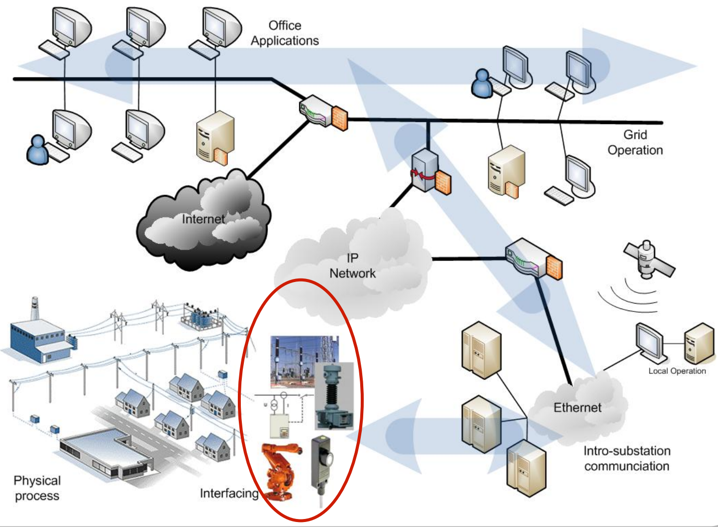
Lecture 3
Power System Measurement

Course map



Outline of the Lecture

- Instrument Transformers *(NPAG Ch. 6)*
  - Voltage Transformer
  - Current Transformers
- Measurement Setups
- Transducers *(NPAG Ch. 22)*

3

The Current Transformer (CT)

High Voltage

Bushing type
Medium Voltage

Medium Voltage

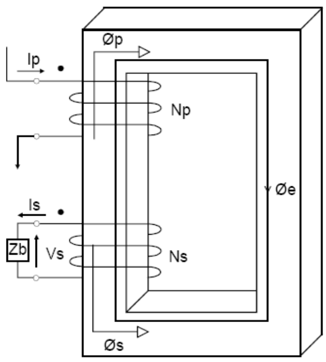
4

CT – General Types

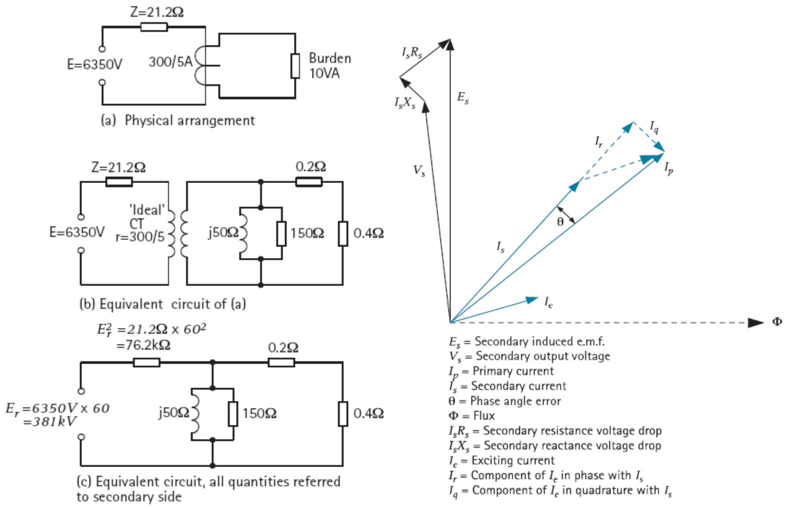
- Wound primary
  - Traditional transformer with secondary and primary windings
- Bar primary
  - The primary winding is a single bar, that passes through a core with the secondary winding.

CT – Principle of Operation

- Traditional Electromagnetic transformer
- Is = Ip*Np/Ns
- Normally Bar type CTs are used



CT – Equivalent Model



CTs Accuracy

Accuracy class		+/- Percentage current (ratio) error				+/- Phase displacement (minutes)			
	% current	5	20	100	120	5	20	100	120
0.1		0.4	0.2	0.1	0.1	15	8	5	5
0.2		0.75	0.35	0.2	0.2	30	15	10	10
0.5		1.5	0.75	0.5	0.5	90	45	30	30
1		3	1.5	1.0	1.0	180	90	60	60

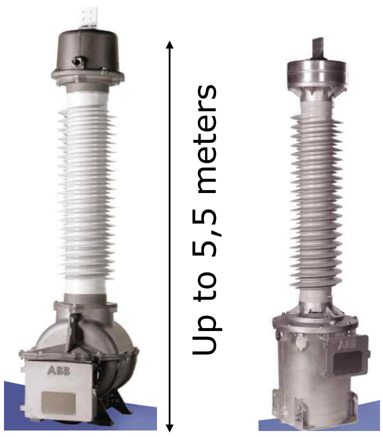
(a) Limits of error accuracy for error classes 0.1 - 1.0

