Common Data Format Requirements for the Analysis of System Disturbances

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I. INTRODUCTION

The recent August 2003 blackout in the North-East [1] demonstrated that the analysis of different electric power system events is a very important and extremely complex process. It is required in order to determine the cause of the abnormal system condition, to speed-up the restoration of the affected parts of the system, and to evaluate the performance of different protection and control systems. System events and the effect they have on deviations of the supply voltage may result in failure of sensitive equipment with significant economical impact. To better understand the effects of different parameters of the power supplied to sensitive customers, it is necessary to provide engineers with the right tools to allow them to establish the correlation between the combination of certain attributes of the power and the failure of equipment.

The integration of multifunctional intelligent electronic devices (IEDs) from different manufacturers in substation automation systems requires a significant effort due to the different formats of the data available from these devices. Measurements, status, event, disturbance, maintenance or configuration data is used at different times by different applications. The paper discusses the requirements for a common data format for all these different types of data in order to allow the development of tools that will simplify the engineering and analysis process in electric utilities.

At this time there are no standard data formats defined for configuration, fault or event data from multifunctional IEDs. The requirements for such a common data format are analyzed. That will allow the development of system disturbance analysis tools, as well as will provide a common interface for testing or short circuit studies/coordination software. The proposed common data format is based on the new IEC 61850 standard and XML.

COMTRADE is an existing standard format for sampled data. However, the difference in the implementation of the standard by different vendors indicates that there is a need to define mandatory requirements in a more descriptive way in order to ensure a consistent format of sampled data records.

Substation level analysis of faults and disturbances can be based on data from different sources. Event logs may be available from the substation event recorder or from fault and event reports retrieved from the different types of IEDs. This is a very promising method for analysis, however it is very difficult to implement today, because the fault and event reports in IEDs from different manufacturers are in different formats that in most cases do not allow automatic processing.

Successful analysis is based not only on event data, but also on system, substation and IED configuration data. The paper discusses this issue and available or proposed common formats for configuration data, event and fault records based on XML.

II. EVENT TYPES

The successful analysis of different power system events requires good understanding of the phenomena, the operating principles of primary and secondary system equipment, as well as the limitations imposed on the analysis by the available data. A proper classification of the types of events is a pre-requisite in the development of a system for automatic event analysis.

The types of events that can be typically analyzed within a substation automation system may be divided in several categories, such as:

- Shunt (short circuit) faults
- Series (open conductor) faults
- Breaker switching
- System parameter variations
- Equipment failure
- Protection operation
- Control system operation
- Operator action

The problem with the analysis of system events, such as the ones listed above, is that usually they are complex events that fall within several of the categories. For example, breaker closing is an event that may be the result of operators action or protection operation. A protection operation may be the result of incorrect setting under maximum load conditions. But it may also be the result of a short circuit fault.

Because of the above, we need to identify two main classifications of events:

- Primary event: This is a single event that may result in a sequence of related events of different types
- Secondary event: Any event that is the result of a primary or other secondary event (caused by the same primary event)

Several simultaneous secondary events may be associated with a single primary event. Or they may represent a sequence of secondary events. An example will help clarify these definitions.

Example:

Primary event: Single phase-to-ground fault in phase A

Secondary event 1: Voltage variation (sag) in phase A

Secondary event 2: Voltage variation (swell) in phases B and C

Secondary event 3: Protection operation

Secondary event 4: Breaker trip

Secondary event 5: Autoreclosing relay operation

Secondary event 6: Breaker close

If we look at the above listed secondary events, we see that events 1 through 3 are simultaneous, while events 4 through 7 are sequential.

