

## **Report on a Common Data Format for IED Sampled Data**

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IEEE PSRC Working Group H5-c to the Relay Communications Subcommittee  
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## **1 OVERVIEW**

### **1.1 Scope of Report**

This report's goal is to present the missing and common data components of sampled data in Intelligent Electronic Devices (IEDs) typical in a power system as identified in various international standards and it attempts to create a roadmap for data exchange between them. It is intended as a recommendation to IEEE PSRC / Relay Communications Subcommittee for consideration in their activities.

### **1.2 Purpose of Report**

This IEEE PSRC Working Group report presents an investigation of "sampled data" utilized in modern IEDs. It summarizes the definitions of "sampled data" pertaining to IED's and relevant new international standards that have been introduced since the IEEE Std C37.111-1999 COMTRADE. The information will be useful to anyone needing to exchange data between the referenced standards outside of the IED or as design considerations for a new IED. Specific recommendations will be made to address any potential changes to the standards that would facilitate the data exchange process.

### **1.3 Introduction to Sampled Data Applications**

There are new requirements that need to be defined for universal exchange and interlocking of sampled data and other related IED data. Three standards were identified as being critical for IED sampled data, these standards are: COMTRADE - IEEE Std C57.111-1999, PQDIF - IEEE Std 1159.3-2002, and IEC-61850.

Creating a synergy of sampled data among these standards would benefit the industry as a whole and resolve future IED compatibility issues. Both PQDIF and IEC61850 have a XML-based data file structure, it was determined that a possible mapping of the existing COMTRADE file structures into the IEC-61850 SCL and XML data modeling could resolve missing logical node definitions, data values, and matching data types. Making COMTRADE a subset of the PQDIF data superset could harmonize many issues including the issue of variable sample rates and how to handle them within COMTRADE. These efforts could result in lossless data conversion between these standards. This report defines the possibilities for data exchange under the present versions and will recommend future beneficial changes as appropriate.

## 2 EXISTING SAMPLED DATA STANDARDS

### 2.1 COMTRADE – IEEE Std C37.111-1999

The Common Format for Transient Data Exchange (COMTRADE) was first published in 1991 as C37.111. It was later revised in 1999 to expand and clarify the definitions of the data exchange format. The standard specifies four files of which one contains the actual sampled data. The data file has the extension (.DAT) and the data can be in either ASCII or binary format. In order to extract the sampled data into meaningful information, it is necessary to use the accompanying configuration file (.CFG) that specifies the sample rate, type of data, number of channels and scaling factors along with other key information.

The data file structure consists of rows and columns, the first column is the sample sequence number, and the second column is the time stamp for that sample number. Beginning with the third column is the analog input(s) and following all analog channels are the columns of the status inputs. In each row (or scan) a comma separates the data and the last value must end with a carriage return/line feed (<CR/LF>) indicating the end of the data row.

From the standard, “Each data sample record shall consist of integers arranged as follows:

**n, timestamp, A<sub>1</sub>, A<sub>2</sub>, ...A<sub>k</sub>, D<sub>1</sub>, D<sub>2</sub>, ...D<sub>m</sub>**

where,

**n** is the sample number. Critical, integer, numeric, minimum length = 1 character, maximum length = 10 characters, minimum value = 1, maximum value = 9999999999.

**Timestamp** is the time stamp. Non-critical if **nrates** and **samp** variables in .CFG file are nonzero, critical if **nrates** and **samp** variables in .CFG file are zero. Integer, numeric, minimum length = 1 character, maximum length = 10 characters. Base unit of time is microseconds ( $\mu s$ ). The elapsed time from the first data sample in a data file to the sample marked by any time stamp field is the product of the time stamp and the time multiplier in the configuration file (**timestamp**  $\times$  **timemult**) in microseconds. When both the **nrates** and **samp** variable information are available and the **timestamp** information is available, the use of **nrates** and **samp** variables is preferred for precise timing.

**A<sub>1</sub>** } are the analog channel data values separated by commas  
\* } until data  
\* } for all analog channels are displayed. Non-critical, integer,  
numeric,  
minimum length = 1 character, maximum length = 6 characters,

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- \* minimum value = Ð99999, maximum value = 99998. Missing analog
- A<sub>k</sub>** values must be represented by placing the value 99999 in the field.
- D1** } are the status channel data values separated by commas until data for all
- \* } status channels are displayed. Non-critical, integer, numeric, minimum
- \* } length = 1 character, maximum length = 1 character. The only valid
- \* } values
- \* } are 0 or 1. No provision is made for tagging missing status data and in such
- Dm** cases the field must be set to 1 or to 0. The last data value in a sample shall be terminated with carriage return/line feed.

An example of ASCII sampled data containing six analog values and six status values could be represented as:

**5, 667, -760, 1274, 72, 61, -140, -502, 0,0,0,0,1,1 <CR/LF>**

Binary data files have the same basic structure except status channel data are compacted. No data separators are used and no carriage return/line feed terminates the data row. Data translation is made by sequential position within the file. The data is stored in LSB/MSB format and must be converted accordingly.

A binary example of the equivalent ASCII record above would be:

**05 00 00 00 9B 02 00 00 08 FD FA 04 48 00 3D 00 74 FF 0A FE 30 00**

## 2.2 PQDIF – IEEE Std 1159.3-2002

IEEE Standard 1159.3 (commonly known as the Power Quality Data Interchange Format – PQDIF), is a file or stream based mechanism of transferring power quality and related measurement or simulation data from a data source to a data sink in a compact, unambiguous, and deterministic way.

PQDIF was developed by the power quality community to address deficiencies in the use of COMTRADE for power quality purposes. In order to ensure that there were clear requirements not being met by COMTRADE, a development effort utilizing requirements driven approach using formal software engineering design techniques was decided upon. The following requirements were identified:

- Must result in a single, compressed, binary file representation using a unique file extension to facilitate OS and MIME file/application associations

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- Must be able to represent all PQ event types defined in the IEEE 1159 power quality monitoring standard, relevant IEC standards (61000-4-7, 4-15, 4-30), and others (e.g. UNIPED DISDIP, EN50160)
- Must be able to contain multiple event, trend, and other recordings over an arbitrary time period (nanoseconds to years) in a single file or stream
- Although compressed binary, the entire file or stream must not be corruptible by a single byte change – i.e. the format must be inherently correctable, partitioned or otherwise re-synchronizable
- Must be streamable over a serial communications channel (e.g. RS-232 or TCP/IP) and serially decodable (i.e. don't need to look at entire file/stream before decoding useful information).
- Must be versionable and user/vendor extensible without the need for a central registration authority
- Extensions must be implemented in a way that readers unaware of the extensions can ignore unknown records, data blocks, and tags without knowing the format of the unknown elements.
- Nanosecond or better time stamp resolution is required

The result of the design effort was a file format that is made up of records which are logically related. There are four types of records:

- Container (start of stream or file identifier, global options)
- Data Source (channel and series definitions generally representing an instrument or simulation program)
- Monitor Settings (optional – PT/CT ratio's, frequency response characteristics, calibration, etc.)
- Observations (e.g. waveforms, RMS traces, events, trends, statistics, etc.)

These records are organized in a hierarchical structure based on the record type as shown in Figure 2-1. The “high-level” record structure is completely separated from the “low-level” element structure.

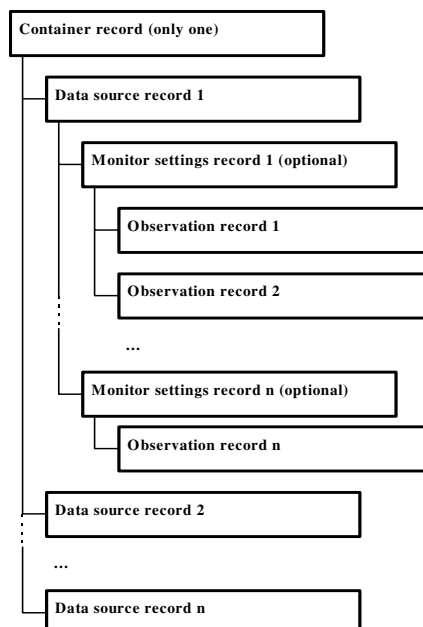


Figure 2-1 – Hierarchical Structure of PQDIF

Physically, the file is made up of a series of linked records of the various types defined above as shown in Figure 2-2. This approach allows the overall structure of the file to be parsed quickly without having to read the entire file.

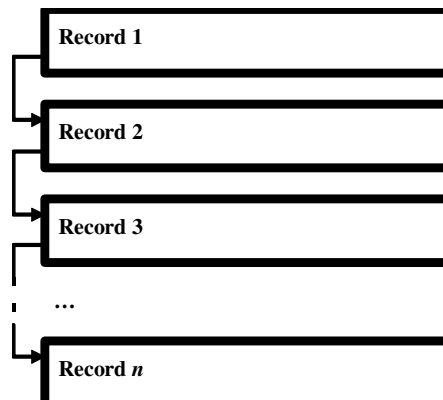


Figure 2-2 – Linked Record Structure of PQDIF

Each record is made up of a “header” and a “body.” The header provides the high-level information. The body contains the low-level information. The contents of the header allow for a parser to determine the record type by the tag field. If the parser doesn’t know about that tag type, it can ignore it by using the size and link information to find the next record in the file. A signature is also provided to further validate the record as a valid PQDIF record.

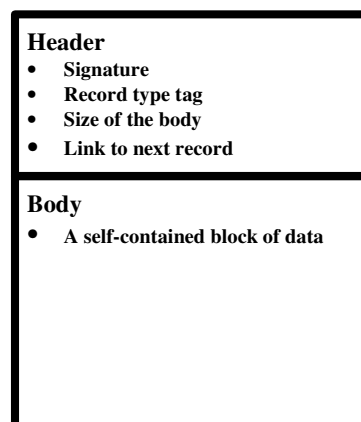


Figure 2-3 – Record Contents of PQDIF

The body of each record is made up of a set of “elements” which contain data. There are three element types:

- Scalar - represents a single data value
- Vector - represents an array of data values
- Collection - contains other elements

In order to be able to identify a specific record or element, each one is given a “tag.” This tag is actually a GUID, which makes extending the list of tags straightforward and does not require a central registration authority.

