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Enabling Interoperability on PV Inverters Using IEC 61850

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Energy Systems Integration Facility (ESIF)

- The Energy Systems Integration Facility (ESIF) is a national user facility located in Golden, Colorado, on the campus of the National Renewable Energy Laboratory (NREL).

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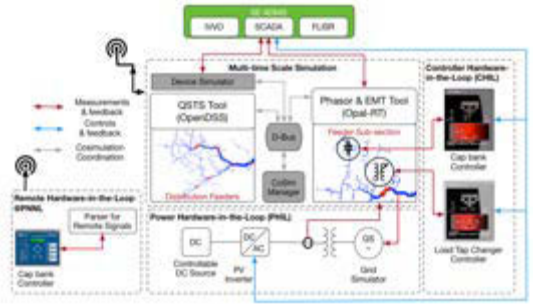
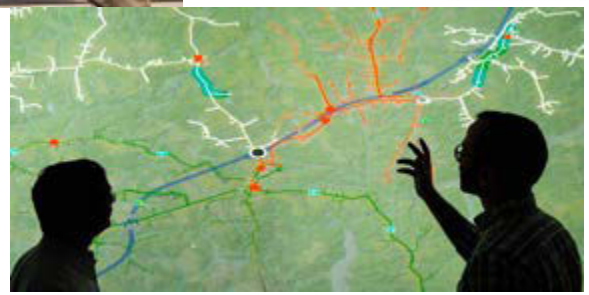
Controller and Power Hardware-in-the-Loop (CHIL/PHIL)

NREL's megawatt-scale controller- and power-hardware-in-the-loop (CHIL/PHIL) capabilities allow researchers and manufacturers to test energy technologies at full power in real-time grid simulations to safely evaluate performance and reliability.

Microgrids



Cosimulation



Power system studies

Team Information

- Power Systems Engineering Center (NREL):
  - Kumaraguru Prabakar
  - Akanksha Singh
- Triangle MicroWorks:
  - Joel Greene
  - Christoph Brunner
- Computational Science Center (NREL):
  - Deepthi Vaidhynathan

Goals of the Webinar

- Introduction to IEC 61850
- Background on the different parts of IEC 61850
- Different information exchange models
- Logical nodes for use with photovoltaic (PV) inverter communication
- Operation of one use case.