Accuracy class		+/- current (ratio) error, %	
	% current	50	120
3		3	3
5		5	5

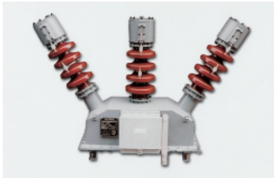
(b) Limits of error for error classes 3 and 5

Table 6.4: CT error classes

Voltage Transformers (VT)



High Voltage



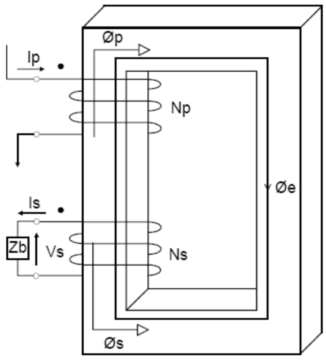
Medium Voltage
< 36kV

VT – General Types

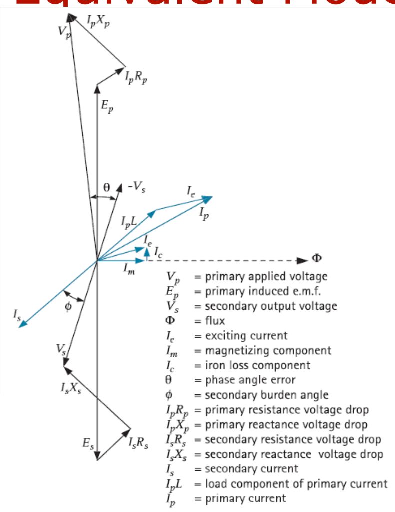
- Electromagnetic type
  - Commonly referred to as VT
  - Traditional Electromagnetic transformer
  - Used up to approx 130kV
    - Thereafter insulation problems arise
- Capacitor Type
  - Commonly referred to as CVT
  - Series coupled capacitors
  - Used up to EHV/UHV levels

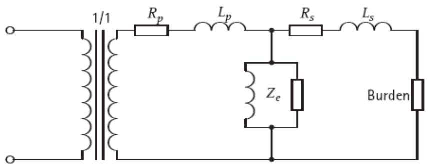
VT – Principle of Operation

- Traditional Electromagnetic transformer
- $V_s = V_p * N_s / N_p$
- Connected either
  - Phase – Earth
  - Phase – Phase
- Single-pole
  - Star coupled



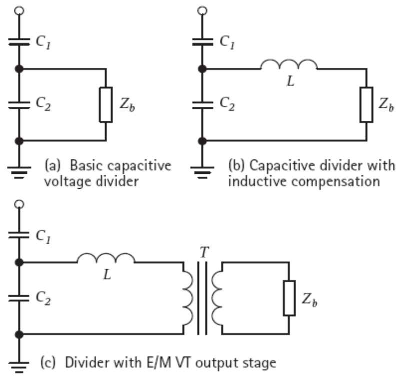
Equivalent Model





CVT – Principle of Operation

- Basic potential divider
- Inductive compensation to cancel effect of capacitive source impedance
- To reduce the size of capacitors, a VT is added on output side.



(a) Basic capacitive voltage divider
(b) Capacitive divider with inductive compensation
(c) Divider with E/M VT output stage

VT – Design Factors

- Electromagnetic VT
  - Flux density in core well below saturation
  - Output design ranges 200-300 VA
  - Insulation larger volume than windings
- Capacitive VTs
  - More space conserving
  - May include a VT
  - Can be used for overloading High-Frequency signals on Power Line.

VT Connection

- VTs are single pole above 36 kV
- CVTs
  - Phase to Earth
- VTs
  - Phase to Phase, Phase to Earth
  - Star coupling

VT - Accuracy

- Accuracy classes for measurement & revenue metering
- Accuracy classes for protection

Accuracy class	0.8 - 1.2 x rated voltage 0.25 - 1.0 x rated burden at 0.8pf	
	voltage ratio error (%)	phase displacement (minutes)
0.1	+/- 0.1	+/- 5
0.2	+/- 0.2	+/- 10
0.5	+/- 0.5	+/- 20
1.0	+/- 1.0	+/- 40
3.0	+/- 3.0	not specified

Table 6.1: Measuring voltage transformer error limits

Accuracy class	0.25 - 1.0 x rated burden at 0.8pf 0.05 - V_f x rated primary voltage	
	voltage ratio error (%)	phase displacement (%)
3P	+/- 3.0	+/- 120
6P	+/- 6.0	+/- 240

Table 6.2: Additional limits for protection voltage transformers.

