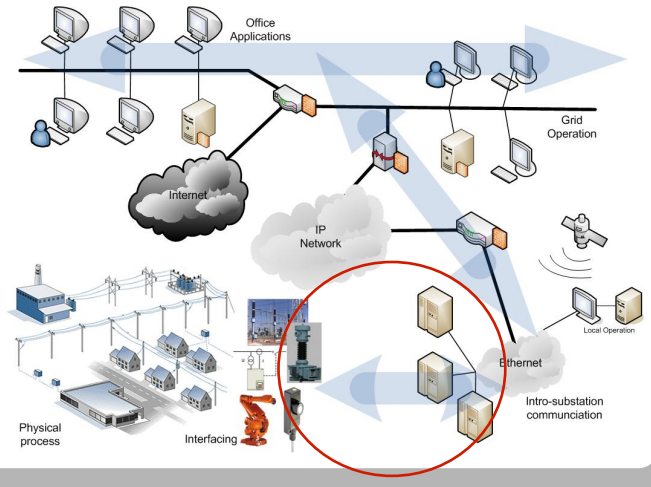
Lecture 4
Power System Protection

Course map



Outline of the Lecture

- Control vs Protection
- Protection Principles
- Protection requirements
- Protection Schemes

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Control vs. Protection

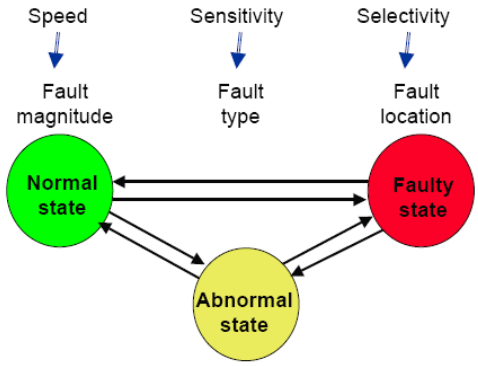
Control functions

Optimization of operation

Minimization of losses

Economical optimization

Protection functions



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Why do we need to control?

- Control actions needed
- Automatic
  - Equipment Protection
    - Disonnection at fault
  - Voltage control
    - Move a tapchanger in a transformer
- Human intervention
  - Frequency control
    - Increase output in hydro plant
  - Voltage control
    - Connect capacitor bank

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What can we control?

- Breakers
- Valves
- Tap changers
- Switches
- Drives
- ……

All done using Relays

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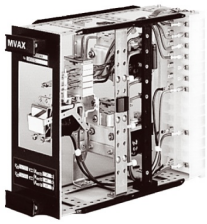
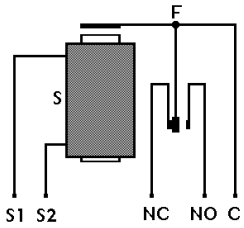
Basic Relay concepts

- Electromechanical — Pre 1970s
- Static — 1970s
- Digital — 1980s
- "Numerical" — Present ->





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The numerical relay

- Current state of the practice
  - A/D & D/A converters
  - Dedicated CPU for Digital Signal Processing
  - Programmable
  - Real-time operating system

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Application examples

Distance Protection- several schemes including user definable)
Overcurrent Protection (directional/non-directional)
Several Setting Groups for protection values
Switch-on-to-Fault Protection
Power Swing Blocking
Voltage Transformer Supervision
Negative Sequence Current Protection
Undervoltage Protection
Overvoltage Protection
CB Fail Protection
Fault Location
CT Supervision
VT Supervision
Check Synchronisation
Autoreclose
CB Condition Monitoring
CB State Monitoring
User-Definable Logic
Broken Conductor Detection
Measurement of Power System Quantities (Current, Voltage, etc.)
Fault/Event/Disturbance recorder

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Numerical relays - issues

- Software Version Control
  - Same problem as for all software systems
- Relay Data Management
  - Large amounts of parameters
  - Vendors specific vs. standardisation
- Testing & Comissioning
  - Complex equipment needed for testing
  - Too complex for field repairs

