Interoperability of Line Differential Protection

The 74st Annual Conference for Protective Relay Engineers

Interoperability of Line differential protection

Substation A, owned by company X

Substation B, owned by company Y

Line differential Protection A —— **Line differential Protection B**

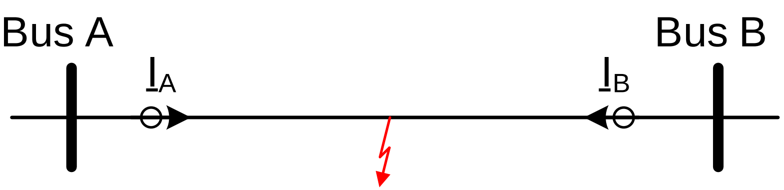
- Line differential protection requires both devices to be from the same manufacturer
- Often the same device type or even the same firmware version is required!

Basic principle of line current differential protection

- Line current differential protection is based on Kirchhoff's current law:

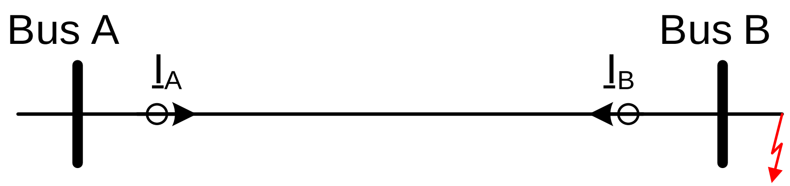
$$\sum_{k=1}^{n} I_k = 0$$

Internal Fault



$\Delta \underline{I} = \underline{I}_A + \underline{I}_B \gg 0$

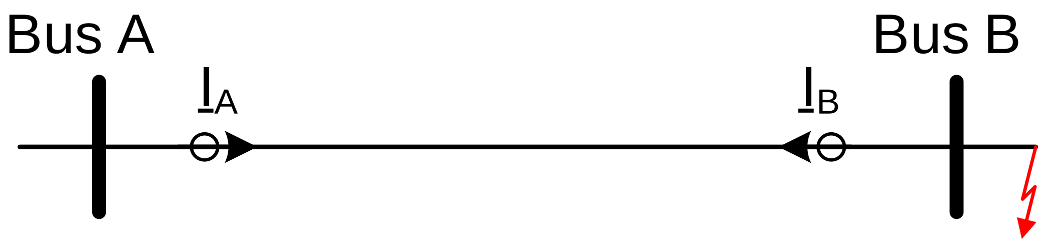
External Fault



$\Delta \underline{I} = \underline{I}_A + \underline{I}_B \approx 0 \quad (\underline{I}_A \approx -\underline{I}_B)$

- Due to this operating principle line differential protection is strictly selective to clear faults on the protected line
- In real operation technical problems need to be solved because primary currents can not be compared as easy as shown in the figures above…

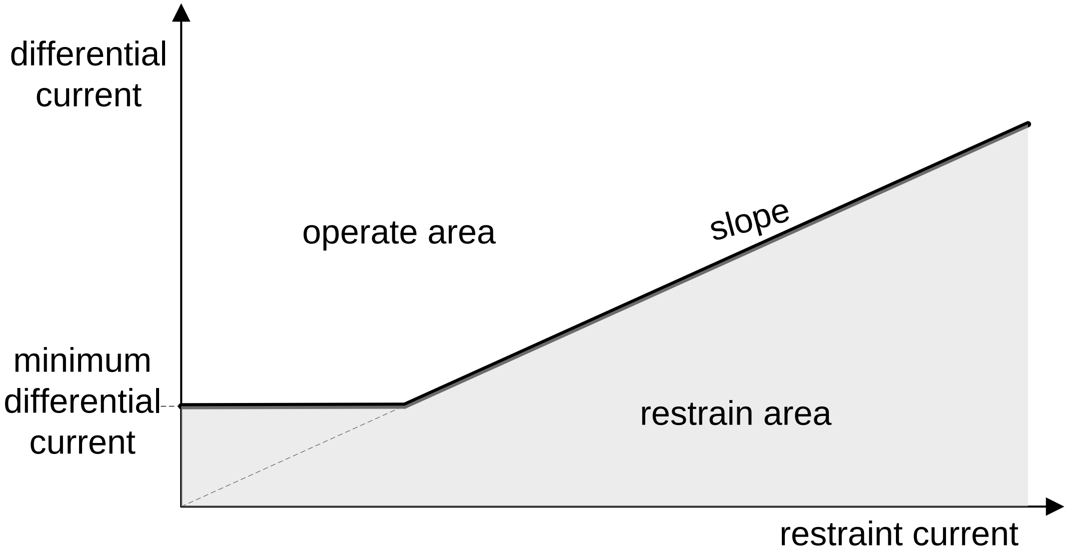
Factors influencing differential current in practical applications