Summary - VTs/CTs

- VTs and CTs are the primary measurement method for medium and high voltage
- Important design characteristics are
  - Accuracy for revenue metering
  - Linearity for protection
  - Size = cost
- The output is further transformed using transducers.

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- Measurement Setups
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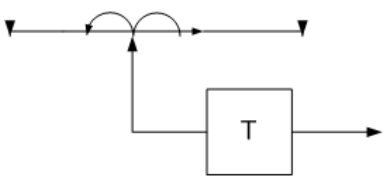
What do we need to measure?

- Voltage V
- Current I
- Frequency f
- Phase angle φ
- Power Q,P
- Position on/off
- …..

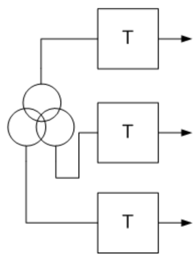
Current Measurement

- Connected to secondary side of CT
- Cannot sense direction
- Measurement types
  - Mean sensing
  - r.m.s. measurement



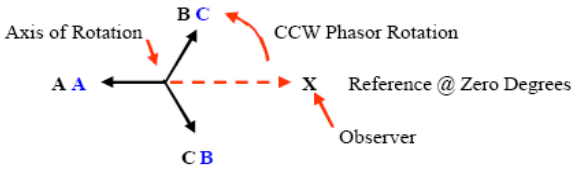
Voltage Measurement

- Connected to secondary of VT/CVT



Phase Angle Measurement

- Implemented using zero-crossing detection
- Sensitive to harmonics
- Connected to phases and quantities (U or I) as needed for measurement

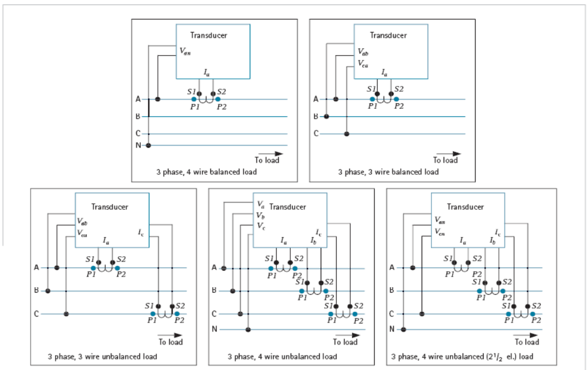


Frequency Measurement

- Important for system operation
- Analog – Digital conversion
  - Fourier Transform for *f* analysis
- Accuracy up to 0,01% available, +/- 5 mHz
- Connected to VT or CT secondary

Power Measurement

- Measurement of P & Q
  - Many configurations available
  - Direction of the flow important



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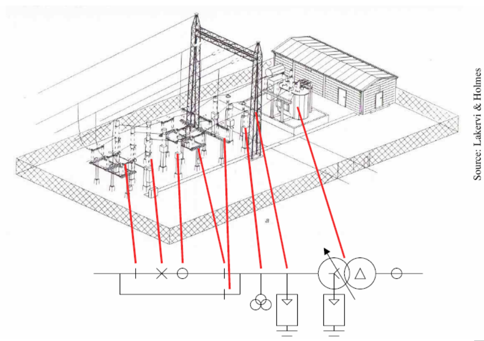
Wiring & Communication



Transducers

- A transducer is a device, usually electrical, electronic, or electro-mechanical, that converts one type of energy to another for various purposes including measurement or information transfer. In a broader sense, a transducer is sometimes defined as any device that converts a signal from one form to another.

www.wikipedia.org

Benefits of using transducers

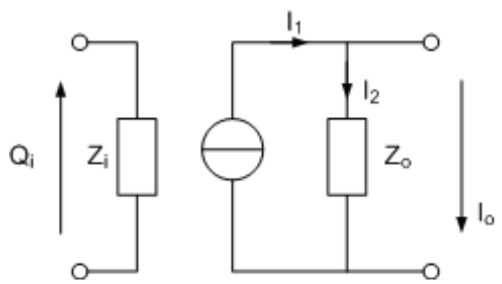
- Reduces the burden on instrument transformers
- Ability to mount display equipment remote from the measurement point
- Ability to use multiple display units per measurement point
- Reducing need for long wiring from instrument transformers

Transducer types

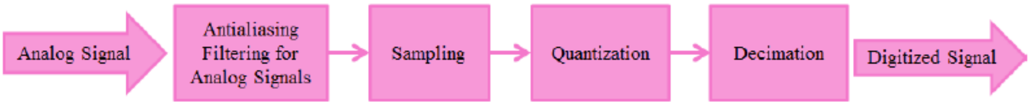
- Analog or Digital transducers
- Digital transducers (A/D conversion)
  - Benefits
    - Improved long-term stability
    - More accurate r.m.s measurement
    - Improved Communications
    - Programmable scaling
    - Reduced size
    - Wider range of functions
  - Output normally a RS-485 or 232 interface

