Data models and protocol mapping for high sampling rate protection applications in digital substations

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Outline

1. Research problem
2. Research hypothesis
3. Data models and protocol mapping
4. Results of communication load estimation
5. Conclusion and future work

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Research problem

Impact of converter-dominated power systems on protection systems

Reduced system inertia

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$$t_{cc} = \sqrt{\frac{2M}{P_m}(\delta_{cc} - \delta_s^{pre})}$$

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Requires **faster** protection systems

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$$I_{sc} = \frac{S_{sc}}{\sqrt{3}U}$$

Requires more **sensitive** protection systems

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Need for transient-based protection functions with high sampling rates

Research problem

Impact of digital substations in power systems on protection systems

Sampled Value based
process-level networks
replace secondary circuits

High degree of
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Impact of digital substations in power systems on protection systems

Sampled Value based process-level networks replace secondary circuits

High degree of functional integrated protection IEDs

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High communication load

High computational burden

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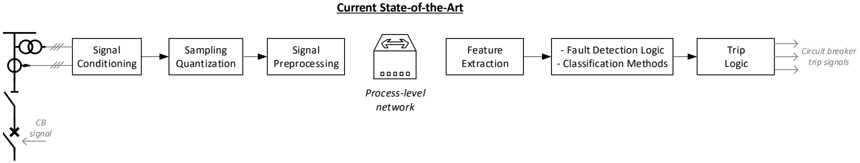
Need for transient-based protection functions with high sampling rates

Research problem and research question

Signal processing chain of protection systems



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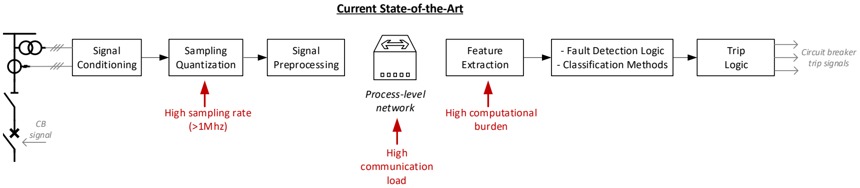

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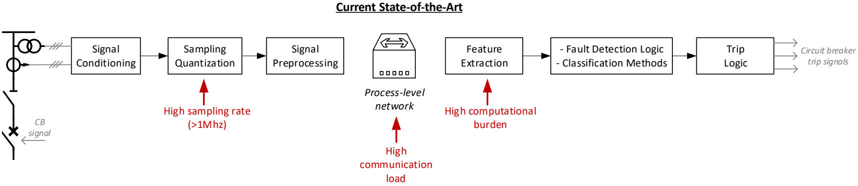

How can a scalable integration of high sampling rate transient protection functions be achieved in a digital substation consisting of a process-level network and a high-degree of functional integration?

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Research hypothesis

Distributing the numerical expansive signal processing algorithms to the edges of the process-level network, a scalable integration of high sampling rate transient protection functions is enabled.

Assumptions:

- Nr. of signal features $<<$ Nr. of samples of the signal
- Signal features are published at a lower rate (e.g. 1 ms)
- Some of the signal features are protection object specific
- Fault detection logic and classification methods are kept either decentralized at the bay level or centralized at the substation level

F. Hohn, T. Rabuzin, J. Wang and L. Nordström, *"Distributed signal processing units for centralised substation protection and control,"* in The Journal of Engineering, vol. 2018, no. 15

Research hypothesis

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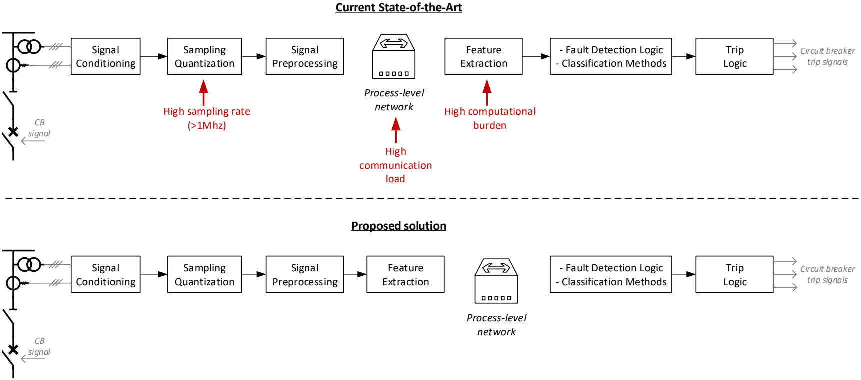