$$\Delta\underline{I} = \underline{I}_A + \underline{I}_B \approx 0 \quad (\underline{I}_A \approx -\underline{I}_B)$$

- Primary system (charging currents, tapped loads)
- Current transformers (measurement inaccuracy, CT-saturation, broken wire)
- Measurement pre-processing (AD conversion, filtering)
- Time synchronization

Typical trip characteristic of line differential protection



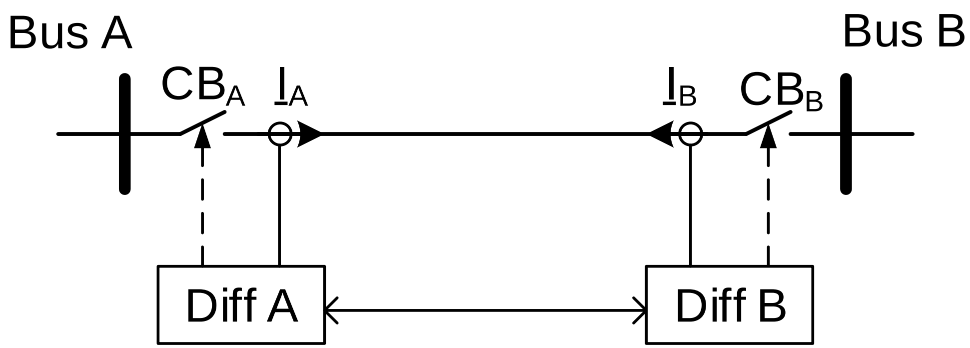
- the operating quantity I_{diff} is equal to the magnitude of the sum of all currents flowing into the protected zone

$$I_{diff} = \left| \sum_{k=1}^{n} i_k \right|$$

- a restraint current I_{res} is created and a trip command is only given if the differential current exceeds a minimum differential current setting and a certain portion of the restraint current like shown in the figure

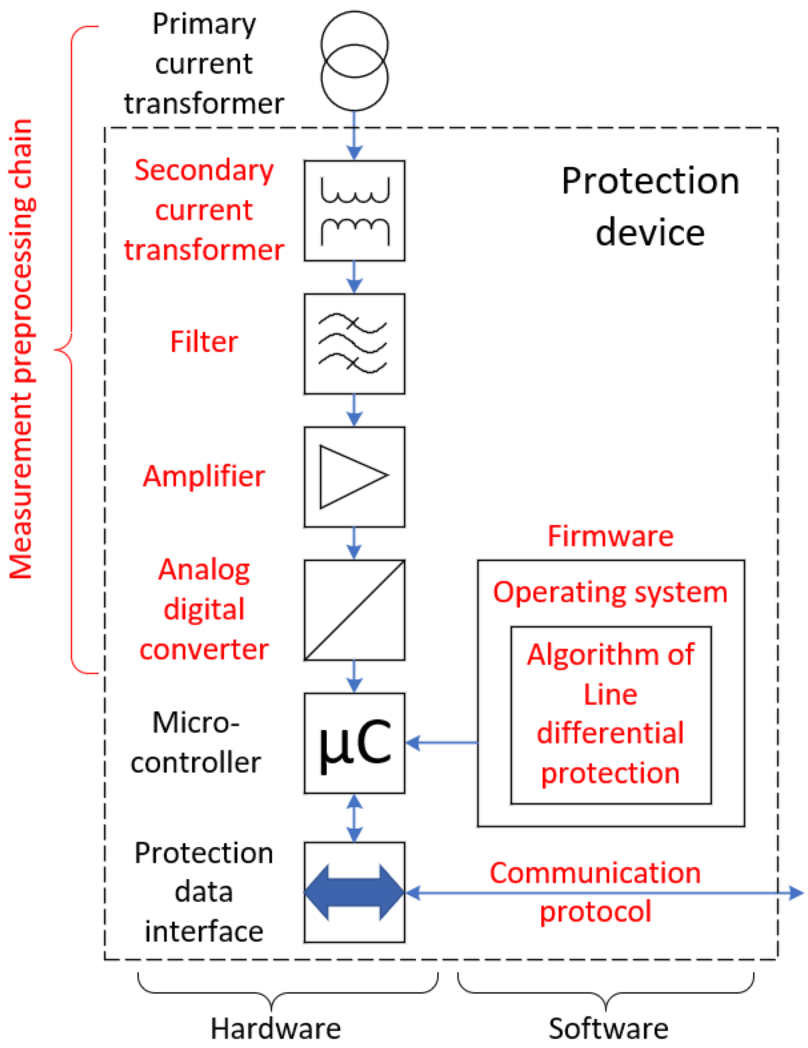
$$I_{res} = \sum_{k=1}^{n} \left| i_k \right|$$