Equivalent Model (analog)

- Output from a transducer normally a current source
- E.g. 4-20 mA as a function of input

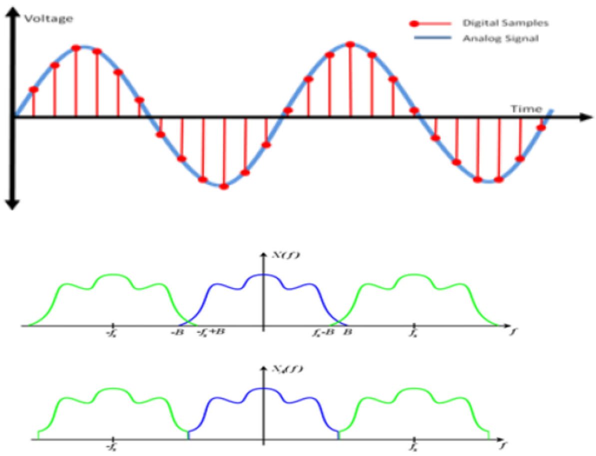


A/D conversion

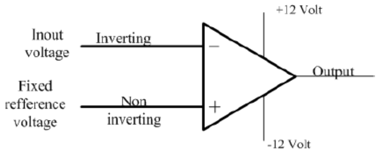


- Accuracy determined by
  - Bit resolution, Least Significant Bit
  - Non-linearity due to imperfections.
  - Sampling & Aliasing

Sampling & Aliasing

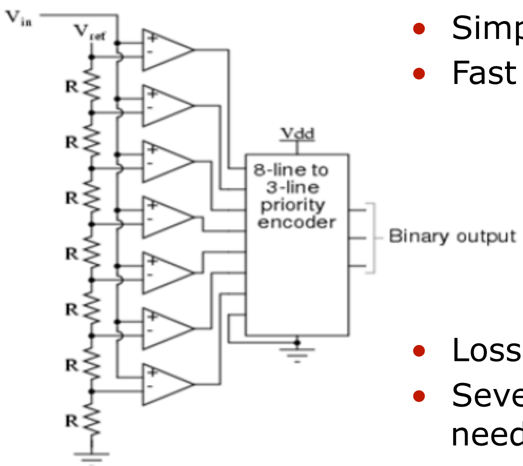


A/D - Quantization



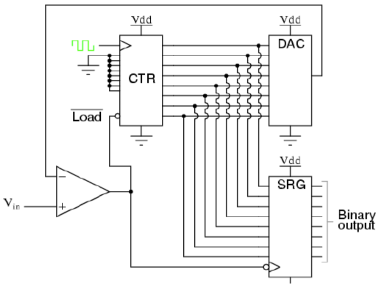
- Base circuit is the comparator
- If Input > Vref output = V+
- If Input < Vref = Output = V-

Flash ADC

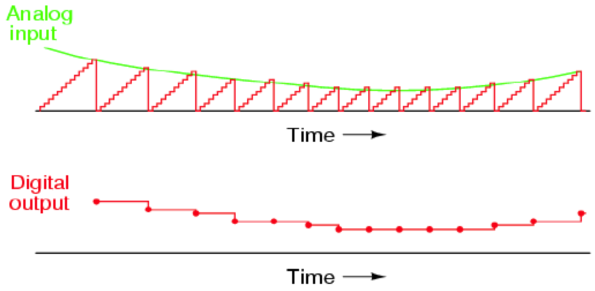


- Simple concept
- Fast
- Losses increase
- Several comparators needed
- Low resultion

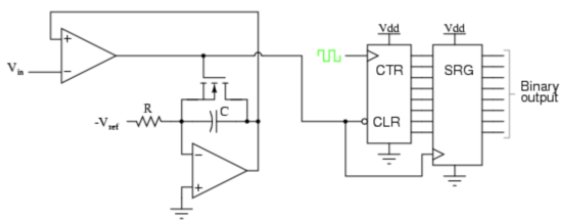
Counting A/D



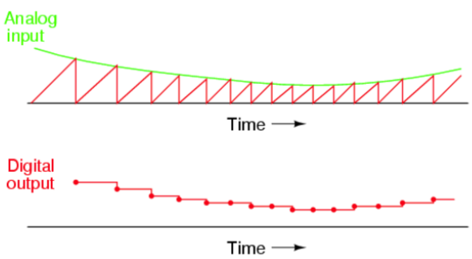
- Counter increases as long as voltage below reference.
- Each step = one discrete pat of V_{ref}



Integrating A/D



- Charging capacitor until V_{in} reached
- Pulse counter increases output
- Once V_{in} reached, counter is register is written
- Counter cleaered



Questions or comments?