



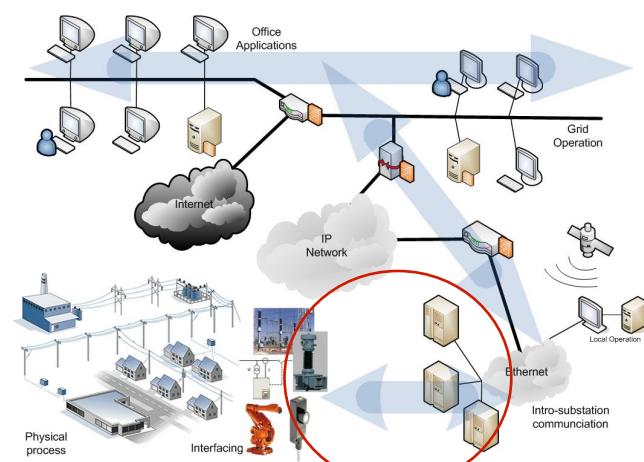
Lecture 4

Power System Protection

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Course map



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Outline of the Lecture

- Relays and IEDs
- Protection Principles
- Protection requirements
- Protection Schemes



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What can we control?

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



All done using Relays
or IED

“Intelligent Electronic Device”

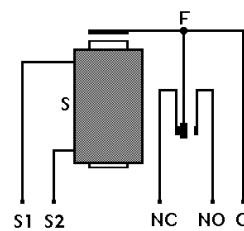
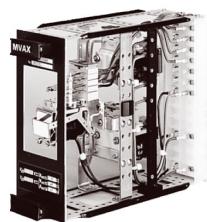
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Basic Relay concepts



- Electromechanical
- Static
- Digital
- “Numerical”

Pre 1970s
1970s
1980s
Present ->



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The numerical relay

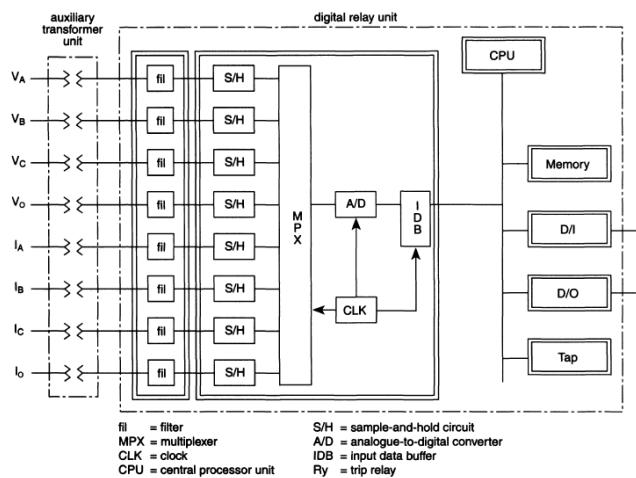


- Current state of the practice
 - A/D & D/A converters
 - Dedicated CPU for Digital Signal Processing
 - Programmable
 - Real-time operating system
- A rugged computer.



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Last slide from Lecture 4



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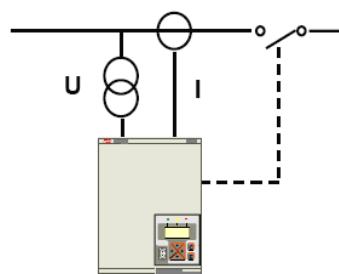
Outline of the Lecture



- Relays and IEDs
- Protection Principles
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Purpose of the Protection System

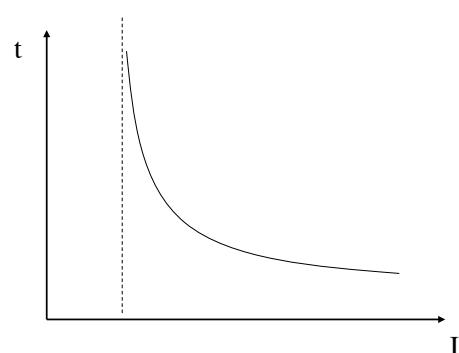


- Protect Equipment
- Protect People & Property
- Separate Faulty section from power system
- Restore normal operation

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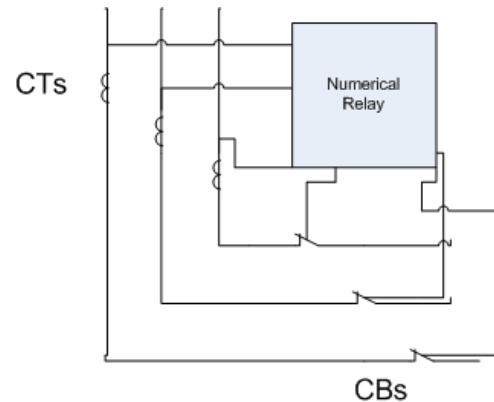
Most basic type of protection?