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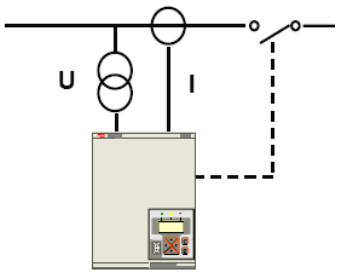
Outline of the Lecture

- Control vs Protection
- Protection Principles
- Protection requirements
- Protection Schemes

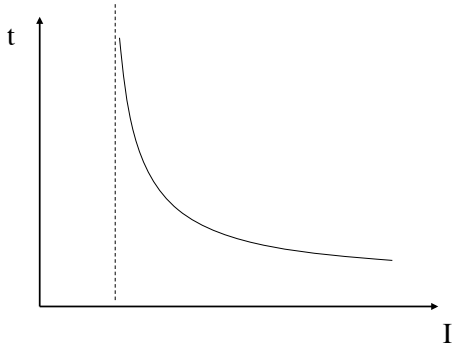
Purpose of the Protection System



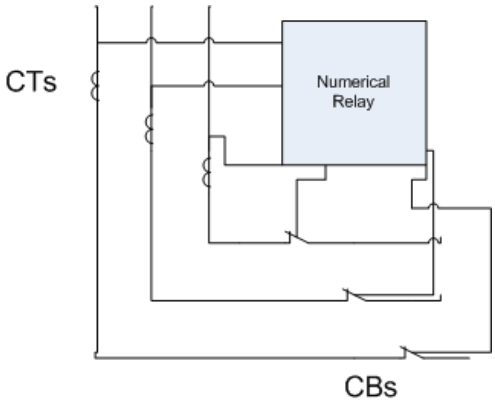
- Protect Equipment
- Protect People & Property
- Separate Faulty section from power system
- Restore normal operation

Most basic type of protection?

- The Fuse



Relay Protection system



Different Types of Protection

By object	By principle
• Line protection	• Distance protection - Impedance protection
• Feeder protection	• Differential protection - Pilot wire protection
• Transformer protection	• Overcurrent protection
• Generator protection	• Residual current protection - Directional earth fault
• Busbar protection	• Over/under frequency protection
• Motor protection	• Over/under voltage protection
• etc	• etc

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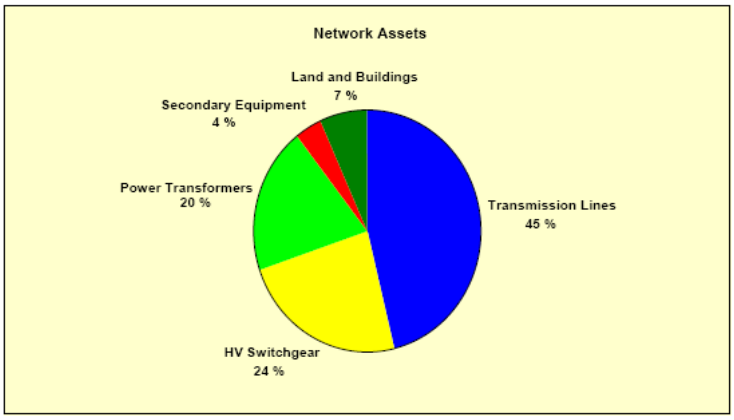
Assets in a Power Grid (value)



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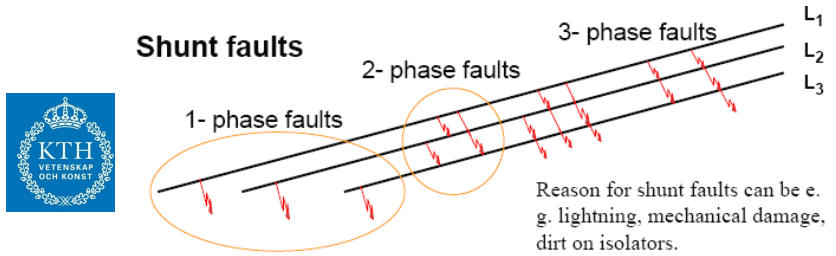
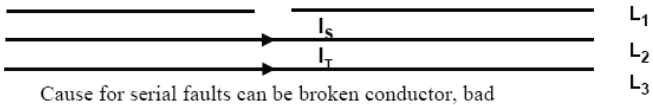
Fault types



Reason for shunt faults can be e. g. lightning, mechanical damage, dirt on isolators.

