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.
ABB is pleased to provide you with technical information regarding protective relays. The material included is not intended to be a complete presentation of all potential problems and solutions related to this topic. The content is generic and may not be applicable for circumstances or equipment at any specific facility. By participating in ABB's web-based Protective Relay School, you agree that ABB is providing this information to you on an informational basis only and makes no warranties, representations or guarantees as to the efficacy or commercial utility of the information for any specific application or purpose, and ABB is not responsible for any action taken in reliance on the information contained herein. ABB consultants and service representatives are available to study specific operations and make recommendations on improving safety, efficiency and profitability. Contact an ABB sales representative for further information.
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

Substation A

Protection Relay → Tele-protection Equipment

HV-line

Physical Link

Tele-protection Equipment → Protection Relay

Substation B

Telecommunication System

Teleprotection System

Protection System
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

**Binary (trip / do not trip) Information**
- BLOCKING of breaker tripping or DIRECT breaker tripping
- PERMISSION for breaker tripping

**Communication is ESSENTIAL**
Communication is SUPPLEMENTARY. It helps to clear the fault in the shortest possible time
Distance Protection

Typical stepped distance/time characteristics

A, B, C

Protection Relay

Stations

Operating Times,

R_{AB}, R_{BA}, R_{BC}, R_{Cx}

Operating Times,

T_{AB1}, T_{AB2}, T_{AB3}

T_{BC1}, T_{BC2}, T_{BC3}

A

B

C

REV. ZONE

ZONE 1

ZONE 2

ZONE 3

Operating Time

Distance
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

Teleprotection

B, C Substations
L_{BC} Protected line section
R_{BC}, R_{CB} Protection relay
BC_{Z1}, CB_{Z1} Zone 1 reach (e.g. 130% of line section)

F Line fault
L Communication channel
BC_{OR} \iff CS_{B} Trip_{C}: CB_{Z1} + CR_{C} \land CB_{Z2} + T_{2}
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

Slide 13

© ABB Nov. 2013

Teleprotection

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: BC_{Z1} + CR_{B}

ABB
• 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
L_{BC}
R_{BC}, R_{CB}

Substations
Protected line section
Protection relay

F
Line fault
L
Communication channel
R_{BC} \Rightarrow C_S, Trip_C: C_{RC}
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

which refers (among others) to:

**ITU-T G.823**

which refers (among others) to:

**IEC 60834-2**

IEC standards:


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

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

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

Command input (local)

Transmission Time

Command output (remote)

Genuine Command

Missing Command

Unwanted Command

Dependability

Security

Disturbance, Impairments
Performance Criteria for Teleprotection

- **Transmission Time**
- **Security** (Probability of an unwanted command $P_{uc}$)
- **Dependability** (Probability of missing a command – $P_{mc}$)
- **Bandwidth or Data Rate**

Optimization / Exchange according to application
## Command Systems, Typical Figures

<table>
<thead>
<tr>
<th>PROTECTION SCHEME</th>
<th>Analog</th>
<th>Digital</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BLOCKING</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>short transmission time</td>
<td>Tac 15 ms</td>
<td>10 ms</td>
</tr>
<tr>
<td>moderate security</td>
<td>Puc &lt; 1E-2</td>
<td>&lt; 1E-6</td>
</tr>
<tr>
<td>high dependability</td>
<td>Pmc &lt; 1E-3</td>
<td>&lt; 1E-3</td>
</tr>
<tr>
<td><strong>PERMISSIVE TRIPPING</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>moderate transmission time</td>
<td>Tac 20 ms</td>
<td>10 ms</td>
</tr>
<tr>
<td>moderate to high security</td>
<td>Puc &lt; 1E-3…&lt; 1E-4</td>
<td>&lt; 1E-6</td>
</tr>
<tr>
<td>moderate to high dependability</td>
<td>Pmc &lt; 1E-2…&lt; 1E-3</td>
<td>&lt; 1E-3</td>
</tr>
<tr>
<td><strong>DIRECT TRIPPING</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>moderate transmission time</td>
<td>Tac 40 ms</td>
<td>10 ms</td>
</tr>
<tr>
<td>very high security</td>
<td>Puc &lt; 1E-5…&lt; 1E-6</td>
<td>&lt; 1E-9</td>
</tr>
<tr>
<td>Very high dependability</td>
<td>Pmc &lt; 1E-3</td>
<td>&lt; 1E-3</td>
</tr>
</tbody>
</table>
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)

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

→ 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:

<table>
<thead>
<tr>
<th>Security</th>
<th>Single Tone</th>
<th>Dual Tone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocking</td>
<td>1E-03</td>
<td>1E-04</td>
</tr>
<tr>
<td>Permissive Tripping</td>
<td>1E-05</td>
<td>1E-06</td>
</tr>
<tr>
<td>Direct Tripping</td>
<td>1E-08</td>
<td>1E-09</td>
</tr>
</tbody>
</table>
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

BLOCKING of breaker tripping or DIRECT breaker tripping

PERMISSION for breaker tripping

Communication is SUPPLEMENTARY. It helps to clear the fault in the shortest possible time
Phase Comparison
Power Line Protection

Teleprotection

B, C
L_{BC}
R_{BC}, R_{CB}

Substations
Protected line section
Protection relay

F
L
Line fault
Communication channel
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 signal.

- 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

HV Power Line

FOX615 with OPIC1 module
IEEE C37.94

SDH network:
STM-1 or STM-4

Substation „A“

FOX615 with OPIC1 module
IEEE C37.94

Voice
Data

Substation „B“
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
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 “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

Transmission Delay $T_d = \frac{T_1 + T_2}{2}$

Time compensation for $T_d$: Up to 20 ms

Delay measurement (loop): Every 5 ms
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
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 **indirect access** to functions in remote stations
- Used if link between substations **does not fully** support Ethernet communications
- Configured for a specific communication configuration

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
ABB NSD570 - GOOSE LAN Interface
IEC 61850-substation to “legacy”-substation

Applying the Proxy Gateway mechanism

Protection Commands in GOOSE messages

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

Stationbus according IEC 61850-8-1

Protection Commands of Contact I/O Type

IP based network

© ABB Inc.
November 6, 2014 | Slide 45
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

Communication is ESSENTIAL

Binary (trip / do not trip) Information

- Blocking of breaker tripping
- Direct breaker tripping

Communication is SUPPLEMENTARY. It helps to clear the fault in the shortest possible time
This webinar brought to you by:

ABB Power Systems Automation and Communication

- **Relion Series Relays** – Advanced flexible platform for protection and control
- **RTU 500 Series** – Proven, powerful and open architecture
- **MicroSCADA** - Advanced control and applications
- **Tropos** – Secure, robust, high speed wireless solutions

*We combine innovative, flexible and open products with engineering and project services to help our customers address their challenges.*
Thank you for your participation

Shortly, you will receive a link to an archive of this presentation.
To view a schedule of remaining webinars in this series, or for more information on ABB’s protection and control solutions, visit:

www.abb.com/relion
Power and productivity for a better world™