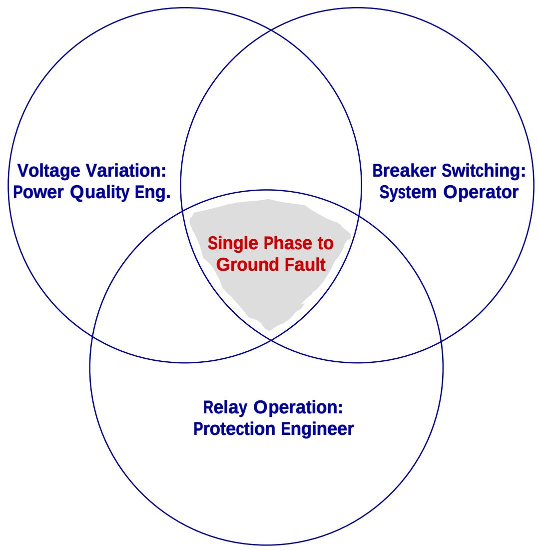

Figure 1. Primary and secondary events and their users

The importance of automatic event analysis is the requirement for converting data into information. And information has a different meaning to different users (see Figure 1). Something that is an important event to one user may not be significant to another. If we analyze the above example, secondary events 1 through 3 will be classified as a Momentary Voltage Variation event – important to some users with equipment sensitive to voltage sags. However, such an event is of no interest to the system operator.

The Protection operation event is of interest to the protection engineer, but of no interest to the power quality engineer. What is of interest to the system operator is the fact that there was a temporary fault in the system, followed by successful relay operation and return to the pre-fault system configuration.

It should be clear from the above that one of the main requirements for an ASEAS (Automatic Substation Event Analysis System) is to be able to analyze a sequence of events, determine the primary event and generate reports for secondary events of interest to specific users. A common format for the different types of data is essential in the development of such systems.

III. XML AS THE COMMON DATA FORMAT

The analysis of fault and event records from multiple devices that operate during an abnormal system condition is very valuable in determining the sequence of operation and the correct performance of the relays. The main obstacle for the wide spread application of such tools is the fact that all IEDs provide their configuration data, as well as event and fault reports in their own proprietary format.

IEC 61850 makes a significant improvement in that process, defining standard reporting models that will allow automatic processing of that data. However, that is not the case for all existing legacy devices.

Considering the importance of the standardization of the data format from all IEDs, the IEEE Power Systems Relaying Committee has initiated work on the development of common data format for the three main types of data available from IEDs: waveform data (a revision of the existing COMTRADE format), event data (event and fault reports) and configuration data (settings and PSL)

This work will be harmonized as much as possible with IEC 61850 and will be based when practical on XML (e**X**tensible **M**arkup **L**anguage). XML is already used as the format of the IEC 61850 Substation Configuration Language.

XML is a relatively new markup language based on existing markup languages that have been used for different applications for many years. Some of the abbreviations that are used later in the text of the paper are as follows:

XML was developed by members of the W3C (**W**orld **W**ide **W**eb **C**onsortium) and released as a recommendation by the W3C in February 1998. It is a simplified version of SGML (**S**tructured **G**eneralized **M**arkup **L**anguage) and a cousin of HTML (**H**yper**T**ext **M**arkup **L**anguage).

SGML was developed to standardize the production process for large document sets and .is an international standard that has been in use as a markup language primarily for technical documentation and government applications since the early 1980s.

The growing popularity of XML is the result of it’s flexibility and strength. It is an extensible, because it allows you to extend the user’s ability to describe the domain specifics of the document.

In appearance XML is quite similar to HTML. This similarity is due to the fact that they both use tags. In HTML, there is a specified set of tags that defines the format of the data

In XML the user can create the tags required by the application domain. That is why XML is extensible – it extends the ability to describe a document, letting you define meaningful tags for your applications. For example, since any IED typically provides current measurements, for the phase A current measurement that is available as a floating point we can create a tag called <PhsAf>. In a similar way we can create as few or as many tags as our document needs. It is obvious that we are extending the tags to identify elements by what they are -- not by how they look.

The extensibility means flexibility, but flexibility requires planning. To make good use of XML, we want to know and understand our documents: what pieces comprise them, how those pieces relate to each other, and how do we want to identify the different pieces. This is where the object models defined by UCA 2.0 and IEC 61850 become the foundation for development of XML files.

XML is a Markup language because it’s purpose is to identify elements within the document. Without markup, the computer sees any document as one long string of text, with each character having equal importance to every other character. By marking up a document, we identify the bits and pieces in a way that gives them value and context.

The big advantage of XML is that it allows extensible markup, i.e. we can mark up the document in ways that match our substation automation needs.

However, markup is nothing but a way of identifying information. It does not program the data to act in a certain way, to display in a certain way, to do anything other than carry an identifying mark.

XML is a **L**anguage because it follows a firm set of rules. It allows us to create an extensible set of markup tags, but its structure and syntax remain firm and clearly defined. This doesn't mean that it is a programming language – it is not used to program a set of actions, but for a well structured markup definition.

