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IMPLEMENTATION GUIDELINE FOR DIGITAL INTERFACE TO INSTRUMENT TRANSFORMERS USING IEC 61850-9-2

1 SCOPE

This document gives additional information on how to implement a digital communication interface to non conventional instrument transformers according to IEC 61850-9-2 and IEC 60044-7/8. The purpose of the document is to define a subset of IEC 61850-9-2 that shall support a fast market introduction of this standard. The subset facilitates first implementations, especially in existing products. It further clarifies uncertainties with respect to the interpretation of the standards and/or to precisely define what options to choose in case the standards permit a choice of options.

The paper defines all the generally binding issues and is intended to be used together with **P**rotocol **I**mplementation **D**ocuments (PID's) that are established for all equipment supporting this digital interface. The PID's of the individual equipment then define what functions a unit supports and how it reacts to error conditions.

The purpose of the definitions stated below is to ensure that equipment designed accordingly is interoperable within the limits defined in the PID documents of the connected units.

2 SUMMARY

The subset of IEC 61850-9-2 defined in this document only supports the service SendMSVMessage. As a consequence, the communication is unidirectional from the merging unit to the bay level devices and does not need to support the MMS stack. Therefore, implementation in existing bay level devices is straightforward.

The document further defines a logical device merging unit and a dataset used for the transmission of the sampled values.

This Revision 2.1 incorporates an improvement of the text in clause 6.2.3 and the following two corrections of mistakes that where identified during implementation and testing:

- ConfRev is of length 4 instead of length 1 (Figure 4)
- Component source of data attribute type quality is encoded in one bit instead of two bits (Figure 5)

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Table of Content

3 Normative Reference

[44-8] International Standard IEC 60044-8: 2002(E), Instrument Transformers – Part 8; Electronic current transformers, First edition 2002-07

[6] IEC 61850-6: Communication networks and systems in substations – Part 6: Configuration description language for communication in electrical substations related to IEDs; Draft FDIS

[7-2] IEC 61850-7-2: Communication networks and systems in substations – Part 7-2: Basic communication structure for substation and feeder equipment – Abstract communication service interface (ACSI); First edition 2003-05

[7-4] IEC 61850-7-4: Communication networks and systems in substations – Part 7-4: Basic communication structure for substation and feeder equipment – Compatible logical node classes and data classes; First edition 2003-05

[9-2] IEC 61850-9-2 : Communication networks an systems in substations, Part 9-2: Specific communication service mapping (SCSM) – Sampled values over ISO / IEC 8802-3; 57/690/FDIS

4 Abbreviations

1PPS	One Pulse Per Second. Time synchronization signal
A-Profile	Application profile
CB	Circuit breaker
CT	Current transducer
ID	Identifier
IEC	International electrotechnical commission
MU	Merging unit
PICS	Protocol implementation conformance statement
PID	Protocol implementation document
SCL	Substation configuration language
SV	Sampled values
T-Profile	Transport profile
VLAN	Virtual local area network
VT	Voltage transducer

5 USE OF IEC 60044-8

The clauses of IEC 60044-8 related to the digital output (clause 5.3 and 6.2) are not applicable. The communication interface shall be designed according to IEC 61850-9-2 and the additional specifications made in this document instead. However, the concept of the merging unit as explained in clause 1.3 shall apply in principle. More details of the merging unit are specified in clause 7 of this document.

The maximum delay time as specified in clause 5.3.2, NOTE 2 shall apply as maximum allowed delay.

The specification of the clock input according to clause 6.2.5 of [44-8] shall apply as well.

6 USE OF IEC 61850-9-2

6.1 Protocol implementation conformance statement (PICS)

The implementation of IEC 61850-9-2 shall be according to the following protocol implementation conformance statement (see also clause 9 of IEC 61850-9-2).

6.1.1 Notation

For the following clause, the following definitions apply:

- m: mandatory support. The item shall be implemented.
- c: conditional support. The item shall be implemented if the stated condition exists.
- o: optional support. The implementers may decide to implement the item.
- x: excluded: The implementers shall not implement this item.
- i: out-of-scope: The implementation of the item is not within the scope of this guideline

6.1.2 Profile conformance

Table 1 and Table 2 define the basic conformance statement.

Table 1 – PICS for A-profile support

		Client		Server		Value/Comment
A1	Client/Server A-Profile	o		o		Refer to clause 5.2 of 61850-9-2
A2	SV A-Profile	m		m		Refer to clause 5.3 of 61850-9-2

Table 2 – PICS for T-profile support

		Client		Server		Value/Comment
T1	TCP/IP T-Profile	c1		c1		
T2	SV T-Profile	m		m		
c1 – shall be 'm' if support for A1 is declared. Otherwise, shall be "i"						

6.1.3 SV services

This clause describes the Protocol Implementation Conformance Statement for sampled values services based on the IEC 61850-7-2 basic conformance statement.

Table 3 – SV conformance statement

Services	Client/ subscriber	Server/ publisher	Value/Comment
Multicast			
SendMSVMessage	m	m	
GetMSVCBValues	o	o	
SetMSVCBValues	o	o	
Unicast			
SendUSVMessage	o	o	
GetUSVCBValues	o	o	
SetUSVCBValues	o	o	

6.2 Additional specifications

6.2.1 Physical Layer ([9-2] 5.3.3)

Fiber optic transmission system 100Base-FX full duplex with ST connectors is recommended. The only allowed alternate solutions are 100Base-FX with MT-RJ connectors or electrical transmission using 100Base-TX full duplex with RJ-45 connectors.

6.2.2 Link layer ([9-2] 5.3.3)

The default settings for priority tag and VLAN ID shall be used as specified in [9-2]. The APPID shall always be 0x4000.

6.2.3 Extension of data attribute type Quality ([7-3] 6.2)

The data attribute type **Quality** defined in IEC 61850-7-3 is extended by adding the following component at the end:

Quality Type Definition			
Attribute Name	**Attribute Type**	**Value/Value Range**	**M/O/C**
…			
derived	BOOLEAN	DEFAULT FALSE	M

derived

This identifier shall be set to FALSE, if the value is based on a real sensor in the process (optionally including some additional calculations behind, e.g. for a RMS calculation). If the identifier is set to TRUE, it is meant that there is no physical sensor within the system to determine the value, but the value is derived from a combination of values from other physical sensors.

EXAMPLE 1 – There may be a CT used to measure the neutral current. In that case, the identifier **derived** shall be set to FALSE. If the neutral current is calculated from the phase values, the identifier shall be set to TRUE.

EXAMPLE 2 – A disconnector and an earthing switch may be combined to one physical switch having multiple positions. In that case, the position values for the disconnector and the earting switch – each modeled in a logical node XDIS – would have the identifier **derived** set to TRUE.

7 SPECIFICATION OF THE LOGICAL DEVICE "MERGING UNIT"

IEC 61850 does not specify logical devices. Logical devices may be described in SCL and configured through several services of IEC 61850. To reduce the first implementations to a minimum of required services without loosing interoperability, this guideline provides a detailed specification of the logical device merging unit as used within the scope of this guideline.

7.1 Definition of the objects according to IEC 61850-7-2

7.1.1 The logical device instance "MU" ([7-2] 8.1.1)

The attributes of the logical device MU shall have the following values:

Table 4 – Logical device instance "MU"

Attribute Name	Value	M/0	Comment
LDName	xxxxMUnn	m	**xxxx** is configurable according to [6], clause 8.4.2 and **MUnn** is the Attribute Inst of the element LDevice in the IED section of the SCL (nn shall identify the measuring point within the bay)
LDRef	xxxxMUnn	m	
LogicalNode	LLN0 LPHD InnATCTR1 InnBTCTR2 InnCTCTR3 InnNTCTR4 UnnATVTR1 UnnBTVTR2 UnnCTVTR3 UnnNTVTR4	m m m m m m m m m m	1 ..5 is the attribute Inst of the element LN in the IED section Unn / Inn is the identification of the Sensor; A, B, Cand N are the phase identification. Both values are part of the substation section of the SCL and are used to build the name according to [6], clause 8.4.2

7.1.2 The logical node instance "LLN0" ([7-2] 9.1.1)

The attributes of the logical node LLN0 shall have the following values:

Table 5 – LLN0

Attribute Name	Value	M/O	Comment
LNName	LLN0	m	
LNRef	xxxxMUnn/LLN0	m	
Data			As defined in 61850-7-4
DataSet	PhsMeas1	m	
MultiCastSampledValueControlBlock	MSVCB01 MSVCB02	c1 c1	
c1 – At least one of the two MulticastSampledValueControlBlock shall be implemented			

7.1.3 The dataset "PhsMeas1" ([7-2] 11.2.1)

The attributes of the dataset shall have the following values:

Table 6 – Dataset "PhsMeas1"

Attribute Name	Value	Comment
DSName	PhsMeas1	
DSRef	xxxxMUnn/LLN0$PhsMeas1	
DSMemberRef	InnATCTR1.Amp[MX] InnBTCTR2.Amp[MX] InnCTCTR3.Amp[MX] InnNTCTR4.Amp[MX] UnnATVTR1.Vol[MX] UnnBTVTR2.Vol[MX] UnnCTVTR3.Vol[MX] UnnNTVTR4.Vol[MX]	

The common data class SAV used for the data above shall support the following MX attributes:

Table 7 – Common data class SAV

Attribute Name	Attribute Type	Comment
instMag.i	INT32	
q	Quality	This includes validity information and test flag and an indication if the value is derived or based on a real sensor
sVC.scaleFactor	FLOAT32	0.001 for current; 0.01 for voltage
sVC.offset	FLOAT32	Always 0

This implementation guideline defines a fixed scaling. See Appendices C and D for more details.