Basic principle of a digital line differential protection



- A line differential scheme requires separate devices for each end of the protected line
- The line differential protection algorithm can run in both devices (Multi master mode) or in one device only (Master slave mode)
- A communication link between both devices is necessary to transmit the current measurements and additional binary information
- Due to this composition of the function a line differential protection scheme in general requires devices of same type delivered by the same manufacturer and often even having the same firmware version

Interoperability problems: Measurement pre-processing



- Any difference introduced into the current measurements appears as a differential current
- The entire measurement chain including primary current transformer, secondary current transformer, filtering, amplification, A/D conversion and time stamping needs to be considered for interoperability of line differential protection
- Primary CT: often suggested to use same CT-type on both ends
- For interoperability also the secondary measuring chain need to be standardized

Interoperability Problems:
Algorithm --- Communication

Algorithm:

- Phase comparison is a method optimized for low bandwidth requirements
- Different techniques using current phasors are very sensitive but not extremely fast
- Different techniques based on sampled measured values for faster tripping time

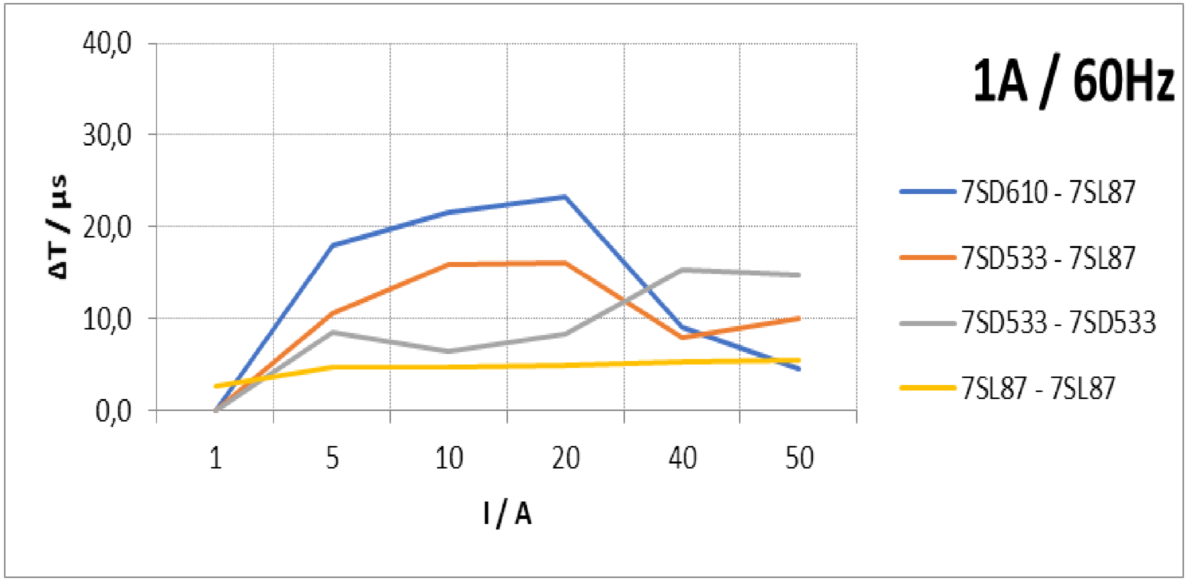
Communication:

- Communication protocol for line differential protection is not standardized
- Optimized for low bandwidth requirements and high performance for the specific algorithm
- Proprietary communication protocols which are tight knit with the implemented line differential protection algorithm

Interoperability of line differential protection between SIPROTEC 4 and SIPROTEC 5

- SIEMENS delivered more than 100,000 line differential relays SIPROTEC 4
- 2012 SIEMENS launched a line differential relay based on SIPROTEC 5
- SIPROTEC 5 uses in general the same method for line differential protection
- In detail however there are some improvements of the algorithm
- Hardware and measurement pre-processing was designed completely different
- there was a pressure from the market to gain interoperability between line differential protection devices based on SIPROTEC 4 and SIPROTEC 5
- Customers which are planning to upgrade their system substation by substation or customers owning only one substation of a line differential scheme asked for an interoperability between SIPROTEC 4 and SIPROTEC 5
- Interoperability would allow to change only one device of the scheme
- Finally, an interoperability mode was implemented into the line differential protection relay SIPROTEC 5

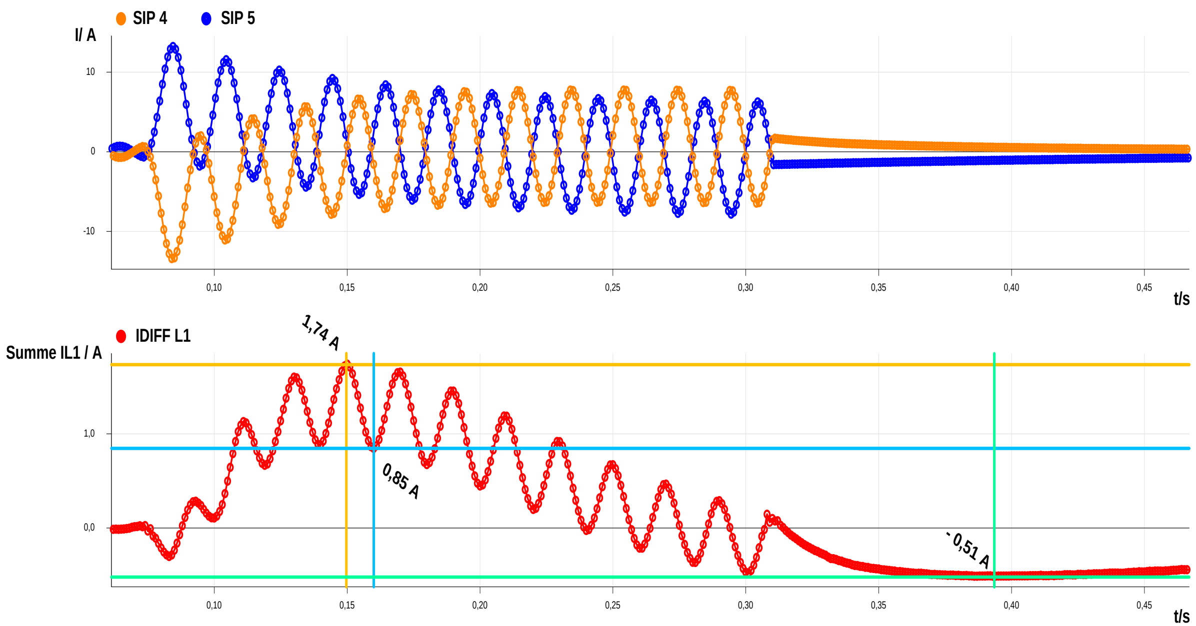
Interoperability SIPROTEC 4 and SIPROTEC 5
Measurement pre-processing