This structure can be thought of in terms of a file system. With this analogy, a tag can be thought of as a file name that inherently indicates what the contents to follow are used for. A collection would be a subdirectory, a scalar is a file with one value (number, string, GUID, timestamp) in it and a vector is a file with a series of values in it. A collection can contain other collections which creates a hierarchy just like a file system.

The scalar or vector elements can hold values of the following types:

- Signed integer (1, 2 or 4 bytes)
- Unsigned integer (1, 2 or 4 bytes)
- Boolean (1, 2 or 4 bytes)
- Real (4-byte single or 8-byte double precision)
- Complex (8-byte single or 16-byte double precision)
- Character (1-byte ASCII or 2-byte Unicode)
- Date stamp (12 bytes)
- GUID (16 bytes)

Because each element is tagged, there is a separation between the “physical” and “logical” structure. This allows the logical structure to be defined separately from the physical structure. The low-level physical format allows each element to have a tag. The logical format defines what the tags are, and what element type and primitive data type(s) are expected for each. Since collections can contain other collections, the logical format also specifies this hierarchy.

Probably the most important logical construct of a PQDIF file is the Observation Record. Observations are time stamped and contain the actual measured or simulated data from one or more logical channels. The type, format, units and other attributes of a channel are defined once in the Data Source Record (channel and series definitions). Observation Records instantiate instances of one or more of those channels and within a channel, one or more data series that are necessary to represent the data associated with that channel.

In general, a channel has the following attributes:

- Quantity Type – waveform, phasor, value log, flash, ...
- Quantity Measured – voltage, current, power, energy, temp, ...
- Quantity Characteristic – instantaneous, rms, thd, tif, TPF, ...
- Series Quantity Units – volts, amperes, watts, vars, ...
- Series Value Type – time, val, min, max, avg
- Phase or channel ID

A channel of an observation can represent power quality event summaries, waveform or phasor domain traces, period recording (time trends) of any quantity, sequence of event logs, and statistical data of any quantity that can be represented in standard SI units.



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For power quality purposes, a variety of fundamental quantity types have been identified:

- **ID\_QT\_WAVEFORM**  
Used to represent instantaneous measured or simulated time series waveform data during a disturbance or manually triggered capture.
- **ID\_QT\_PHASOR**  
Used to represent time series RMS (Phasor) domain disturbance data – primarily used for voltage sag/swell event recording.
- **ID\_QT\_VALUELOG**  
Used to represent any steady-state measured quantity over time (trend data). Individual observations normally contain 24 hours of trend data by convention but can support any arbitrary period
- **ID\_QT\_MAGDUR**  
Magnitude, duration and related quantities for RMS variation events
- **ID\_QT\_CPF**  
Cumulative probability data for any quantity as often used in IEC flicker, harmonic, unbalance, and other measurements
- **ID\_QT\_FLASH**  
Lightning flash data

Figure 2-4 illustrates the channel definition for a channel that represents an instantaneous waveform recording. This channel contains two series within the definition – a series to represent the time coordinates and a series to specify the magnitude coordinates. This channel definition is analogous to the COMTRADE .CFG file. The primary difference is that the quantity type, measured, units, and phase information are all rigorously defined and unambiguous.

Level	Element Tag	Example Value
0	tagRecDataSource	--NA--
1	tagNominalFrequency	60.0
1	tagChannelDfns	--NA--
2	tagOneChannelDfn	--NA--
3	tagPhaseID	<i>ID_Phase_AN</i>
3	tagQuantityTypeID	<i>ID_QT_Waveform</i>
3	tagQuantityMeasuredID	<i>ID_QM_Voltage</i>
3	tagSeriesDfns	--NA--
4	tagOneSeriesDfn	--NA--
5	tagValueTypeID	<i>ID_Series_Value_Type_Time</i>
5	tagQuantityUnitsID	<i>ID_QU_Seconds</i>
5	tagQuantityCharacteristicID	<i>ID_QC_None</i>
5	tagStorageMethodID	<i>ID_Series_Method_Values</i>
4	tagOneSeriesDfn	--NA--
5	tagValueTypeID	<i>ID_Series_Value_Type_Val</i>
5	tagQuantityUnitsID	<i>ID_QU_Volts</i>
5	tagQuantityCharacteristicID	<i>ID_QC_Instantaneous</i>
5	tagStorageMethodID	<i>ID_Series_Method_Values</i>

Figure 2-4 – Channel definition of PQDIF

Figure 2-5 illustrates the channel instance data found in an observation record. This record contains a reference to the channel definition that describes the meaning of the channel instance data. This eliminates the need to represent redundant information in the observation channel instance data. Note that the standard also provides multiple ways to represent time series points to save space. The time series can be specified as discrete values (one per data value), or as one or more delta values and point counts. A channel can also be defined to point to the time series of another channel – a shared time series – so that it doesn't have to be specified again at all.

Level	Element Tag	Example Value
0	TagRecObservation	--NA--
1	TagObservationName	<i>Phase A Voltage Waveform</i>
1	TagTimeCreate	<i>12/9/1998 11:42:24.453813818</i>
1	TagTimeStart	<i>2/13/1998 23:17:44.086079597</i>
1	TagTriggerMethodID	<i>ID_Trigger_Meth_Channel</i>
1	TagTimeTriggered	<i>2/13/1998 23:17:44.086079597</i>
1	TagChannelInstances	--NA--
2	TagOneChannelInst	--NA--
3	TagChannelDefnIdx	<i>57</i>
3	TagSeriesInstances	--NA--
4	TagOneSeriesInstance	--NA--
5	TagSeriesValues	<i>0,0.00013,0.00026, . . .</i>
4	TagOneSeriesInstance	--NA--
5	TagSeriesValues	<i>-4607.4621, -5030.9689, -5428.9193, . . .</i>

Figure 2-5 – Channel instance data of a record in PQDIF

High end power quality monitors typically have data sources defining 200 or more channels. Most of these channels represent steady state ID\_QT\_VALUELOG type data. Other channels represent transient, rms variation, harmonic, lightning, and event statistical information. Typically an instrument or gateway produces a single PQDIF file per day containing all event and trend observations for that day. When compressed, a typical daily PQDIF file of this sort may be around 1 MB in size.

Since the release of IEEE 1159.3, implementers have identified a few additions to the standard they would like to make. The use of GUID's for extensibility has allowed them to make those changes themselves without breaking existing reader/analysis programs or colliding with other implementer changes. The changes can then be implemented in the formal standard definition during the next maintenance release.

## 2.3 IEC 61850

### 2.3.1 Introduction

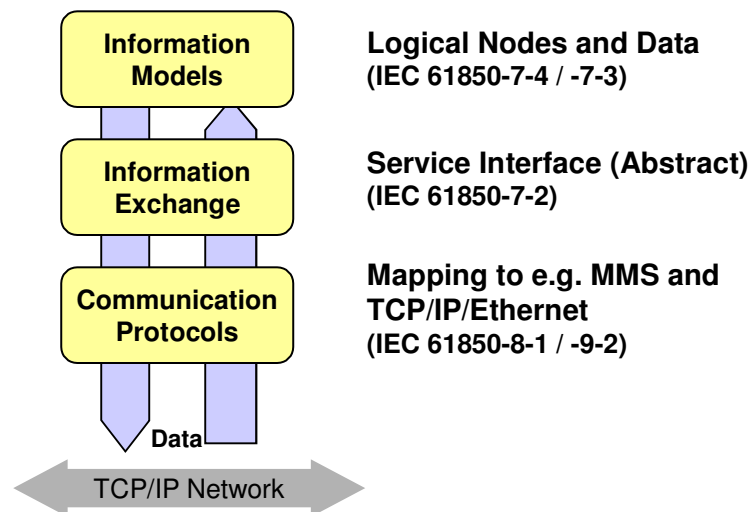
IEC 61850 is a series of standards that consists of 14 parts. The title of IEC 61850 is "Communication Networks and Systems in Substations". However, IEC 61850

specifies more than the communication interfaces. It includes information models of the substation equipment, the specification of a configuration language used to exchange configuration information between tools from different manufacturers of substation automation equipment and specification of conformance testing of the communication interfaces.

The goals of IEC 61850 are:

- Interoperability: The ability of IED from one or several manufacturers to exchange information and use that information for their own functions.
- Free configuration: The standard shall support different philosophies and allow a free allocation of functions e.g. it will work equally well for centralized (RTU like) or decentralized (SCS like) systems.
- Long Term Stability: The standard shall be future proof, i.e. it must be able to follow the progress in communication technology as well as evolving system requirements.

The specification method of IEC 61850 is based on a layered approach. The basic concept of this approach is shown in Figure . In part 7-3 and 7-4, the information model of the substation equipment is specified. This includes models for primary devices like circuit breakers or instrumental transformers as well as models for secondary functions like e.g. any kind of protection function or a metering function. In part 7-2, the models used for the information exchange and the related communication services are described abstract, independent from any communication protocol. This is called abstract communication service interface (ACSI). In part 8-x and 9-x finally, it is explained how real communication protocols are used to transmit the information specified in IEC 61850-7-3 and -7-4 using the services of IEC 61850-7-2. In the terminology of IEC 61850, this is called “specific communication service mapping” (SCSM). With that approach, the usage of newer communication technologies in the future may be easily achieved without influencing the information models and the information exchange models.



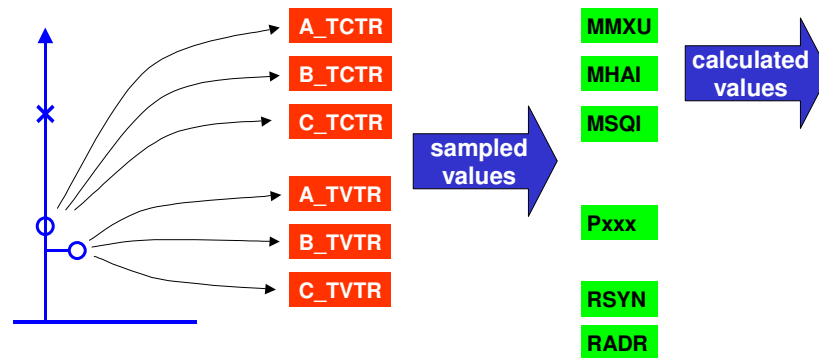
**Figure 2-6 – The concept of the specification method used in IEC 61850**

### 2.3.2. The information model according to IEC 61850

The core element of the information model is the logical node. A logical node can be considered as a basic container of related functional data of any definable element. Logical nodes represent a function's information as defined by its data and data attributes. There are two basic kinds of logical nodes:

- Logical nodes representing information of the primary equipment (e.g. Circuit breaker – XCBR or current transformer – TCTR). These logical nodes implement the interface between the switchgear and the substation automation system.
- Logical nodes representing information of substation automation functions. Examples are any kind of protection functions (e.g. distance protection – PDIS) or the measurement unit – MMXU.