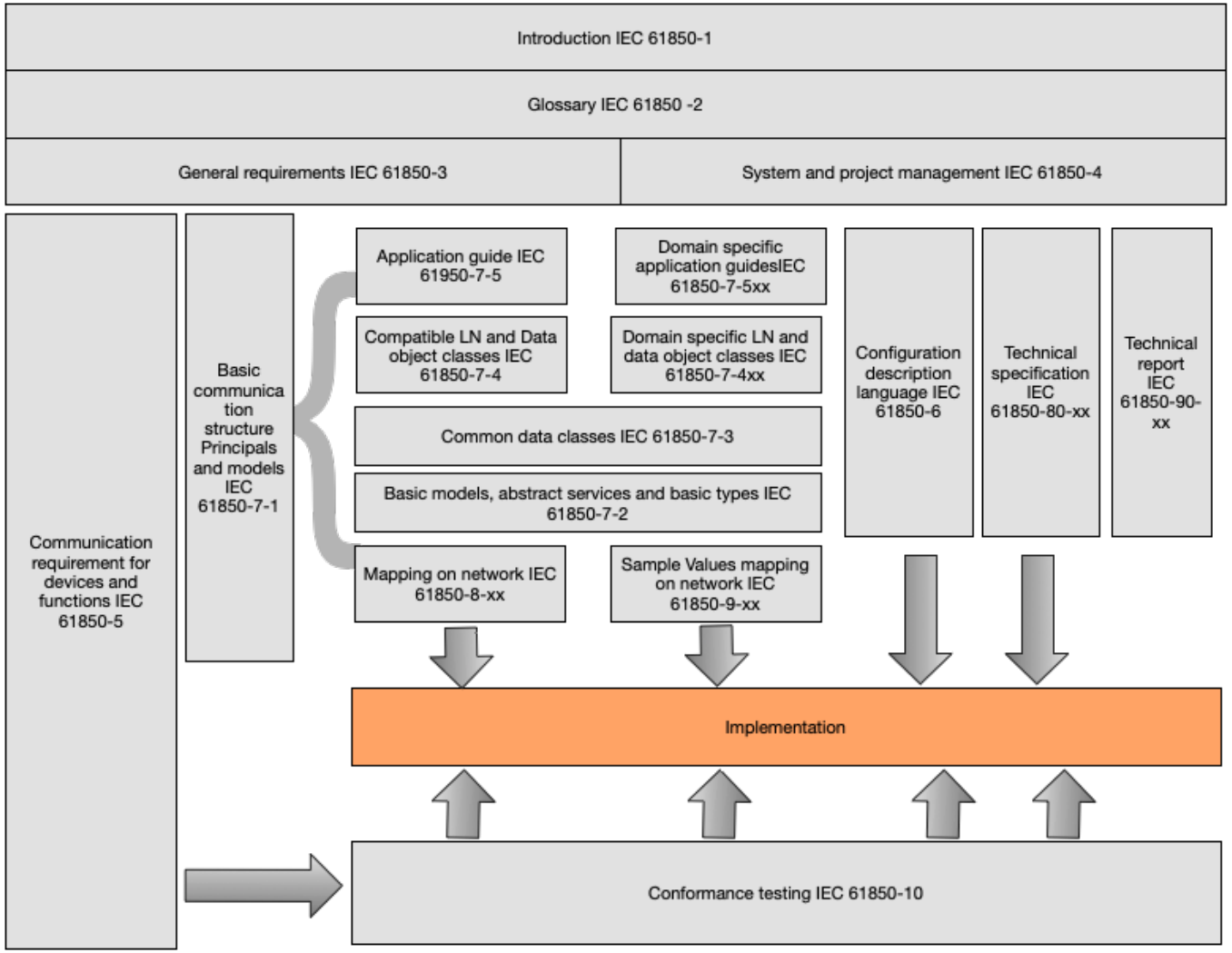
Interoperability and Interchangeability

- Interoperability—The ability of two or more intelligent electronic devices (IEDs) from the same vendor, or from different vendors, to exchange information and use that information for correct execution of specified functions.
- Interchangeability—The ability to replace a device supplied by one manufacturer with a device supplied by another manufacturer, without making changes to the other elements in the system.

IEC 61850 Background

- More than 14 parts (documentation)
- More than 1,000 pages of documentation
- Decades of development involved
- Can be abstract and dry at times to power engineers.

Different IEC 61850 Parts



IEC 61850 Background

- Part 1: Introduction and overview
- Part 2: Glossary
- Part 3: General requirements
- Part 4: System and project management
- Part 5: Communication requirements for functions and device models
- Part 6: Configuration description language for communication in electrical substations related to IEDs

IEC 61850 background

- Part 7-1: Basic communication structure – Principles and models
- Part 7-2: Basic communication structure – Abstract communication service interface
- Part 7-3: Basic communication structure – Common data classes
- Part 7-4: Basic communication structure – Compatible logical node classes and data classes
- Part 7-410: Hydroelectric power plants – Communication for monitoring and control

IEC 61850 background

- Part 7-420: Basic communication structure – distributed energy resources logical nodes
- Part 7-5: IEC 61850 – Modelling concepts
- Part 7-500: Use of logical nodes to model functions of a substation automation system
- Part 7-510: Use of logical nodes to model functions of a hydro power plant
- Part 7-520: Use of logical nodes to model functions of distributed energy resources – under consideration

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IEC 61850 background

- Part 8-1: Specific communication service mapping (SCSM) – Mappings to MMS (ISO 9506-1 and ISO 9506-2) and to ISO/IEC 8802-3
- Part 80-1: Guideline to exchange information from a CDC based data model using IEC 60870-5-101/104
- Part 9-2: Specific communication service mapping (SCSM) – Sampled values over ISO/IEC 8802-3
- Part 90-1: Use of IEC 61850 for the communication between substations

IEC 61850 background

- Part 90-2: Using IEC 61850 for the communication between substations and control centres - under consideration
- Part 90-3: Using IEC 61850 for condition monitoring – under consideration
- Part 90-4: Network engineering guidelines – technical report – under consideration
- Part 90-5: Using IEC 61850 to transmit synchrophasor information according to IEEE C37.118
- Part 10: Conformance testing