7.1.4 The multicast sampled value control block "MSVCB01" and "MSVCB02" ([7-2] 16.2.1)

The sampled value control block shall be preconfigured as follows:

Table 8 – Multicast sampled value control block "MSVCBxx"

Attribute Name		Value MSVCB01	Value MSVCB02	Comment
MsvCBNam		MSVCB01	MSVCB02	
MsvCBRef		xxxxMUnn/LLN0$MSVCB01	xxxxMUnn/LLN0$MSVCB02	
SvEna		TRUE / FALSE	TRUE / FALSE	Value is defined by configuration (see clause 7.3)
MsvID		xxxxMUnn01	xxxxMUnn02	**xxxxMUnn** is the LDName; **01/02** is the number of the MSVCB instance
DatSet		xxxxMUnn/LLN0$PhsMeas1	xxxxMUnn/LLN0$PhsMeas1	
ConfRev		1	1	
SmpRate		80	256	
OptFlds				
	refresh-time	TRUE / FALSE	TRUE / FALSE	
	sample-synchronized	TRUE	TRUE	
	sample-rate	FALSE	FALSE	

NOTE – since this implementation guideline defines both the datasets used for the transmission of the sampled values as well as the values of the MSVCB, the attribute ConfRev always has the same value.

In addition, the mapping specific attributes shall be preconfigured as follows:

Table 9 – Mapping specific attributes of "MSVCBxx"

Attribute Name		Value MSVCB01	Value MSVCB02	Comment
NoASDU		1	8	
MACDestinationAddress				Needs to be configured; the recommendations of [9-2], Annexe C shall be followed
OptFlds				
	security	FALSE	FALSE	
	data-set	FALSE	FALSE	

7.2 Further specifications

7.2.1 Operating modes

The following operation modes are supported (see [7-4] clause 6)

ON
This is the normal operation mode. In this operation mode, the function of the merging unit is active, the merging unit transmits the frames.

TEST
While in test mode, the merging unit transmits the frames, but the information is flagged as "test" with the respective bit in the quality information. The implementation of test mode is optional. The PID has to specify if it is implemented or not and what kind of test data are sent.

OFF
During startup of the device, the merging unit is in the mode OFF. No frames are transmitted until the merging unit is fully operational.

7.2.2 Synchronization

The MU shall have the capability to accept an external synchronizing signal, so that its sampling can be synchronized both between MUs and to an external time reference. The synchronization signal shall be a 1PPS input according the specification in IEC 60044-8, clause 6.2.5, subclause "optical input" with the fiber as specified in IEC 60044-8, clause 6.2.2.1, Table 10, column "glass fiber".

The PPS pulse rise time may have an impact on the synchronization of the internal MU clock. This impact can be ignored, if a maximum trigger time imperfection of ±10% and the rise time of 200 ns will be assumed. See Figure 1.

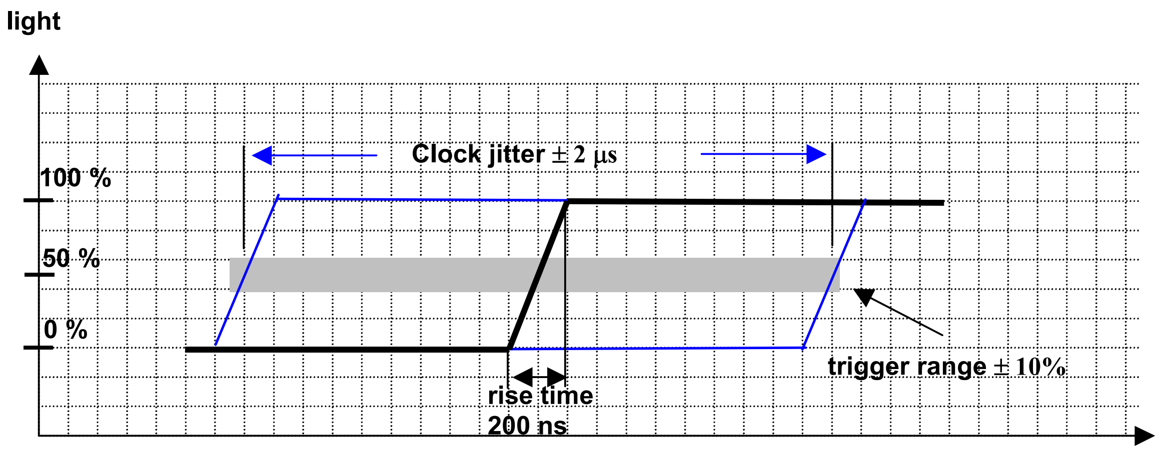

Figure 1 – Definition of the maximum clock jitter and rise time at the MU clock input

Synchronization accuracy

The source for time synchronization shall have an accuracy of ± 1µsec. The samples from a merging unit shall be time stamped with an accuracy of class 4 according to IEC 61850-5 (± 4µsec). It is assumed that the communication network may add 0..2µsec delay. Therefore, the MU clock input may have a jitter of ± 2µsec (see Figure 2 for more details). If there is more than 2µsec propagation delay between 1 PPS signal output of the clock and merging unit input, each merging unit shall be able to compensate the signal delays.

NOTE – If more than one clock is needed, GPS based clocks are necessary. The specified accuracy shall be a global accuracy between each clocks or merging units.

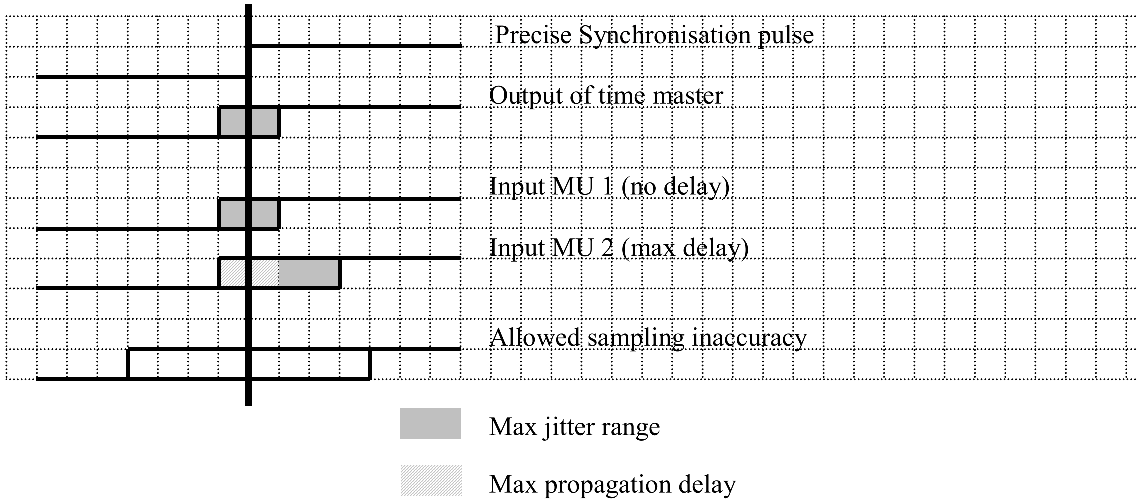

Figure 2 – Accuracy of synchronization

Operating with synchronization

As long as the merging unit is synchronized, the attribute "SmpSynch" in the SV message shall be set to TRUE. The attribute "SmpCnt" shall behave as specified in IEC 61850-7-2.

Loss of synchronization signal

If the synchronization signal is lost, the merging unit may go in a hold-over mode. This means, for a couple of seconds – depending on the drift of the internal clock, the merging unit is able to send samples still fulfilling the synchronization requirements. During this time, "SmpSynch" shall still be set to TRUE. As long as this is the case, "SmpCnt" shall wrap as if a synchronization pulse would be present (i.e. at 3999 in the case of 80 samples per period and 50 Hz network frequency).