XML applies structure to documents. Since SCL documents are sets of related information, the structure is quite important. It is the way we put a skeleton behind the information, so that the pieces of information work together and make sense as a whole.

The document structure defines the elements which make up a document, the information we want to collect about those elements, and the relationship those elements have to each other. You use XML to markup the document, following the structure you have decided upon. That is why XML is appropriate for describing the different aspects the substation configuration from the perspective of the substation automation system.

The document structure is called the Document Tree. The main trunk of the tree is the parent. All the branches and leaves are children.

Document trees are usually visually represented as a hierarchical chart. Fig. 2 shows a part of a document chart view in Internet Explorer.

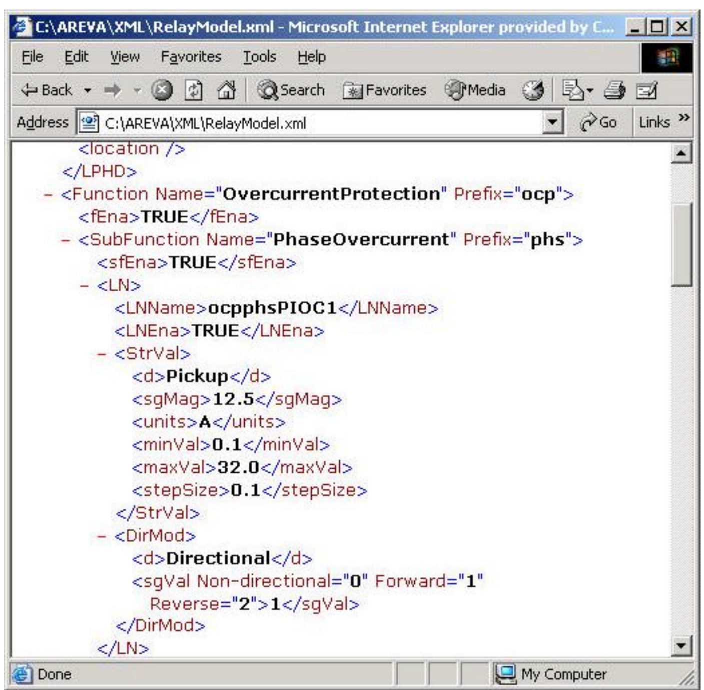

Figure 2 Document tree view in Internet Explorer

Considering that the data object structure in IEC 61850 is also hierarchical, it is obvious that XML is very well suited for use as a SCL file format.

IV. Substation Configuration Language

One of the important requirements for any event analysis system is the accurate data about the location and connection of primary and secondary equipment in the substation.

If the event analysis tools based their event classification on wrong substation configuration data, the results from the analysis will be misleading as well.

For example, if a short circuit fault on a distribution feeder is followed by the tripping of a distribution feeder and unsuccessful reclosing, the final state of the affected distribution feeder will be “de-energized”. From the point of view of all users connected to this feeder the classification of the power quality event by the ASEAS should be “Voltage Interruption”. This will work fine if the voltage is measured on the feeder side of the breaker. However, at the distribution level usually the voltage transformers are on the bus side. As a result, when the feeder breaker is tripped, the voltage will go back to normal, and the system may decide that there is no Voltage Interruption.

If it is known to the system that the voltage source is on the bus, another data source – for example the distribution breaker status – should be used.

In order to provide a standard way of documenting the substation primary and secondary equipment configuration, IEC TC 57 has developed as part of IEC 61850 the so called SCL (Substation Configuration Language). It is used to describe substation configurations, including communication systems and allows the formal description of the relations between the substation automation system and the substation.

V. IED Configuration Data

The requirements for a standard IED configuration data file format apply not only to IEC 61850 based devices, but to all IEDs on the market today and in the future. They can be even applied to electromechanical or solid state relays that do not have communications capabilities, but still can represent the setting (configuration) file of the relay.

The basic idea is to have a standard configuration file that can be used or produced in several different ways. Fig. 3 below shows a simplified diagram of this process for a generic protective relay.

Since legacy protective relays have different proprietary formats of their configuration files, the interface to the relay is based on a proprietary configuration tool. This requires the development by each vendor of proprietary tools that will allow the conversion and export of the proprietary configuration file as a standard XML file. The same tool will allow the import of a standard XML configuration file and its conversion to the proprietary file format required by the IED configuration software.