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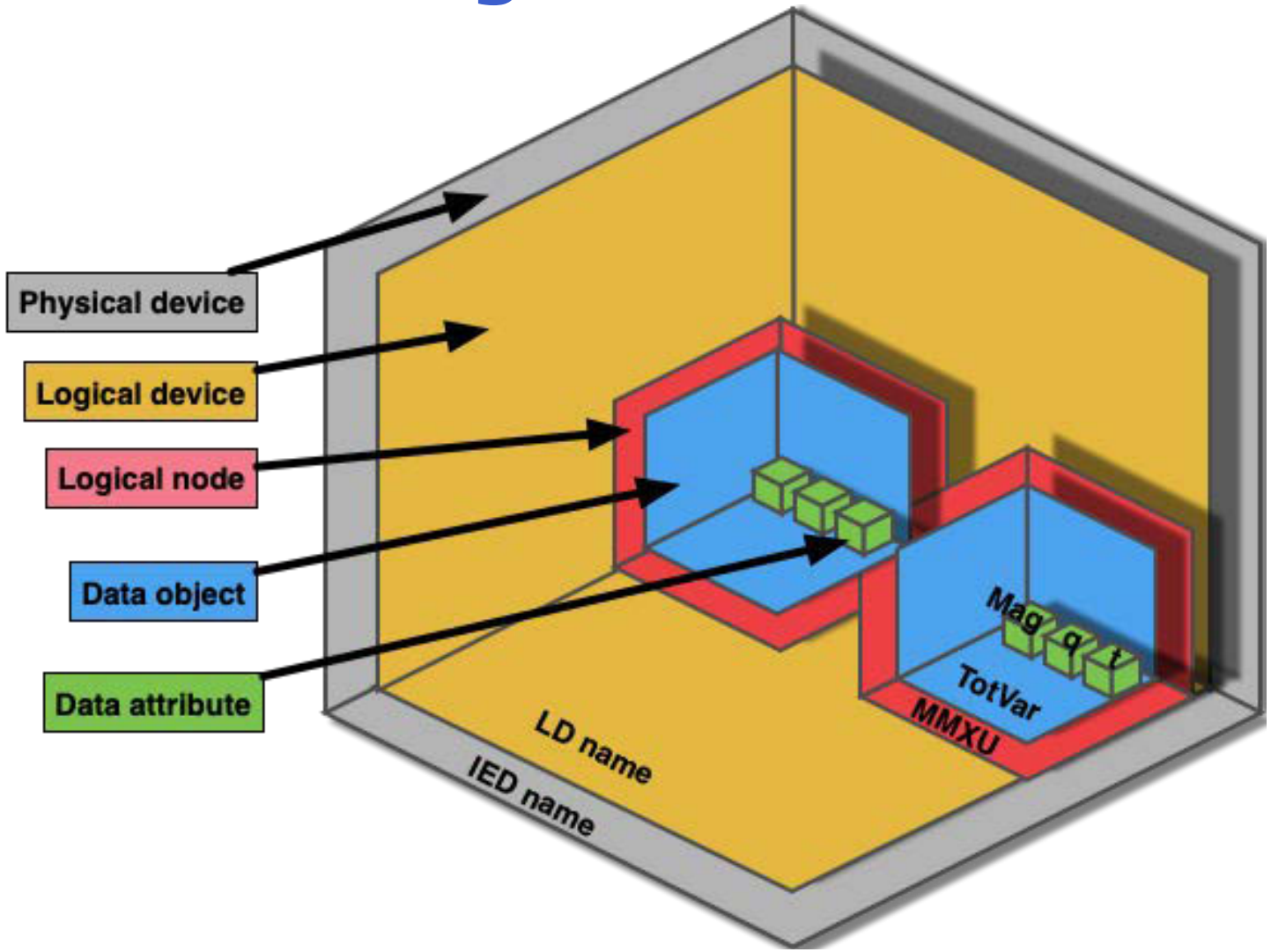
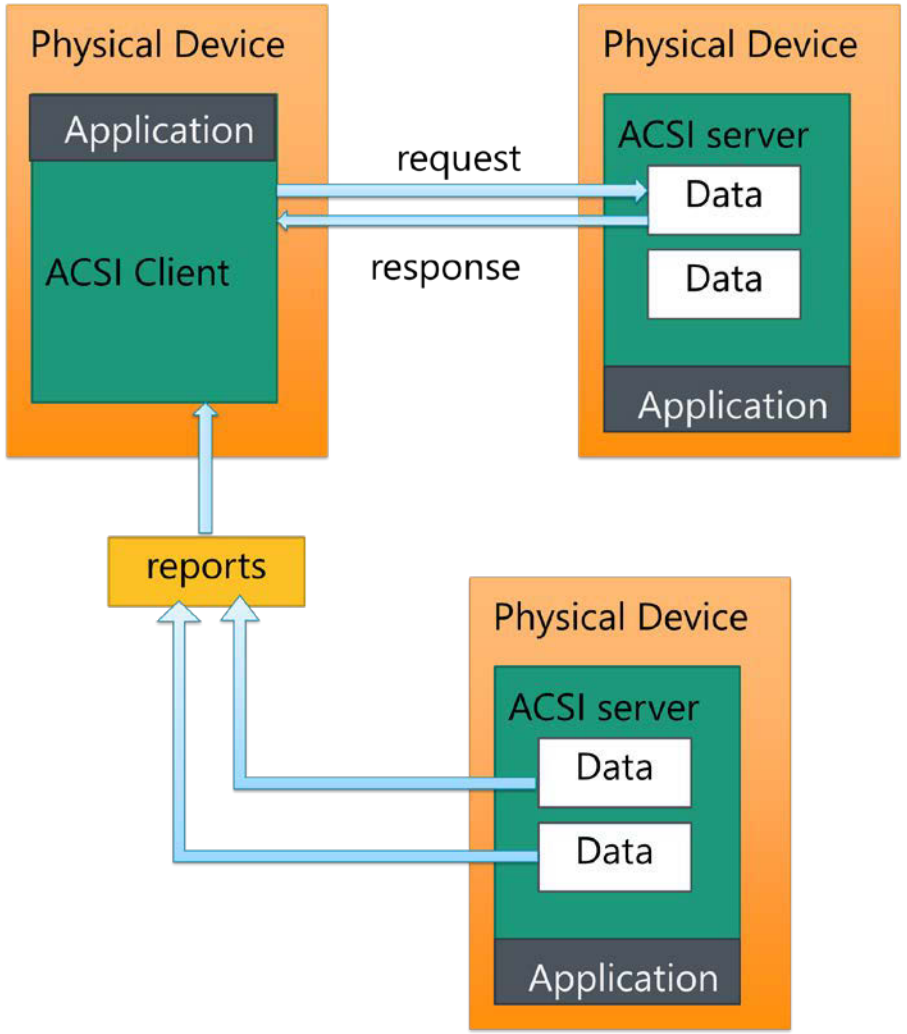
Data Model Using IEC 61850