The logical nodes involved in the acquisition of measured information are shown in Figure -7. TCTR is the logical node for a current transformer, TVTR the one for a voltage transformer. (Note that the logical nodes representing primary equipment are typically single phase.) Therefore we need three instances of a logical node TCTR or TVTR to represent a three-phase device. In the example of Figure -7, the instance name includes the phase identification as a prefix (e.g. A for phase A). The output of the logical nodes TCTR and TVTR is representing the waveform on the power line. Several logical nodes representing substation automation functions are using that waveform. The examples shown in Figure -7 are MMXU – Measurement unit (the function to calculate e.g. rms values), MHAI – harmonic calculation, MSQI – sequence calculation, Pxxx – any kind of protection functions, RSYN – synchrocheck and RADR – waveform recording, analog channel.



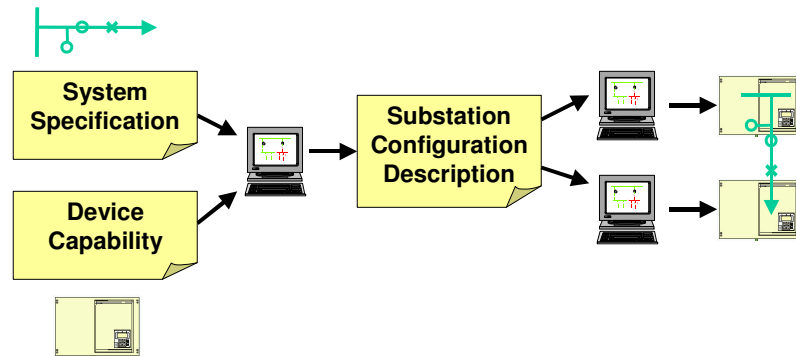
**Figure 2-7 - Acquisition of measured information**

### 2.3.3 Substation Configuration Language

IEC 61850-6 is describing the substation configuration language. This is an XML based representation of configuration information needed to configure the substation. The purposed of the files according to SCL is, to exchange configuration information between the different tools.

Figure shows the different files defined with the substation configuration language. The system specification includes all aspects of the substation itself; i.e. it describes the single line diagram of the substation and the required substation automation functionality. The device capability describes the capabilities of an IED that may be used to implement a part of the substation automation functionality. These files – one system specification and one device capability description per IED type used – are used as input to the substation configuration tool. The substation configuration description is the result of the engineering process and contains all configuration information. This includes:

- the association of functions realized in the IEDs to the primary equipment; i.e. the association of a protection relay with the feeder it protects
- the complete communication configuration like IP addresses
- the data flow between IEDs
- the detailed data models implemented in the IEDs
- the values of preconfigured configuration attributes in the data model of the IED



**Figure 2-8 – Use of SCL**

#### 2.3.4 Sampled data in IEC 61850

IEC 61850 has two areas where it deals with sampled data. The first is the modeling of the acquisition of sampled data from current and voltage measurement as shown already in Figure above. The data object A of the LN TCTR is representing a sample of the current waveform (similar for V of TVTR). The communication services defined in IEC 61850-7-2 and IEC 61850-9-2 describe how a series of samples is transmitted over the communication network. While the main purpose of these communication services is for the online transmission of sampled values between e.g. a CT or VT and the protection relay, it would be possible to use these communication services to replay a recorded sequence of sampled data.

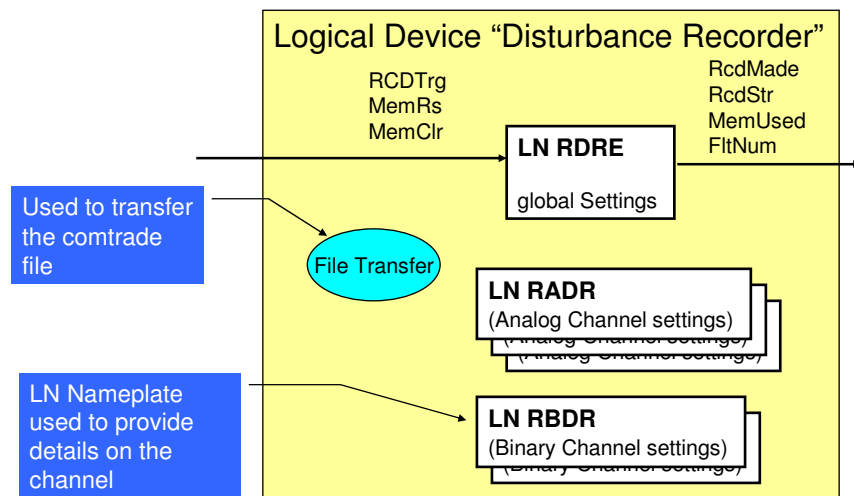
The second area is the description concerning the recording of a series of sampled data. Here, IEC 61850 does not describe a new format for the file, where the sampled data are stored. Instead, IEC 61850 refers to COMTRADE. Using file transfer, a COMTRADE file can be retrieved from the device. However, what IEC 61850 defines, is the structure to configure the recording of sampled data.

For that purpose, IEC 61850 introduces three logical nodes:

- RDRE: Disturbance recorder function
- RADR: Disturbance recorder channel analog
- RBDR: Disturbance recorder channel binary

With these logical nodes, a disturbance recorder can be modeled as shown in Figure . For each channel, an instance of the logical node RADR or RBDR is

required. These logical nodes contain all channel specific settings and information if that specific channel has triggered. The logical node RDRE is required once. This logical node contains the global settings and information concerning the status of the recorder and the required control, e.g. to clear the memory of the recorder.



**Figure 2-9 – principles of modeling a disturbance recorder in IEC 61850**

In Table 2-1, the data of these logical nodes are listed, including an explanation.

LN RDRE:

OpCntRs	Resetable operation counter	O
<b>Controls</b>		
RcdTrg	Trigger recorder	O
MemRs	Reset recorder memory	O
MemClr	Clear Memory	O
<b>Status Information</b>		
RcdMade	Recording made	M
FltNum	Fault Number	M
GriFltNum	Grid Fault Number	O
RcdStr	Recording started	O
MemUsed	Memory used in %	O
<b>Settings</b>		
TrgMod	Trigger mode (internal trigger, external or both)	O
LevMod	Level Trigger Mode	O
PreTmms	Pre-trigger time	O
PstTmms	Post-trigger time	O
MemFull	Memory full level	O

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MaxNumRcd	Maximum number of records	O
ReTrgMod	Retrigger Mode	O
PerTrgTms	Periodic trigger time in seconds	O
ExclTmms	Exclusion time	O
OpMod	Operation mode (Saturation, Overwrite)	O

#### LN RADR

OpCntRs	Resetable operation counter	O
<b>Status Information</b>		
ChTrg	Channel triggered	M
<b>Settings</b>		
ChNum	Channel number	O
TrgMod	Trigger mode (internal trigger, external or both)	O
LevMod	Level Trigger Mode	O
HiTrgLev	High (positive) trigger level	O
LoTrgLev	Low (negative) trigger level	O
PreTmms	Pre-trigger time	O
PstTmms	Post-trigger time	O

#### LN RBDR

OpCntRs	Resetable operation counter	O
<b>Status Information</b>		
ChTrg	Channel triggered	M
<b>Settings</b>		
ChNum	Channel number	O
TrgMod	Trigger mode (internal trigger, external or both)	O
LevMod	Level Trigger Mode	O
PreTmms	Pre-trigger time	O
PstTmms	Post-trigger time	O

Table 2-1 – LN details for Disturbance Recorder function

Using the logical nodes with the setting attributes, the behavior of the disturbance recorder can be configured online with the required communication services. It is also possible to read out the current settings from the device by reading the data of these logical nodes. The information contained in these logical nodes is similar to the information of the COMTRADE configuration file.

Assuming that the values are preconfigured in the IED, they are also described in the SCL file of the IED implementing the disturbance recorder function. The extract of the SCL file with the data model of the disturbance recorder including its preconfigured settings is therefore similar in content to the COMTRADE configuration file. Details of the mapping of IEC 61850 LN data on the elements of the COMTRADE configuration file are described in section 4.4 of this report.



### 3 DATA FORMATS / DATA TYPES / ATTRIBUTES IN USE

#### 3.1 COMTRADE - C37.111-1999

##### Data Formats

- ASCII
- Binary

##### Data Types

- Signed integer (1, 2 or 4 bytes) \*
- Unsigned integer (1, 2 or 4 bytes) \*
- Boolean (1, 2 or 4 bytes) \*

##### Sampled Data Attributes

A COMTRADE sampled data channel typically has the following attributes:

- Quantity Type – analog or status
- Quantity Measured – voltage, current, other
- Quantity Characteristic – series sampled value
- Series Quantity Units – volts, amperes, other
- Series Value Type – time, val
- Channel ID

#### 3.2 PQDIF – IEEE 1157.3-2002

##### Data Formats

- ASCII
- Binary

##### Data Types

- Signed integer (1, 2 or 4 bytes)
- Unsigned integer (1, 2 or 4 bytes)
- Boolean (1, 2 or 4 bytes) – used for “digital” channels
- Real (4-byte single or 8-byte double precision)
- Complex (8-byte single or 16-byte double precision)
- Character (1-byte ASCII or 2-byte Unicode)
- Date stamp (12 bytes)
- GUID (16 bytes)

##### Sampled Data Attributes

A PQDIF sampled data channel has the following attributes:

- Quantity Type – *waveform*, phasor, value log, flash, ...
- Quantity Measured – *voltage*, *current*, power, energy, temp, ...
- Quantity Characteristic – *instantaneous*, rms, thd, tif, TPF, ...

