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Protection Communication Systems

Douglas Wardell

Aug. 27, 2015

Presenter

- Speaker name: Douglas Wardell
- Speaker title: Electrical Engineer
- Location: Burlington, ON, Canada
- With ABB's Utility Communication group since 2000.
- Specializing in Teleprotection and Power Line Carrier

Learning objectives

Binary (Command) Protection Systems

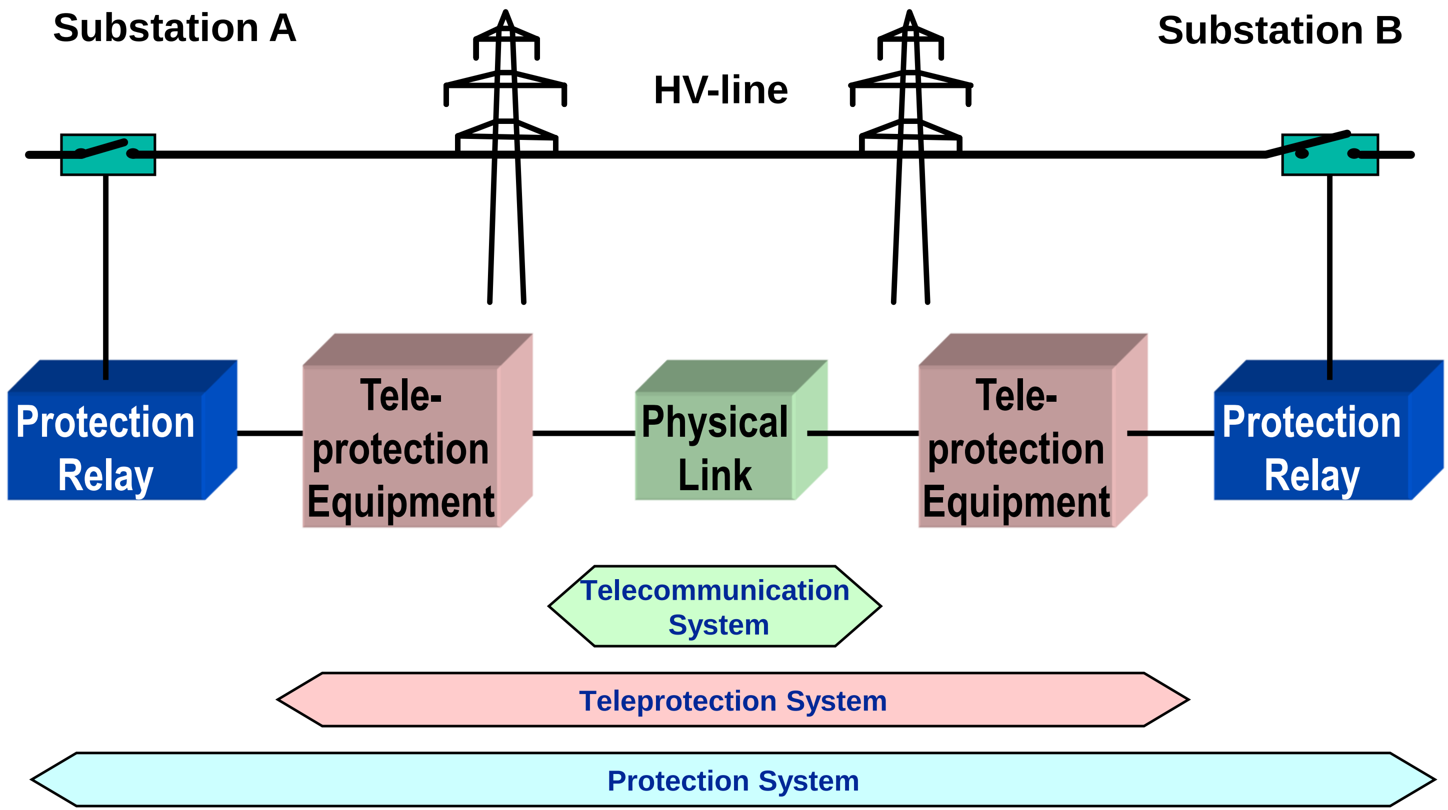
Quantitative Protection Systems

IEC 61850-90-1 Inter-substation Communications

Content

- Protection Systems
  - Binary (Command) Systems
    - Distance Protection Concept
      - PUTT, POTT, Blocking & DTT Schemes
    - Teleprotections
      - Definition, standards
      - Channels impairments and performance criteria (typical figures)
      - Design and operation considerations using WAN
  - Quantitative Systems
    - Phase Comparison Protection
    - Current Differential Protection
    - IEEE C37.94-2002
- IEC 61850-90-1 Inter-substation communications
- Other Requirements (EMC, Environment, LTC, Redundancy)
- Open Discussion

Overview of a Line Protection System



Line Protection Schemes

- Current differential protection
- Phase comparison protection

- Distance protection
- High impedance earth fault protection
- Directional comparison protection

Quantitative (analogue) Information

Binary (trip / do not trip) Information

Amplitude and/or Phase

Commands for …..

BLOCKING of breaker tripping or **DIRECT** breaker tripping

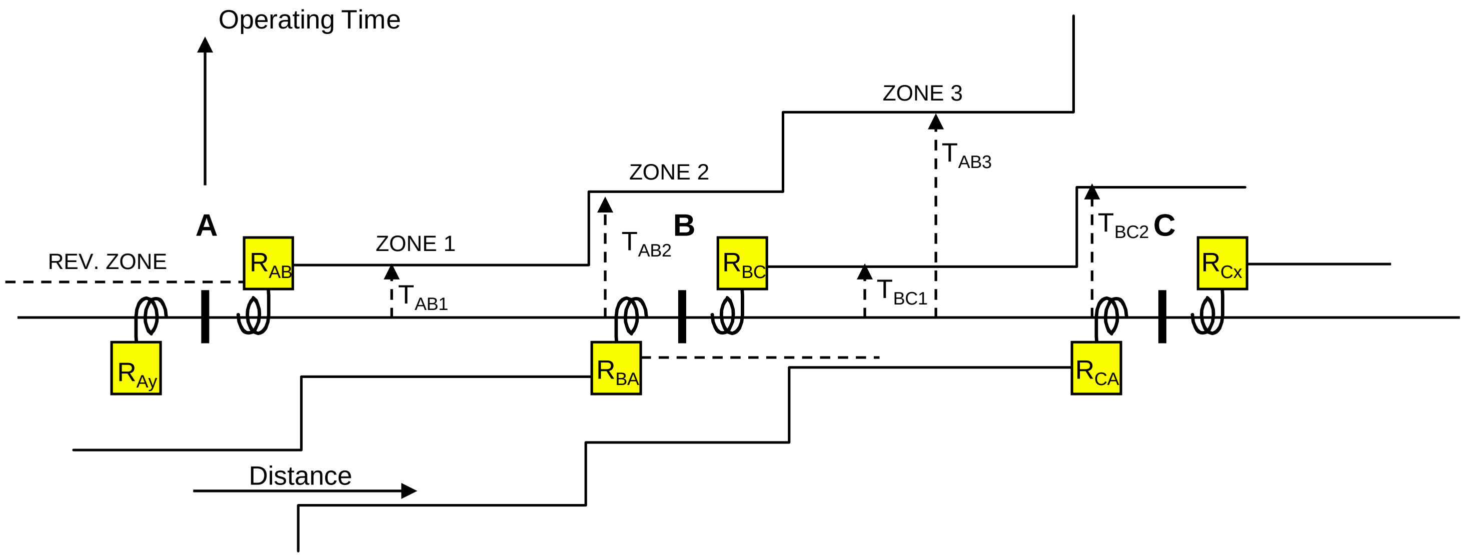
PERMISSION for breaker tripping

Communication is ESSENTIAL

Communication is SUPPLEMENTARY. It helps to clear the fault <u>in the shortest possible time</u>