- The Fuse



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Relay Protection system



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Different Types of Protection



What we protect

By object

- Line protection
- Feeder protection
- Transformer protection
- Generator protection
- Busbar protection
- Motor protection
- etc

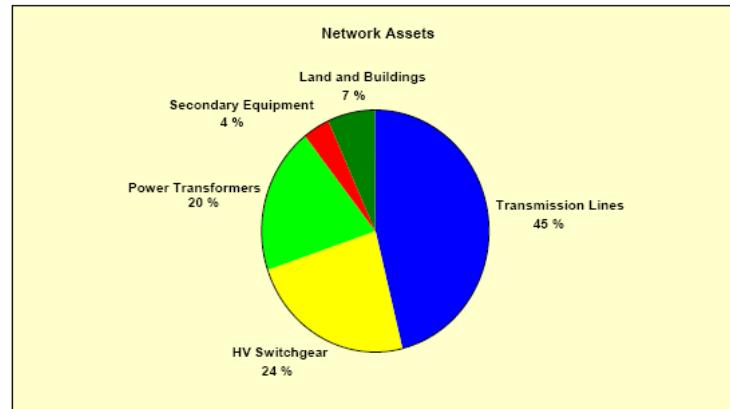
By principle

- Distance protection
 - Impedance protection
- Differential protection
 - Pilot wire protection
- Overcurrent protection
- Residual current protection
 - Directional earth fault
- Over/under frequency protection
- Over/under voltage protection
- etc

How we protect

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Assets in a Power Grid (value)

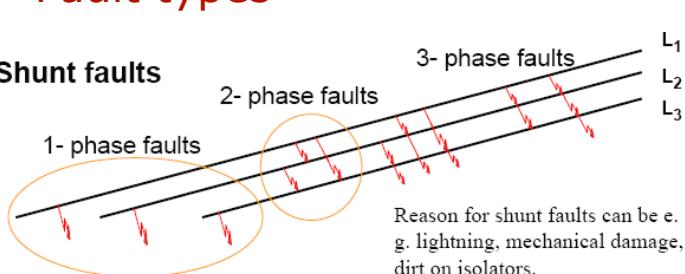


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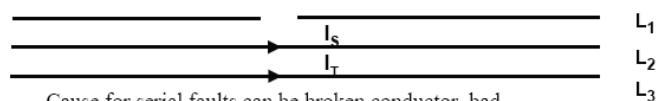
Fault types



Shunt faults



Serial faults



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

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Fault Statistics



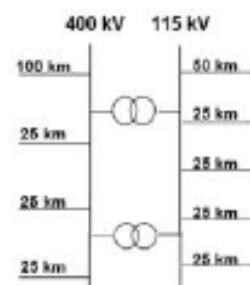
Transmission systems	<ul style="list-style-type: none">Transmission lines 85 %Busbars 12 %Generators / transformers 3 %
Transmission lines Type of fault	<ul style="list-style-type: none">Single phase to ground 80 %Two phases to ground 10 %Two phase 5 %Three phase 5 %
Faults per 100 units/year	<ul style="list-style-type: none">Hydro turbine 6.2Hydro generator 14.6Transformer 2-3Breaker 1CT & 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
- Protection requirements
- Protection Schemes

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Protection requirements



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

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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

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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.

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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

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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.

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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

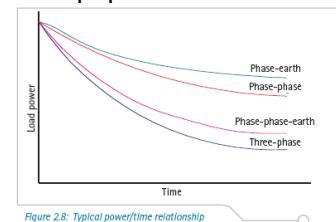
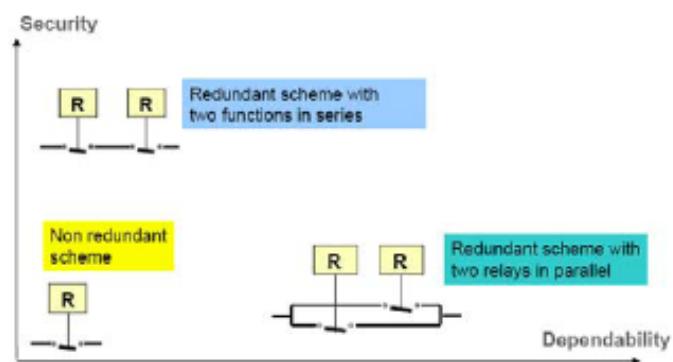


Figure 2.8: Typical power/time relationship for various fault types

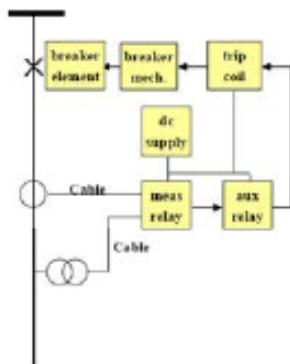
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Stability vs Reliability



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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.

