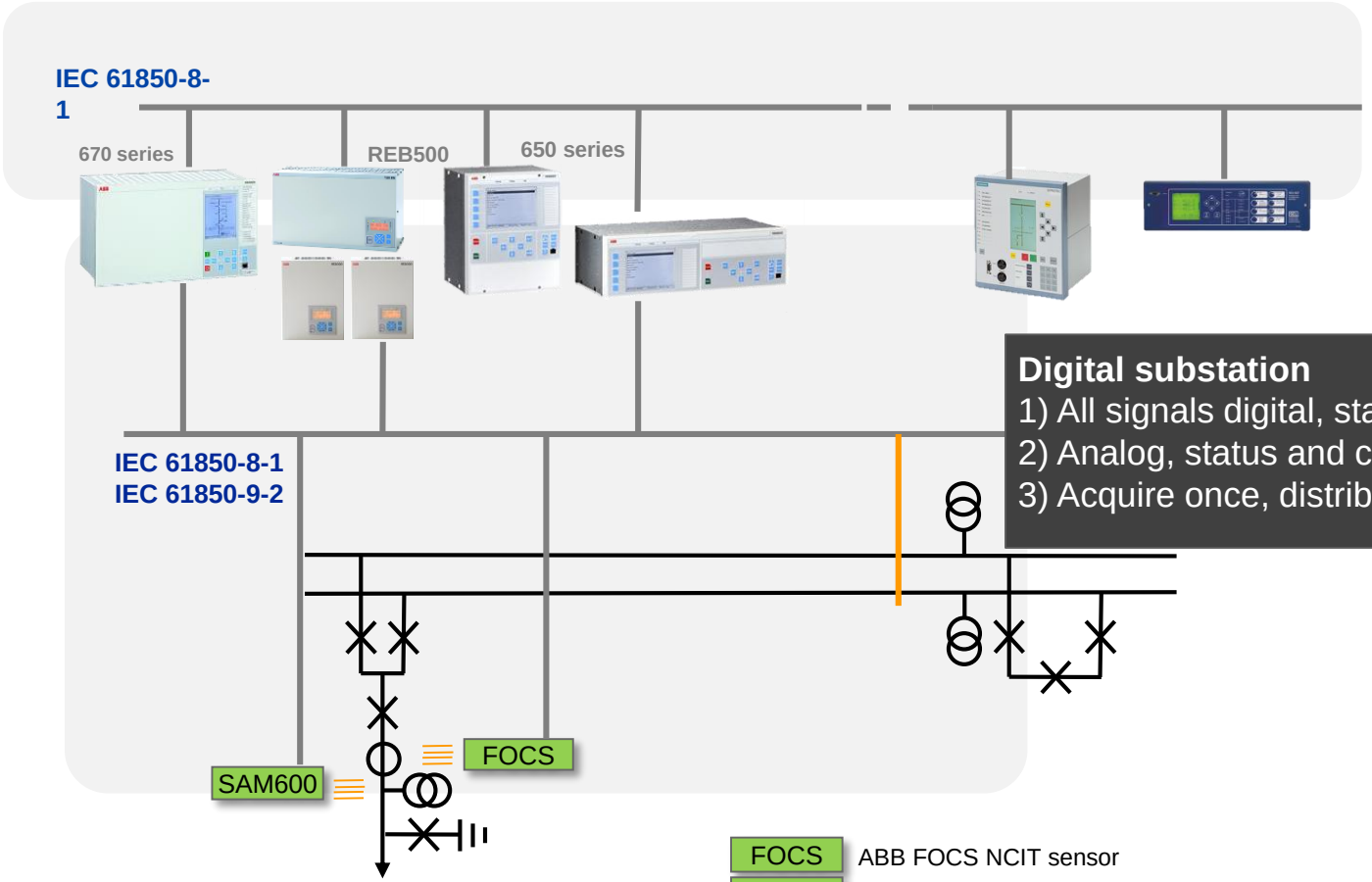
IEC 61850 Station Bus
Replace wiring and legacy protocols between bays by digital communication



Interface to field
Hardwired point to point connections between primary and all secondary equipment

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Digital Substation and IEC61850 Tomorrow



Digital substation

1) All signals digital, station and process
2) Analog, status and commands
3) Acquire once, distribute on a bus

FOCS ABB FOCS NCIT sensor

SAM600 SAM600 – Standalone merging unit

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Digital Substation Designs

- Advantages
  - From copper wiring to process bus
    - Increased Safety: No open CT conditions, Shorting of VTs.
    - Less Material.
  - Shorter installation time, outage time, Engineering change time.
  - Quicker Fault clearing time.
  - NCITs very linear response over wide operating conditions.
    - No need to worry about CT saturation, burden requirements.
  - Ability to retrofit existing designs with merging units.

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Conclusion

Conventional ITs

- CCVT's are commonly used in HV and EHV relaying applications
- Transient response of the CCVT needs to be taken into consideration
- Current transformer application needs to consider both static and dynamic performance when sizing
- Time to saturation of a current transformer is an important criteria in relaying
- Burden is a critical factor in CT selection

Non-Conventional ITs

- Non conventional instrument transformers avoid many of the traditional concerns while improving safety and reliability
  - GIS and AIS solutions available
- Hybrid solution with MU offers path to digital substation

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Standards

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Standards

- ANSI C93.1-1990
  - Power-Line Carrier Coupling Capacitors and Coupling Capacitors and Coupling Capacitor Voltage Transformers (CCVT) – Requirements (http://www.ansi.org)
- IEC 60186 (1987-01) (http://www.iec.ch)
  - Voltage transformers
  - (89 pp, Maintenance date 2000)
- IEC 60044 : Refer different parts of the standard

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Standards

- ANSI/IEEE C57.13-1993
  - IEEE Standard Requirements for Instrument Transformers (http://www.ansi.org)
- IEEE C37.110-2007
  - Guide for the Application of Current Transformers used for Protective Relaying (http://standards.ieee.org/) (http://standards.ieee.org/catalog/olis/relaying.html)
- IEC 60044 – Refer different Parts (http://www.iec.ch/)

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for a better world™



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