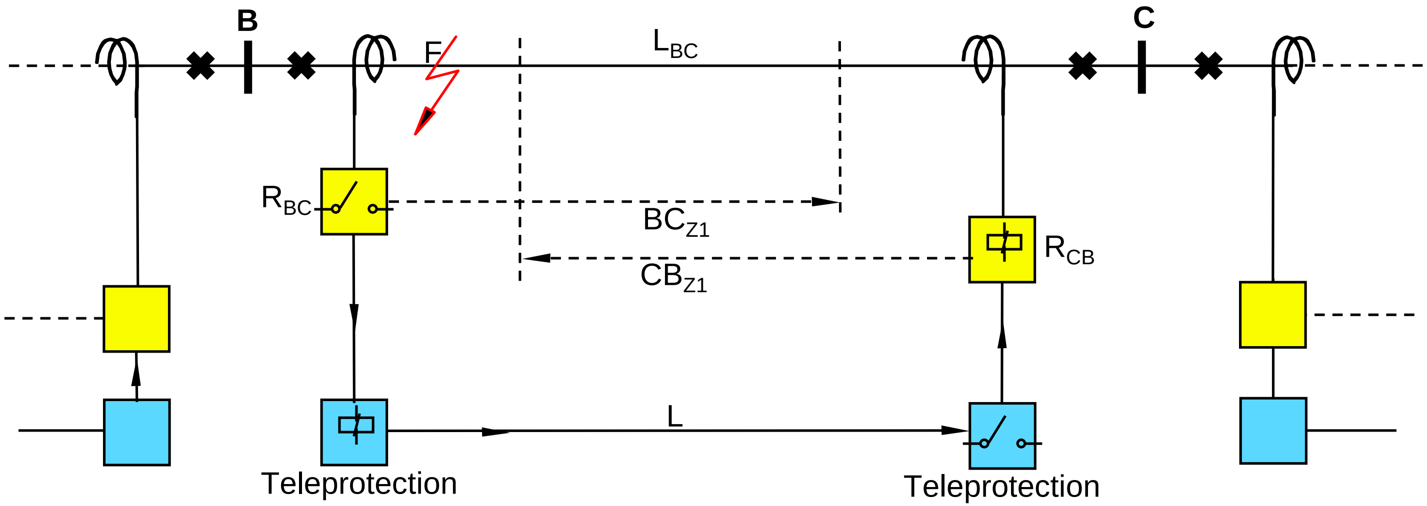
Distance Protection

Typical stepped distance/time characteristics



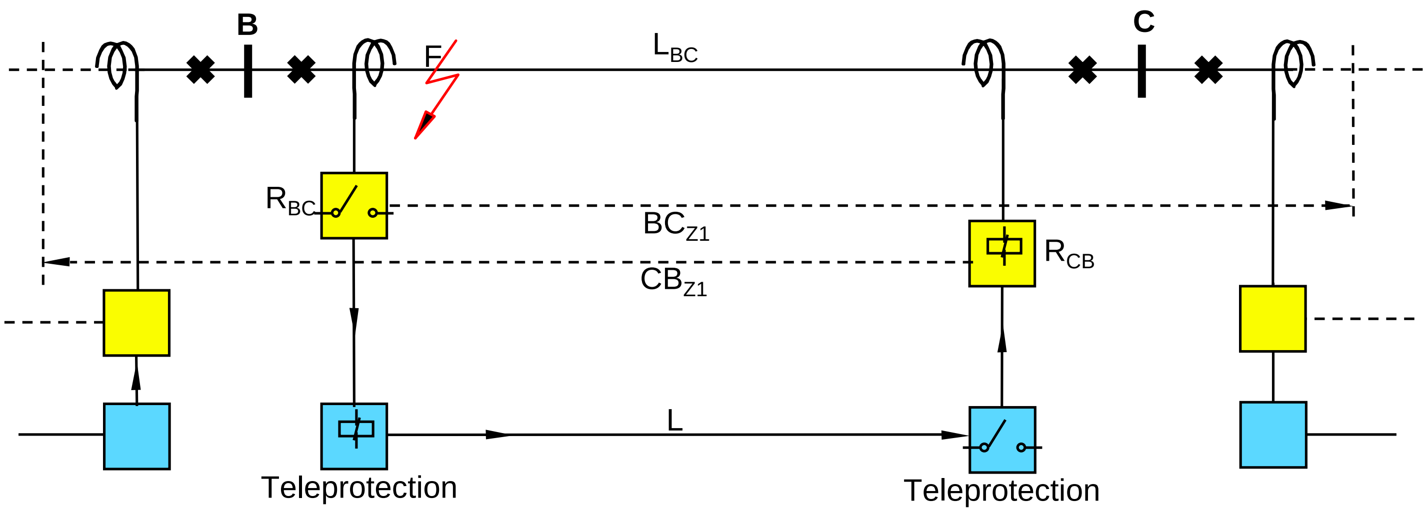
A, B, C	Stations
R_{AB}, R_{BA}, $R_{BC,}$ R_{Cx}	Protection Relay
T_{AB1}, $T_{AB2,}$ T_{AB3}	Operating Times, Relay $_{AB}$
T_{BC1}, T_{BC2}, T_{B3}	Operating Times,

Permissive Underreach Transferred Trip (PUTT)
Power Line Protection



B, C	Substations	F	Line fault
L_{BC}	Protected line section	L	Communication channel
R_{BC},R_{CB}	Protection relay	$BC_{UR} \Rightarrow CS_B$	$Trip_C$: CB_{Z1}, $CR_C + CB_{OR}$
BC_{Z1}, CB_{Z1}	Zone 1 reach (e.g. 85% of line section)		

Permissive Overreach Transferred Trip (POTT)
Power Line Protection



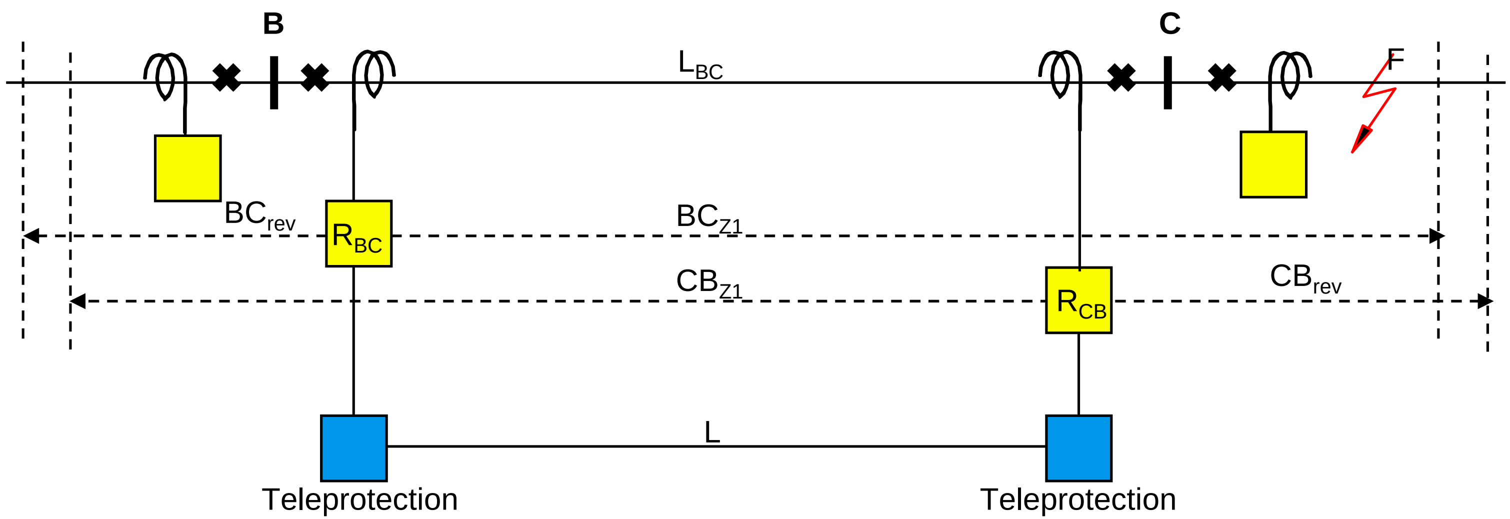
B, C	Substations	F	Line fault
L_{BC}	Protected line section	L	Communication channel
R_{BC}, R_{CB}	Protection relay	$BC_{OR} \Rightarrow CS_B$, $Trip_C$: $CB_{Z1}+CR_{C}$, $CB_{Z2}+T_2$	

BC_{Z1}, CB_{Z1} Zone 1 reach (e.g. 130% of line section)

Permissive Schemes (POTT, PUTT)
Power Line Protection

- It the most frequently used scheme for the protection of transmission lines.
- The transfer tripping link between the protection equipment at the ends of the line ensures that all faults can be cleared in the time of Zone 1 along 100% of the line.
- Transfer tripping signal is connected in series with a local criterion (protection starting, directional decision or phase selection). Tripping can only take place if a transfer tripping signal is received and the local protection relay detects the fault.
- Teleprotection equipment has to fulfill stringent requirements.
  - Reception of a spurious tripping signal (faulted communications) cannot give rise on its own to unwanted tripping. A delayed transfer tripping signal may mean that a fault on the line is tripped in the time of Zone 2 instead of undelayed in Zone 1.
  - **High dependability** and a **short transmission** time therefore take priority over **security** in a permissive scheme.
  - Either end may send command to trip to the other end. The teleprotection needs to be able to receive while transmitting.