Operating without synchronization

If the merging unit does not receive a synchronization signal and has left the hold-over mode as described above, "SmpSynch" in the SV message shall be set to FALSE. "SmpCnt" shall wrap as if a synchronization pulse would be present.

NOTE – If a physical device implements more than one logical device merging unit, it is assumed that the samples from the merging units of the same physical device are synchronized to each other even when "SmpSynch" is set to FALSE.

Clock source

The time master generating the 1PPS signal is typically based on a GPS receiver. The 1PPS pulse shall have an accuracy of ± 1µsec compared to an absolute time (GPS standard time). In case of a loss of GPS reception, the internal clock of the time master will drift away from the GPS standard time. There are two possibilities to handle that situation:

(a) The time master continues to generate the 1PPS signal. The merging unit will continue to operate with synchronization.
(b) The time master stops to generate the 1PPS signal. The merging unit will operate without synchronization.

In case (a), functions receiving information from merging units using different time masters (e.g. line differential protections) will not be aware that the samples are not synchronized anymore and will not operate correctly. However, functions receiving information from merging units using the same time master (typically functions dealing with information from the same substation only) will continue to operate. In case (b), all functions receiving information from more than one merging unit will not operate anymore. It is an issue of the system integrator, to decide which option to use.

NOTE – This situation is due to the fact, that the merging unit can only mark the samples as synchronized or not synchronized. A better approach would be to differentiate at least between global synchronized and local (e.g. station wide) synchronized. This is an open issue that should be further considered in future revisions of IEC 61850.

7.2.3 Reference arrow orientation system

See Appendix E for more details.

7.2.4 Calculations to be done in the Merging Unit

If neutral current and / or voltage are not measured, the merging unit has to calculate these values as a sum of the phase values. However, since the receiver needs to know, if the values are calculated or measured, the merging unit has to indicate that in the respective quality field.

7.3 Configuration of the Merging Unit

This clause lists the configuration parameters of the merging unit according the specification in this clause that need to be configurable.

Table 10 – Configuration parameters of the merging unit

Parameter	Value Range	Comment / SCL configuration
LDName	xxxxMUnn	xxxx is, according to [6], clause 8.4.2, the concatenation of substation name, voltage level and bay MUnn is, according to [6] the attribute **Inst** of the element **LDevice**. MU is predefined by this standard while nn needs to be configured and is used to differentiate several merging units within the same bay; i.e. nn identifies the measuring point.
MACDestinationAddress for MSVCB01	01-0C-CD-04-xx-xx	xx-xx needs to be configured if MSVCB01 is enabled
MACDestinationAddress for MSVCB02	01-0C-CD-04-xx-xx	xx-xx needs to be configured if MSVCB02 is enabled
MSVCB01 Enabled	TRUE/FALSE	Transmission of 80 samples per nominal line cycle enabled
MSVCB02 Enabled	TRUE/FALSE	Transmission of 256 samples per nominal line cycle enabled
Nominal frequency	ENUMERATION (50, 60, …)	Values like 16.7 or 25 may be used in the future

NOTE 1 - Further not uniquely defined values like the sensor identification in the LN instance names (Inn / Unn) are not relevant, since they are not visible in the SV message.

NOTE 2 – The first parameter mentioned above is a real configuration parameter. The other parameters are data of control blocks or logical nodes instantiated in the merging unit. The parameter nominal frequency is a data of the LNs TCTR and TVTR. In most cases, it is a read only configuration parameter that is preset by the merging unit.

8 PHYSICAL DEVICES

No specifications are made with regard to physical devices (IEDs). An IED may consist of more than one logical device merging unit sharing the same communication interface.

9 OPEN POINTS

In a future revision of this implementation guideline, the following topics will be considered:

- Use of IRIG-B time synchronization as alternate solution to 1PPS
- Improved flagging of synchronization status (e.g. local synch / station wide synch / global synch)

APPENDIX A: CONTENT OF AN ETHERNET FRAME

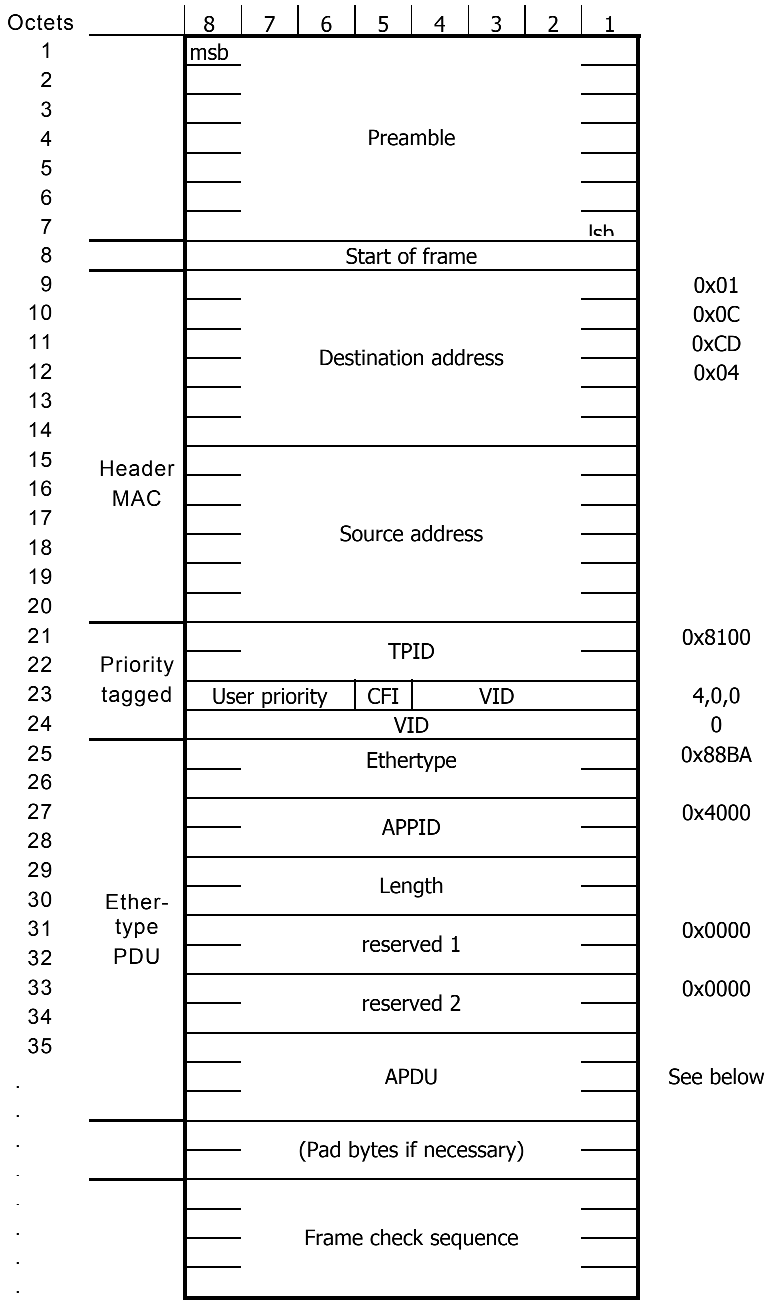

Figure 3 - Content of an Ethernet frame

Remarks to Figure 3

- Data fields consisting of one byte have the most significant bit on the left and the least significant on the right.
- Data fields consisting of more than one byte have the most significant bit in the upper left and the least significant bit in the lower right corner (as shown in the field 'Preamble').
- The octets are sent over the wire with bit 1 as the first bit.

The APDU resulting from the definitions in clause 7.1 (MSVCB02) is shown below.

