NTNU

#### ProSmart Project - An outlook on Laboratory developments for IEC61850 based communication and protection

Part 1 – Overview of NTNU ProSMART Project and Real-Time HIL Testing of IEC61850 based  $\mu$ Processor Hardware.



#### **ProSMART Project**



- Recommendations
- Distributed energy resources
- Wide-area protection
- Relay laboratory
- Communication



#### IEC61850

- IEC 61850 is designed to work inside the substation and assist SCADA systems with faster update on measurements and status messages.
- Station Bus: transfer GOOSE messages (e.g. a Trip) from the Protection Device to an Intelligent Electronic Device (Typically a breaker or a relay).
- Process Bus: send sampled values (SV) of V,I from the Merging Unit to the Protection device.





### IEC61850



Station Bus – Ring & Process Bus - Star





### IEC61850 – Implementation on the µProcessor

Sampled Values Subscription	Estimation	Protection
Receive Sampled Value measurements from the substation bay level.	Estimate the phase, angle and frequency Filter the unwanted frequencies and compensate data loss.	Detect and Protect the network from faults. Trip the breakers by GOOSE Message





### Phasor estimation methods implemented





Least squares error

$$v = a_1 x_1 + a_2 x_2 + \dots + a_m x_m$$
$$\begin{bmatrix} v(0) \\ \vdots \\ v(n) \end{bmatrix} = \begin{bmatrix} a_{01} & \dots & a_{0m} \\ \vdots & \ddots & \cdots \\ a_{n1} & \dots & a_{nm} \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_m \end{bmatrix}$$



### Frequency estimation methods implemented





## Frequency estimation in RT-HIL simulations of islanding cases







#### **Results**

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INTEGER\_0\_65535 (sv.noASDU), 1 byte

Packets: 19939 ' Displayed: 19939 (100.0%)

Profile: Default

#### **Future Aspects**

#### Algorithms:

- Sampled Values Estimation using Kalman filter.
- Implementation of Dynamic filter to address communication issues related with publishing sampled values in wide-area.

#### Applications:

- Multi-Terminal Line Differential protection based on IEC61850, to remove vendor dependency.
- μPMU & IED design based on IEC61850, to design DER protection algorithms.





#### IEC61850 based Wide-Area Network Setup



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Part 2 - Laboratory tests of New Protection Schemes using Co-Simulation Platform.



#### Hardware-in-the-loop relay testing



- Faster and reliable results due to availability of actual power system model and components.
- Solving the problem in presence of actual environmental conditions, such as noise, none ideal conditions as well as hidden or neglected factors which may be concealed in simulation-only techniques.
- Identification of factors when accomplishing the solution through replication of experiments.
- Compare different solutions and approaches in the existing power system.



# Communication network inclusion in HIL tests



- Validation and deployment of new protective schemes involving communication technologies.
- Investigation of communication network parameters appearing at intra/inter substation traffic and their impact on protection performance.
- Real time simulator has limited ability to simulate communication network impairments.

### **Communication network emulator**

#### **Click Modular Router**

a software framework for building flexible and configurable routers

- Flexibility
  - Adding new features to enable experimentation
- Openness
  - Allow users to build and extend
- Modularity
  - Simplify the composition of existing features & addition of new features

Emulator is capable of:

- Controlling communication properties between multiple source relays and destination relays.
- Impairing specific subsets of the network traffic.
- Changing delays, jitters and packet corruption in real time.
- Bandwidth restriction.
- Emulation different queueing schemes and traffic priorities.



#### **Real-time HIL test platform at NTNU**



Opal-RT simulator
ABB Relion 670 relays
OMICRON CMC 356
IEC61850 based
communication network



 5. Host PC and HMI for Opal simulator and network analyzer
6. Communication switch emulator-Click and Network analyzer-Wireshark
7. Host PC and HMI for PCM
600 and ABB relays

# Application example: problem statement

- Testing of impedance protection with compensation of fault impedance and DG infeed current.
- Problem:



# Application example: problem solution

- Universal communication based compensation method (interphase faults), ISGT 2017
- No need in information about detailed multitapped system topology and loads





# Application example: test setup





#### **Results: no network imperfections**





- Proper appearance of tripping signals for all fault locations (except adjacent feeder) and different fault resistances
- Acceptable operation time
- Impact on fault location accuracy:
  - Overreaching (tripping signal is always present)



#### **Results: impact of jitters on protection performance**



Percentage of successful tripping (Zone1/Zone2) among 30 consecutive faults

Fault	Low-ohmic faults		High impedance faults	
location	Jitters 0.1-0.5 ms	Jitters 1-5 ms	Jitters 0.1-0.5 ms	Jitters 1-5 ms
1	100%/100%	100%/100%	100%/100%	6.7%/53.3%
2	100%/100%	100%/100%	100%/100%	3.3%/13.3%
3	100%/100%	100%/100%	<mark>40%</mark> /100%	10%/26.7%
4	100%/100%	<mark>13.3%</mark> /100%	<mark>0%</mark> /100%	3.3%/20%

Dependability analysis in case of unsynchronized signals (i.e. no GPS)

# Results: impact of data loss on protection performance

- Low-ohmic fault at the middle of the feeder
- Packets of sample values from DG are dropped with probability 20% and 80%