The Figure shows the remaining phase shift or time base offset between the measured currents of two devices for different current values at nominal current of 1A

- The measurement pre-processing chains in both product families are different:
  Secondary CT, A/D converter, frequency response of filters and the pre-processing time are different
- Knowing the transfer function of the measurement chain in SIPROTEC 4 a compensation for the current phasors was implemented in SIPROTEC 5 line differential protection

Interoperability SIPROTEC 4 and SIPROTEC 5
Measurement pre-processing



The figure shows the differential current for an external fault with a large DC offset based on current samples

- Different time constants of secondary CT in SIPROTEC 4 and SIPROTEC 5 cause a remarkable differential current especially for algorithm based on current samples
- Effects of different measurement pre-processing cannot be corrected completely
- SIEMENS recommends increasing the slope of the restrain characteristic of the line differential protection function according to the primary CT class

Interoperability SIPROTEC 4 and SIPROTEC 5
Algorithm – Communication – Firmware version

Algorithm:

- SIPROTEC 5 and SIPROTEC 4 use same methods of line differential protection
- There are functionalities in the SIPROTEC 5 line differential protection which are not available in the SIPROTEC 4 line differential protection and vice versa

Communication:

- Communication protocol of the line differential protection in SIPROTEC 5 was enhanced to support new functionality only available in SIPROTEC 5
- To reach interoperability a special mode was implemented in SIPROTEC 5 which supports the interoperability to SIPROTEC 4

Firmware:

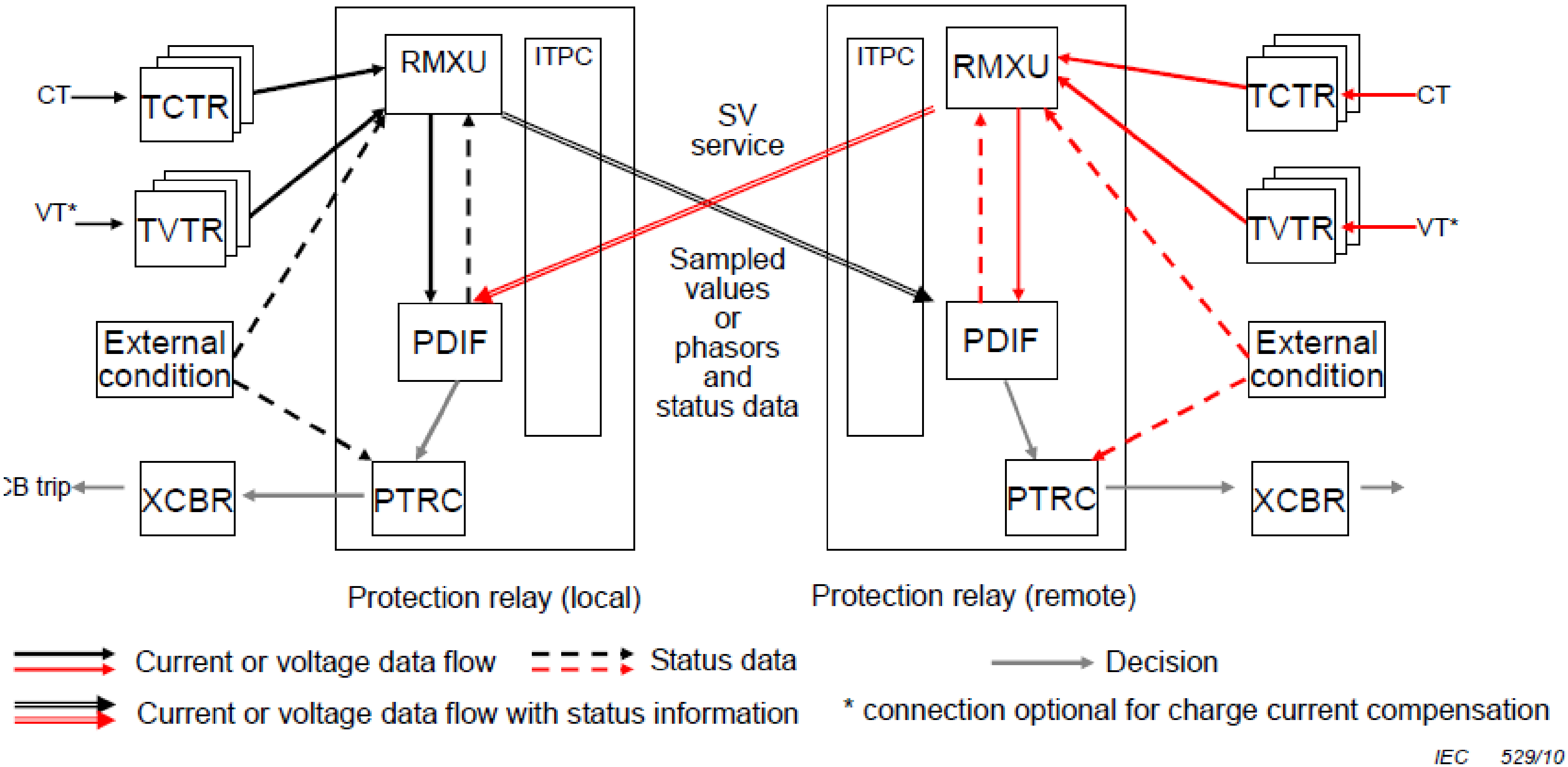
- During the start-up both devices exchange their firmware versions
- If both versions are interoperable, the functional behaviour of the local device can be switched according to the firmware version of the remote device