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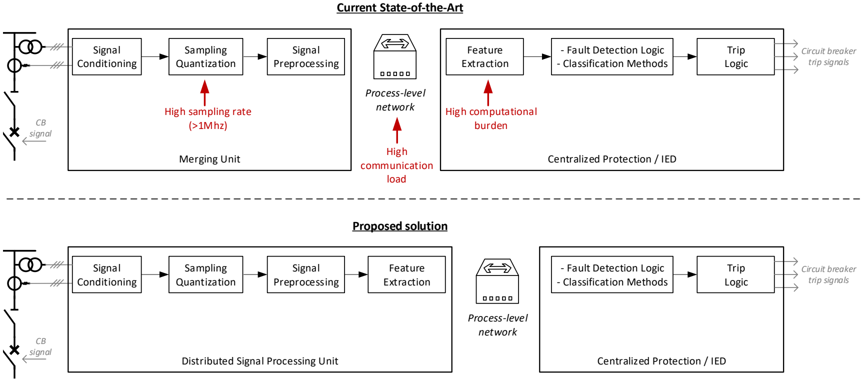

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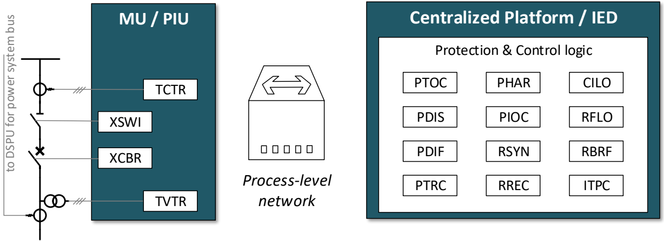
Research Hypothesis

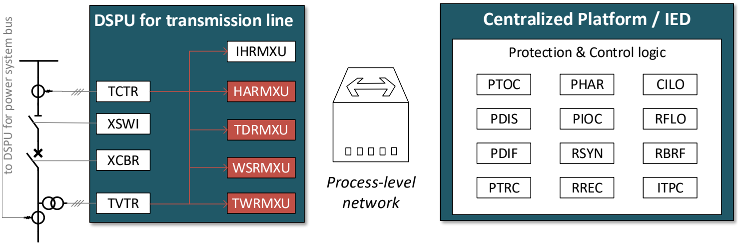
Data model view point based on IEC 61850 logical nodes



F. Hohn and L. Nordström, *"Data Models and Protocol Mapping for Reduced Communication Load in Substation Automation with High Sampling Rate Protection Applications,"* IEEE SmartGridComm, Aalborg, 2018

Research Hypothesis

Data model view point based on IEC 61850 logical nodes



- Dedicated logical nodes of signal feature extraction data for protection functions

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Proposed data models of signal features

For transmission line protection DSPU

- Based on IEC 61850-7-3 common data classes (CDC)
- Utilizing IEC 61850-7-4 data object classes, if available

Signal features	**Logical node**	**CDC**
Fundamental & 2nd, 3rd, 5th harmonic phasors	HARMXU	CMV
DC components	HARMXU	MV
Incremental quantities based	TDRMXU	MV
Root mean square values	TDRMXU	MV
Waveform based supervision features	WSRMXU	ACD
Travelling-wave features	TWRMXU	MV