Serial faults



Cause for serial faults can be broken conductor, bad contact in disconnector or breaker element, etc.

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Fault Statistics

Transmission systems	• Transmission lines	85 %
	• Busbars	12 %
	• Generators / transformers	3 %
Transmission lines Type of fault	• Single phase to ground	80 %
	• Two phases to ground	10 %
	• Two phase	5 %
	• Three phase	5 %
Faults per 100 units/year	• Hydro turbine	6.2
	• Hydro generator	14.6
	• Transformer	2-3
	• Breaker	1
	• CT & VT	0.2

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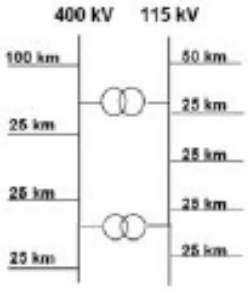
Line fault statistics

Voltage	Faults per 100 km / year
400 kV	0.2 – 1.0
220 kV	0.7 – 3.5
130 kV	3 – 15
70 kV	2 – 10
40 kV	6 – 30
20 kV	18 – 90



300 km 400 kV line: 0.6 - 3 fault / year
10 km 40 kV line: 0.6 - 3 fault / year

5 - 25 faults/ year

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Outline of the Lecture

- Control vs Protection
- Protection Principles
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Protection requirements

- The protection system must be
  - Reliable
  - Stable
  - Sensitive
  - Selective
  - Timely

Reliability

- The protection system **must** provide its function when required to avoid damage to equipment, people or property
- Reliability problems stem from
  - Incorrect design
  - Incorrect installation/testing
  - Deterioration
- The study of the reliability of a protection system is critical

Stability

- The protection system shall not react to non-fault situations
- The protection system must not react to faults in neighboring zones or high load currents.

Sensitivity

- Sensitivity refers to the minimal changes in measured parameter that the system can react to.
- For electromagnetic relays, this was a main design characteristic.
- Presently, the sensitivity is determined by the CT/VT and design of the system

Selectivity

- Only the effected parts of the power system shall be disconnected.
- Is achieved by two main methods
  - Time-grading/Current Grading
    - Relays are set to operate depending on the time and current characteristics
  - Unit systems
    - Current is measured at several points and compared.

Timeliness - Speed

- Faults must be isolated as fast as possible.
- Speed is necessary for two main reasons
  - Maintain stability of the overall power system
  - Reduction of damage to equipment & property

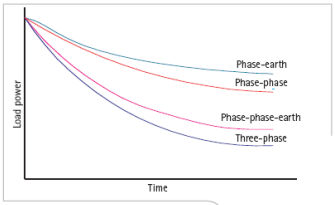
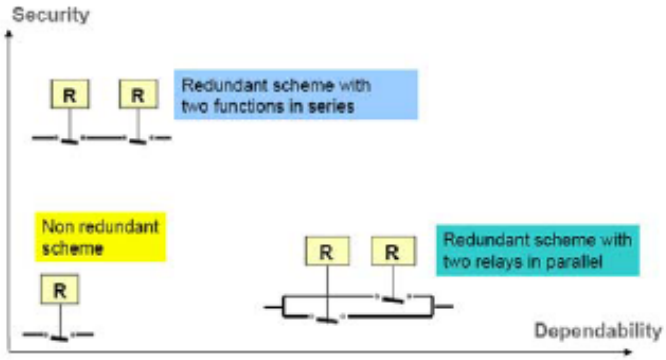


Figure 2.8: Typical power/time relationship for various fault types

Stability vs Reliability



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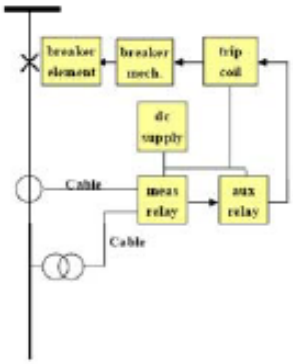
Fault Clearance Chain



The fault clearance chain consists of many elements all of equal importance.

