E.ON Energy Research Center

Laboratory

Laboratory Implementation of Automation Functions for Monitoring and Control

Session 8

THEORY

Automation of MTDC grid

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1. Introduction

In this module the Multi-terminal dc (MTDC) grids based on Voltage Source Converters (VSCs) are modelled according to the standard IEC 61850. The MTDC grid is a promising option to integrate the increasing share of generation from the Distributed Energy Resources (DERs) both in the transmission and distribution grids. However, with the broader use of VSCs for the transmission and distribution grid, there is an absence of a standardised data model for the VSC. In this work, the authors propose an IEC 61850 based data model for VSCs and an existing IEC 61850 model is extended for the Dual-Active Bridge (DAB) converter as an interlink between various dc terminals and the Modular Multilevel Converter (MMC). Furthermore, a generic data-modelling guideline is proposed for Intelligent Electronic Devices (IEDs), which are responsible for the interoperability among converters in the MTDC grid. The implementation of the real-time monitoring system of a hybrid ac-dc MTDC grid with the proposed IED is presented as an exemplary case.

2. MTDC grid

MTDC transmission is increasingly considered a viable solution for various power distribution applications. In the connection of large off-shore wind farms to the onshore ac grid, they can power for longer distances to multiple connection points on shore. A pan-European multi-terminal HVDC super grid has been proposed to interconnect various European countries and the regions close to their borders to reduce the spinning reserve requirement and the cost of electric power generation. Although there are existing point-to-point connections, there are proposed Multi-terminal grids (MTDC)   since MTDC configuration offers more flexibility and reliability to the operator due to the bi-directional capability in the converters. The bi-directional flow of power in the converter makes the dc system more flexible because, at the event of deficiency or surplus of power in the electrical network, the power between the nodes is redistributed. However, the power redistribution is only possible, if the converters are interoperable in the dc electrical network or hybrid ac-dc electrical network. Therefore, schemes for automating ac and dc grids are designed so that the converters are interoperable in the same automation architecture.

The Smart Grid Architecture Model (SGAM) provides a method to use a structured approach for designing the automation architecture. The SGAM suggests a methodology to facilitate interoperability by dividing an automated grid into five layers. The IEC 61850 standard series is widely used for substation automation, and the standard can be mapped onto three interoperable SGAM layers, which are communication layer, information layer and a function layer. The IEC 61850 standard series was introduced to facilitate the interoperability of the automation devices, modular expansion, and upgrading of the substation automation design. This is achieved through the standardized data-modelling framework and communication services. However, the data-models defined in the initial standard series correspond to the components within a typical ac substation. In the later editions, data-models for the devices automating the distributed energy resources (DER) control were also included.

In this the module, two converter topologies have been considered for data-modelling of a converter: The Modular Multi-level Converter topology (MMC) and the Dual-Active Bridge (DAB) topology. The DAB topology is a dc-dc converter used in MTDC grids for various applications like load sharing, integration of photo-voltaic panels and energy storage devices . The MMC topology based converters are ac-dc converters, which are widely used as voltage source converters for HVDC applications. The authors provide the generic design of the Intelligent Electronic Device (IED) for automating the converter operation. The specific extension of the current logical node ZCON for representing the converter controller modes and data-models for bi-directional converters (Dual Active Bridge and Modular Multilevel converter) is proposed.

Substation Automation with IEC 61850

The IEC 61850 standard series was first designed for the substation automation. It primarily provides the basic data-models for all physical components deployed within the substation and DER controllers. The data models facilitate a logical representation of the physical component implemented in the substation. The data model enables a generic microprocessor based device with standard I/Os, known as Intelligent Electronic Device (IED) to host these logical representations of the physical tools. They are hence providing interoperability between all the substation automation devices. The essential fundamental functions of the IED are defined as the Logical Nodes (LNs), and the different parameters required for the function are modelled as the data objects with their attributes. A set of LNs is grouped under a single Logical Device (LD) instance that is hosted within a dedicated IED. The data-modelling structure is summarized in the Fig.\ref{fig.61850model}. Each Intelligent Electronic Device (IED) could support multiple LDs with multiple LNs, thus enabling the virtualization of various devices in one IED. The transformer is depicted with the logical node YPTR along with three data-attributes of the transformer such as Over-time (OvlTm), status value (statVal) and Start Time (strtTime).