Evaluation of existing standards regarding interoperability of line differential protection

	IEEE C37.118	SMV according to IEC 61850 and IEC 61869
Measurement quantity	phasors	sampled measured values
Measurement accuracy	1% total vector error	Accuracy classes
Reporting rates	up to 60 Hz	4800 Hz
timing accuracy	≈1us	1us
Measurement reference	primary value in A	primary value in A

- Measurement pre-processing and communication protocols have the greatest impact to the interoperability of line differential protection
- Today there is no standardization for measurement pre-processing and communication protocol of line differential protection
- Table above shows an evaluation of two existing standards regarding their usage in line differential schemes
- SMV gives more flexibility to the implementation of a line differential scheme

2-terminal current differential feeder protection relay model according to IEC 61850-90-1

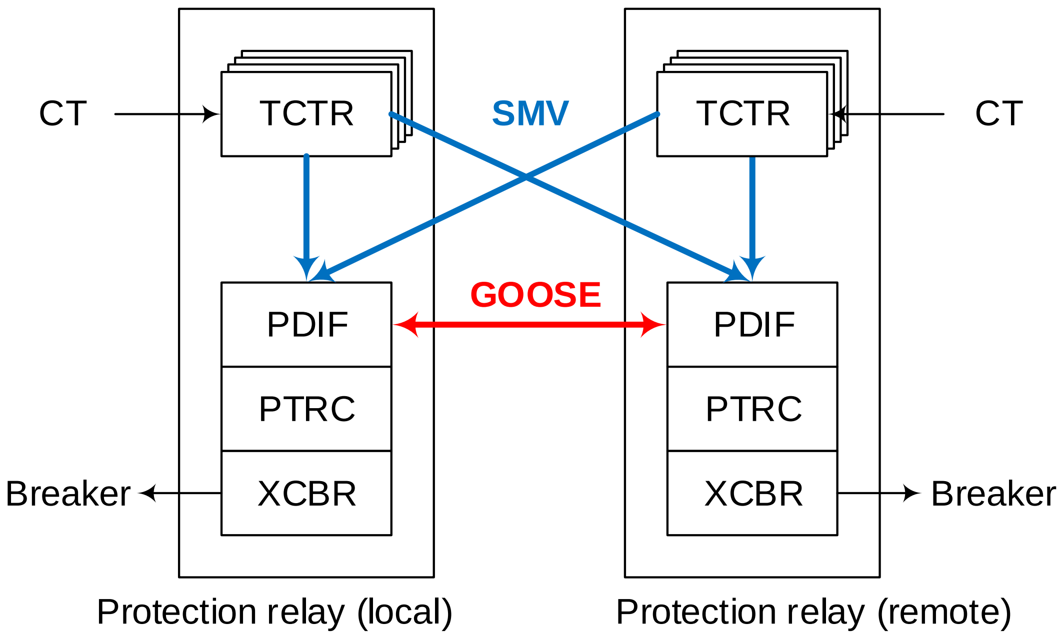


- excellent model to explain all existing implementations of line differential protection relays by terms of IEC 61850
- inappropriate model to reach interoperability