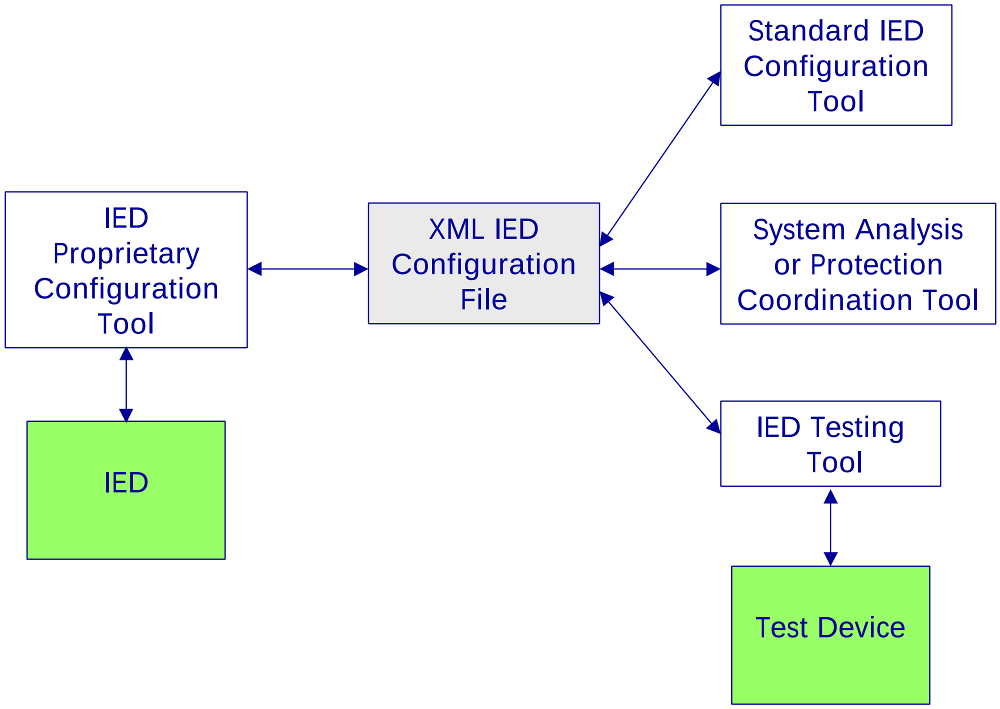

Figure 3. IED simplified XML Configuration process

This standard XML IED configuration file then can be viewed or edited by a standard configuration tool, imported by a System Analysis tool or by an IED Testing Tool.

This process is simplified (as shown in Fig. 4) when using IEC 61850 compliant IED.

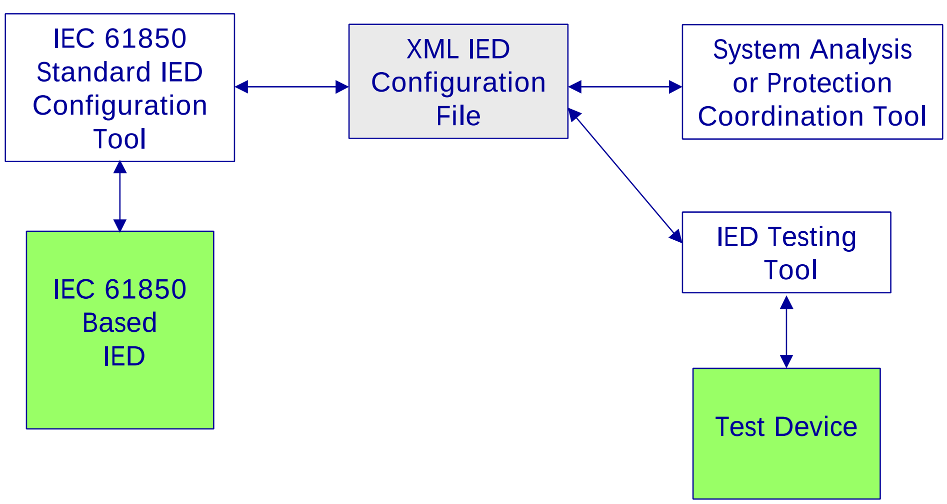

Figure 4. IEC 61850 IED simplified XML Configuration process

In this case the IEC 61850 standard IED Configuration Tool will upload from or download to the IEC 61850 compatible IED a set of configuration data objects. These configuration data objects are used to create the standard XML IED configuration file that is used by the different applications as described earlier in the document.