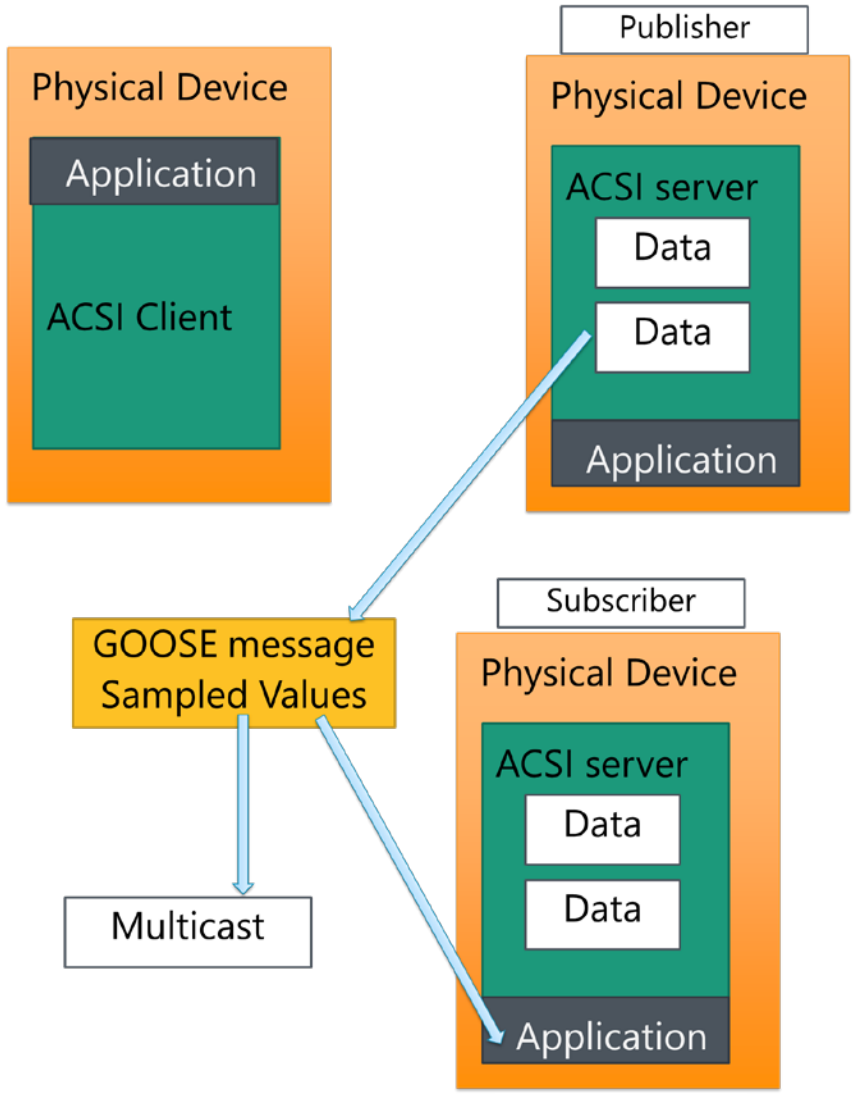
Information Exchange

- Client – server
- Publisher – subscriber
- Reports
- Generic object-oriented substation event (publisher—subscriber)
- Sampled values (publisher—subscriber)

Client-Server Architecture



Publisher-Subscriber Architecture



IEC 61850 7-420 Basic communication structure—Distributed energy resources

- Defines the information models to be used in the exchange of information with distributed energy resources (DERs).
- Dispersed generation devices, dispersed storage devices
- Reciprocating engines, fuel cells, microturbines, PV, combined heat and power, and energy storage

Logical Nodes Defined Under 7-420

Logical nodes for the DER plant electrical connection point (ECP) logical device:

- DCRP—DER plant corporate characteristics at the ECP
- DOPR—operational characteristics at the ECP
- DOPA—DER operational authority at the ECP
- DOPM—Operating mode at ECP
- DPST—Status information at the ECP
- DCCT—DER economic dispatch parameters
- DSCC—DER energy and/or ancillary services schedule control

Logical Nodes for Photovoltaic (PV) Logical Device

Logical nodes for the PV logical device

- DPVM—PV module ratings
- DPVA—PV array characteristics
- DPVC—PV array controller
- DTRC—Tracking controller

Logical Nodes for Inverter

- ZINV – Logical node for inverter defined under 7-420
- Used to define the characteristics of the inverter
  - Maximum power rating
  - Maximum volt ampere reactive (VAR) rating
  - Switch type
  - Cooling type
  - Grid mode status
  - Type of isolation
  - Nominal frequency of switching
  - And more

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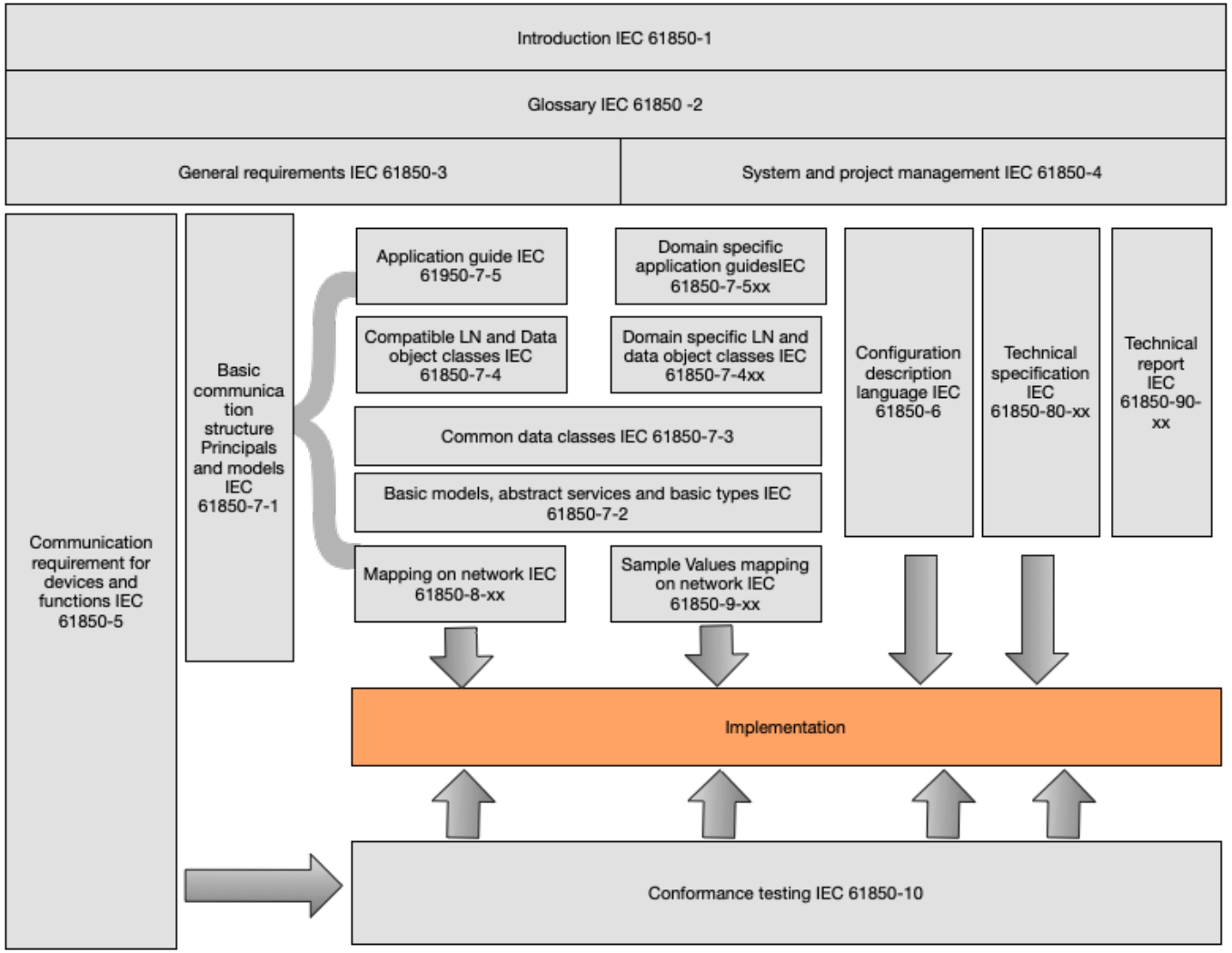
Logical Nodes Borrowed from 7-4

Additional logical nodes:

- XCBR—Describes breakers used in the protection of the PV array
- MMXU—Electrical measurements.