Proposed data models of signal features

Data sets for phasor, time-domain & travelling-wave based protection

Phasor-based transmission line protection	
Data attribute	**Total**
Base data set for all transmission lines	
HARMXU.A.phsX.cVal.mag.i	128 bit
HARMXU.A.phsX.cVal.ang.i	128 bit
HARMXU.A.phsX.cVal.q	128 bit
HARMXU.PhV.phsX.cVal.mag.i	128 bit
HARMXU.PhV.phsX.cVal.ang.i	128 bit
HARMXU.PhV.phsX.cVal.q	128 bit
WSRMXU.StrCurVar.phsX	3 bit
WSRMXU.StrCurVar.q	32 bit
WSRMXU.StrMhoSup.phsX	3 bit
WSRMXU.StrMhoSup.q	32 bit
	838 bit
Additional data for long transmission lines	
HARMXU.A.phsX.cVal.mag.i	96 bit
HARMXU.A.phsX.cVal.ang.i	96 bit
HARMXU.A.phsX.cVal.q	96 bit
Additional data for in-zone transformers	
HARMXU.HA.phsXHar.cVal.mag.i[]	384 bit
HARMXU.HA.phsXHar.cVal.ang.i[]	384 bit
HARMXU.HA.phsXHar.cVal.q	128 bit
TDRMXU.A.phsX.mag.i	96 bit
TDRMXU.A.phsX.q	96 bit
WSRMXU.StrWav.phsX	3 bit
WSRMXU.StrWav.q	32 bit

Time-domain based transmission line protection	
Data attribute	**Total**
Data set *TdProtLine*	
TDRMXU.TdDirFwdX.mag.i	96 bit
TDRMXU.TdDirFwdX.q	96 bit
TDRMXU.TdDirRevX.mag.i	96 bit
TDRMXU.TdDirRevX.q	96 bit
TDRMXU.TdDirOpX.mag.i	96 bit
TDRMXU.TdDirOpX.q	96 bit
TDRMXU.TdDisValX.mag.i	192 bit
TDRMXU.TdDisValX.q	192 bit
	960 bit

Travelling-wave based transmission line protection	
Data attribute	**Total**
Data set *TwProtLine*	
TWRMXU.TwDirValX.mag.i	96 bit
TWRMXU.TwDirValX.q	96 bit
TWRMXU.TwDifValX.mag.i	96 bit
TWRMXU.TwDifValX.q	96 bit
	384 bit

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Protocol mapping of data sets

GOOSE application layer protocol

- ASN.1 Basic Encoding Rules
- Fixed-length GOOSE message encoding
- Published synchronously
- UTC timestamp
- Ethernet overhead 42 bytes

GOOSE header field	Size
goosePdu	4 bytes
gocbRef	12 bytes
timeAllowedToLive	7 bytes
datSet	12 bytes
goID	4 bytes
t	10 bytes
stNum	7 bytes
sqNum	7 bytes
simulation	3 bytes
confRev	7 bytes
ndsCom	3 bytes
numDatSetEntries	7 bytes
allData	4 bytes
Total:	**87 bytes**

Outline

Results of network bandwidth estimation

Calculation basis

- Derived data sets for phasor, time-domain and travelling-wave based protection function
- Mapping of data sets to GOOSE application layer protocol and Ethernet data link protocol
- Compare communication load with the Sampled Value variants of IEC 61869-9 => F *f* S *s* I *i* U *u*

F*4800*S*2*I*4*U*4*	Phasor-based protection
F*14400*S*6*I*4*U*4*	Time-domain protection
F*96000*S*1*I*4*U*4*	Travelling-wave protection

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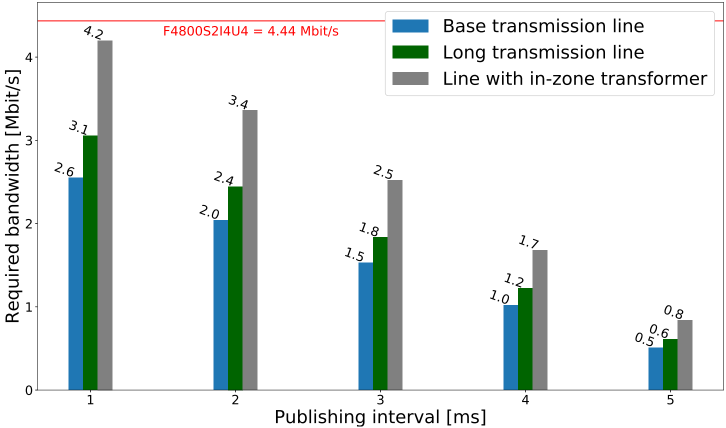
Results of network bandwidth estimation