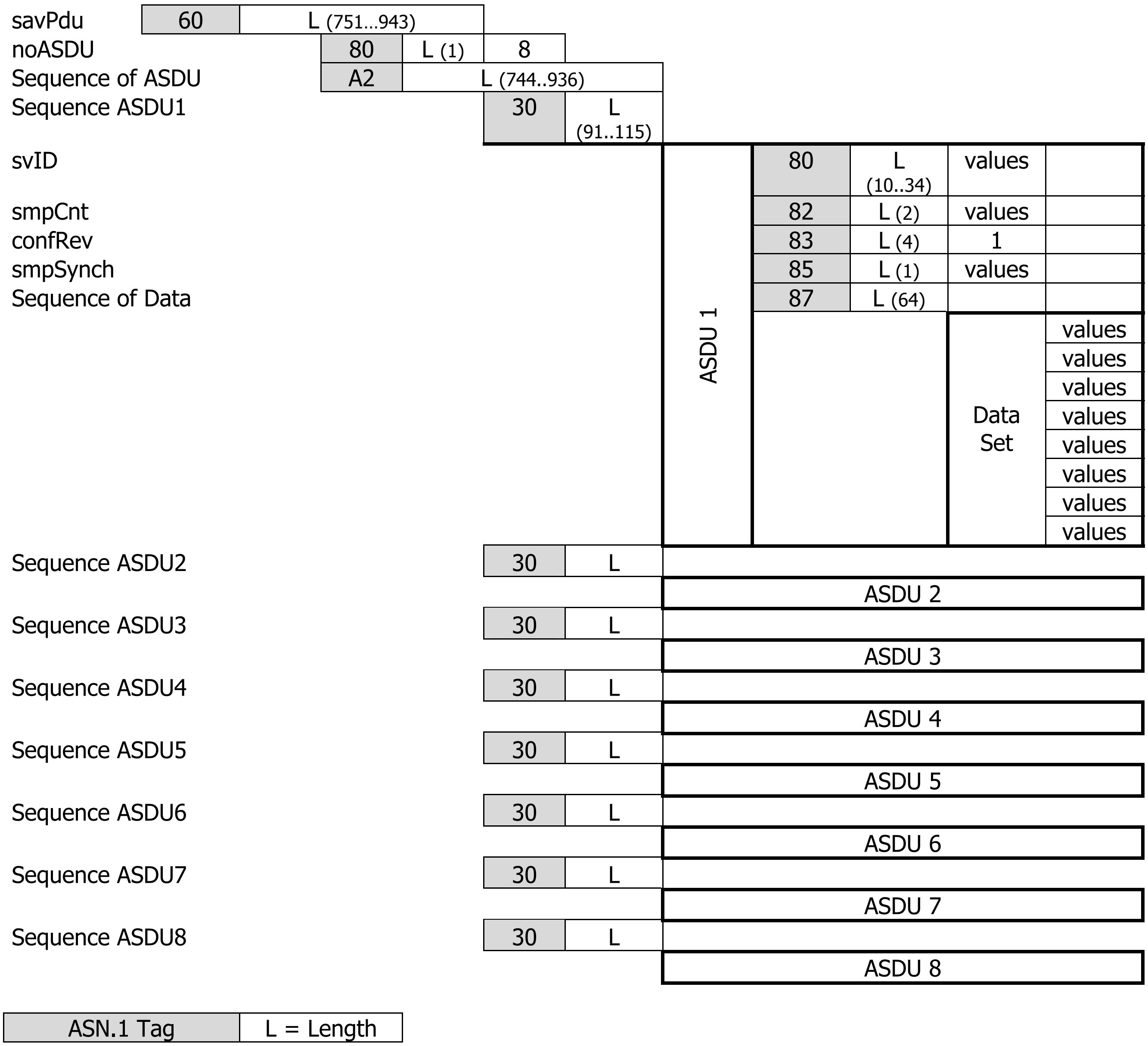

Figure 4 – APDU according the definitions of clause 7.1

The encoding of the dataset PhsMeas1 will be as follows:

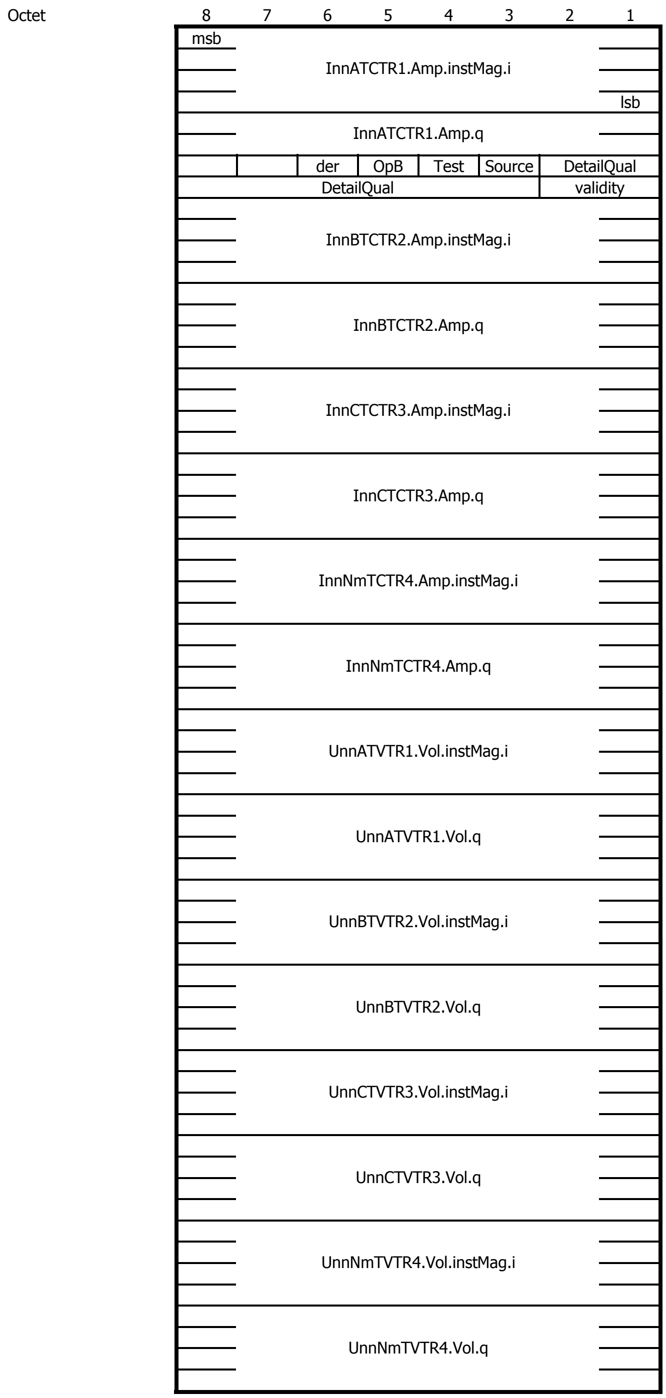

Figure 5 – Encoding of the dataset

Appendix B: XML File

The XML file below is a .icd file for a merging unit with 80 samples per period.


```xml
<?xml version="1.0" encoding="UTF-8"?>
<!-- edited with XMLSPY v5 rel. 4 U (http://www.xmlspy.com) by Christoph Brunner (ABB Switzerland Ltd) -->
<SCL xmlns="http://www.iec.ch/61850/2003/SCL" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:schemaLocation="http://www.iec.ch/61850/2003/SCL
SCL.xsd">
    <Header id="9-2LE-Spec" nameStructure="FuncName" version="0.7" revision="1"/>
    <Substation name="">
        <VoltageLevel name="">
            <Bay name="">
                <ConductingEquipment name="Inn" type="CTR">
                    <SubEquipment name="A" phase="A">
                        <LNode lnClass="TCTR" lnInst="1"/>
                    </SubEquipment>
                    <SubEquipment name="B" phase="B">
                        <LNode lnClass="TCTR" lnInst="2"/>
                    </SubEquipment>
                    <SubEquipment name="C" phase="C">
                        <LNode lnClass="TCTR" lnInst="3"/>
                    </SubEquipment>
                    <SubEquipment name="N" phase="N">
                        <LNode lnClass="TCTR" lnInst="4"/>
                    </SubEquipment>
                </ConductingEquipment>
                <ConductingEquipment name="Unn" type="VTR">
                    <SubEquipment name="A" phase="A">
                        <LNode lnClass="TVTR" lnInst="1"/>
                    </SubEquipment>
                    <SubEquipment name="B" phase="B">
                        <LNode lnClass="TVTR" lnInst="2"/>
                    </SubEquipment>
                    <SubEquipment name="C" phase="C">
                        <LNode lnClass="TVTR" lnInst="3"/>
                    </SubEquipment>
                    <SubEquipment name="N" phase="N">
                        <LNode lnClass="TVTR" lnInst="4"/>
                    </SubEquipment>
                </ConductingEquipment>
            </Bay>
        </VoltageLevel>
    </Substation>
    <IED name="TEMPLATE">
        <AccessPoint name="">
            <Server>
                <Authentication/>
                <LDevice inst="MUnn">
                    <LN0 lnType="9-2LELLN0" lnClass="LLN0" inst="">
                        <DataSet name="PhsMeas1">
                            <FCDA lnClass="TCTR" ldInst="1" fc="MX" doName="Amp"/>
                            <FCDA lnClass="TCTR" ldInst="2" fc="MX" doName="Amp"/>
                            <FCDA lnClass="TCTR" ldInst="3" fc="MX" doName="Amp"/>
                            <FCDA lnClass="TCTR" ldInst="4" fc="MX" doName="Amp"/>
                            <FCDA lnClass="TVTR" ldInst="1" fc="MX" doName="Vol"/>
                            <FCDA lnClass="TVTR" ldInst="2" fc="MX" doName="Vol"/>
                            <FCDA lnClass="TVTR" ldInst="3" fc="MX" doName="Vol"/>
                            <FCDA lnClass="TVTR" ldInst="4" fc="MX" doName="Vol"/>
                        </DataSet>
                        <SampledValueControl name="MSVCB01" datSet="PhsMeas1" smvID="xxxxMUnn01"
smpRate="80" nofASDU="1" confRev="1">
```

```
                        <SmvOpts    refreshTime="false"    sampleSynchronized="true"    sampleRate="false"
security="false" dataRef="false"/>
                    </SampledValueControl>
                </LN0>
                <LN lnType="9-2LETCTR" lnClass="TCTR" inst="1"/>
                <LN lnType="9-2LETCTR" lnClass="TCTR" inst="2"/>
                <LN lnType="9-2LETCTR" lnClass="TCTR" inst="3"/>
                <LN lnType="9-2LETCTR" lnClass="TCTR" inst="4"/>
                <LN lnType="9-2LETVTR" lnClass="TVTR" inst="1"/>
                <LN lnType="9-2LETVTR" lnClass="TVTR" inst="2"/>
                <LN lnType="9-2LETVTR" lnClass="TVTR" inst="3"/>
                <LN lnType="9-2LETVTR" lnClass="TVTR" inst="4"/>
            </LDevice>
        </Server>