Blocking Scheme
Power Line Protection



B, C	Substations
L_{BC}	Protected line section
R_{BC},R_{CB}	Protection relay
BC_{Z1}, CB_{Z1}	Zone 1 reach, e.g. 130% in direction of the protected line section
BC_{rev}, CB_{rev}	Range of protection relay in direction of busbars

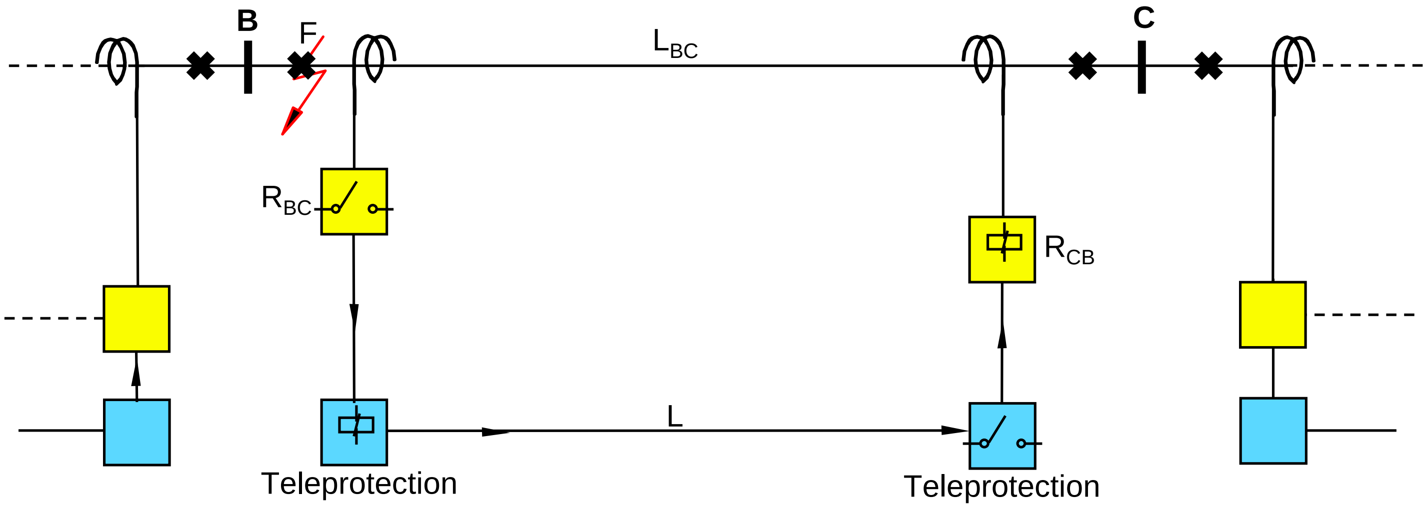
F	Line fault
L	Communication channel

$CB_{REV} \Rightarrow CS_C$, $Trip_B$: BC_{Z1}+ CR_B

Blocking Scheme
Power Line Protection

- No tripping signals transmitted along faulted line. Instead the blocking schemes of surrounding healthy lines transmit signals to their remote ends *to prevent tripping* of the overreaching relays there.
- Relays of a blocking scheme consists of distance relays with overreaching Zone 1 measuring into the line and reverse-looking directional units.
- A through-fault is seen by the directional unit which sends a signal to block the distance relay on the healthy line behind it.
- For a fault on the line, the reverse-looking directional units at the two ends do not send blocking signals and the overreaching first zones trip their respective circuit-breakers.
- Teleprotection equipment has to fulfill only modest requirements.
  - Blocking scheme is **very dependable**. It will operate for faults anywhere on the protected line if the communication channel is out of service.
  - It is **less secure** than permissive schemes. It will trip for external faults within the reach of the tripping function **if** the communication channel is out of service.
  - **Short transmission time and good dependability are more important than security.**

Direct Transfer Trip (DTT)
Power Line Protection



B, C	Substations	F	Line fault
L_{BC}	Protected line section	L	Communication channel
R_{BC},R_{CB}	Protection relay	$R_{BC} \Rightarrow CS_B$, $Trip_C$: CR_C	

Direct Transfer Trip (DTT)
Power Line Protection

- Typical applications are breaker back-up protection, compensator and power transformer protections.
- Line protection with direct transfer tripping is rare.
- Tripping command from the teleprotection equipment goes directly to the circuit-breaker tripping coil. A spurious tripping signal resulting either from interference or human error will cause unwanted, usually three-phase tripping and will block the operation of any auto-reclosure relay.
- A genuine transfer tripping signal must not be lost because then a fault would not be isolated with correspondingly serious consequences.
  - The requirements with respect to **transmission time** are generally not too demanding.
  - **Extremely high security** and **high dependability** are therefore more important than **transmission time**.

Teleprotection - Introduction

- What is it ?
  - Tele-Communication + Protection – Signalling
- Where is it used ?
  - Mainly at the higher voltage levels
- Why is it used ?
  - Clearance of faults within the shortest possible time
  - Disconnection of Distributed Generation (DG)

Teleprotection Standards and Publications

IEC standards:

IEC 60834-1 and — Teleprotection equipment of power systems - Performance testing. Part 1: Command systems (Second Edition, 1999)

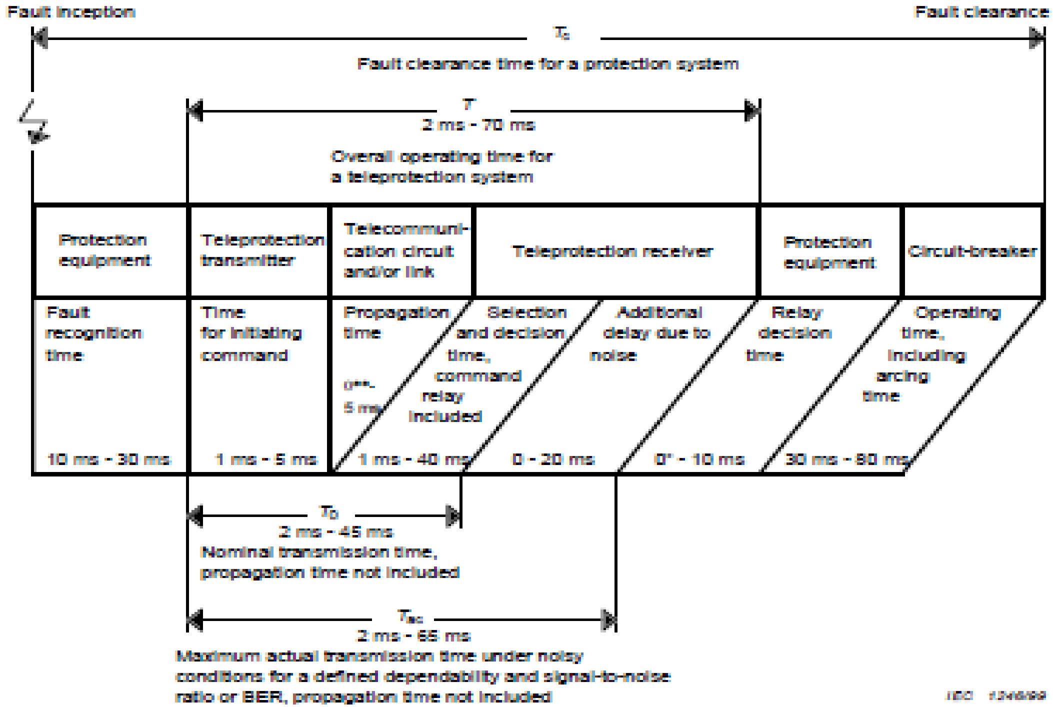
which refers (among others) to:

ITU-T G.823 — The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy (1993)

IEC standards:

IEC 60834-2 — Performance and testing of teleprotection equipment of power systems - Part 2: Analogue comparison systems (First Edition 1993)

Typical Operating Times
Teleprotection Based Systems



* Can apply to intertripping (direct tripping equipment).