Different IEC 61850 Parts



Example PV Inverter Use Case with Advanced Grid Support Functions

- Measurement:
  - Voltage
  - Current
  - Frequency
  - Real power
  - Reactive power
  - DC measurements.
- Control:
  - Volt-VAR
  - Volt-watt
  - Frequency-watt.
- Protection:
  - Voltage ride-through
  - Frequency ride-through.

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Example PV use case with advanced grid support functions

- IED Capability Description (ICD) file
- XML file that has the configuration of the equipment.
- Creating an ICD file to do the following:
  - Create simple logical nodes for measurements from an inverter.
  - Create protection logical nodes:
    - Overvoltage
    - Undervoltage.
  - Create control logical nodes:
    - Volt-VAR
    - Volt-watt
    - Freq-watt.

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Logical Node: Measurement

- MMXU:
  - Voltage, current, frequency

```
<LN lnType="MMXU_example" lnClass="MMXU" inst="1" prefix="">
  <DOI name="Hz">…
  </DOI>
  <DOI name="PhV">…
  </DOI>
  <DOI name="A">…
  </DOI>
</LN>
```

Logical Node: Measurement

```
<DOI name="Hz">
  <SDI name="instMag">
    <DAI name="f">…
    </DAI>
  </SDI>
  <SDI name="mag">…
  </SDI>
  <DAI name="q">…
  </DAI>
  <DAI name="t">
    <Val />
  </DAI>
  <DAI name="db">…
  </DAI>
  <DAI name="d">…
  </DAI>
</DOI>
```

```
<DOI name="PhV">
  <SDI name="phsA">
    <SDI name="cVal">
      <SDI name="mag">…
      </SDI>
    </SDI>
    <DAI name="t" />
    <SDI name="units">…
    </SDI>
    <DAI name="q">…
    </DAI>
    <DAI name="t">…
    </DAI>
    <DAI name="db">…
    </DAI>
  </SDI>
</DOI>
```

```
<DOI name="A">
  <SDI name="phsA">
    <SDI name="cVal">
      <SDI name="mag">…
      </SDI>
    </SDI>
    <DAI name="q" />
    <DAI name="t" />
    <SDI name="units">…
    </SDI>
    <DAI name="t">…
    </DAI>
    <DAI name="db">…
    </DAI>
  </SDI>
</DOI>
```

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Logical Node: Control (Volt-VAR)

```
<LDevice inst="InverterFunction">
  <LN0 lnType="LLN0_7-420" lnClass="LLN0" inst="" />
  <LN lnType="DVVR_TYPE" lnClass="DVVR" inst="1" prefix="">
    <DOI name="VArSetRef">
      <DAI name="setVal" >
        <Val>Reactive power in percent of VArMax</Val>
      </DAI>
    </DOI>
    <DOI name="VVArCrv">
      <SDI name="crvPts" ix="0">
        <DAI name="xVal" >
          <Val>0.8</Val>
        </DAI>
        <DAI name="yVal" >
          <Val>0.5</Val>
        </DAI>
      </SDI>
      <SDI name="crvPts" ix="1">
        <DAI name="xVal">
          <Val>0.9333</Val>
        </DAI>
        <DAI name="yVal">
          <Val>50</Val>
        </DAI>
      </SDI>
      <SDI name="crvPts" ix="2">
        <DAI name="xVal">
          <Val>0.95</Val>
        </DAI>
        <DAI name="yVal">
          <Val>0</Val>
        </DAI>
      </SDI>
      <SDI name="crvPts" ix="3">
        <DAI name="xVal">
          <Val>1</Val>
        </DAI>
        <DAI name="yVal">
          <Val>0</Val>
        </DAI>
      </SDI>
      <SDI name="crvPts" ix="4">
        <DAI name="xVal">
          <Val>1.017</Val>
        </DAI>
        <DAI name="yVal">
          <Val>-50</Val>
        </DAI>
      </SDI>
      <SDI name="crvPts" ix="5">
        <DAI name="xVal">
          <Val>1.2</Val>
        </DAI>
        <DAI name="yVal">
          <Val>-50</Val>
        </DAI>
      </SDI>
      <DAI name="numPts">
        <Val>6</Val>
      </DAI>
      <DAI name="maxPts">
        <Val>10</Val>
      </DAI>
      <DAI name="xD">
        <Val>Voltage in PU</Val>
      </DAI>
      <DAI name="yD">
        <Val>VAR in percent of Max</Val>
      </DAI>
    </DOI>
  </LN>
```