Furthermore, the standard also prescribes specific transfer times that the IEDs and the communication infrastructure should comply with the monitoring, control and protection applications. The standardized communication services are mapped on to specific protocols for notifying emergency status changes, streaming transducer data (from Instrument Transformers) and regular measurement and control updates.

The MMS protocol service can be used over Wide Area Network (WAN), thus making it a viable option for an ac-dc hybrid grid, since hybrid grids could span over a large geographical area.

2.1. Substation Automation with IEC 61850

The automation architecture for a converter in substation has been presented in and the data-models for network topology, switch status, power flow between the station is described. However, the data models are not used for MTDC applications. Whereas in DERs are automated with controllers which are not interoperable with other devices. Thus, standard IEC 61850 for MTDC grid provides data-models and function templates for information exchange in the substation. The IEC 61850 data-model of battery, DER and parts of the converters have been used to represent automation architecture of the grid. The bi-directional converter is represented using inverter represented by ZINV logical node, rectifier represented by ZRCT logical node and the dc measurement represented by MMDC logical node. However, the misrepresentation of the converter data model can be attributed to the standard itself. The latest extension of the standard IEC 61850 7-420, defines data-models for different types of power electronic based converter controllers. However, they specifically address the functionalities of DER management systems, DER generation systems, types of DERs and their auxiliary systems but the DER in the standard is falsely represented as ZINV and ZRCT. The converter data-model and converter applications are currently described in part IEC 61850-90-7, which uses an umbrella term of „inverter“for the dc-dc converter, ac-dc converter, ac-ac converter and dc-ac converter. Furthermore, in IEC 61850-90-7 the data models to represent the different operation modes of the DER interfacing „inverters“ are defined. However, the data models are defined for specific DER integration for ac grids and they cannot be directly used to represent dc-dc converters (such as DAB Topology) or the ac-dc converters(such as MMC Topology) that are used in MTDC grids. The data models currently defined for

DER operation are not sufficient to represent the physical topological configuration of the converter and the different control modes that are required for the operation of the MTDC grid, which differ from the standard operational modes of DERs integrated to ac grids.

2.2. Proposed data model extensions

In IEC 61850 the logical nodes are further represented with the necessary data attributes. The data attributes are classified according to status information, measurand information and control. The classification of the data attributes is termed as Common Data Classes(CDC) in the IEC 61850 standard. The parameters such as control, measurements and current limits introduced in the previous section are represented according to the CDC present in the IEC 61850-7-3 standard. CDCs define the structure and data type of the data object. The hierarchical data-model extensions to represent bi-directional converters is depicted in Fig.1.

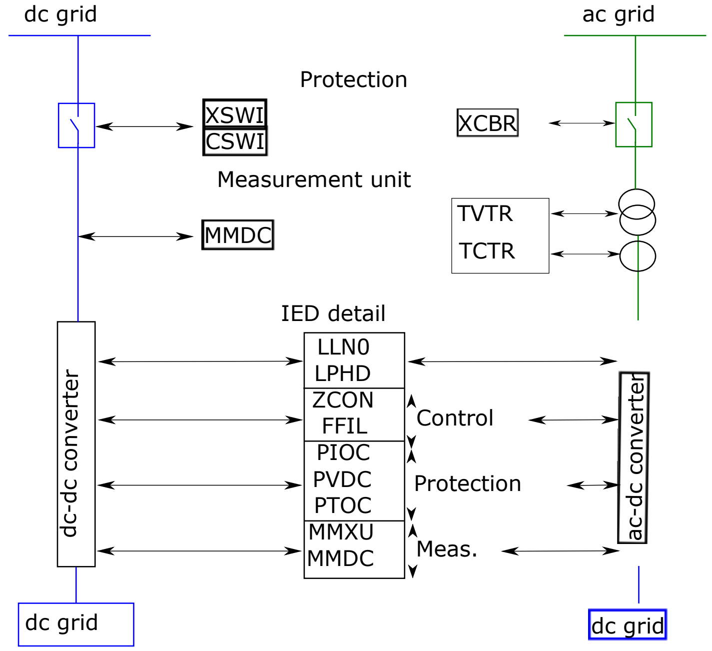

Figure 1 Data-model for IED-Converter for DAB and MMC [1]

SwHz: The data attribute represents a nominal switching frequency. It is modelled with data attributes of Analog Setting (ASG) CDC.