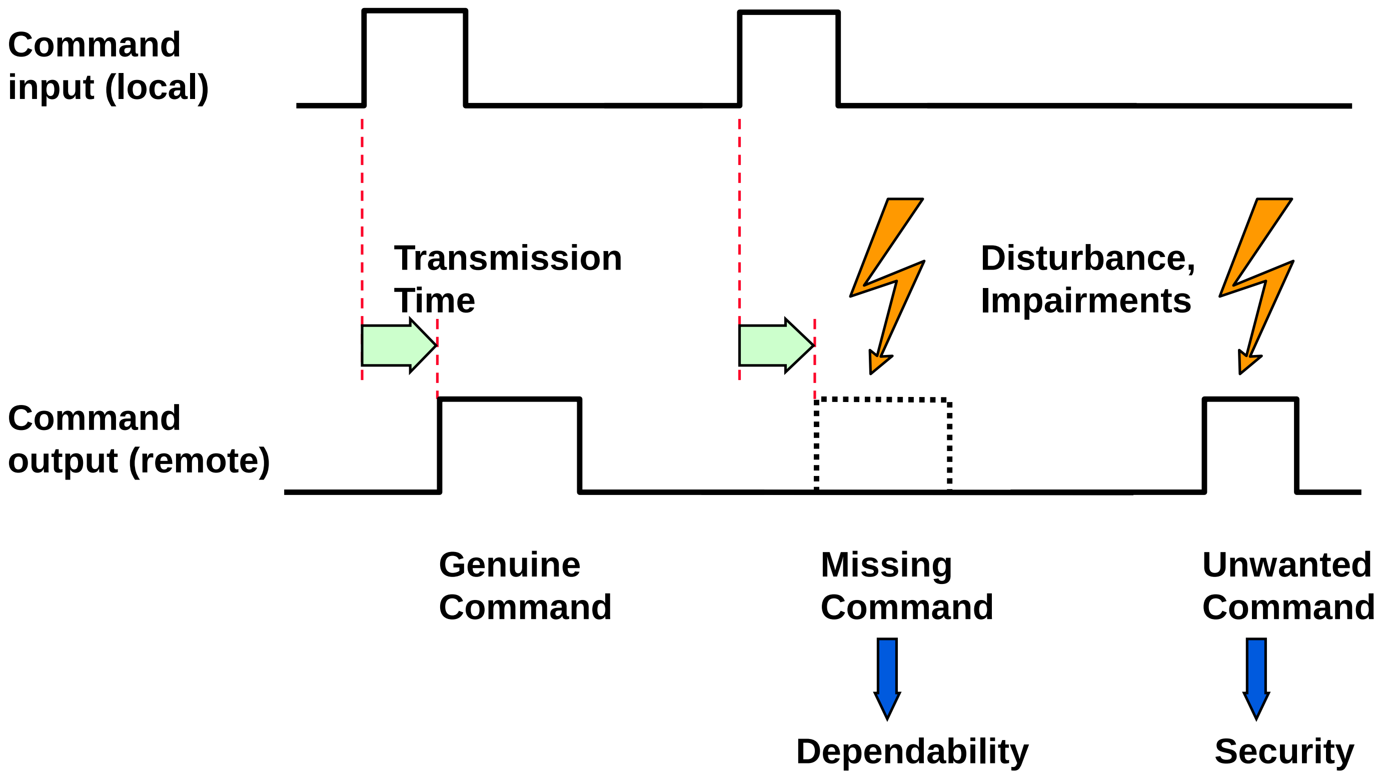
** Applies when equipment is back to back.

Source: IEC 60834-1, 2nd Edition, 1999

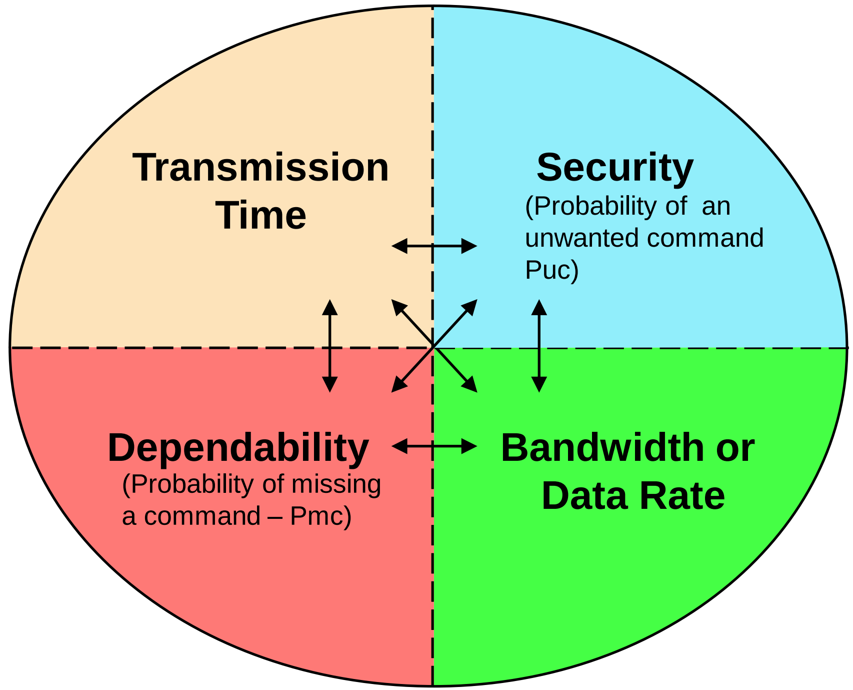
Telecommunication Channel Impairments

- ➔ Impairments resulting from interference and noise
  - Disconnector switches / breaker operation
  - 50/60 Hz harmonics (pilot cables)
  - Corona noise (PLC channels)
  - Fading (microwave channels)
  - Latency, Jitter/wander, loss of synchronism (digital networks)
  - Channel symmetry (*) (digital networks)
  - Signal interruptions
  - etc.
- ➔ Disturbed signals may cause protection equipment to maloperate

Teleprotection Command Transmission



Performance Criteria for Teleprotection



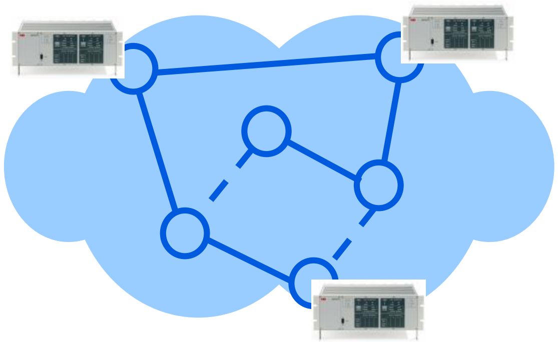
Optimization / Exchange according to application

Command Systems, Typical Figures

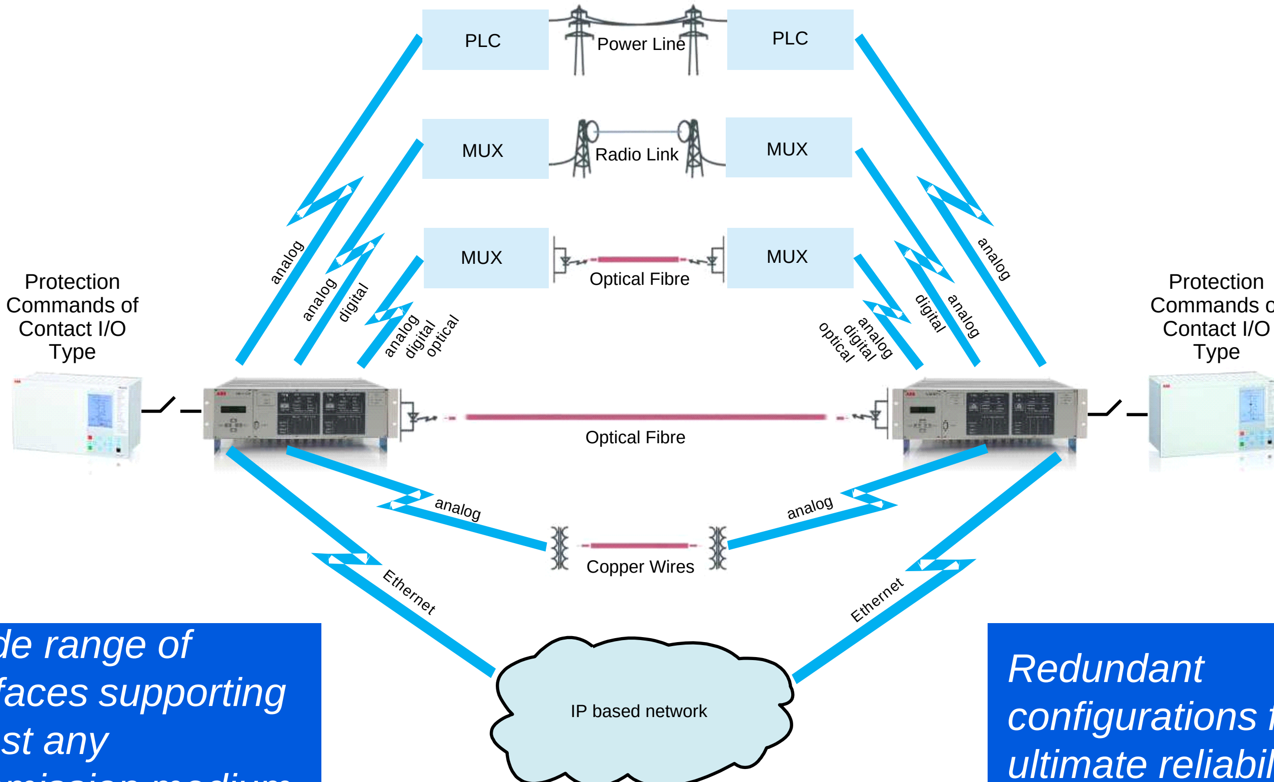
PROTECTION SCHEME		*Analog*	*Digital*
BLOCKING			
short transmission time	Tac	15 ms	10 ms
moderate security	Puc	< 1E-2	< 1E-6
high dependability	Pmc	< 1E-3	< 1E-3
PERMISSIVE TRIPPING			
moderate transmission time	Tac	20 ms	10 ms
moderate to high security	Puc	< 1E-3…< 1E-4	< 1E-6
moderate to high dependability	Pmc	< 1E-2…< 1E-3	< 1E-3
DIRECT TRIPPING			
moderate transmission time	Tac	40 ms	10 ms
very high security	Puc	< 1E-5… < 1E-6	< 1E-9
Very high dependability	Pmc	< 1E-3	< 1E-3