    </AccessPoint>
</IED>
<DataTypeTemplates>
    <LNodeType id="9-2LELLN0" lnClass="LLN0">
        <DO name="Mod" type="9-2LEINC"/>
    </LNodeType>
    <LNodeType id="9-2LETCTR" lnClass="TCTR">
        <DO name="Amp" type="9-2LESAVAmp"/>
    </LNodeType>
    <LNodeType id="9-2LETVTR" lnClass="TVTR">
        <DO name="Vol" type="9-2LESAVVol"/>
    </LNodeType>
    <DOType id="9-2LESAVAmp" cdc="SAV">
        <DA name="instMag" bType="Struct" type="9-2LEAV" fc="MX"/>
        <DA name="q" bType="Quality" fc="MX"/>
        <DA name="sVC" bType="Struct" type="9-2LEsVCAmp" fc="CF"/>
    </DOType>
    <DOType id="9-2LESAVVol" cdc="SAV">
        <DA name="instMag" bType="Struct" type="9-2LEAV" fc="MX"/>
        <DA name="q" bType="Quality" fc="MX"/>
        <DA name="sVC" bType="Struct" type="9-2LEsVCVol" fc="CF"/>
    </DOType>
    <DOType id="9-2LEINC" cdc="INC">
        <DA name="ctlVal" fc="CO" bType="INT32"/>
        <DA name="stVal" fc="ST" bType="INT32" dchg="true"/>
        <DA name="q" fc="ST" bType="Quality" dchg="true"/>
        <DA name="t" fc="ST" bType="Timestamp" dchg="true"/>
    </DOType>
    <DAType id="9-2LEAV">
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</SCL>

APPENDIX C: TABLES WITH MEASUREMENT ACCURACY REQUIREMENTS

The two tables comprise a summary of technical data out of IEC60044–7 and –8. Accuracy and dynamic range data, which is of interest for protection functions has been added both to the current and the voltage table.

Current transformers, measuring classes — **IEC60044-8**

Accuracy class	+/- current error at percentage of rated current shown below: 1	5	20	100	120	13'000 or at accuracy limit: composite error	13'000 or at accuracy limit: peak instantantaneous error	+/- phase error δ at percentage of rated current shown below: 1 min	1 tan δ	5 min	5 tan δ	20 min	20 tan δ	100 min	100 tan δ	120 min	120 tan δ	13'000 or at accuracy limit min	13'000 or at accuracy limit tan δ
0.2S /2 [1]	*0.40%*	*0.20%*	*0.10%*	*0.10%*	*0.10%*			*15*		*8*		*6*		*5*		*5*			
0.1		0.40%	0.20%	0.10%	0.10%					15		8		5		5			
0.2S	0.75%	0.35%	0.20%	0.20%	0.20%			30		15		10		10		10			
0.2		0.75%	0.35%	0.20%	0.20%					30		15		10		10			
0.5S	1.50%	0.75%	0.50%	0.50%	0.50%			90		45		30		30		30			
0.5		1.50%	0.75%	0.50%	0.50%					90		45		30		30			
1.0		3.00%	1.50%	1.00%	1.00%					180		90		60		60			
5 TPE				1.00%		5.00%	10.00%							60					
5 P				1.00%		5.00%								60					
10 P				3.00%		10.00%								-					
IEC 61850-9-2LE shall cope with																			
	0.40%	***0.20%***	***0.10%***	***0.10%***	***0.10%***	*NCIT's are inherently superior*		***15***	***0.44%***	***8***	***0.23%***	***6***	***0.17%***	***5***	***0.15%***	***5***	***0.15%***	***5***	***0.15%***
For Protection purposes																			
	2.00%	0.40%	***0.10%***	***0.10%***	***0.10%***	*NCIT's are inherently superior*		***15***	***0.44%***	***8***	***0.23%***	***6***	***0.17%***	***5***	***0.15%***	***5***	***0.15%***	***5***	***0.15%***

[1] Class 0.2S / 2 (could also be called class 0.1S) does not exist neither in IEC60044-8, nor in other standards. It should however be discussed for NCIT's

Functions using these requirements	Metering Reverse power for large generators i.e., valve position control before shut down		Wattmetric functions in resonant grounded networks		Disturbance recording Distance protection without extrapolation at overflow condition	Metering Reverse power for large generators i.e., valve position control before shut down		Wattmetric functions in resonant grounded networks		Disturbance recording Distance protection without extrapolation at overflow condition

An angular error of 1 minute equals to a time difference of 0.772 µs @ 60 Hz and of 0.926 µs @ 50 Hz

Synchronisation has to consider the time (sampling) accuracy and time-jitter accuracy needs mentioned above (5 minutes for currents and voltages). The jitter must not exceed 5 minutes for correct distance protection with SIR ≥ 100.

Voltage transformers, measuring classes — **IEC60044-7**