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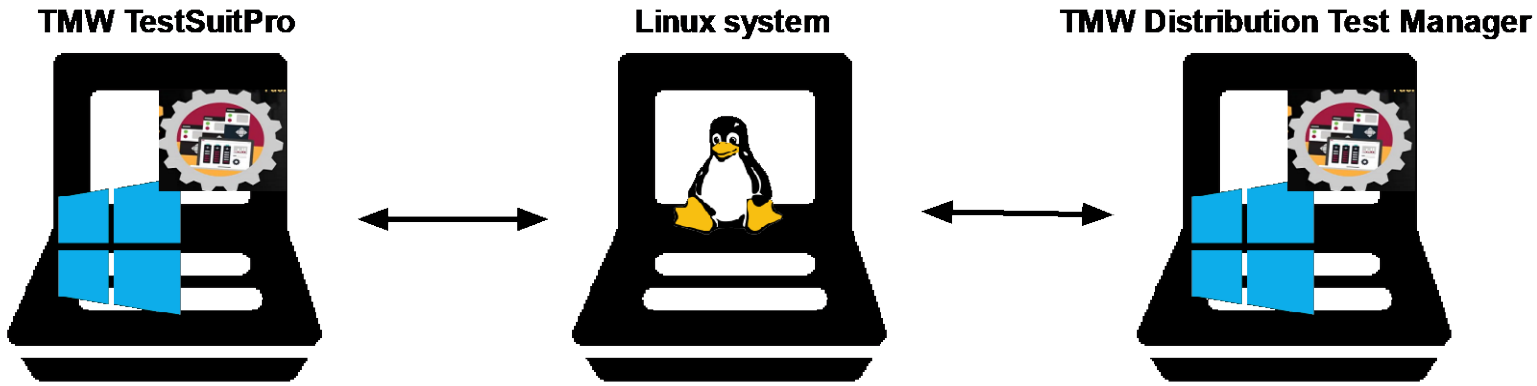
Logical Node: Protection (Overvoltage)

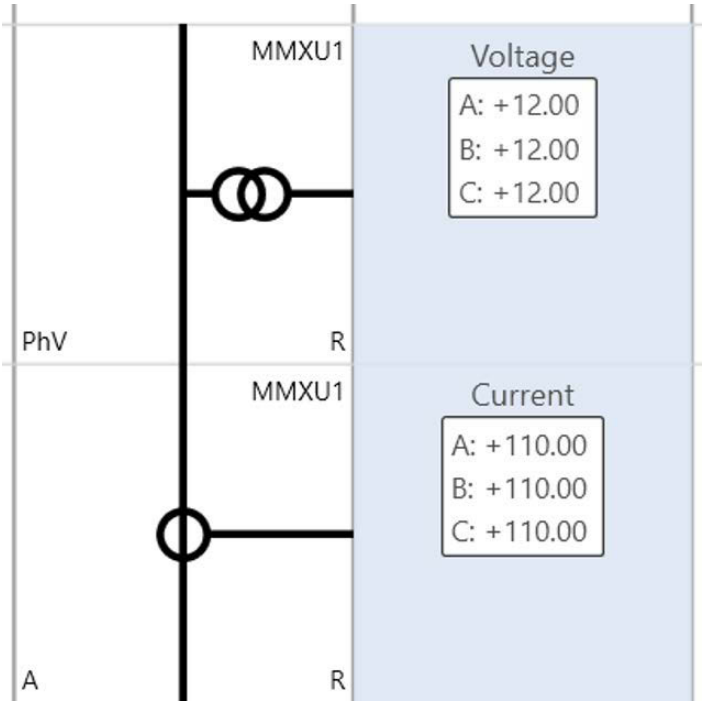
Time: 920, Voltage: 110

```
<LN lnType="PTOV_VoltageRideThrough" lnClass="PTOV" inst="1" prefix="OVR1" desc="OV 1 Momentary cessation">
  <DOI name="StrVal">
    <SDI name="setMag">
      <DAI name="f" \>
        <Val>110</Val>
      </DAI>
    </SDI>
  </DOI>
  <DOI name="OpDlTmms">
    <DAI name="setVal" >
      <Val>920</Val>
    </DAI>
  </DOI>
</LN>
```