How to achieve an interoperable interface

- Regarding interoperability there is only one interface between both devices
- The logical node RMXU in one relay is sending data to the logical node PDIF in the relay at the remote end
- RMXU provides phasors **or** samples representing the local current values
- RMXU on both sides of the line represents also the function to synchronize the samples or phasors
- Sampled measured values are more flexible than phasors for the implementation of a line differential scheme
- All known algorithm of line differential protection can be chosen according to protection requirements like sensitivity or trip time
- Using only sampled measured values the logical node RMXU can be replaced by logical nodes TCTR which are already delivering synchronized sampled measured values according to IEC 61850-9-2 and IEC 61869-9

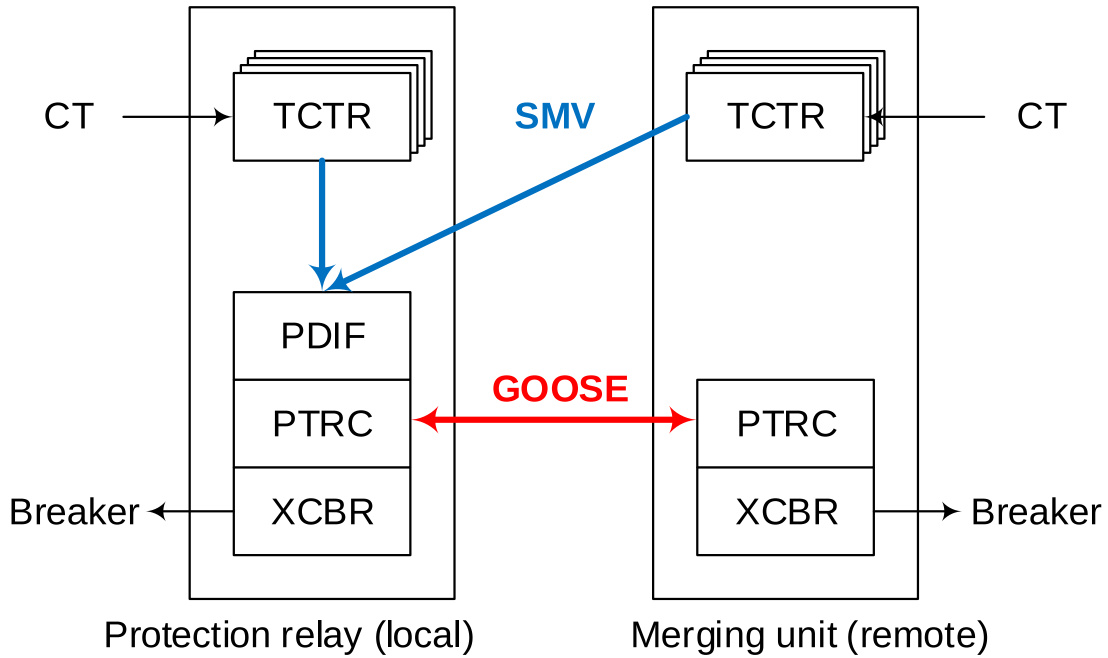
Interoperable line differential protection scheme using two similar devices



Interoperability is achieved by using only **sampled measured values** and **GOOSE** as standardized interface between both devices

- TCTR are delivering synchronized SMV to the local and remote PDIF
- Based on these SMV the algorithm of line differential protection is running in the local and remote relay in parallel
- In case of an internal fault PDIF will send an operate signal which is converted to a trip command by the logical nodes PTRC and XCBR