- Series Quantity Units – *volts, amperes*, watts, vars, ...
- Series Value Type – *time, val*, min, max, avg
- Phase or *Channel ID*

Note: Attributes in *italic* are common to the COMTRADE standard. PQDIF can represent event details, trends, sequence of event logs, and statistical data of any quantity that can be represented in standard SI units. Also note that *digital* time series are treated the same way as waveforms in PQDIF – they simply have a Boolean data type instead of scaled integer or floating point type.

### 3.3 IEC 61850 (7-2)

#### Data Formats

- ASCII
- Binary

#### Data Types

- Signed integer (1, 2 or 4 bytes) \*
- Unsigned integer (1, 2 or 4 bytes) \*
- Boolean (1, 2 or 4 bytes) \*
- Real (4-byte single or 8-byte double precision)
- Complex (8-byte single or 16-byte double precision)
- Character (1-byte ASCII or 2-byte Unicode)
- Date stamp (12 bytes)

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**Table 2 – BasicTypes**

BasicTypes			
Name	Value range	Remark	Used by
BOOLEAN			IEC 61850-7-3 IEC 61850-7-2
INT8	-128 to 127		IEC 61850-7-3 IEC 61850-7-2
INT16	-32,768 to 32,767		IEC 61850-7-3 IEC 61850-7-2
INT24	-8388608 to 8388607	for TimeStamp type	IEC 61850-7-2
INT32	-2,147,483,648 to 2,147,483,647		IEC 61850-7-3 IEC 61850-7-2
INT128	-2**127 to (2**127)-1	Required for counters	IEC 61850-7-3
INT8U	Unsigned integer, 0 to 255		IEC 61850-7-3 IEC 61850-7-2
INT16U	Unsigned integer, 0 to 65,535		IEC 61850-7-3 IEC 61850-7-2
INT32U	Unsigned integer, 0 to 4,294,967,295		IEC 61850-7-3 IEC 61850-7-2
FLOAT32	Range of values and precision as specified by IEEE 754 single- precision floating point		IEC 61850-7-3
FLOAT64	Range of values and precision as specified by IEEE 754 double- precision floating point		IEC 61850-7-3
ENUMERATED	Ordered set of values, defined where type is used	Custom extensions are allowed	IEC 61850-7-3 IEC 61850-7-2
CODED ENUM	Ordered set of values, defined where type is used	Custom extensions shall not be allowed. Type shall be mapped to an efficient encoding in a SCSM	IEC 61850-7-3 IEC 61850-7-2
OCTET STRING	Max. length shall be defined where type is used		IEC 61850-7-3 IEC 61850-7-2
VISIBLE STRING	Max. length shall be defined where type is used		IEC 61850-7-3 IEC 61850-7-2

**Table 3-1 – Data types defined in IEC 61850**

## 4 CONVERSION OF SAMPLED DATA BETWEEN STANDARDS

### 4.1 Conversion considerations of PQDIF-2002 and COMTRADE-1999

This section describes how to map power system waveform and event data stored in the IEEE Std 1159.3-2002 PQDIF to the IEEE Std C37.111-1999 COMTRADE and vice versa. In specifying this mapping, there are many instances where arbitrary conventions must be adopted to facilitate the mapping. These cases will be explicitly identified and options given for alternative solutions. In general, the conventions suggested are those that are in common practice in at least one or more software implementations of COMTRADE and/or PQDIF.

#### High Level Issues

There are a few key differences between the COMTRADE and PQDIF standards that merit attention and our first set of arbitrary mapping conventions. PQDIF permits (and encourages) storing multiple “Observations” in a single PQDIF file as illustrated in Figure 4-1. An observation in PQDIF is an event such as a multi-channel recording of voltage, current, and binary status variables during a fault. COMTRADE easily represents such data in a single .CFG/.DAT file pair. PQDIF however, can represent multiple such recordings (observations) in a single file. Note that the PQDIF equivalent of a .CFG file is the Data Source Record shown in the figure.

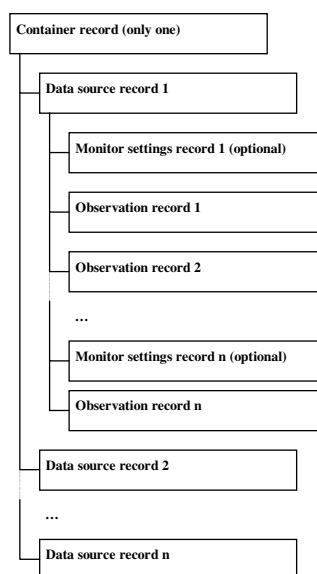


Figure 4-1 – PQDIF Logical Structure

When converting a PQDIF file (e.g. rootname.pqd) containing multiple observations to COMTRADE format, multiple .CFG/.DAT file pairs result. Arbitrary

conventions must be adopted to name and optionally archive these files. A convention sometimes used is to create a root file name for the .CFG/.DAT file pairs that consists of the original PQDIF file name and the ISO 8601 ASCII representation of the time stamp of the PQDIF observation. Further, the resulting multiple files set is often archived into a single file using the ZIP or GZIP archiving algorithms into a single file. No single extension naming convention has yet evolved, but two common ones could be:

1. **rootname.ctz**

COMTRADE ZIP file using the PKZIP or compatible algorithm (PC's)

2. **rootname.ctgz**

COMTRADE TGZ file using the GNU TAR / GZIP archiver (Unix/Linux)

The contents of these single archive files might contain a set of files like the following when converting a PQDIF file containing three such observations:

```
rootname20040822T175122.cfg  
rootname20040822T175122.dat  
rootname20040822T175419.cfg  
rootname20040822T175419.dat  
rootname20040822T180157.cfg  
rootname20040822T180157.dat
```

Another complication arises when converting PQDIF files that contain observations with channels that have different time bases within a single observation. For example, one of the most common power quality disturbances that PQDIF was designed to represent is the RMS Variation of which sags and swells are specializations. In the power quality domain, such events are usually represented by a continuous recording of the RMS value of each monitored channel of voltage and current as well as instantaneous waveform data for all or portions of the event (e.g. beginning and end of a long event). Figure 4-2 illustrates how such an event is commonly visualized.

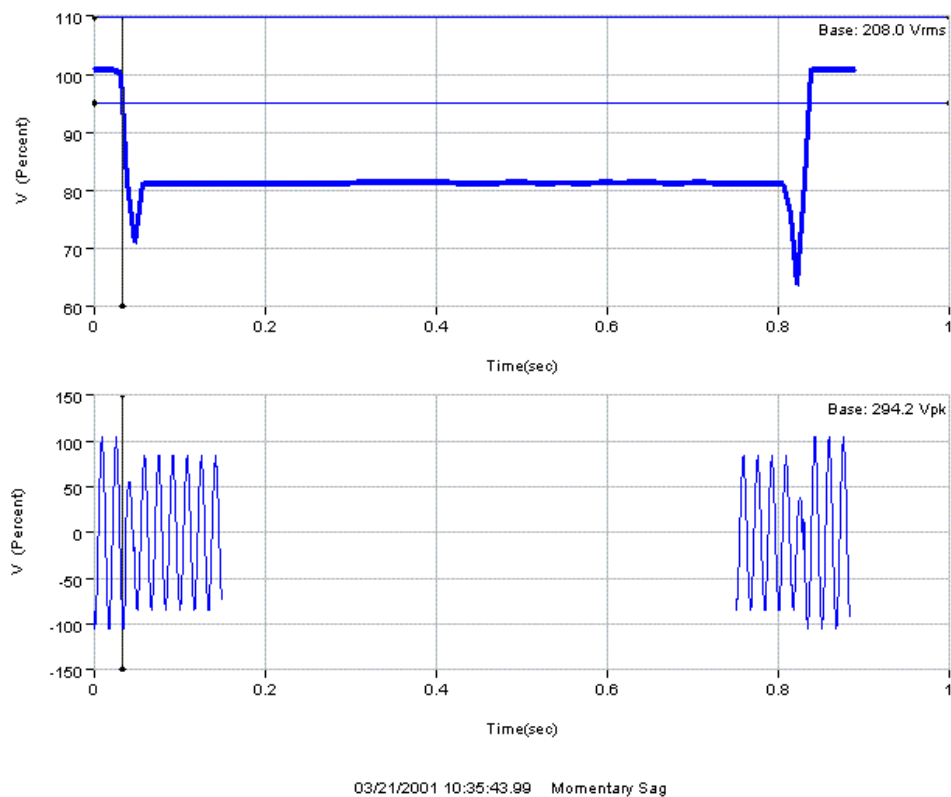


Figure 4-2 – RMS Variation with RMS Domain and Waveform Domain Components

In this example, there is a single RMS trace for the entire duration of the event and two waveforms captured. The RMS data is usually captured at a two points per cycle rate (as per IEC 61000-4-30) and the waveform data is captured at 64, 128, or 256 points per cycle (not standardized – many rates possible). The IEEE Std C37.111-1999 COMTRADE does not support different data rates and point counts for different channels in a single COMTRADE file. Some arbitrary means must be identified to split the observation up into multiple files.