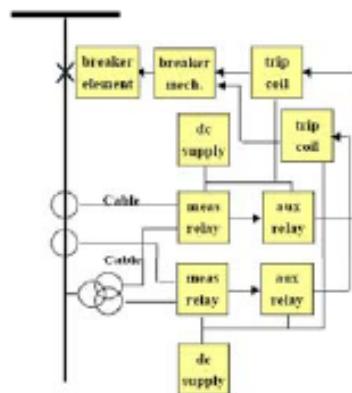
Back-up protection can be of type:

- 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 of 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.

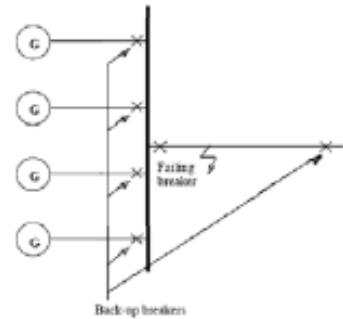
The local back-up includes two protection relays, covering the same primary fault, operating on the same circuit breaker.

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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Outline of the Lecture



- Control vs Protection
- Protection Principles
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Fundamentals of Protection



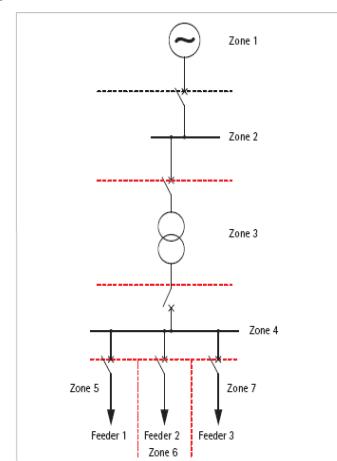
- Protection System
 - A complete arrangement of equipment that fulfills the protection requirements
- Protection Equipment
 - A collection of devices excluding CT, CB etc
- Protection Scheme
 - A collection of protection equipment providing a defined function.

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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

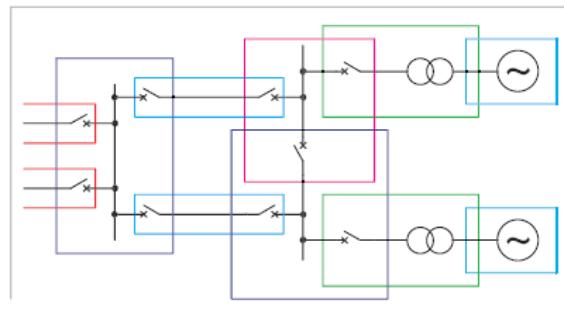
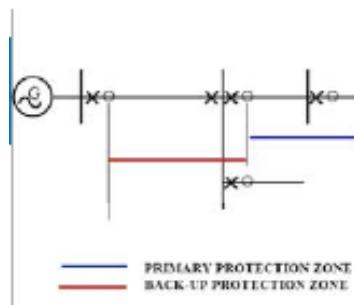


Figure 2.7: Overlapping zones
of protection systems

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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.

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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

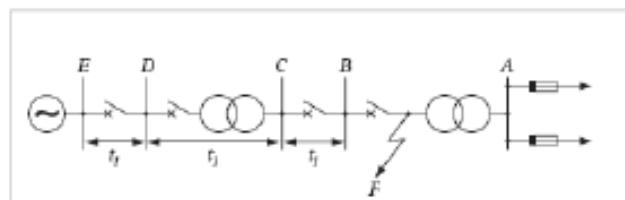


Figure 9.1: Radial system with time discrimination

DTOC
Definite Time Over Current

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Discrimination by Time & Current