To secure fault clearance protection system must include back-up protection.

Back-up protection can be of type:

- Remote back-up
- Local back-up

A common requirement, world-wide, on the protection system is that fault clearance shall be secured also with a single-failure in the fault clearance chain. This is called "the single-failure criteria" and is the lead star at designing the protection system.

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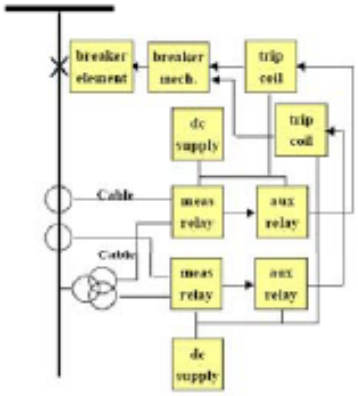
FCC with Local backup



Local back-up must be used when remote back-up cannot be arranged. This is mostly the case on the transmission level.

The local back-up includes two protection relays, covering the same primary fault, operating on the same circuit breaker.

When the protection relays are of equal type, the protection system is said to include "redundant protection".

The circuit breaker and the CT and VT are not duplicated of cost reason. However, two trip coils, two CT cores, two VT secondary cores or fuse groups etc are provided to achieve high dependability.

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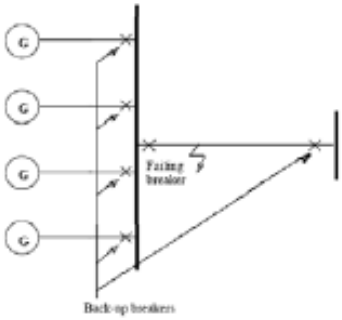
Breaker Failure Protection



Breaker failure protection (BFP):

Breaker failure function is the Local back-up for breaker failures.

The breaker failures can be due to trip coil, breaker drive or breaking components failure.

At a breaker failure the surrounding breakers are used to clear the fault.

Due to the big impact a breaker failure trip will have on the power system service, the BFP function has very high requirements on security against unnecessary tripping.

The BFP function is started at CB tripping and if current still flows within, about 150 ms the surrounding breakers are tripped.

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• Motor protection	• Over/under voltage protection
• etc	• etc

Fundamentals of Protection

- Protection System
  - A complete arrangement of equipment that fulfills the protection requirements
- Protection Equipment
  - A collection of devices excluding CT, CB etc
- Protection Scheme
  - A collection of protection equipment providing a defined function.

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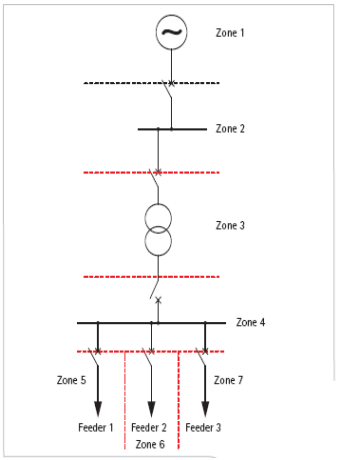
Zones of Protection

- By dividing the power system into protection zones the extent of disconnections can be limited



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Overlapping protection zones

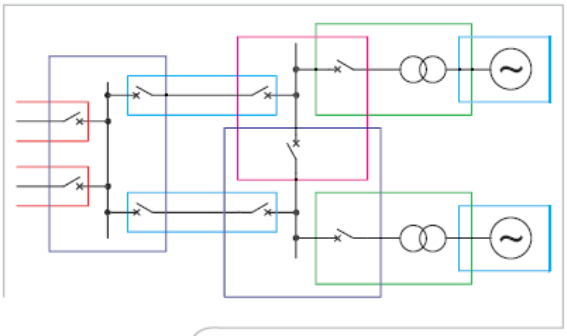
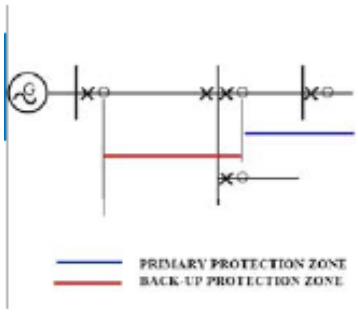