Again, there is no standard or industry dominant method of splitting up multi-rate channels in a PQDIF file into multiple COMTRADE files, but the industry has used the following method. The RMS traces for all channels are stored in a single COMTRADE file that is named by prefixing the root file name with R\_. Since the PQDIF observation may contain one or more waveform recordings and each of them may be of different lengths (point counts), each one must be mapped to a new COMTRADE .CFG/.DAT file pair. These files are named by prefixing the root file name with W\_, and post fixing the root file name with an instance number starting at 0. For example, the event shown in Figure 4-2 would be mapped into three PQDIF files as follows:

```
r_rootname20040822T175122.cfg  
r_rootname20040822T175122.dat
```

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```
w_rootname20040822T175122_0.cfg  
w_rootname20040822T175122_0.dat  
w_rootname20040822T175122_1.cfg  
w_rootname20040822T175122_1.dat
```

When converting COMTRADE to PQDIF, there are fewer decisions to be made since any COMTRADE .CFG/.DAT file pair can be represented in a single PQDIF file. A common technique is to simply map each .CFG/.DAT file pair into a single .PQD file by retaining the original root file name and appending the standard .PQD extension. Optionally, a conversion program may choose to append the ISO ASCII date of the event trigger time to the root file name as shown in the earlier examples.

Another possibility when converting multiple COMTRADE files to PQDIF is to take advantage of PQDIF's ability to contain multiple observations. This is especially efficient where there are groups of .CFG/.DAT file pairs with identical .CFG files. Such groups can be mapped into a single PQDIF "Data Source Record" and just the .DAT files converted into observations. This approach can be helpful when working with PQDIF viewer programs that only load or analyze one PQDIF file at a time.

### **Channel Definition Specifics**

With some of the key high-level issues being covered, one can concentrate on some of the details of mapping specific internal elements of COMTRADE and PQDIF to each other. The first of these is the concept of channel definitions.

A channel definition (contained in the Data Source Record) in PQDIF parlance completely and uniquely specifies the type of data measured and how it is recorded including:

- The quantity being measured (Voltage, current, power, temperature, etc.)
- The SI units of value (volts, amps, watts, vars, degrees Celsius)
- Characteristic of the quantity being measured (RMS, peak, instantaneous)
- Quantity Type (Waveform, Value Log, Phasor, Spectrum, etc.)
- Value Type information (present value, minimum, average, mMaximum, statistic, etc.)
- Location Parameter, normally a phase designation for power systems data
- Scaling information to transform the stored data to the SI units given above

Not all combinations will be valid and in some cases the information in various parameters may seem redundant but the full set of parameters is required to uniquely identify the channel for all situations. The value type information is actually used to form the instances of a channel but that will be discussed later.

## 4.2 COMTRADE-1999 to PQDIF-2002

When converting from COMTRADE to PQDIF, some information for the channel definitions may be developed from the COMTRADE .CFG files *but because of the nature of “non-critical” data items in COMTRADE* it is usually necessary to separately map most of these fields manually. Also, much latitude has been taken over the years in *how the COMTRADE standard has been implemented by various vendors, which leads to certain ambiguities*.

A software implementation for partially automating the configuration to channel definitions process can read the configuration file and attempt to infer quantity measured, SI units, and scale information. Typically, the software would have difficulty determining the remaining information including characteristic, quantity type, value type and location or phase.

Possible automated mappings could be as follows:

Phase could be derived from *ch\_id* and/or *ph* fields in the analog channel definition information records if well defined rules are used to assign this field. However, this is a non-critical field and for general-purpose translators this will have to be manually overridden.

Units can be derived from the *uu* field of the analog channel definition information records if strict rules are used to create this field. If this is possible, the PQDIF quantity measured can be inferred directly.

Scale and offset information can be derived directly from the ‘a’ and ‘b’ fields. These are critical data and so should always be present. However, PQDIF requires that the scale be a base SI unit. If the units of the scaled values are not base SI, i.e. kilo volts, the scales provided must be adjusted.

In practice, existing implementations of COMTRADE to PQDIF converters require an external mapping file due to the ambiguities mentioned above. Appendix A describes one such mapping file.

## 4.3 PQDIF-2002 to COMTRADE-1999

Conversion from PQDIF to COMTRADE can be accomplished without any loss of data and without the need for a configuration file for a subset of the PQDIF quantity types. The PQDIF quantity types easily converted to COMTRADE are:

- WAVEFORM – any instantaneous waveform data
- PHASOR – any instantaneous RMS variation trace with, or without phase information
- VALUELOG – any trend of any steady state parameter over time



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Notable quantities that do not have a clear mapping include the following PQDIF quantity types:

- RESPONSE – arbitrary spectra and frequency domain measurements
- FLASH – Lightning strike events
- HISTOGRAM – PQ event statistics
- CPF – PQ event cumulative probability functions
- MAGDUR, MAGDURCOUNT, MAGDURTIME – PQ event summary tables

During the conversion process from PQDIF to COMTRADE, some naming conventions are required to identify the multiple “views” of individual channels that may be present in a PQDIF file. For example, most power quality measurement devices record instantaneous, maximum, minimum, and average traces on a single channel (phase) for RMS Variations depending on the length of the recording as shown in Figure 4-3.

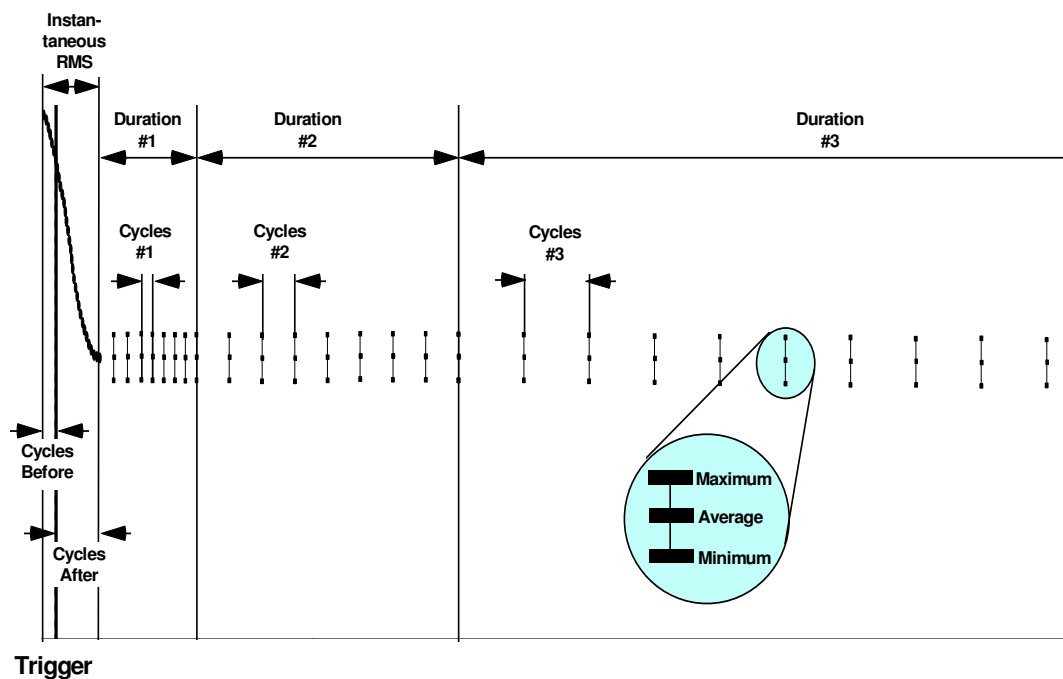


Figure 4-3 – Instantaneous, Min, Max, and Average Traces in a Long RMS Variation

The following conventions have been used to facilitate identifying each of the channels associated with an RMS Variation such as this.

The following values are valid for the phase identifier (ph) parameter:

- AN - represents phase A line-neutral voltage
- BN - represents phase B line-neutral voltage
- CN - represents phase C line-neutral voltage
- NG - represents neutral-ground voltage
- AB - represents phase A-B line-line voltage

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BC - represents phase B-C line-line voltage  
CA - represents phase C-A line-line voltage  
A - represents phase A line current  
B - represents phase B line current  
C - represents phase C line current

In general, the *ch\_id* parameter is used to represent the quantity characteristic and series value type (using PQDIF terminology). The COMTRADE *ccbm* parameter is used to represent the PQDIF quantity type and the trigger reason.

When the data in the COMTRADE file represents a waveform:

The *ch\_id* parameter can have the following values:

*inst\_val* - indicates instantaneous value of waveform  
*inst\_min* - indicates instantaneous value of negative peak detector  
*inst\_max* - indicates instantaneous value of positive peak detector

The *ccbm* parameter can have the following values:

*waveform\_samp* - indicates waveform captured due to periodic sample  
*waveform\_int* - indicates waveform captured due to internal trigger  
*waveform\_ext* - indicates waveform captured due to external trigger  
*waveform\_man* - indicates waveform captured due to manual trigger

When the data in the COMTRADE file represents an RMS trace:

The *ch\_id* parameter can have the following values:

*rms\_min* - indicates minimum rms value for last sample period  
*rms\_max* - indicates maximum rms value for last sample period  
*rms\_avg* - indicates average rms value for last sample period  
*ang\_min* - indicates minimum phase angle value for last sample period  
*ang\_max* - indicates minimum phase angle value for last sample period  
*ang\_avg* - indicates minimum phase angle value for last sample period

The *ccbm* parameter can have the following values

*phasor\_samp* - indicates phasor captured due to periodic sample  
*phasor\_int* - indicates phasor captured due to internal trigger  
*phasor\_ext* - indicates phasor captured due to external trigger  
*phasor\_man* - indicates phasor captured due to manual trigger

When the *ccbm* parameter is *waveform\_int*, *waveform\_ext*, *waveform\_man*, *phasor\_int*, *phasor\_ext*, or *phasor\_man*, an additional post-fix (*\_trig*) can be used to indicate if this channel was involved in the triggering process. More than one channel can have the *\_trig* post-fix appended if more than one channel satisfied the trigger criteria simultaneously. For example, if both phase A and phase B were

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triggered on a double line-ground fault, the following excerpted lines from the resulting .CFG file would result:

```
2,rms_avg,A,phasor_int_trig,V,0.1,0,, -600,600,1,1,P
3,rms_avg,BN,phasor_int,V,0.1,0,, -600,600,1,1,P
4,rms_avg,B,phasor_int_trig,V,0.1,0,, -600,600,1,1,P
```

This example indicates that an internally generated trigger was generated for phase A and phase B voltage. Here is another example .CFG file for an RMS Variation and an accompanying waveform file.