Accuracy class	+/- ratio error at percentage of rated voltage shown below									+/- phase error δ at percentage of rated voltage shown below															
	1	2	5	50	80	100	120	190 [2]	250 [3]	1		2		5		50		80		100		120		190 [2]	
										min	tan δ	min	tan δ	min	tan δ	min	tan δ	min	tan δ	min	tan δ	min	tan δ	min	tan δ
0.1					0.10%	0.10%	0.10%											5		5		5			
0.2					0.20%	0.20%	0.20%											10		10		10			
0.5					0.50%	0.50%	0.50%											30		30		30			
1.0					1.00%	1.00%	1.00%											40		40		40			
3.0					3.00%	3.00%	3.00%																		
3P		6.00%	3.00%					3.00%	3.00%			240		120										120	
6P		12.00%	6.00%					6.00%	6.00%			480		140										140	
IEC 61850-9-2LE shall cope with	*10.0%*	6.0%	3.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	360	10.5%	240	7.0%	120	3.5%	5	0.15%	5	0.15%	5	0.15%	5	0.15%	5	0.15%

Functions using these requirements	Distance protection, phase-to-ground loop			Calculation of U_{ph-ph} for distance function, ph-ph loop, SIR=100 U0 calculation in directly grounded networks U_0 calculation in resonant grounded networks						Distance protection, phase-to-ground loop						Calculation of U_{ph-ph} for distance function, ph-ph loop, SIR=100 U0 calculation in directly grounded networks U0 calculation in resonant grounded networks									

[2] IEC60044-7 asks for:
- 190% for resonat grounded systems or systems without neutral grounding
- 150% for directly grounded systems

This is rather modest, a minimum shall be:
- In directly grounded systems: $0.8 \times 1.73\ U_{rated} \times 1.2 = 1.7\ U_{rated}$,
  where $0.8 \times 1.73\ U_{rated}$ represents the highest voltage in the healthy phases during a single line to ground fault and the factor 1.2 stands for the highest network voltage.
- In resonant grounded systems: $1.73\ U_{rated} \times 1.2 = 2.1\ U_{rated}$,
  where $1.73\ U_{rated}$ represents the highest voltage in the healthy phases during a single line to ground fault and the factor 1.2 stands for the highest network voltage.

[3] To cover most cases, it isproposed to fix the rated voltage factor to 2.5

When using NCIT's, all phase-to-phase voltages as well as U_0 and $3I_0$ have to be calculated from the phase values. For such calculations the tolerances for angular errors are often more important than the amplitude errors.
For conventional CT's and VT's similar ratio- and phase-errors in each of the three phases have been historically assumed. This assumption is not valid for NCIT's anymore. Arbitrary errors (within the tolerance band) have to be admitted instead (i.e., errors are different for each of the three NCIT in a thre phase system).
This is the reason why NCIT's will have to fulfill a more narrow error tolerance band to satisfy the protection requirements than conventional CT's and VT's.

An angular error of 1 minute equals to a time difference of 0.772 µs @ 60 Hz
and of 0.926 µs @ 50 Hz

Synchronisation has to consider the time (sampling) accuracy and time-jitter accuracy needs mentioned above (5 minutes for currents and voltages).
The jitter must not exceed 5 minutes for correct distance protection with SIR $\geq$ 100.

Appendix D: Nomograms for checking of dynamic ranges

Appendix D demonstrates that the INT32 representation with the scaling as defined within IEC 61850-9-2LE will satisfy the complete dynamic range required by all practical cases. The two nomograms illustrate the need for dynamic ranges versus the possibilities of the INT32 data representation.

The chosen values for the LSB's are:

- Current: LSB = 1 mA (instantaneous value)
- Voltage: LSB = 10 mV (instantaneous value)
- One bit is used for the sign (+ or -)

The bit-range required has been determined as shown in the example below for a current measurement according to class 0.1 and application of protection and disturbance recording. The LSB value is chosen to be around 4 times less than the minimum voltage or current error allowed.

Example:
Object with 100 A rated current.