Figure 2.7: Overlapping zones of protection systems

Backup Protection Zones



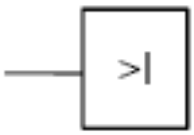
The protection zones are decided by the location of current transformers. Normally the CT is located close to the circuit breaker to have measuring zone and breaking point close-up.

Back-up protection can be remote, as on figure, or local where primary and back-up zones starts at same CT and operates on same CB.

Remote back-up is the common principle on distribution voltage levels whereas local back-up is used on transmission voltage levels.

Over-Current Protection

- Simplest form next to the fuse
- Use extensively in Distribution networks



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Achieving Selectivity

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Discrimination by Time

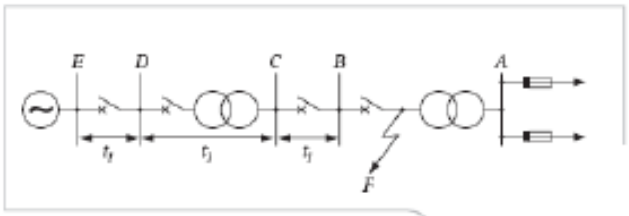


Figure 9.1: Radial system with time discrimination

DTOC
Definite Time Over Current

Discrimination by Time & Current

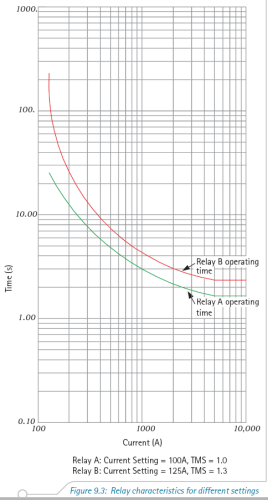


Figure 9.3: Relay characteristics for different settings

Directional Relays

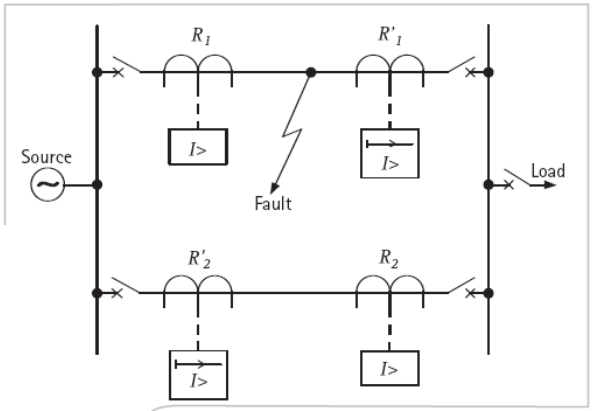
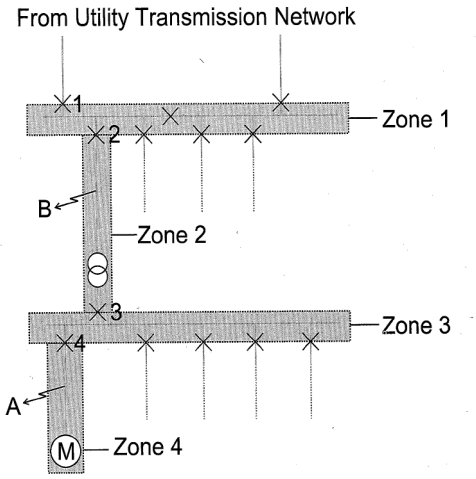


Figure 9.13: Directional relays applied to parallel feeders

Time grading

- Example from Strauss 4.4.2.