```
Company, SCADA, 2000
11,11A,0D
1,rms_avg,AB,phasor_int_trig,V,0.0310961,0,, -600,600,1,1,P
2,rms_avg,A,phasor_int,A,0.0716014,0,, -10,10,1,1,P
3,rms_avg,BC,phasor_int_trig,V,0.031198,0,, -600,600,1,1,P
4,rms_avg,B,phasor_int,A,0.0714563,0,, -10,10,1,1,P
5,rms_avg,CA,phasor_int_trig,V,0.031087,0,, -600,600,1,1,P
6,rms_avg,C,phasor_int,A,0.0714089,0,, -10,10,1,1,P
7,rms_avg,NG,phasor_int,V,0.0321524,0,, -600,600,1,1,P
8,rms_avg,N,phasor_int,A,0.0714464,0,, -10,10,1,1,P
9,rms_avg,AN,phasor_int,V,0.0103823,0,, -600,600,1,1,P
10,rms_avg,BN,phasor_int,V,0.0103808,0,, -600,600,1,1,P
11,rms_avg,CN,phasor_int,V,0.0103638,0,, -600,600,1,1,P
60.009
1
120.018,16
07/04/2004,20:41:13.541
07/04/2004,20:41:21.023
binary
1

Company, SCADA, 2000
8,8A,0D
1,inst_val,AB,waveform_int_trig,V,0.124384,0,, -600,600,1,1,P
2,inst_val,A,waveform_int,A,0.286406,0,, -10,10,1,1,P
3,inst_val,BC,waveform_int_trig,V,0.124792,0,, -600,600,1,1,P
4,inst_val,B,waveform_int,A,0.285825,0,, -10,10,1,1,P
5,inst_val,CA,waveform_int_trig,V,0.124348,0,, -600,600,1,1,P
6,inst_val,C,waveform_int,A,0.285636,0,, -10,10,1,1,P
7,inst_val,NG,waveform_int,V,0.12861,0,, -600,600,1,1,P
8,inst_val,N,waveform_int,A,0.285785,0,, -10,10,1,1,P
60.0090
1
7680,896
07/04/2004,20:41:13.541
07/04/2004,20:41:21.040
binary
1
```

## 4.4 IEC61850 to/from COMTRADE-1999

When IEC 61850 disturbance recorder models were created, COMTRADE was the basis for the modelling. However, the focus was to supply all required configuration attributes. It was not intended to map descriptive information from the COMTRADE configuration file into the logical nodes (LN's). That's why some information that is part of the COMTRADE configuration file is not available as data directly in IEC 61850. However, it is easy to add this information to the LNs of IEC 61850 so that at the end the IEC 61850 data model would contain the complete content of a COMTRADE configuration file.

The following table provides an overview on the information in the COMTRADE configuration file and the place where that information can be found in IEC 61850. There are two different ways to have the information in IEC 61850 available:

- (1) The information is contained in an attribute of the data model. In that case, the information can be read and optionally be written while the device is in operation using the communication services of IEC 61850-7-2.
- (2) The information is available in the SCL file of the substation. Note that information available in the data model can also be represented in the SCL file.

In order to have all information from the COMTRADE configuration file available in IEC 61850, the following extensions to the logical nodes currently defined have been proposed:

RDRE class				
Attribute Name	Attr. Type	Explanation		
<b>Settings</b>				
SmpRte	ASG	Sample Rate in Hertz. (If zero, time stamp of ChTrg is used for COMTRADE conversion.)		O
EndSmp	ING	Last sample number at SmpRte.		O
Ft	ING	Indication of the File type. (binary, ASCII, B64,...)		O
TmMult	ASG	Time multiplication factor		O
RevYr	ING	COMTRADE Revision Year (1991, 1999, etc.)		O

RADR class				
Attribute Name	Attr. Type	Explanation		M/ O
<b>Measured values</b>				
AnVal	SAV	Analogue input channel		M
AnSkew	ASG	Analog channel skew due to anything. (Time skew in COMTRADE in microseconds.)		O
Ref				

RBDR class				
Attribute Name	Attr. Type	Explanation		
<b>Settings</b>				

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RBDR class				
Attribute Name	Attr. Type	Explanation		
ActSt	ING	Active state (0, 1)		O
Ref				

Table 4-1 – LN definitions of Disturbance Recorder function

With these extensions, an extract of the data model for a disturbance recorder could be the following:

Logical Device Logical Node Data.DataAttribute	Comtrade Configuration file
Atlanta_110kV_Line1_DR/ RDRE FltNum.stVal	
PreTmms.setVal	Used together with ChTrg.t to calculate time stamp of first value
PstTmms.setVal	
SmpRte.setVal	Sample rate
FtBin.setVal	File type
TmMult.setMag	Time stamp multiplication factor
RADR1	
AnVal.units	Units
AnVal.sVC	Scaling
AnVal.min	Min value
AnVal.max	Max Value
ChTrg.stVal	
ChTrg.t	Time stamp of trigger point
ChNum.setVal	Channel number
RADR2	
....	
RBDR1	
ChNum.setVal	Channel number
ActSt.setVal	Normal state of channel

Table 4-2 – Disturbance Recorder Data Model

With these extensions to the data model, a XML file (illustrated in Annex B) based on the SCL file can be created that can replace the COMTRADE configuration file. That SCL file would contain the following sections:

- an extract of the substation section that contains the switchgear equipment representing the recorded information (i.e. the current and voltage transformers measuring the recorded waveforms or circuit breaker and switches, when position indications are also recorded)
- The relevant part of the data model from the IED sections of the disturbance recorder itself and the IED where the LNs TCTR and TVTR are implemented
- The relevant section of the data template section.

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<b>COMTRADE configuration file</b>	<b>IEC 61850 data model</b>
Station name	The information can currently not be directly found in the data model. However, it can be retrieved from the substation section of the SCL file.
Identification of device	The information can currently not be directly found in the data model. However, it can be retrieved from the IED section of the SCL file.
Revision	A new attribute in the RDRE logical node is proposed to handle the year of COMTRADE standard used. E.g. 1991, 1999, etc.
Number and type of channels	Indirectly through the number of instances of LNs RADR and RBDR.
Line frequency	From one of the related LN TCTR/TVTR. The related LN TCTR/TVTR can be found through the substation section of SCL.
Sampling rate	Sample Rate in Hertz. (If zero, time stamp of ChTrg is used for COMTRADE conversion.)
Time stamp of first data value and trigger point	Use time stamp of ChTrg of the individual channel LN that triggered together with PreTmms of that channel; if no individual PreTmms per channel, use PreTmms of LN RDRE
Data file type	New data is Ft in RDRE LN
Time stamp multiplication factor for data file	New data is TmMult in RDRE LN
<i>For each analogue channel</i>	
Channel no	RADR.ChNum.setVal
Phase	The information can currently not be directly found in the data model. However, in the substation section of the SCL file, the association between a logical node instance (i.e. the channel) and the single line diagram can be made.
Circuit component	Same as phase
Units and scaling	New data AnVal in RADR LN
Skew	New data AnSkew in RADR LN.
Min / max values	In the data type of RADR LN
Primary / secondary ratio	DO Rat and VRtg/ARtg of related LN TCTR/TVTR. The related LN TCTR/TVTR can be found through the

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	substation section of SCL.
Indication if value is primary	IEC 61850 assumes that values are always primary values
<i>For each binary channel</i>	
Channel no	RBDR.ChNum.setVal
Phase	See above for analogue channel
Circuit component	Same as phase
Normal state of channel	New data ActSt in RBDR LN

Table 4-3 – Mapping of COMTRADE to IEC 61850

#### **4.5 IEC61850 to/from PQDIF-2002**

IEC 61850 is currently being amended to represent power quality data. The current Committee Draft (CD) adds new logical nodes to represent RMS Variation and Transient events. The logical nodes are primarily focused on containing summary representations of the underlying detailed time series data. This summary information includes the magnitude and duration of an RMS variation event for example. An optional element under consideration by the PQ task force in the 61850 power quality logical node definitions is to specify the name of a PQDIF, COMTRADE, or other formatted file that contains the original time series data. Conversion to/from PQDIF would therefore not really be a conversion – it is simply a matter of configuring the logical device to produce the desired COMTRADE / PQDIF event detail files and then retrieve those files using 61850 file transfers.



## 5 RECOMMENDATION FOR DATA FORMATS AND DATA TYPES FOR SAMPLED DATA IN IEDS

### 5.1 Future Considerations for IED Sampled Data

Any new IED should support the current standard applicable to its designed application. As such, a protection IED should support the IEC-61850 data types and a power quality IED should support the PQDIF data types. As noted in Table 5-1 this would mean both could have a seamless exchange of sampled data if a conversion path is provided.

As revision of the COMTRADE 1999 standard is certain, the investigation of the aforementioned standards clearly illustrates the need to harmonize the data formats to simplify data exchange for industry users. This would eliminate the need for conversions of the raw data formats between the various standards without loss and only require a handling of the configuration information which requires much less effort. Since these are already documented in this report, the effort to implement such conversion programs would be minimal.

Depending on the IED, both ASCII and Binary data should be supported as the norm. Table 5-1 shows the extension of the data types and possible harmonized mapping of all three standards:

C37.111 (COMTRADE)		IEEE 1159.3 (PQDIF)		IEC-61850
Signed Integer 1,2 or 4 bytes		Signed Integer 1,2 or 4 bytes		Signed Integer 1,2 or 4 bytes
Unsigned Integer 1,2 or 4 bytes		Unsigned Integer 1,2 or 4 bytes		Unsigned Integer 1,2 or 4 bytes
Boolean 1,2 or 4 bytes		Boolean 1,2 or 4 bytes		Boolean 1,2, or 4 bytes
<i>Real 4-byte single or 8-byte DP</i>		Real 4-byte single or 8-byte DP		Real 4-byte single or 8-byte DP
<i>Complex 8-byte single or 16-byte DP</i>		Complex 8-byte single or 16-byte DP		Complex 8-byte single or 16-byte DP
<i>Character 1-byte ASCII or 2-byte Unicode</i>		Character 1-byte ASCII or 2-byte Unicode		Character 1-byte ASCII or 2-byte Unicode
<i>Date Stamp 12-bytes</i>		Date Stamp 12-bytes		Date Stamp 12-bytes
		GUID 16-bytes		

Table 5-1 – Comparison of data types and possible additions for COMTRADE.  
(Shaded attributes of column one are recommended additions.)

Those listed in *Italic text* and shaded box are the data types being recommended for addition to the COMTRADE standard revision. Support of these additional data types will reflect present practice in the industry and allow loss less data conversion when required.

It is also recommended that an expansion of supported and defined channel attributes be adopted along with these new data types to complete the support for the industry's present practice and reflect the way in which COMTRADE is already being used. The following additional Sampled Data Attributes are proposed for a future revision to COMTRADE in Table 5-2:

Attribute	Proposed Additions
Quantity Type	Phasor, value log, flash
Quantity Measured	Power, energy, temp
Quantity Characteristic	Rms, thd, tif, TPF
Series Quantity Units	watts, vars
Series Value Type	min, max, avg
Channel ID	Phase

Table 5-2 – Proposed new attributes for COMTRADE

## 5.2 Advantages of Expanded Formats

One of the main goals of the industry today is the seamless exchange of data and information between multifunctional IEDs and different analysis or configuration applications related to various types of power system events. It is driven by the requirement for the development of analysis tools that can process the data from multiple sources that record such power system events.

The use of XML as a data format that allows the clear identification of each data object in a human readable and easily parsed format will help in the creation of tools that ensure interoperability between the devices and tools that produce COMTRADE (and other data) files and the applications that use them.

The object oriented models defined in IEC 61850 support the representation of waveform and disturbance recording functions, as well as the time-stamped sampled analog or binary values. An expanded COMTRADE file should be able to support the data objects and their attributes supported by IEC 61850 in order to allow their analysis and visualization.

Use of an XML schema to validate the COMTRADE Configuration file portion will help to achieve the interoperability goal and support the introduction of Conformance Testing procedures.

Considering the fact that power system events are detected and recorded by different types of devices that produce different types of records, it makes logical sense to harmonize the data types and data models in order to be able to convert between the different types of record formats. This will allow the creation of analysis tools that can perform their tasks based on the different types of records available for the same event(s).

The expanded COMTRADE format will also support its use for both legacy and IEC 61850 based devices or distributed recording systems using the IEC 61850 Process bus or GOOSE messages.

It helps to also distinguish between physical and virtual analog and binary inputs into the device performing the recording functions.

The use of the standard data object names in IEC 61850, as well as the object hierarchy and substation configuration language (SCL) will support the self configuration of the analysis or visualization tools that could be based on future COMTRADE files.

## **6 SUMMARY / CONCLUSIONS**

This report presented different methods of sampling data in modern IED's. Three standards were identified and reviewed, COMTRADE - IEEE Std C37.111-1999, PQDIF - IEEE Std 1159.3-2002 and IEC-61850. The different data formats, types and attributes to the corresponding standards were compared. Different possible conversions of sampled data between the different standard formats were presented for consideration. Recommended changes to the COMTRADE standard were made in order to harmonize these data between the three standard formats. It is a recommendation of this working group that consideration be given to formally harmonize these standards in the next revision of COMTRADE and also to adopt the XML format for self-description of data and file verification. Finally, after that revision is prepared have a new working group provide a guide for loss less conversion between these standards for the industry at large.

## APPENDIX - A

### COMTRADE 1999 - File Import Definition to PQDIF

In order for the COMTRADE to PQDIF converter to fully understand the meaning of the data in the COMTRADE files in a data directory, a configuration file is needed. This configuration file is used to map the data channels to appropriate quantity, characteristics and phase. It also specifies some general parameters such as scale factors, base quantities and date format.

The configuration file contains the following:

```
<comtrade_to_pqdif>
<directory location="dir1" />
<general
  numchan="{num channels for import}"
  sysfreq="{Frequency in Hz}"
  dateformat="MMDDYYYY"
/>

<Channel number="{channel number}"
  NAME="{Reference name}"
  PHASE="{One of phase labels, see below}"
  QUANTITYMEASURED="{Raw physical quantity measured, see below}"
  CHARACTERISTIC="{Characteristic}"
  QUANTITYTYPE="{Type of quantity measured by this channel, see below}"
  VALUETYPE="{Value type as defined below, selected from list}"
  NOMINAL="{Base or Nominal value for channel}"
  SCALE="{Optional scale factor}"
/>
```

The <general> section of the configuration file supports the following attributes:

The *numchan* attribute specifies the number of channels that will be imported from the COMTRADE files in this directory (the directory specified in the directory tag). This is not required to be the same as the number as in the COMTRADE files, allowing some channels of data in the COMTRADE file to be skipped. This is a required directive.

The *sysfreq* attribute allows specification of the system frequency. If omitted it assumed to be 60 Hz unless it is available in the COMTRADE .CFG file.

The *dateformat* attribute is used when the date stamps in the configuration and data files use a different format from that specified in the COMTRADE standard. This directive is optional.

The channel section of the configuration mapping file supports the following attributes:

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For each channel to be converted, there must be a channel definition section. There is an instantiation of the channel tag for each desired channel to be mapped with the number attribute containing the COMTRADE file channel number at 1 and ending at *numchan* value set in the general tag

The NAME attribute allows specification of a “friendly” name for the channel. The contents are arbitrary. This directive is required.

The PHASE directive is used to specify what phase designator should be associated with this data. The value must be one from the list in Table 1. This is a required directive.

**Table 1: Valid Phase ID Strings**

A	B	C	N
NG	AN	BN	CN
AB	BC	CA	RESIDUAL
NET	TOTAL	LN_AVG	LL_AVG
WORST			

The QUANTITYMEASURED directive specifies the physical quantity that is being measured by the channel. This is a required directive and must be one of the values in Table 2.

**Table 2: Valid Quantity Measured Values**

VOLTAGE	CURRENT	POWER	ENERGY
TEMPERATURE	PRESSURE	CHARGE	EFIELD
MFIELD			

The CHARACTERISTIC directive is used to specify what characteristic of the quantity is being measured. There are many possibilities for this value but it must be one of a list. The full list is in an appendix but a few of the most common values are presented in Table 3.

**Table 3: Common Characteristic Values**

INSTANTANEOUS	RMS	PEAK
HRMS	FREQUENCY	TOTALTHD

For waveform type data, INSTANTANEOUS would be the choice. For steady state information RMS would be the correct value.

The QUANTITYTYPE directive specifies how the data should be interpreted. The valid options at this time are listed in Table 4.

**Table 4: Valid Quantity Type Settings**

WAVEFORM	VALUELOG	PHASOR
----------	----------	--------

WAVEFORM specifies standard time domain waveform information.

VALUELOG implies longer term averaging of RMS or DC type numbers. This would normally indicate a steady-state logging function.

PHASOR indicates the values are RMS magnitudes from a phasor value. This translator does not yet support Magnitude and phase into a single channel.

The QUANTITYTYPE directive is required.

The VALUETYPE directive further specifies the interpretation of the data for this channel. There are many possible values for this required directive. The full list is in an appendix but a few of the most common values are listed below.

**Table 5: Common Values for the VALUETYPE Directive**

VALUE	TIME	MINIMUM
MAXIMUM	AVERAGE	

The VALUE type indicates that the numbers in the COMTRADE channel are single measurements where the MINIMUM, MAXIMUM or AVERAGE types indicate that some processing is performed over some interval to produce the values.

The NOMINAL directive allows the specification of base or nominal value for the channel. This is normally only important for voltage channels as the characterizer uses this value to determine appropriate thresholds for disturbance analysis. This is an options directive and the default value is 1.0.

The SCALE directive allows the specification of an additional scale factor to be applied to the data for the channel. An example application of this directive is when the values in a data file are expressed in kV and the data should be imported in volts. A scale factor of 1000.0 can be specified to scale the values to the desired units.

The RMSWAVES directive instructs the translator to generate pseudo-channels for this waveform type channel. The pseudo-channels will be a moving  $\frac{1}{2}$  cycle RMS value for the wave. To enable this function, use RMSWAVES=1. Use of this option allows analysis of the waveform data by the characterizer's RMS variation analysis module. This directive is optional.

## VALUES FOR CHANNEL DEFINITION DIRECTIVES

### Phase ID Strings

A	B	C	N
NG	AN	BN	CN
AB	BC	CA	RESIDUAL
NET	TOTAL	LN_AVG	LL_AVG
WORST			

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### Quantity Type Strings

WAVEFORM	VALUELOG	PHASOR
RESPONSE	FLASH	HISTOGRAM
HISTOGRAM3D	CPF	XY
MAGDUR	XYZ	MAGDURTIME
MAGDURCOUNT		

### Quantity Measured Strings

VOLTAGE	CURRENT	POWER
ENERGY	TEMPERATURE	PRESSURE
CHARGE	EFIELD	MFIELD

### Quantity Characteristic Strings

INSTANTANEOUS	PEAK	RMS
HRMS	FREQUENCY	SPECTRA
TOTALTHD	EVENTHD	ODDTHD
CRESTFACTOR	FORMFACTOR	ARITHSUM
SOS1	S2S1	POSSEQ
NEGSEQ	ZEROSEQ	AVEIMBAL
TIF	FLICKERMAGAVG	FLICKERMAXDUU
FLICKERFREQMAX	FLICKERMAGMAX	FLICKERWGTAVG
FLICKERSPECTRUM	FLICKERPST	FLICKERPLT
IT	RMSDEMAND	ANSITDF
KFACTOR	P	Q
S	PF	DF
PDEMAND	QDEMAND	SDEMAND
DFDEMAND	PFDEMAND	PPREDICTEDDEMAND
QPREDICTEDDEMAND	SPREDICTEDDEMAND	P@QDEMAND
P@SDEMAND	Q@PDEMAND	Q@SDEMAND
DF@SDEMAND	PF@SDEMAND	PF@PDEMAND
PF@QDEMAND	VIANGLE	QFUND
PFVECTOR	DFVECTOR	SVECTOR
SVECTORFUND	SFUND	S@PDEMAND
S@QDEMAND	PFARITH	DFARITH
SARITH	SARITHFUND	PINT
PINTPOS	PINTPOSFUND	PINTNEG
PINTNEGFUND	QINT	QINTPOS
QINTPOSFUND	QINTNEGFUND	QINTNEG
SINT	SINTFUND	

### Value Type Strings

VALUE	TIME	MINIMUM
MAXIMUM	AVERAGE	PHASEANGLE
PHASEANGLEMIN	PHASEANGLEMAX	PHASEANGLEAVG

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AREA	LATITUDE	DURATION
LONGITUDE	POLARITY	ELLIPSE
BINID	BINHIGH	BINLOW
XBINHIGH	XBINLOW	YBINHIGH
YBINLOW	COUNT	TRANSITION
PROBABILITY	P1	P5
P10	P90	P95
P99	FREQUENCY	



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## APPENDIX - B

### IEC-61850 Disturbance Recorder Model Mapped to COMTRADE as XML.

The following XML file is an example of the IEC-61850 disturbance recorder model as described in tables 4-1, 4-2, and 4-3 illustrating a possible COMTRADE representation in this format. (*Note: this example may not reflect the latest version of SCL and does not include complete data values*) A full description of the extensions needed are described in section 4.4 of the report.