Communication load for phasor-based protection functions



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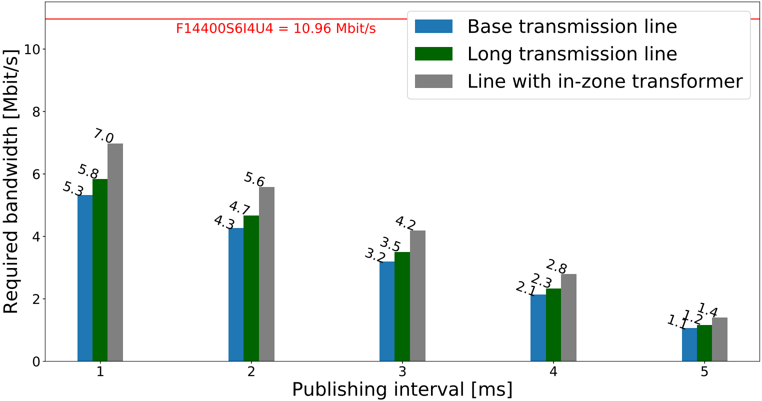
Results of network bandwidth estimation

Communication load for time-domain protection functions



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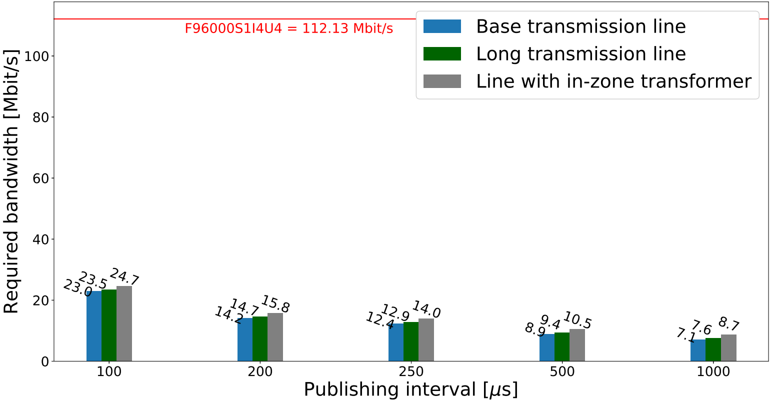
Results of network bandwidth estimation

Communication load for travelling-wave protection functions



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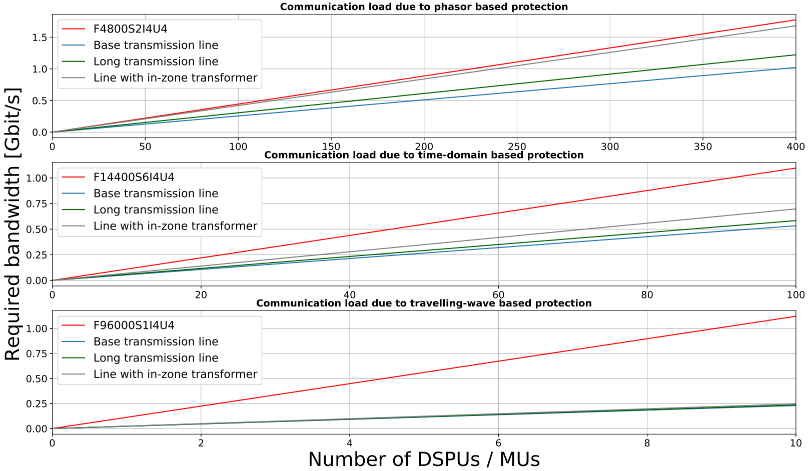
Results of network bandwidth estimation

Communication load with increasing number of DSPUs / MUs



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Conclusion and Future Work

Conclusion

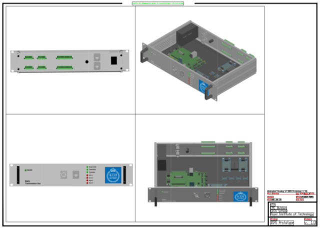
- New digital substation architecture to facilitate high sampling rate protection functions
- Data models and protocol mapping for reduced communication load of process-level networks
- Design of DSP algorithms for the distributed signal processing unit (*reference below*)

F. Hohn, J. Wang and L. Nordström, *"Design of a Distributed Signal Processing Unit for Transmission Line Protection in a Centralized Substation Protection Architecture,"* IEEE IECON, Washington, 2018

Conclusion and Future Work

Future work

- Experimental validation of distributed signal processing concept
- Further development of traveling-wave DSP algorithms
- Performance evaluation in a hardware-in-the-loop setup



Questions!