Teleprotection using telecom networks (WAN)
Design and Operation Considerations

- Restricted authorisation for re-routing in the WAN
- Inhibit auto-rerouting (possibility of excessive delay)
- Use (tele)protection equipment with terminal addressing facility
- Use pre-defined fixed paths for protection signalling
- Use dedicated (point-to-point) links for protection signalling



NSD570
Connection interfaces to communication channels



A wide range of interfaces supporting almost any transmission medium

Redundant configurations for ultimate reliability

NSD570 – G3LA for Analog Channels

- Up to 4 simultaneous commands
  - Individually configurable for blocking, permissive or direct tripping
- Programmable Bandwidth
  - 120 / 240 / 360 / 480 / 960 / 1200 / 2400 / 2800 Hz
- Programmable center frequencies
  - From 360 Hz to 3900 Hz in 60 Hz steps
- No need to set transmission times
  - Adaptive signal processing always ensures shortest transmission times for all applications, without compromising security
- EOC (embedded operation channel)
  - For remote monitoring/configuration and display of remote alarms
  - Operated in the guard channel - needs no additional bandwidth
- Boosting facility (command signal power boosting)
  - Internally, or externally by means of contact signaling (e.g. when connected to Power Line Carrier equipment)

NSD570 - Bandwidth and Operating Times

Nominal transmission times (acc. No. of commands)

Bandwidth	1 Single	2 Single	2 Dual	3 Dual	4 Dual
120 Hz	50 ms	-	-	-	-
240 Hz	27 ms	38 ms	43 ms	-	-
360 Hz	19 ms	26 ms	30 ms	31 ms	-
480 Hz	15 ms	20 ms	23 ms	24 ms	28 ms
960 Hz	8.5 ms	11 ms	13 ms	14 ms	15 ms
1200 Hz	7.0 ms	9.5 ms	11 ms	11 ms	12 ms
2400 Hz	4.5 ms	6.0 ms	7.0 ms	7.0 ms	7.0 ms
2800 Hz	4.5 ms	5.5 ms	6.0 ms	6.0 ms	6.5 ms

→ including operating times of the relay interface (solid state outputs), **EOC** configured to **ON**

→ command application set to **direct** tripping (except for 1 single-tone command).

Security / Dependability: complies with or exceeds IEC 60834-1

→ Puc for worst case SNR:

Security	Single Tone	Dual Tone
Blocking	1E-03	1E-04
Permissive Tripping	1E-05	1E-06
Direct Tripping	1E-08	1E-09

NSD570 – G3LD for Digital Channels

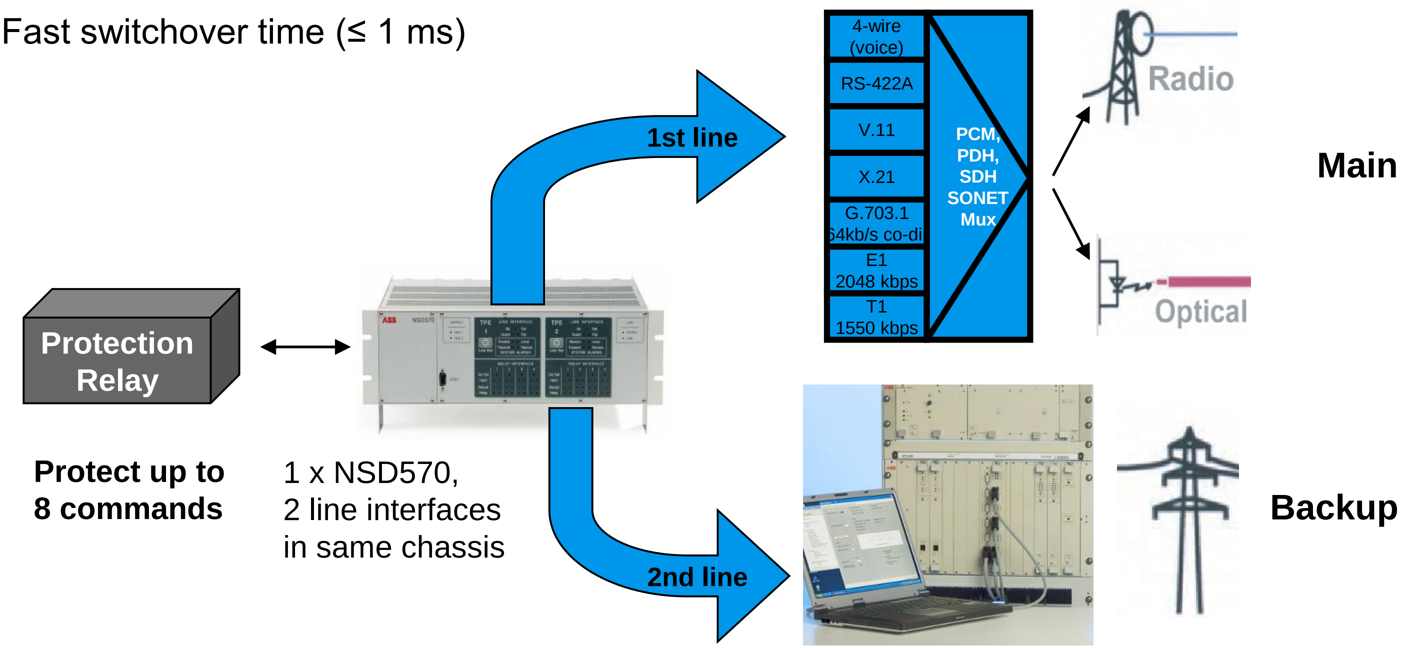
- Up to 8 simultaneous commands
  - Individually configurable for blocking, permissive or direct tripping
- Set of digital on-board line interfaces
  - 56 / 64 kbps RS-422 / V.11 / X.24, X.21, RS-530, RS-449
  - 64 kbps G.703 codirectional
- Connector for optional line interfaces
  - 2.048 Mbps E1 / 1.544 Mbps T1 for direct connection to SDH / SONET Multiplexer (G1LE)
  - Optical fiber interface for direct fiber connection and optical connection to FOX512/515 or non-ABB multiplexers supporting IEEE C37.94 (G1LOa)
- No need to set transmission times
  - Adaptive signal processing always ensures shortest transmission times for all applications, without compromising security
- EOC (embedded operation channel)
  - for remote monitoring/configuration and display of remote alarms
- Terminal addressing
  - to prevent unwanted tripping in case of accidental channel crossovers in switched or routed telecom networks

NSD570 - Digital Operation Principle

- 56, 64, 1544 or 2048 kbps data rate
- Cyclic block code (BCH) with error detection & correction capability
- Transmitted in frames of 48 bit length
- Adaptive frame evaluation
  - 2 to 6 frames for tripping
  - Nominal transmission time 4 … 6 ms
  - Actual number of frames depending on application and prevailing channel conditions (bit errors)
  - Error correction for enhanced dependability
  - Ensuring shortest transmission time without compromising security

1+1 Path Protection
Example NSD570

- Channel redundancy with two line interfaces in the same rack
  - Analog, digital/optical or mixed
  - Main / standby operating mode
  - Fast switchover time (≤ 1 ms)



Line Protection Schemes

- Current differential protection
- Phase comparison protection

- Distance protection
- High impedance earth fault protection
- Directional comparison protection