Example - Protection Scheme



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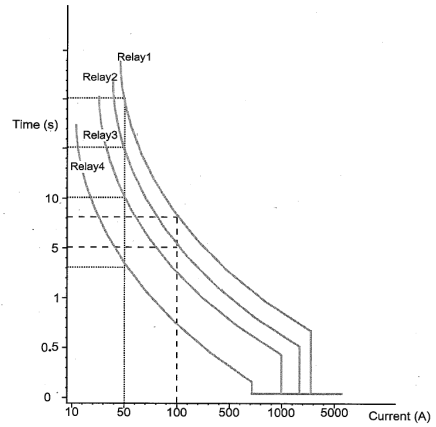
Example – relay settings



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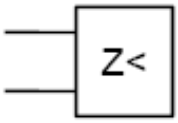
Distance Protection

- Dual input V & I
- Based on ratio Z



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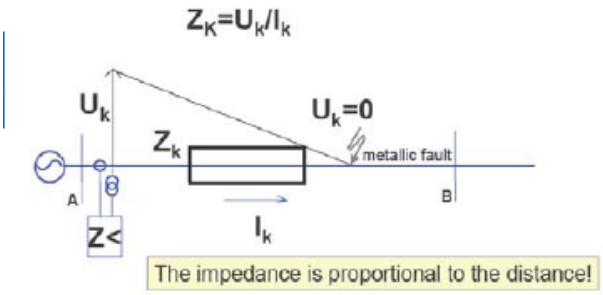
Principle of Distance Protection

Principle of Distance Protection



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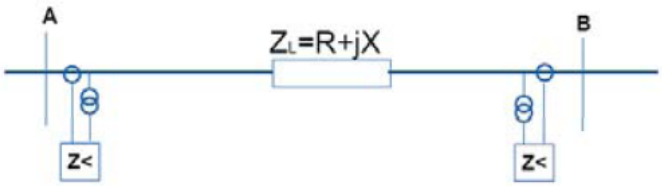
Power Line Characteristics

Power lines have impedances of size 0,3- 0,4 ohm/ km and normal angles of 80 - 85 degrees in a 50Hz systems.



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Benefits of Distance Protection

- Local current and voltage: No need for communication
- Fault on protected line: Reach independent of fault current level
- Enables remote back-up protection.

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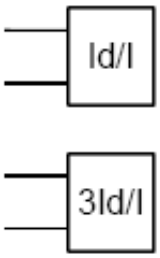
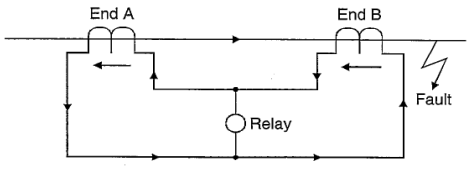
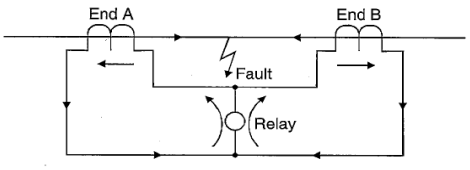
Differential Protection

- Dual input
- At each end of protected device



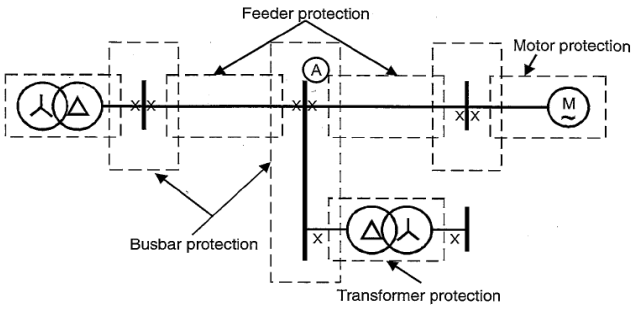
Unit – Differential Protection





Mathias Ekstedt

Diffferent Protection schemes



Protection Summary

- The Power System must be protected
  - To avoid damage to equipment, people & property
- Protection systems are created using CT/VTs, relays and circuit breakers
- Key characteristics are:
  - Selectivity
  - Speed
  - Reliability
  - Stability
  - Sensitivity
- Numerical Relays are essentially small computers - The Intelligent Electronic Device