PSang: The data attribute represents the phase angle between the primary and secondary side. The phase angle is an essential factor to be monitored since it decides the direction of power flow in the converter. The data attribute is exclusive for DAB. The data attribute is modelled with data attribute of ASG CDC.

SubMoCnt: The data attribute represents the number of submodules present in the MMC converter. This data attribute is exclusive to the MMC converter, and it decides the voltage level for the MMC converter. This is modelled with data attribute of ASG CDC.

PQVLimSet: The data attribute represents the active, and reactive power curve limits set points. It is modelled with data attributes Curve Shaping setting (CSG) CDC.

CtrlMod: The data attribute represents the control mode for the dc grid control with a value given below. It is modelled with data attributes Enumerated Status Setting (ENG) CDC.

(a) 0=Unknown

(b) 1=Master-Slave mode

(c) 2=Droop control mode

(d) 3=Deadband control mode

(e) 4=Undeadband control mode

(f) 5=Voltage margin control mode

MsCtrlMod : The data attribute represents, which converter is the master and which converters operate as slaves. This is notified with a value below. It is modelled with data attributes Enumerated Status Setting (ENG) CDC.

Bndctrl: The data attribute represents, the band for the specific droop control of converters for voltage based power sharing. It is modelled with data attributes of Analog Setting (ASG) CDC.

InDALim: The data attribute represents, the input dc current limit. It is modelled with data attributes of Analog Setting (ASG) CDC.

InDVLim: The data attribute represents the input dc voltage limit. It is modelled with data attributes of Analog Setting (ASG) CDC.

OutWSet: The data attribute represents the output active power setpoint for ac grid support. It is modelled with data attributes of Analog Setting (ASG) CDC.

OutVarSet: The data attribute represents the output reactive power setpoint for ac grid voltage regulation. It is modelled with data attributes of Analog Setting (ASG) CDC.

OutPFSet: The data attribute represents the output power factor set point for ac grid support. It is modelled with data attributes of Analog Setting (ASG) CDC.

OutHZSet: The data attribute represents the output frequency set point for ac grid support functions. It is modelled with data attributes of Analog Setting (ASG) CDC.

InAALim: The data attribute represents the input ac current limit. It is modelled with data attributes of Analog Setting (ASG) CDC.

InAVLim: The data attribute represents the input ac voltage limit. It is modelled with data attributes of Analog Setting (ASG) CDC.

OutAALim: The data attribute represents the output ac current limit. It is modelled with data attributes of Analog Setting (ASG) CDC.

OutAVLim: The data attribute represents the output ac voltage limit. It is modelled with data attributes of Analog Setting (ASG) CDC.

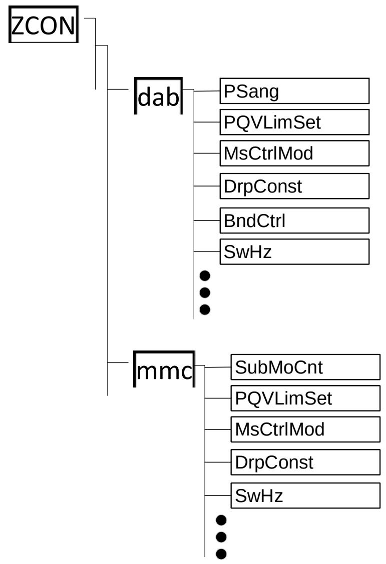

Figure 2: ZCON data-model extension

3. Tasks

3.1. Software perquisites

The following softwares are necessary for running this module:

- Notepad ++ (https://notepad-plus-plus.org/downloads/)
- OpenSCL configuration (The Zip file is uploaded on moodle)

3.2. Tasks

The SCL file for a ac-dc converter is provided, which can be used as a template for integrating the data attributes of the logical node into the SCL file of ZCON. The following steps must be completed to finish the module.