Test Scenario

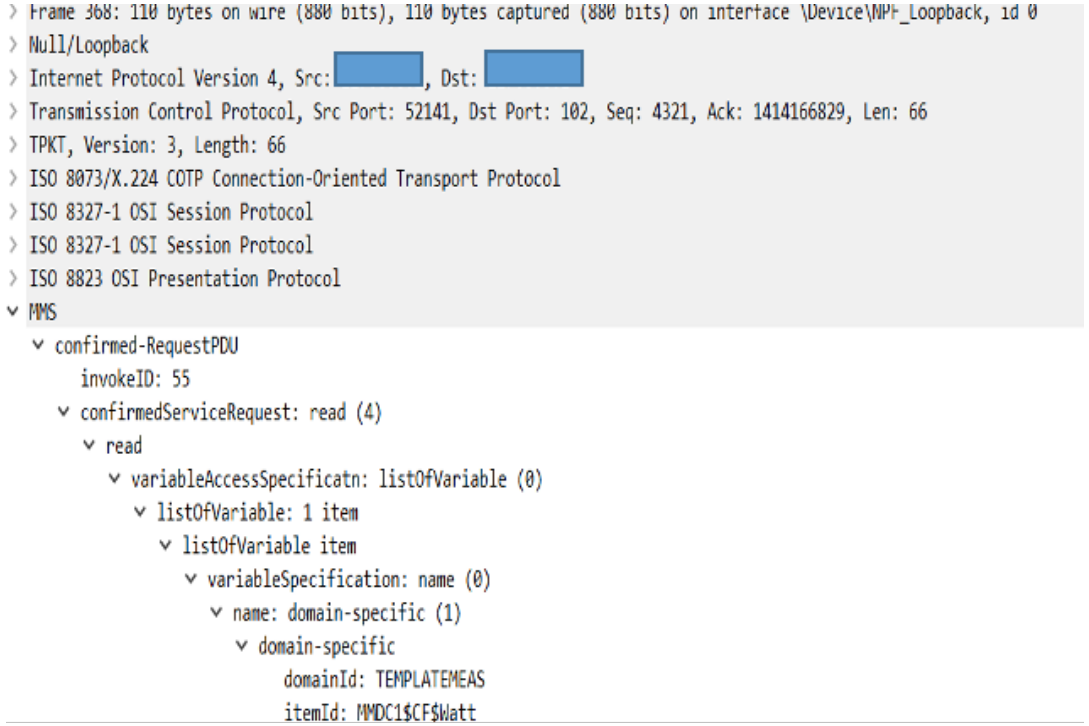
- The ICD file was programmed in a microcontroller using commercial off-the-shelf IEC 61850 library.

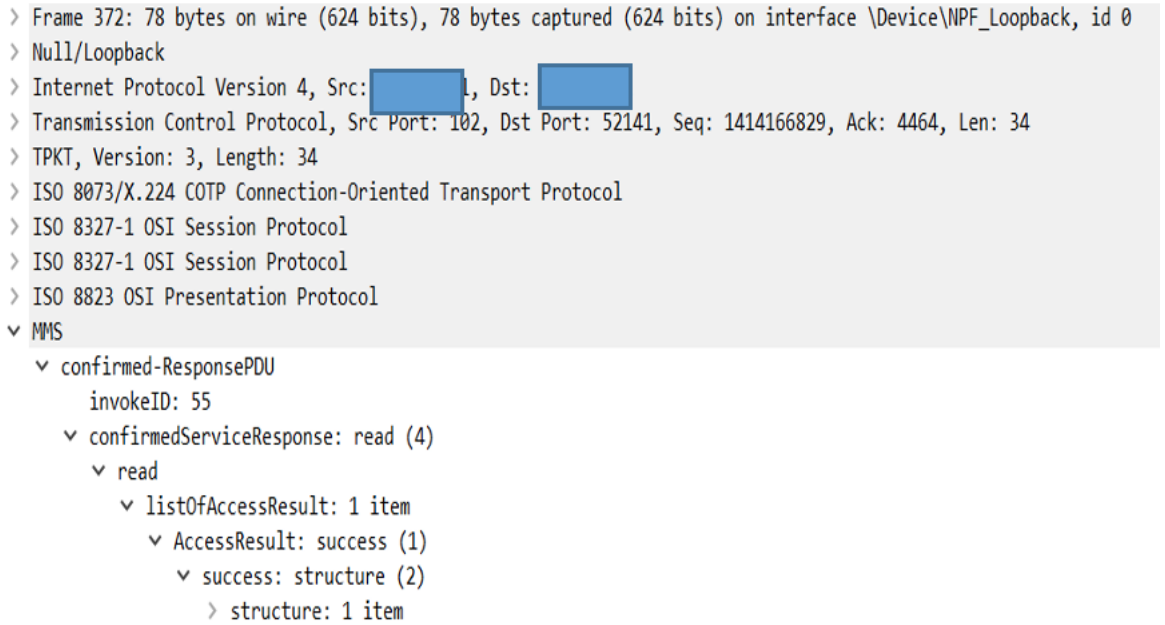




Wireshark

- Open-source tool to capture and analyze network data
- Can view MMS, SV, and GOOSE messages.





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Summary

- Background on IEC 61850
- Background on data model, logical devices, logical nodes
- Background on information exchange (client—server, publisher—subscriber)
- Background on XML based ICD file development
- Simulated test PV inverter with advanced grid support functions communicating through IEC 61850.

References

- K. Prabakar, A. Singh and C. Tombari, "IEEE 1547-2018 Based Interoperable PV Inverter with Advanced Grid-Support Functions," 2019 IEEE 46th Photovoltaic Specialists Conference (PVSC), Chicago, IL, USA, 2019, pp. 2072-2077, doi: 10.1109/PVSC40753.2019.8980956.
- IEC 61850: "Communication networks and systems in substations", (www.iec.ch).

Thank you

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