Quantitative (analogue) Information

Amplitude and/or Phase

Communication is ESSENTIAL

Binary (trip / do not trip) Information

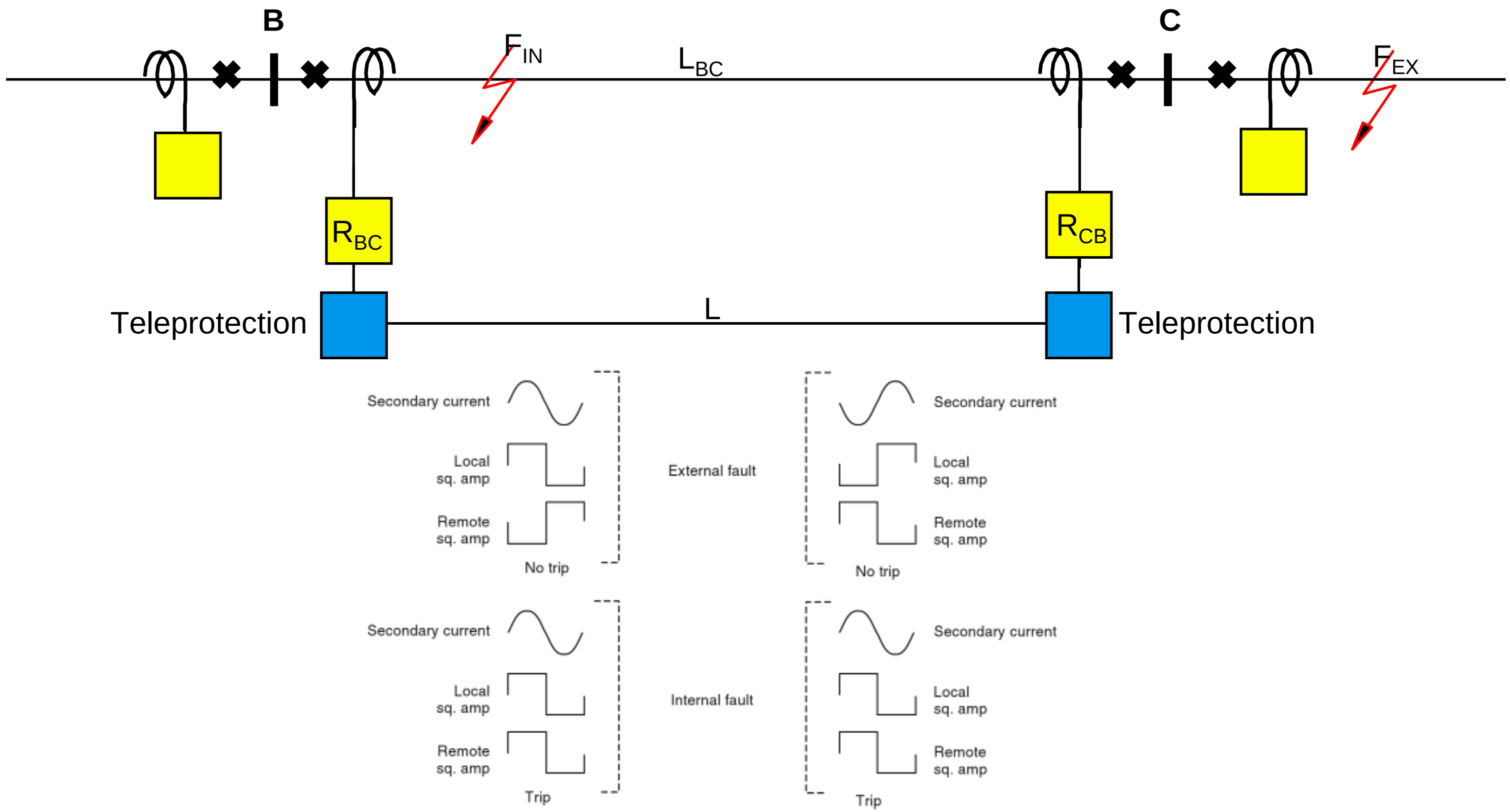
Commands for …..

BLOCKING of breaker tripping or **DIRECT** breaker tripping

PERMISSION for breaker tripping

Communication is SUPPLEMENTARY.
It helps to clear the fault <u>in the shortest possible time</u>

Phase Comparison
Power Line Protection

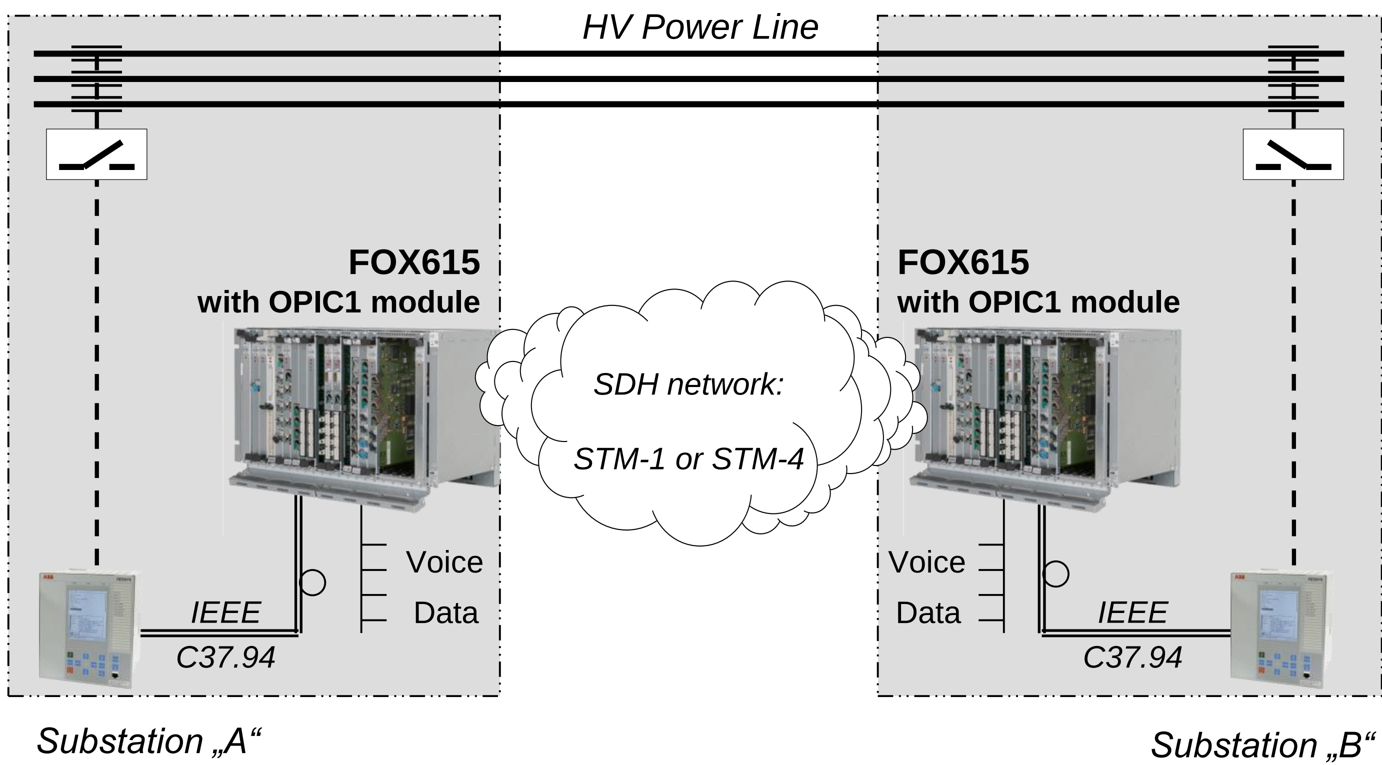


B, C	Substations	F	Line fault
L_{BC}	Protected line section	L	Communication channel
R_{BC},R_{CB}	Protection relay		

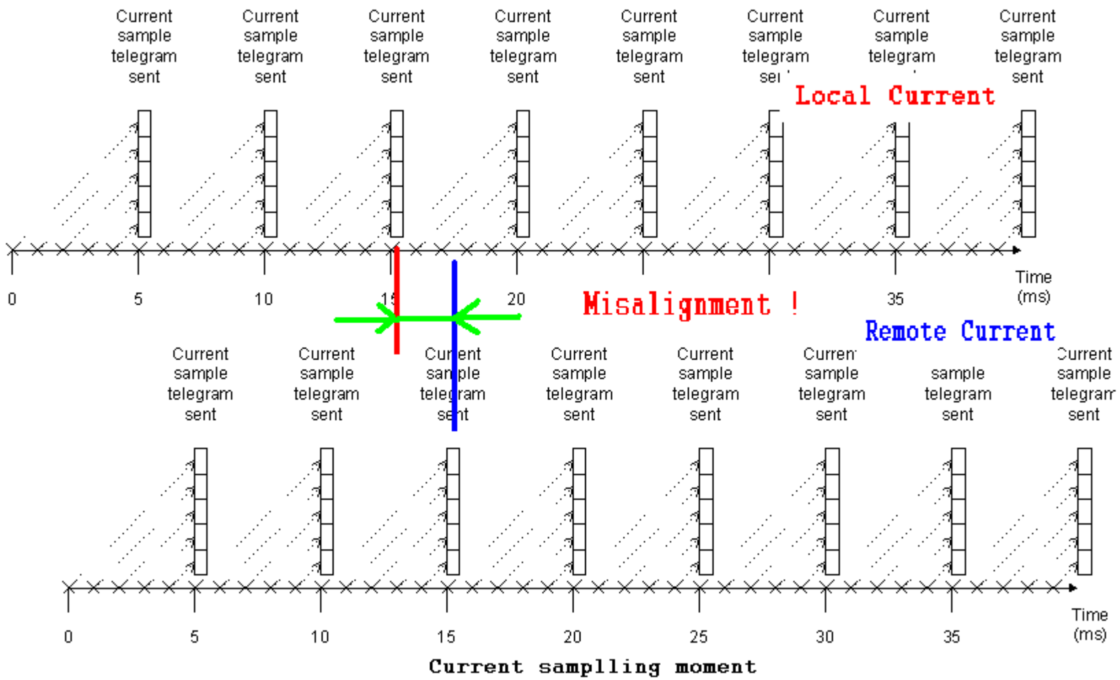
Phase Comparison
Power Line Protection

- Operate Time: Require channel time of around 8 ms. Channel delay should be constant, as excessive channel delay time will cause a phase shift in the composite current signal.
- Security: Utilize a “Blocking” philosophy, and can over trip on loss of signalHigh Dependability: Receipt of a tripping command is not required to trip the system.
- Analog Channel: Frequency shift audio tones are commonly used for this application. On/Off Powerline carrier is used for single phase comparison systems, while FSK carrier is used for dual phase comparison systems.
- Digital & Fiber Optic: Becoming more popular because of the fast channel times, and increasing availability. Channel delay could be critical if the teleprotection is applied on a switched network.