1. Identify the data attributes for ZCON in the logical nodes of MMXU, MMDC, ZINV and ZRCT essential for data-model of a dc-dc converter from the standard IEC 61850-420 and IEC 61850-7-4

```xml
<LN inst="1" lnClass="ZCON" lnType="ZCON_0">

  <DataSet name="ENG">
      <FCDA daName="setVal" doName="CmutTyp" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setVal" doName="IsoTyp" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setVal" doName="VRegTyp" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setVal" doName="ACTyp" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setVal" doName="ConTyp" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setVal" doName="CoolTyp" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setVal" doName="FilTyp" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setVal" doName="MsCtrlMod" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setVal" doName="CtrlMode" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
  </DataSet>


  <DataSet name="ASG">
      <FCDA daName="setMag" doName="SwHz" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setMag" doName="OutWSet" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setMag" doName="OutVarSet" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setMag" doName="OutPFSet" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setMag" doName="OutHZSet" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setMag" doName="InAALim" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setMag" doName="InDALim" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setMag" doName="OutAALim" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setMag" doName="OutDALim" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setMag" doName="InDVLim" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setMag" doName="InAVLim" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setMag" doName="DrpConst" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setMag" doName="BndCtrl" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setMag" doName="OutAVSet" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
      <FCDA daName="setMag" doName="OutDVSet" fc="SP" ldInst="L1" lnClass="ZCON" lnInst="1"/>
  </DataSet>
```

Figure 3: Sample snippet of ENG and ASG for ZCON

2. What does the data-attribute ENG, ASG and CSG represent?
    a. Could you name any other examples for inverter and rectifier that the data attribute can be used?
3. Explore the CID file of a INVRECT.SCL at OPEN SCL configurator.

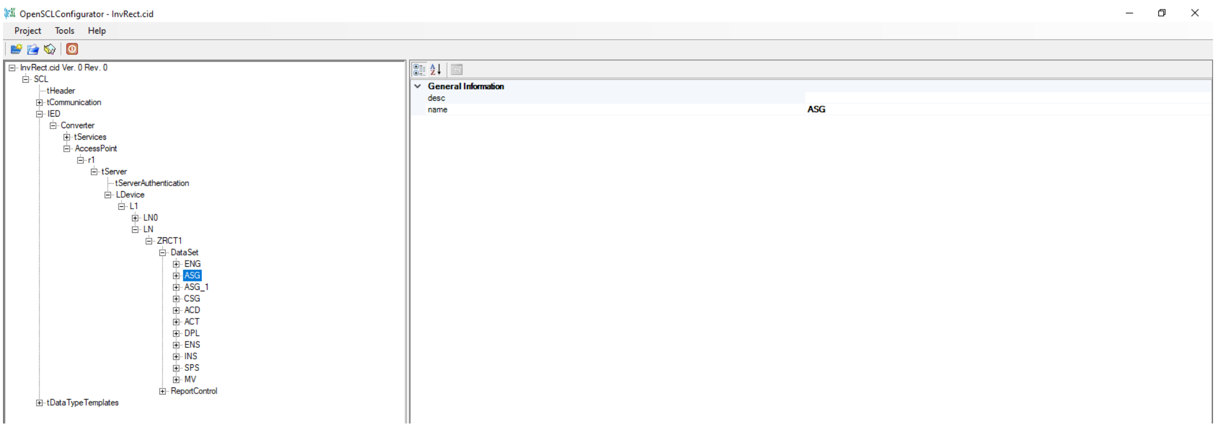

Figure 4: OPEN SCL configurator

4. What could be the use of ZCON in MTDC grid and what are the neccesary data attributes?
5. Add the proposed data extension and discussed data attributes in ZCON

5.18.7 LN: Converter Name: ZCON

For a description of this LN, see IEC 61850-5.

ZCON class				
Data object name	**Common data class**	**Explanation**	**T**	**M/O/C**
LNName		The name shall be composed of the class name, the LN-Prefix and LN-Instance-ID according to IEC 61850-7-2, Clause 22.		
Data objects				
Descriptions				
EEName	DPL	External equipment name plate		O
Status information				
EEHealth	ENS	External equipment health		O
OpTmh	INS	Operation time		O
Settings				
VArRtg	ASG	Rated bidirectional VArs		O
VRtg	ASG	Rated voltage		O

Figure 5: ZCON logical node

6. Append the CID file with the logical node of ZCON using notepad ++
7. After the CID file has the logical node ZCON appended, is it visible using SCL configurator?

4. Bibliography

[1] IEC 61850-7-4:2010, " Part 7-4: Basic communication structure – Compatible logical node classes and data object classes"