```
<?xml version="1.0" encoding="UTF-8"?>
<!-- edited with XMLSPY v5 rel. 4 U (http://www.xmlspy.com) by Christoph Brunner
(UTInnovation) -->
<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/SCLSCL.xsd">
  <Substation name="">
    <VoltageLevel name="">
      <Bay name="">
        <ConductingEquipment name="Inn" type="CTR">
          <SubEquipment name="A" phase="A">
            <LNode lnClass="TCTR" lnInst="1"/>
            <LNode lnClass="RADR" lnInst="1"/>
          </SubEquipment>
          <SubEquipment name="B" phase="B">
            <LNode lnClass="TCTR" lnInst="2"/>
            <LNode lnClass="RADR" lnInst="2"/>
          </SubEquipment>
          <SubEquipment name="C" phase="C">
            <LNode lnClass="TCTR" lnInst="3"/>
            <LNode lnClass="RADR" lnInst="3"/>
          </SubEquipment>
          <SubEquipment name="Nm" phase="Nm">
            <LNode lnClass="TCTR" lnInst="4"/>
          </SubEquipment>
        </ConductingEquipment>
      </Bay>
    </VoltageLevel>
  </Substation>
  <IED name="Disturbance-Recorder">
    <AccessPoint name="">
      <Server>
        <Authentication/>
        <LDevice inst="DRnn">
          <LN0 lnType="" lnClass="LLN0" inst=""/>
          <LN lnType="PSRC-RDRE" lnClass="RDRE" inst="1">
            <DOI name="FltNum">
              <DAI name="stVal">
                <Val>e.g. 125</Val>
              </DAI>
            </DOI>
            <DOI name="PreTmms">
              <DAI name="setVal"/>
            </DOI>
            <DOI name="PstTmms">
              <DAI name="setVal">
                <Val/>
              </DAI>
            </DOI>
            <DOI name="smpRte">
              <DAI name="setVal">
                <val/>
              </DAI>
            </DOI>
          </LN>
        </LDevice>
      </Server>
    </AccessPoint>
  </IED>
</SCL>
```

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---

```
</DOI>
<DOI name="FtBin">
  <DAI name="setVal">
    <val/>
  </DAI>
</DOI>
<DOI name="TmMult">
  <DAI name="setMag">
    <val/>
  </DAI>
</DOI>
</LN>
<LN lnType="PSRC-RADR" lnClass="RADR" inst="1">
  <DOI name="AnVal">
    <DAI name="units">
      <val/>
    </DAI>
    <DAI name="sVC"/>
    <DAI name="min"/>
    <DAI name="max"/>
  </DOI>
  <DOI name="ChTrg">
    <DAI name="stVal">
      <val/>
    </DAI>
    <DAI name="t"/>
  </DOI>
  <DOI name="ChNum">
    <DAI name="setVal">
      <Val>1</Val>
    </DAI>
  </DOI>
</LN>
<LN lnType="PSRC-RADR" lnClass="RADR" inst="2">
  <DOI name="ChNum">
    <DAI name="setVal">
      <Val>2</Val>
    </DAI>
  </DOI>
</LN>
<LN lnType="PSRC-RADR" lnClass="RADR" inst="3">
  <DOI name="ChNum">
    <DAI name="setVal">
      <Val>3</Val>
    </DAI>
  </DOI>
</LN>
<LN lnType="PSRC-RBDR" lnClass="RBDR" inst="1">
  <DOI name="ChNum">
    <DAI name="setVal">
      <Val>1</Val>
    </DAI>
  </DOI>
</LN>
</LDevice>
</Server>
</AccessPoint>
</IED>
<IED name="Merging-Unit">
  <AccessPoint name="">
    <Server>
      <Authentication/>
      <LDevice inst="MUnn">
        <LN0 lnType="" lnClass="LLN0" inst=""/>
        <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="9-2LETVTR" lnClass="TVTR" inst="1"/>
        <LN lnType="9-2LETVTR" lnClass="TVTR" inst="2"/>
        <LN lnType="9-2LETVTR" lnClass="TVTR" inst="3"/>
      </LDevice>
    </Server>
  </AccessPoint>
</IED>
```

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---

```
        </LDevice>
    </Server>
</AccessPoint>
</IED>
<DataTypeTemplates>
    <LNodeType id="9-2LETCTR" lnClass="TCTR">
        <DO name="Amp" type="9-2LESVAmp"/>
    </LNodeType>
    <LNodeType id="9-2LETVTR" lnClass="TVTR">
        <DO name="Vol" type="9-2LESVVol"/>
    </LNodeType>
    <LNodeType id="PSRC-RDRE" lnClass="RDRE">
        <DO name="FltNum" type="PSRC-INS"/>
        <DO name="PreTmms" type="PSRC-ING"/>
        <DO name="PstTmms" type="PSRC-ING"/>
    </LNodeType>
    <LNodeType id="PSRC-RADR" lnClass="RADR">
        <DO name="ChNum" type="PSRC-ING"/>
    </LNodeType>
    <LNodeType id="PSRC-RBDR" lnClass="RBDR">
        <DO name="ChNum" type="PSRC-ING"/>
    </LNodeType>
    <DOType id="9-2LESVAmp" 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="9-2LESVVol" 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="PSRC-ING" cdc="ING">
        <DA name="setVal" bType="INT32" fc="SP"/>
    </DOType>
    <DOType id="PSRC-INS" cdc="INS">
        <DA name="stVal" bType="INT32" fc="ST"/>
    </DOType>
    <DAType id="9-2LEAV">
        <BDA name="i" bType="INT32"/>
    </DAType>
    <DAType id="9-2LEsVCamp">
        <BDA name="scaleFactor" bType="FLOAT32">
            <Val>0.001</Val>
        </BDA>
        <BDA name="offset" bType="FLOAT32">
            <Val>0</Val>
        </BDA>
    </DAType>
    <DAType id="9-2LEsVCVol">
        <BDA name="scaleFactor" bType="FLOAT32">
            <Val>0.01</Val>
        </BDA>
        <BDA name="offset" bType="FLOAT32">
            <Val>0</Val>
        </BDA>
    </DAType>
</DataTypeTemplates>
</SCL>
```

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## DEFINITIONS

ASCII	A character representation specified in ANSI X3.4-1986. This is often called "ASCII format" or "Text (.TXT) format" by word processor programs
Binary	Defining 8 bits as a byte, and using 2 bytes (16 bits) to represent numbers from 0 to 65 535, then bytes interpreted in this fashion is commonly known as binary data.
Boolean	This is the logic that computers use to determine if a statement is true or false. There are 4 main Boolean operators: AND, NOT, OR, and XOR.
Complex Number	A number of the form $a+bi$ where $a$ and $b$ are real numbers and $i$ is the square root of -1
Character	A single alphabetic letter, numeric digit, or special symbol such as a decimal point or comma.
Date Stamp	Date and time expressed as a 12 byte expression typically in UTC form.
GUID	A "Globally Unique Identifier" is a 16-byte integer which is defined by a standard algorithm utilizing random numbers and other techniques to ensure uniqueness. Any computer in the world can generate a GUID and be reasonably assured that it is absolutely unique.
IED	Intelligent electronic device is a generic term referring to traditional protection relays of digital design that incorporate external communications.
Logical Node (LN)	Logical nodes are defined in IEC 61850 in Part 7 of the standard and contain the data objects and attributes describing the referenced device.
Real Number	A number that is rational or irrational, not imaginary.
RS-232	(Recommended Standard-232) A TIA/EIA standard for serial transmission between computers and peripheral devices
SCL	IEC 61850 defines a Substation Configuration Language in Part 6 of the standard that provides a common data structure for defining all devices within the substation proper. It is XML based and self described.

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Signed Integer	A whole number whose value lies anywhere in a domain that extends from a negative to a positive.
TCP/IP	(Transmission Control Protocol/Internet Protocol) is the basic communication language or protocol of the Internet and common for Ethernet based networks.
Unicode	A character code that defines every character in most of the speaking languages in the world. The Unicode specification also includes standard compression schemes and a wide range of typesetting information required for worldwide locale support.
Unsigned Integer	A whole number that is equal to or greater than zero and does not carry a positive or negative.
UTC	Universal Time Co-ordinated, the international time standard, also known as Greenwich Meridian Time (GMT)
XML	(Extensible Markup Language) is a W3C initiative that allows information and services to be encoded with meaningful structure and semantics that computers and humans can understand. XML is great for information exchange, and can easily be extended to include user-specified and industry-specified tags.

#### REFERENCES

- [R1] IEEE Std C37.111-1999; “**IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems**”.<sup>1</sup>
- [R2] IEEE Std 1159.3 - 2003; “**IEEE Recommended Practice for the Transfer of Power Quality Data**”.<sup>1</sup>
- [R3] IEC TS 61850, “**Communication Networks and Systems in Substations**”.
- [R4] ANSI X3.4-1986 (R1997), “**Information Systems Coded Character Set—7-Bit American National Standard Code for Information Interchange**” (7-bit ASCII).<sup>2</sup>
- [R5] IEEE Std 260.1-1993, “**American National Standard Letter Symbols For Units of Measurement**” (SI Units, Customary Inch-Pound Units).
- [R6] IEEE Std 280-1985 (R1996), “**IEEE Standard Letter Symbols for Quantities Used in Electrical Science and Electrical Engineering**” (DoD).

<sup>1</sup>IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

<sup>2</sup>ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).