Current Differential
Power Line Protection



Line Current Differential Protection
Effect of Time Synchronization Error and Accuracy



- Sum of currents at **the same time** is equal to 0
- Sample **times differ** => incorrect calculations and operation !
- Sample **times within expected range** => min operating current defined by time synchronization accuracy

Line Current Differential Protection
Effect of Bit Errors

- Data corruptions in communication channel result in Bit Errors, and lead to discarding, i.e. loosing data
- Line current calculations can not be performed if data is not available
- Lost of one sample leads to operation delay of 1 sample period (e.g. 5ms)
- Lost of communication leads to blocking the protection scheme
- Rigorous requirements are imposed on Bit Error Rate (BER) of the communication channels used for line current differential protection
  - 10^{-12} - 10^{-9} during normal operation
  - 10^{-6} during disturbance
  - 10^{-4} channel is blocked

ANSI / IEEE C37.94-2002
Facts and Benefits

ANSI / IEEE C37.94- 2002 "IEEE Standard for N x 64 kbps Optical Fiber Interfaces Between Teleprotection and Multiplexer Equipment"

Standard for interfacing (Differential) Protection Relays and Teleprotection equipment.

- Supported by ABB's relays (e.g. RED670), teleprotection (NSD570), and multiplexers (FOX515 and FOX615).
- … and by many other suppliers too.
- 1 - 12 time slots per channel: (64 – 768 kbit/s)

Bit rate: 2,048 kbit/s, ITU-T G.703 with a dedicated framing structure

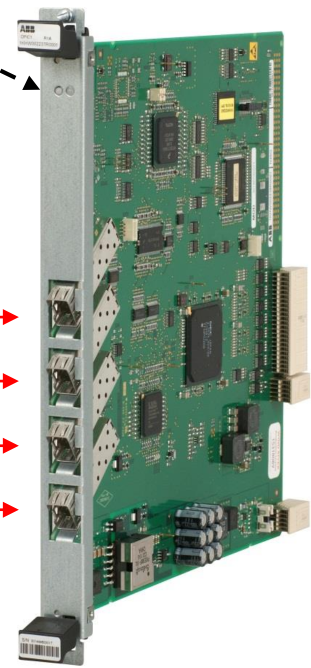
Connection media: Optical fiber, λ= 830nm, multi mode (core ϕ: 50 or 62.5 μm), ST connector. Optical budget: aprox. 2 km.
Note: Several manufacturers also support single mode fiber with SFP.

Benefits: This standardization offers

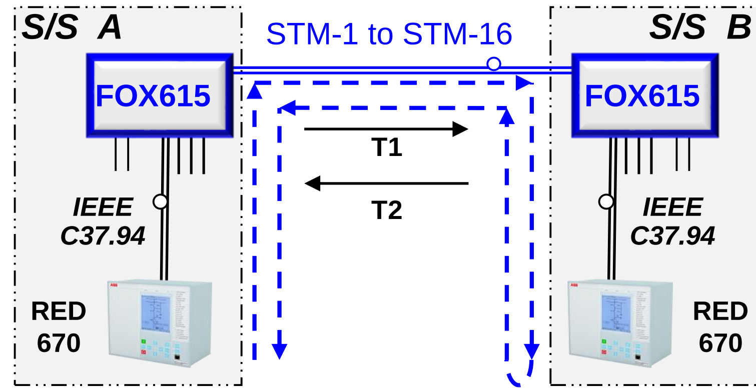
- Simple and secure interconnections
- Interoperability between relay and communication equipment (LOS)

Example FOX615
OPIC1: Differential Protection Interface

LED indication:
Status, alarms



4 x IEEE C37.94
with SFP cages



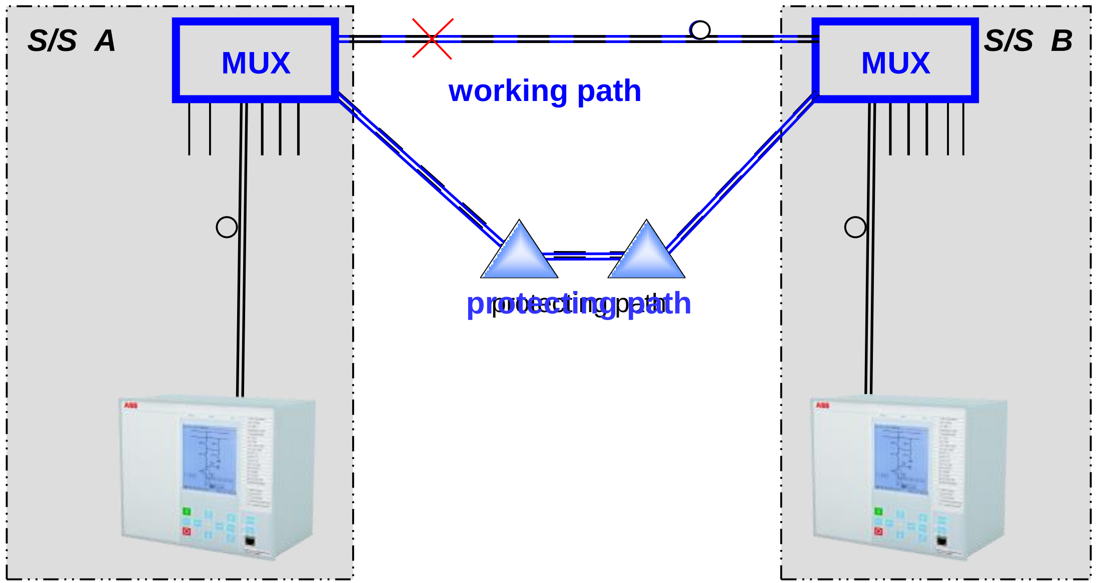
RED670 with Echo Timing:

$$\textbf{Transmission Delay Td} = \frac{(T1 + T2)}{2}$$

Time compensation for Td: Up to 20 ms

Delay measurement (loop): Every 5 ms

FOX615: Technical information
OPIC1: Differential Protection Interface



To avoid false tripping after switchover from working to protecting path protection services require:
Bi-Directional (symmetrical) switching of receive and transmit path

IEC 61850
From intra-substation to inter-substations

- IEC 61850 was initiated as information exchange between substation automation devices
- Becoming the foundation for a globally standardized utility communication network
- Its concept is being extended to other utility power system application domains
- It offers the basic features but must be extended to properly address new domains
- IEC/TR 61850-90-1 addresses information exchange between substations
- New domain specific parts being added (e.g. substations-to-control centers, wide-area RAS)

IEC/TR 61850-90-1
Information exchange between substations

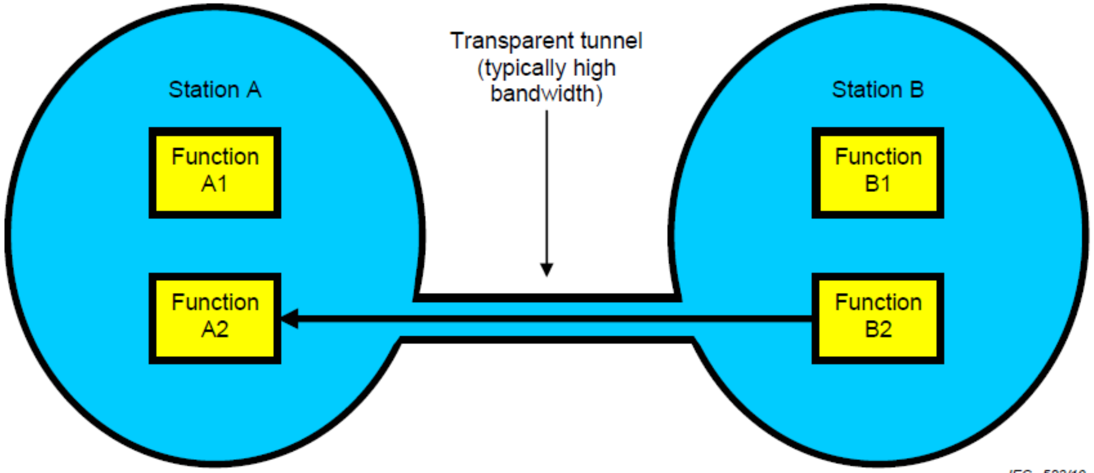
- IEC 61850 concept is based on a local (high bandwidth) Ethernet network
- IEC/TR 61850-90-1 defines
  - use cases and how they can be modeled with IEC 61850:
    - Protection (21, 87L, 87P, direct tripping)
    - Interlocking
    - Reclosing
    - Other applications (FL, SIPS, GenShed, RAS, etc)
  - communications requirements and guidelines for communications services and architecture
  - data for interoperability