The functional hierarchy of a protection and control IED is based on the models defined in IEC 61850. It may include Functions, Sub-functions and Function Elements (see Fig. 5). Its foundation are the functional elements as described below.

Function Element: A Function Element is equivalent to a Logical Node as defined in IEC 61850. A Logical Node from the perspective of the Configuration Data is a collection of settings that allow the configuration of a Functional Element. A Functional Element can be Enabled only when the Sub-Function and Function that it belongs to are Enabled.

Examples of Functional Elements are Instantaneous and Time-Delayed Overcurrent Elements – for example **PIOC** and **PTOC,** or a distance zone **PDIS**. Several functional elements may be needed to model a functional element. For example a directional overcurrent element will be modeled by the combination of an overcurrent element and associated with it directional element **RDIR**. They are not combined in a single logical node, because the directional element is usually used for directional supervision of all overcurrent elements in the sub-function.

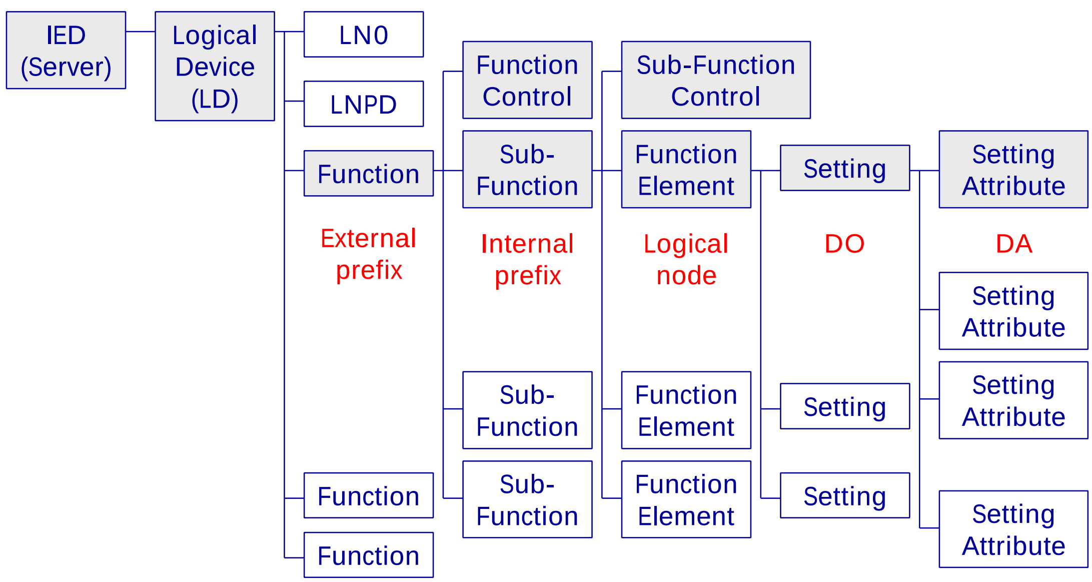

Figure 5. Functional hierarchy for XML configuration file based on IEC 61850

A modern microprocessor based protection relay can have multiple instances of a Function Element – for example six distance zones. They also might be supervised by a common directional element RDIR.

Settings: Data Objects are used to model the individual settings of a Function Element. They are defined as such in IEC 61850.

Examples of Data Objects are the Pickup **StrVal** of an Overcurrent Element or the Characteristic Type of a Time-Delayed overcurrent element.

Setting Attributes: Data Attributes are used to represent the attributes of a setting and are defined as such in IEC 61850. Some examples of attributes of a setting are value, setting range – Min and Max, step size, etc.

The above described components of the IED configuration model will be represented with their own layer in the hierarchy of the XML file.

The IEC 61850 based IED configuration file will be an XML representation of a collection of functions, sub-functions and logical nodes according to the functional hierarchy shown in Fig. 5. The XML configuration file is using the object names as defined by different sections of IEC 61850. Since Functions and Sub-Functions are not defined in IEC 61850 from the IED configuration point of view discussed here, they are represented as part of the Logical Node names as described below.