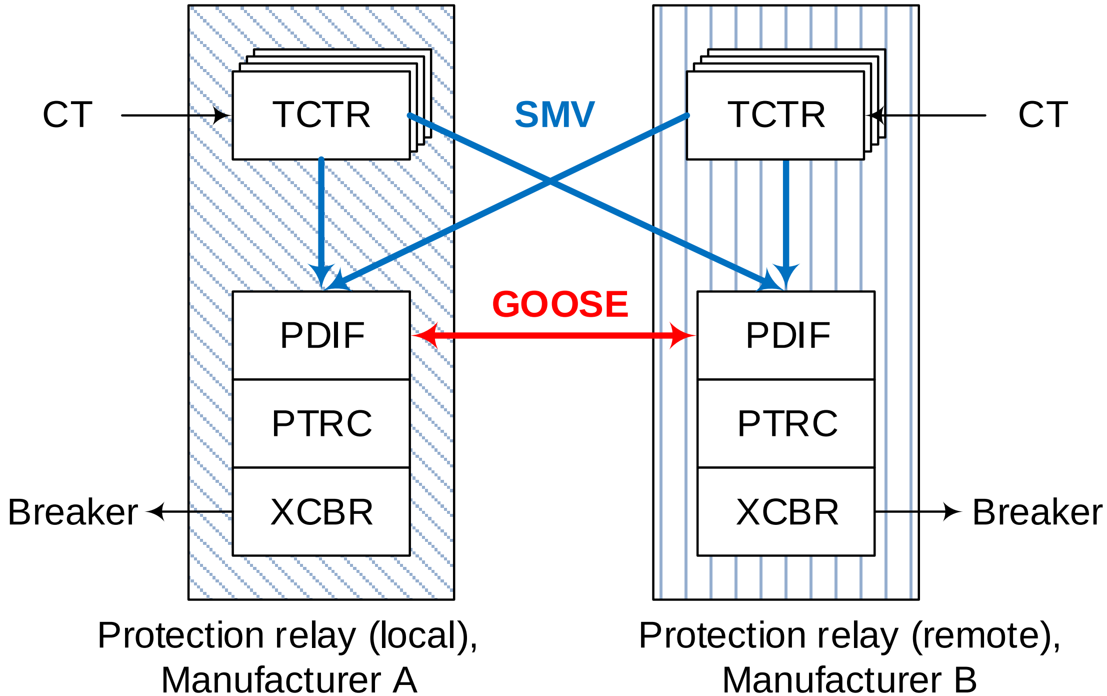
Interoperable line differential protection scheme using one line differential protection relay only and a merging unit



In general, it is not necessary to run the same algorithm of line differential protection with the same data in both devices

- In this scheme the line differential relay is receiving SMV from a merging unit located at the remote end
- The trip command for the remote end might be transferred back via GOOSE to the merging unit located at the remote end

Interoperable line differential protection scheme using two line differential protection relays from different manufacturers



For redundancy even two different line differential protection relays could be used feeding each other with the sampled measured values from the remote end…

- Different algorithms can run in the relays at local and remote end:
- Sensitive current differential algorithm + fast phase comparison algorithm
- A trip command for the breaker could be given if any algorithm gives an operate or only if both algorithms give an operate signal

Communication aspects

- The available bandwidth of communication systems is increasing permanently
- It becomes possible to transmit sampled values in real time via great distances
- Communication problems like data packet loss, switching of the used communication path or long response times can occur / need to be considered
- Communication problems are not related to the interface between the line differential relays
- These problems also occur, if a line differential protection scheme is using a proprietary communication interface via a switched network
- If data packets are lost or delayed, the line differential protection must react in a specific manner

Time synchronization

- Synchronization of the current measurement is utmost important for the function of line differential protection
- Today synchronization is done by proprietary methods based on the so-called ping-pong method via the proprietary protection data communication
- In the proposed solution the function of time synchronization is taken over by standardized solutions based on IEEE1588

Conclusion

- Interoperability is important for line differential protection
- It was shown that later implementation of interoperability into existing relays is possible but with certain restrictions
- For future applications it was suggested and explained to achieve interoperability of line differential protection by using sampled measured values and GOOSE

Thank you for your attention!

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