IEC/TR 61850-90-1
Substation-substation communications

- Implementation of integrated utility networks will gradually provide **high bandwidth** channels between substations
- Currently in many cases only **low bandwidth** traditional protection communications are available (PLC or PDH) which is a restriction that must be taken into consideration
- Communication mechanisms:
  - Tunneling
  - Gateway
- Modeling introduces Logical Nodes:
  - ITPC “Teleprotection Communication Interface”
  - RMXU “Differential Measurements”

Tunneling
Communication mechanisms

- Method to connect multiple substation networks (by means of switches and routers) that allows direct access to functions in remote stations.
- Configured for a specific type of traffic (e.g. based on a VLAN ID):
  - TCP/IP (Client /Server communication)
  - Multicast messages on Ethernet layer 2 (GOOSE and SV)



Source: IEC/TR 61850-90-1 Ed. 1.0 2010-03
Communication networks and systems for power utility automation – Part 90-1: Use of IEC 61850 for the communication between substations

Gateway ('proxy' approach)
Communication mechanisms

- Method to connect multiple substation networks (by means of specific teleprotection equipment) that allow <u>indirect access</u> to functions in remote stations
- Used if link between substations <u>does not fully</u> support Ethernet communications
- Configured for a specific communication configuration

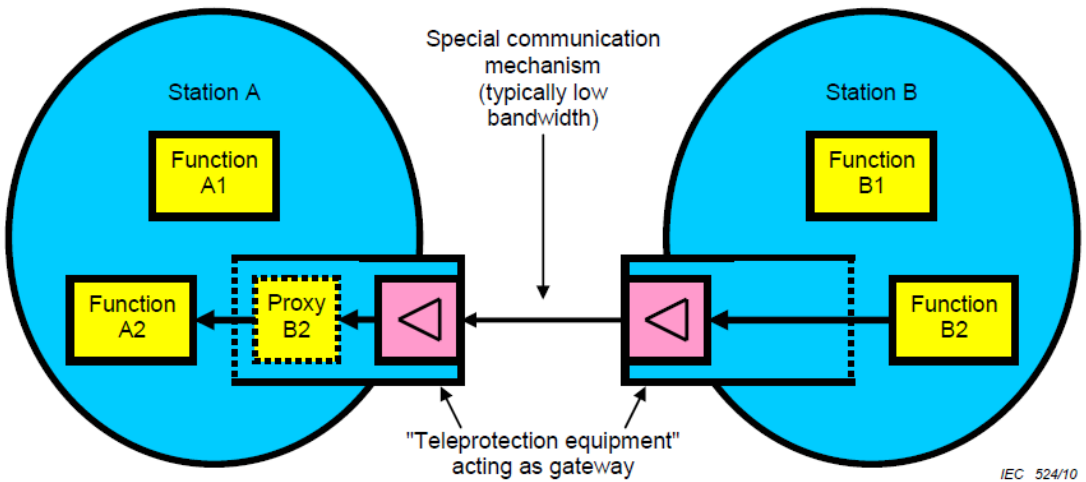


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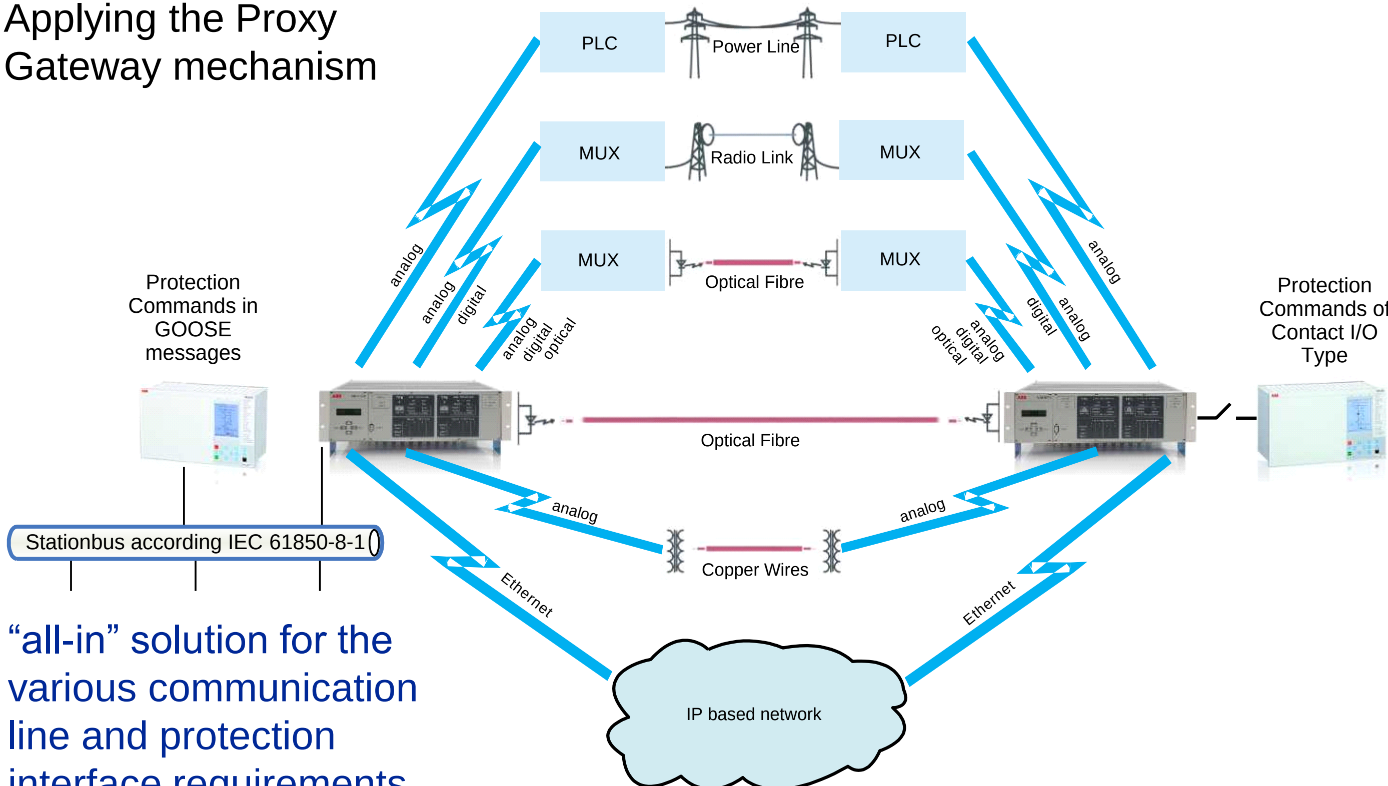
ABB NSD570 - GOOSE LAN Interface
IEC 61850-substation to "legacy"-substation

Applying the Proxy Gateway mechanism



"all-in" solution for the various communication line and protection interface requirements

Requirements for utility communication
EMC/ EMI

Substation environment faces:

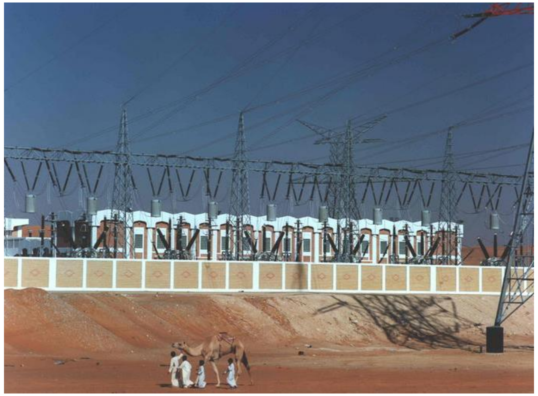
- Very high voltage levels
- Very high current levels (specially in case of short circuit)

→ Strong electrical- & magnetic fields

- Utility communication equipment must withstand this stress without any influence on communication
- IEEE 1613 defines EMC/ EMI requirements for substation environment

Requirements for utility communication
Environmental conditions

- Utility communication equipment will be installed in locations with enhanced environmental requirements
- Proper air conditioning might not always be the case



- Utility Communication equipment must be designed for enhanced temperature range and provide reliable communication services even under very high or low temperatures

Requirements for utility communication
Life time cycle

- Equipment in substation/ utility environment will be operating much longer in comparison to public telecom networks
- Very high MTBF of the equipment required to guarantee correct operations over total life cycle
- Long time availability of spare parts & extension material required

Requirements for utility communication
Redundancy requirements

- Utility communication networks transmit mission critical signals. If service can not be provided there is a potential risk for
  - Blackouts in wide areas of the electrical grid
  - Potential damage in case of missing Teleprotection commands

- Therefore utility networks usually provide redundancy on different levels
  - Hardware redundancy
  - Traffic protection using diverse path for signal transmission

Line Protection Schemes

- Current differential protection
- Phase comparison protection

- Distance protection
- High impedance earth fault protection
- Directional comparison protection

Quantitative (analogue) Information

Amplitude and/or Phase

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- **RTU 500 Series** – Proven, powerful and open architecture
- **MicroSCADA** - Advanced control and applications
- **Tropos** – Secure, robust, high speed wireless solutions

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Thank you for your participation

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