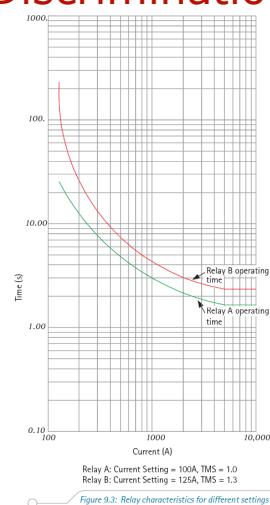


Figure 9.3: Relay characteristics for different settings

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Directional Relays

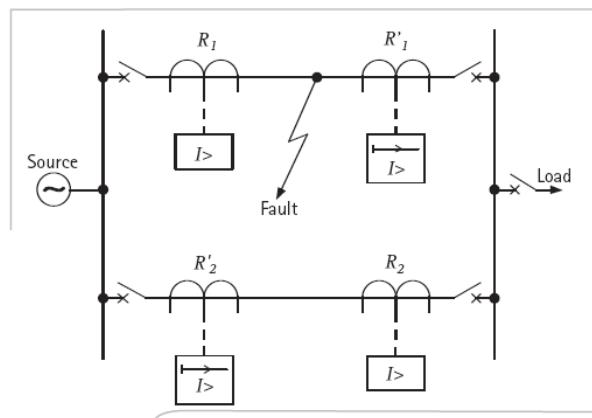
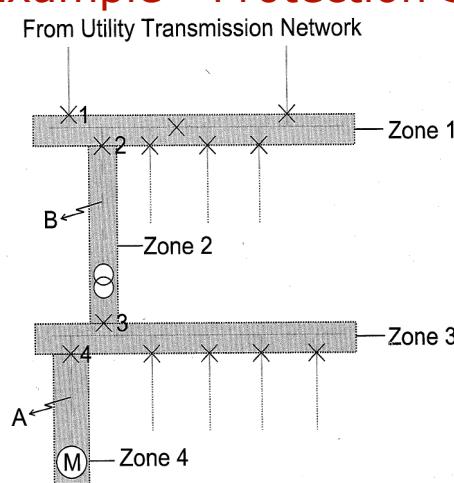


Figure 9.13: Directional relays applied to parallel feeders

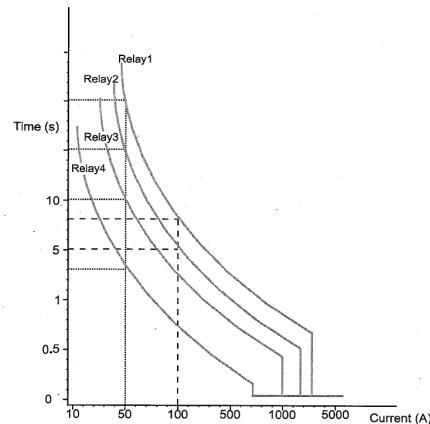
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Example - Protection Scheme



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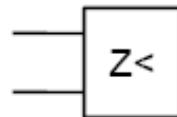
Example – relay settings



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Distance Protection

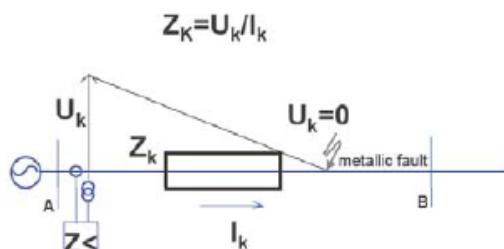
- Dual input V & I
- Based on ratio Z



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Principle of Distance Protection

Principle of Distance Protection

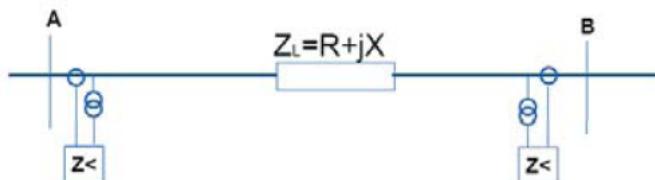


The impedance is proportional to the distance!

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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



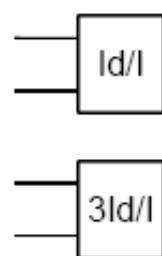
- Local current and voltage: No need for communication
- Fault on protected line: Reach independent of fault current level
- Enables remote back-up protection.

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Differential Protection

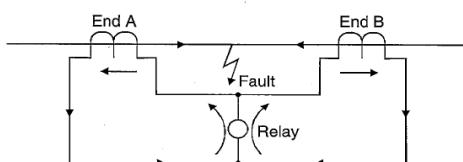
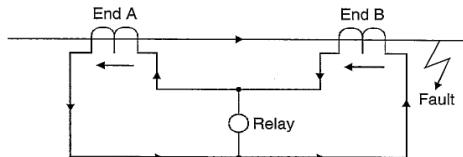


- Dual input
- At each end of protected device



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Unit – Differential Protection



Mathias Ekstedt

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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

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