100 A (r.m.s.) = 141'421 mA (peak) for pure sinusoidal signals.
141'421 = $2^{17.1}$ represents the numerical expression for the rated object current in this example.

- The maximum current error tolerated for an ECT according to class 0.1 at 5% of its rated current equals to 0.4%.
- The tolerated error thus becomes 0.0002 I_{rated}. The value of 0.0002 / 4 equals to 0.00005 and further equals to $2^{-14.3}$
- The highest current value at accuracy limit is in this case 65 I_{rated} x 2 = 130 I_{rated}. 130 = $2^{7.0}$
- We get the minimal binary peak value as: $2^{17.1} \times 2^{-14.3} = 2^{2.8}$ → o.k., since $2^{2.8} > 2^0$
- The max binary value becomes $2^{17.1} \times 2^{7.0} = 2^{24.1}$ → o.k., since $2^{24.1} < 2^{31}$

Note:
Voltage measurement:

- Distance- and accurate reverse power- functions are not applied for voltages below 6 kV.
- For voltage measurement on objects with rated voltages below 3 kV, class 0.5 for metering is sufficient.

Current measurement:

- For current measurement on objects with rated current below 100 A, class 0.5 for metering is sufficient.
- Highest current values have to be expected for faults near terminals of large generators.

In such cases the maximum short-circuit current is limited by the block transformer to below 10 times the rated generator current.

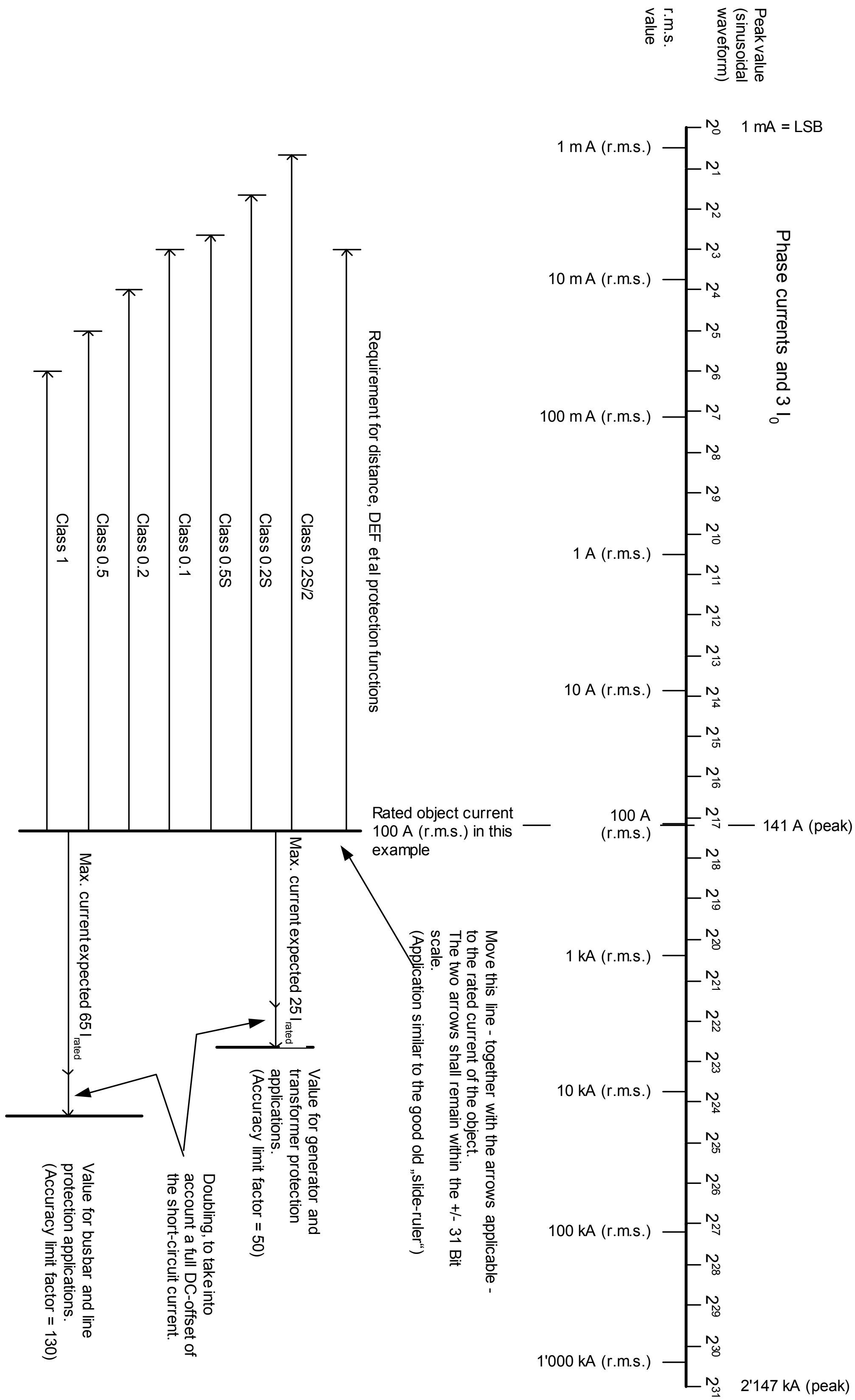

Figure 6 – Nomogram for current

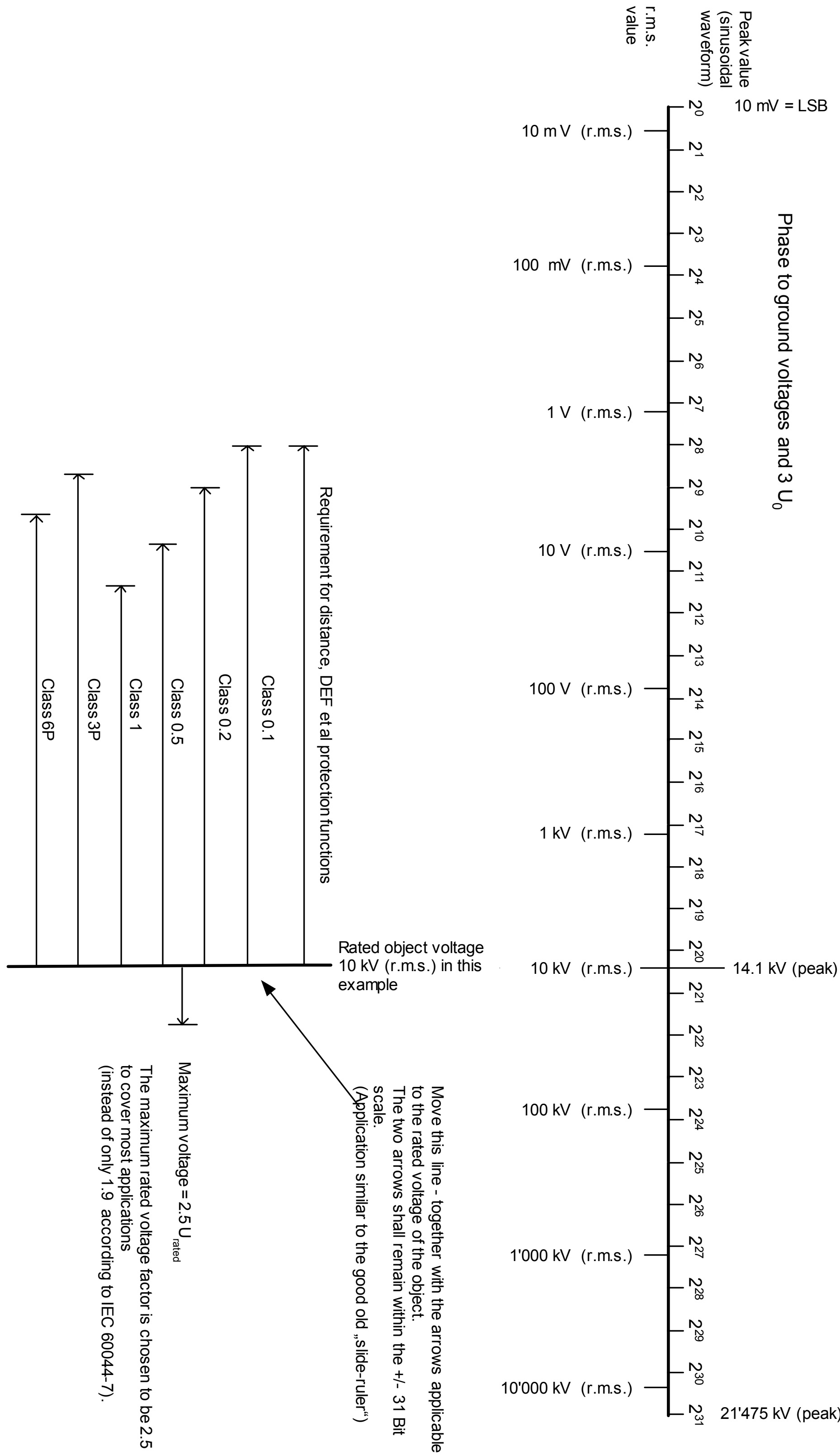

Figure 7 - Nomogram for voltage

APPENDIX E: REFERENCE ARROW ORIENTATION SYSTEM

Legend

U Voltage
I Current
N Neutral
E Earth (IEC notation) = Ground (ANSI notation)

Indices (subscript)
A Phase A
B Phase B
C Phase C
N Neutral
E Earth = Ground
P Parallel overhead line, if applicable
1 Positive sequence
2 Negative sequence
0 Zero sequence

The positive sense of arrows (phasors) follows the „load vector system" i.e., the voltage-drop across a resistor is in phase with the current.

DBB Double Bus Bar arrangement
OHB 1½ (One and a Half) Breaker arrangement
I_E Earth (ground) return current

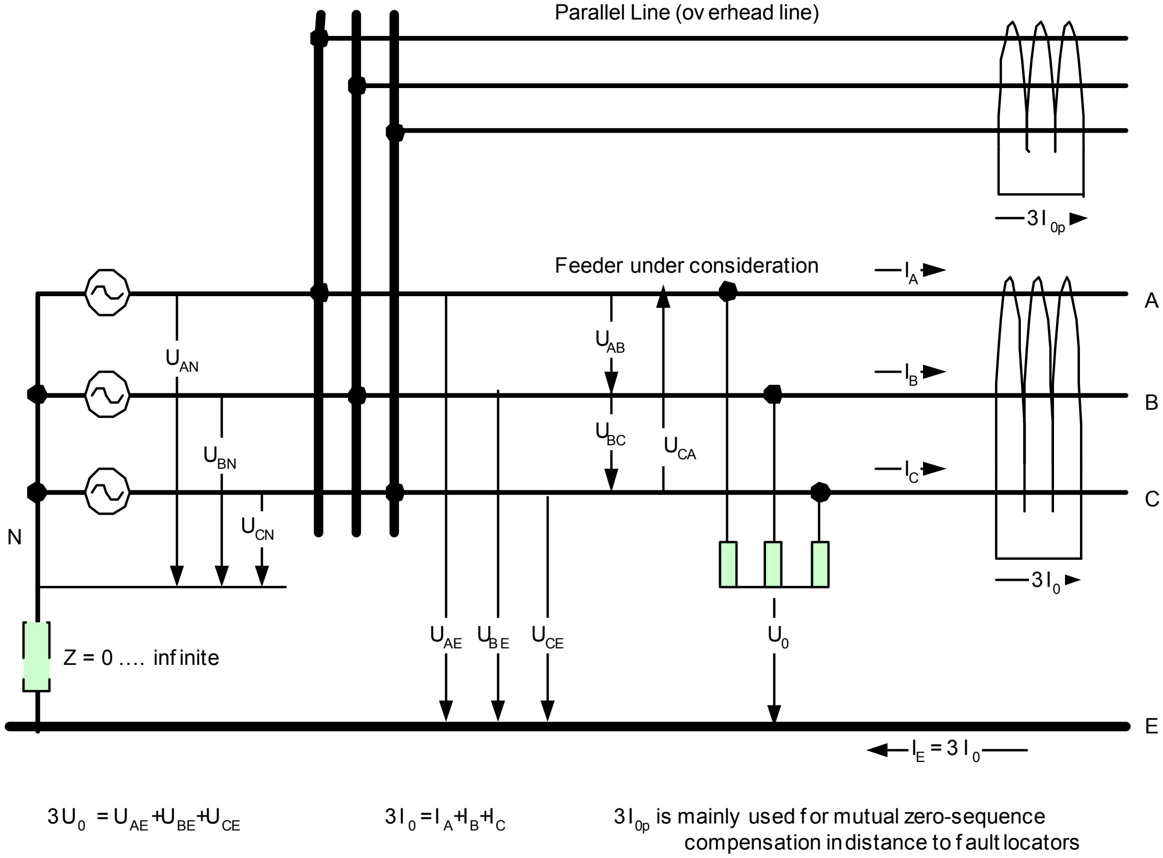

Figure 8 - Generic three phase system including voltages and currents

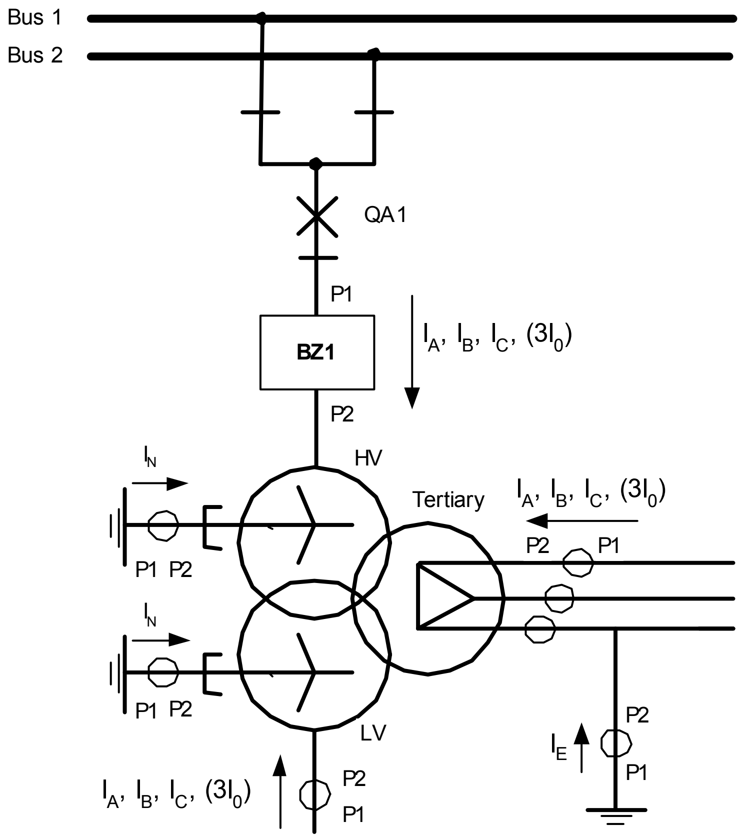

Figure 9 - Currents in DBB (double bus bar) arrangement

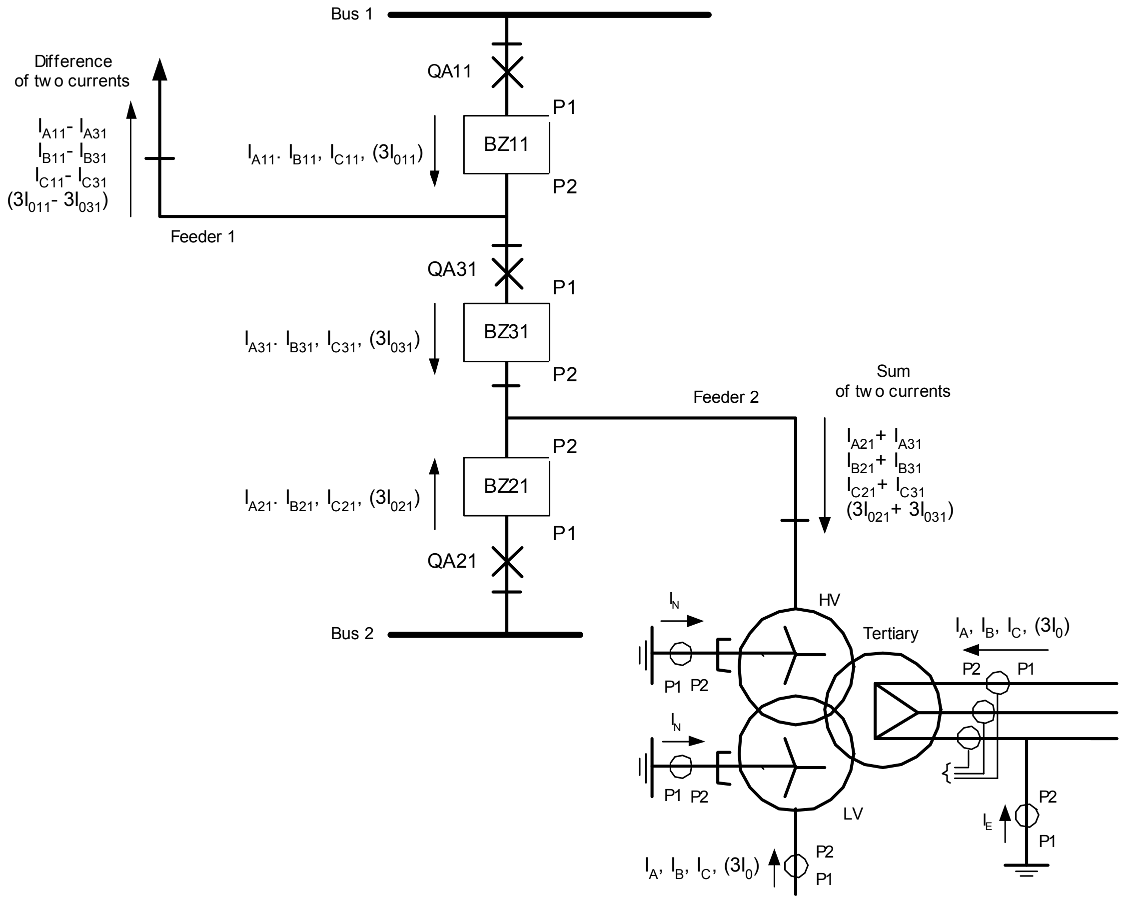

Figure 10 - Currents in OHB (one and a half breaker) arrangement

Figure 11 shows the connections between conventional equipment and CT's. The neutral of the CT's is formed on object-side. The primary current and the current in the protection relay are "in phase". The arrow orientation is in line with the system used for NCIT's (as defined in IEC 60044-8, clause 11.1.3). The drawing shall help to co-ordinate mixed mode configurations (mixed-mode uses digital data streams from NCIT's and inputs from conventional CT's and VT's). Furthermore the diagram shall illustrate that IN, as it is used with conventional CT's, results in I_N = - 3 I_0.

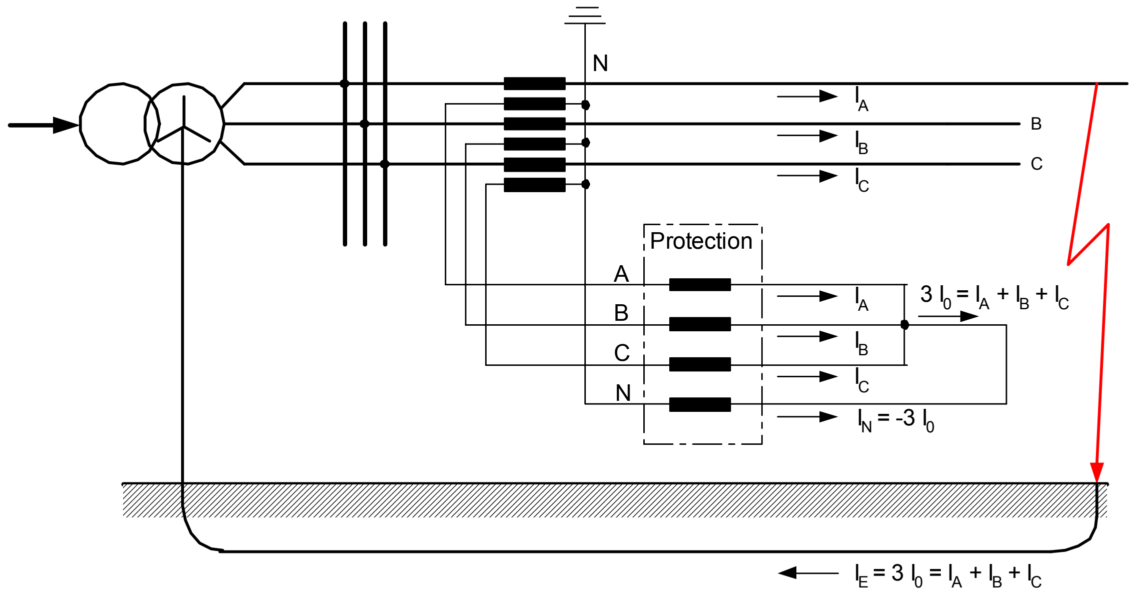

Figure 11 – Reference arrow orientation system, conventional CTs with CT star-point (neutral) on object side

Figure 12 shows an alternative connection for conventional equipment as used by several vendors i.e., the neutral of the CT's is formed on bus-side. In this case the arrow orientation for the secondary equipment is inverted (The primary current and the current in the protection unit are "in counter phase". This must be considered for directional- and differential- functions. To ease adaptation to the two conventions, the IEC61850-9 inputs should preferably be selectable: direct or inverted.

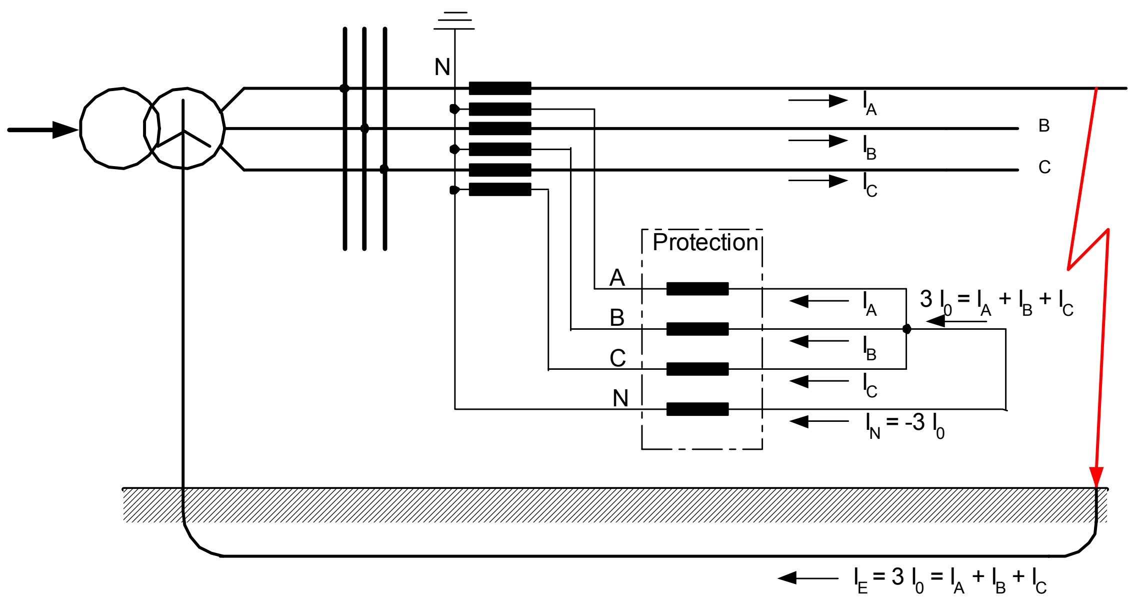

Figure 12 - Reference arrow orientation system, conventional CTs with CT star-point (neutral) on bus-side

Change Information

Date	Change Index	Document State	Author	Remarks
04-03-01	2.0a	Released	Ch. Brunner	Version released at UCA usersgroup meeting
04-07-07	2.1	Released	Ch. Brunner	Modifications in Figure 4 (Length of ConfRev) and 5 (Quality fields)