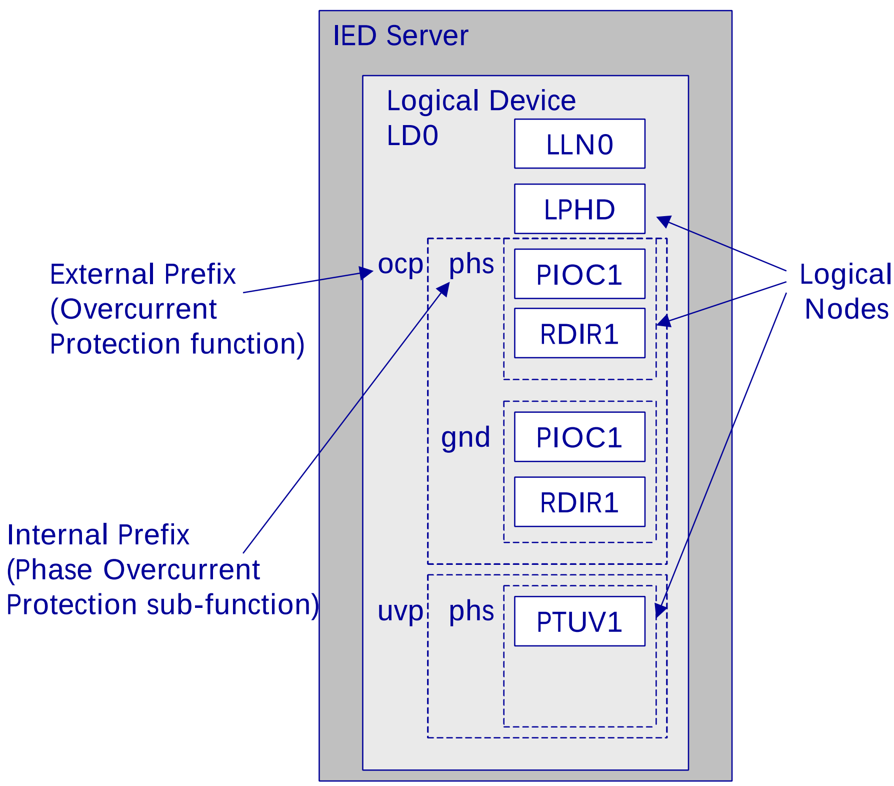

Figure 6 Simple multifunctional protection IED object model

Logical nodes LLN0 and LPHD are used to provide the global IED information that is mostly read only.

The individual logical node names are composed of **External Prefix** (3 letters), **Internal Prefix** (3 letters), **Logical Node Class** name (4 letters), **Instance Number**. For example **ocpphsPIOC1** is the name of the logical node representing an Instantaneous Phase Overcurrent Elements.

The elements used to set a Function (fEna), Sub-Function (sfEna) and Function Element (LNEna) do not have matching data objects in IEC 61850. This is an issue that has to be addressed by the UCA International Users Group Technical Committee, since the user should be able to change the configuration of the IED to Enable or Disable them over the substation LAN.

Figure 2 earlier showed an example of a Logical Node in the XML configuration file format.

VI. Common Format for Event Data

Event reports in IEC 61850 are based on Report Control Blocks. They control the procedures required for reporting values of event data from one or more logical nodes to one client. Instances of report control are configured in the IED at configuration time.

IEC 61850 defines two classes of report control:

- Buffered Report Control Block (**BRCB**)
- Unbuffered Report Control Block (**URCB**)

Buffered Report Control Blocks are used for sequence of event purposes. They define internal events (caused by trigger options data-change, quality-change, and data-update) that issue immediate sending of reports or buffer the events for transmission. This prevents from data being lost in case of loss of connection.

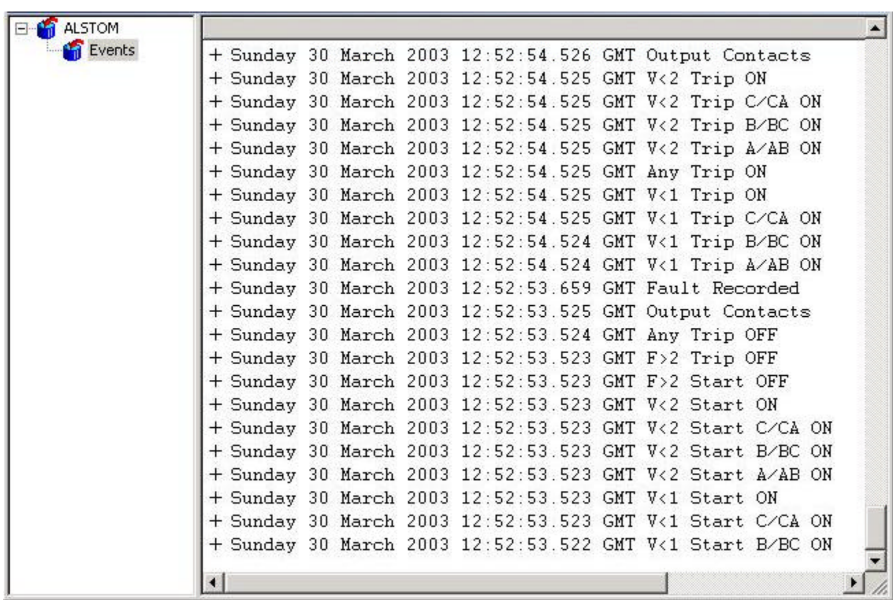

Figure 7. Event report from multifunctional protection IED

Unbuffered Report Control Blocks are quite similar to the **BCRB**, butthey don't buffer the data, so event information may be lost in the case of communication problems. Obviously they do not support sequence of events reporting in case of loss of communications.

The data from the report control blocks of IEC 61850 compliant devices can be used to create an event log to be further processed for the analysis of the behavior of different protection and control devices during abnormal power system conditions. That is not the case with legacy devices that typically have a different file format for different vendors or even for different products from the same vendor. Such proprietary files (see Fig. 7) can not be processed by an automatic analysis program. The data has to be manually entered in a spreadsheet, or another common format used by the analysis software. This results in significant costs and slows down the analysis process.

If a common event data format is available, and if it is easily processed by software, the result will be significant improvement in the speed with which system events are being analyzed. Since there will be no more manual data entry, the cost will decrease, while at the same time the quality will improve because of the reduced probability for human errors. Fig. 8 shows a simplified block diagram of the conversion process - from a proprietary event report format to a standard XML based file format.

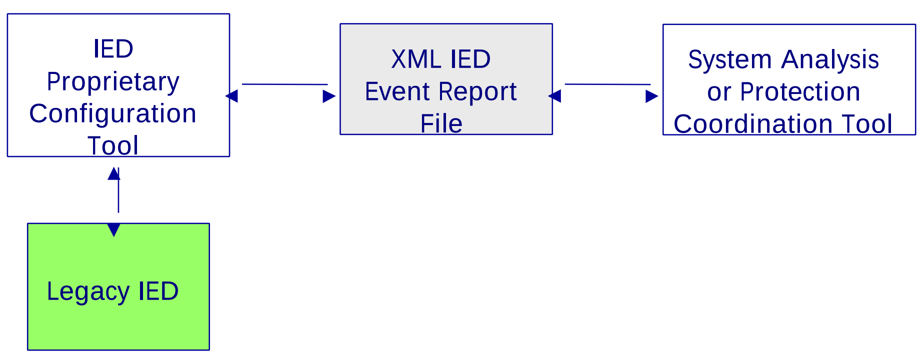

Figure 8. Event report conversion process

Below is an example of an event entry in the XML file format being currently discussed by the PSRC working group. The file will include as many such entries as available in the proprietary event report file downloaded from the relay.


```
- <LogEntry>
    <t>00-12-07 16:55:54.135</t>
    <entryId>13</entryId>
  - <ev>
      <LDInst>C1</LDInst>
      <LNName>CSWI1</LNName>
      <DORef>Pos</DORef>
    - <At>
        <n>stVal</n>
        <v>off</v>
      </At>
    </ev>
  </LogEntry>
```

VII. COMMON FORMAT FOR SAMPLED DATA

For more than 10 years the industry has used a common format for sampled data - COMTRADE. Its latest version is IEEE Std C37.111-1999 (Revision of IEEE Std C37.111-1991) IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems. It is also accepted as IEC 60255-24 and is used for the interchange of various types of fault, test, or simulation data for electrical power systems.

Each COMTRADE record has a set of up to four files associated with it. Each of the four files carries a different class of information, with some of them being mandatory and other being optional. The four file types are:

- Header (.HDR) File
- Configuration (.CFG) File
- Data (.DAT) File
- Information (.INF) File

The Header File and the Information File are defined as optional.

The Configuration File and the Data File are mandatory.

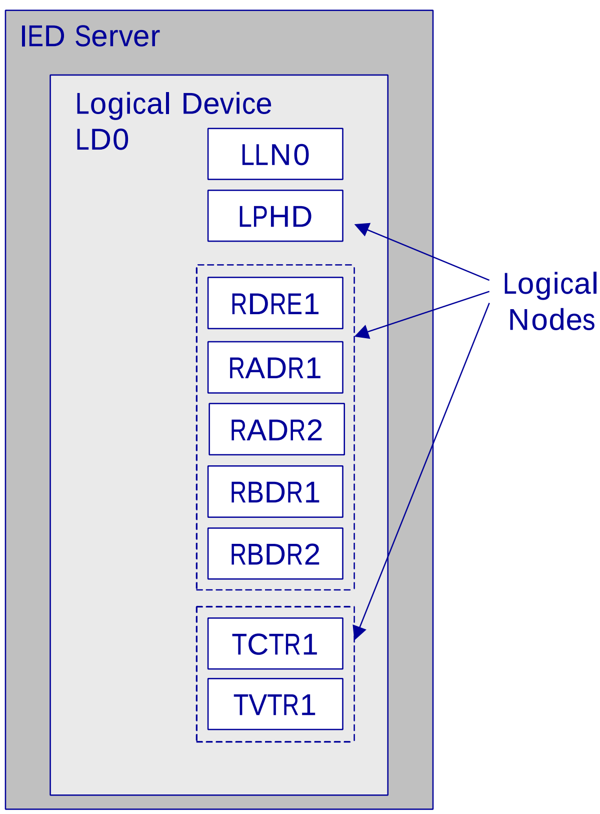

Figure 9. Disturbance recorder simplified object model

Some of the data in the Configuration File is not absolutely necessary, is defined as non-critical The Configuration File shall have the following information:

- Station name, identification of the recording device, and COMTRADE Standard revision year
- Number and type of channels
- Channel names, units, and conversion factors
- Line frequency
- Sample rate(s) and number of samples at each rate
- Date and time of first data point
- Date and time of trigger point
- Data file type
- Time Stamp Multiplication Factor

and may be omitted. This and the fact that this is a comma separated text file that allows empty fields results in some cases of misinterpretation of the COMTRADE files and the fact that they can not be read by all COMTRADE viewers.

The IEEE PSRC working groups that are looking into standard formats for IED data are also considering some changes in COMTRADE. Of specific interest is the Configuration File. Replacing the text file with an XML file will result in a more clear definition because of the use of tags that describe each data object in the file.

This file as well should be based on the object models defined in IEC 61850. A Logical Node Disturbance recorder function **RDRE** is used to describe the basic functionality, while instances of **RADR** are used for modeling of analog channels and **RBDR** for binary channels. Fig. 9 above shows a simplified block diagram of a disturbance recorder that can be used for the XML based Configuration File of a sampled data recorder.

VIII. Conclusions

Multiple applications, such as protective relays settings programs, protection coordination programs, relay testing tools or automatic event analysis software require common data formats to be defined in order to allow computer processing of data from devices manufactured by different vendors.

Several working groups in the IEEE Power Systems Relaying Committee are in the process of defining common data formats for:

- IED configuration data
- Event data
- Sampled data

XML is the obvious selection for file format because it allows the user to create the tags required by the application domain and match the functional hierarchy of the protection and control IEDs object models.

IX. References

[1] U.S.-Canada Power System Outage Task Force, “Interim Report: Causes of the August 14th Blackout in the United States and Canada”, Nov. 2003 [Online]. Available: http://www.nerc.com/

[2] IEC 61850-6 Communication networks and systems in substations, Part 6: Configuration description language for communication in electrical substations related to IEDs

[3] IEC 61850-7-1 Communication networks and systems in substations, Part 7-1: Basic communication structure for substation and feeder equipment – Principles and models