Conformance Errors in COMTRADE Records

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I – Abstract

Since its initial publishing the COMTRADE standard has become internationally recognized as the foremost standard for storing fault and disturbance data. As the use of the standard increases, so too does the need to check COMTRADE records for accuracy and readability. COMTRADE records are mainly susceptible to three types of conformance errors: formatting errors, interpretation errors, and designation errors. Each category of conformance errors has its own set of negative effects on the analysis process.

The purpose of this paper is to bring awareness to the issue of conformance errors in COMTRADE records, and the negative effects these errors can create. This paper will be broken into five sections, with the first being the abstract. The second section will be an in-depth analysis of potential formatting, interpretation, and designation errors in all three revisions of the COMTRADE standard. The third section titled “The Experiment” will be a summary of the current efforts being taken to prevent conformance errors in COMTRADE records. The fourth section will be a brief conclusion and the fifth and final section will be an overview of the evolution of the COMTRADE standard, and the differences between the three revision years.

II – Potential Conformance Errors

Any standard that defines a format is susceptible to conformance errors. A conformance error is any deviation from or misinterpretation of the defined standard format. This may appear to be a trivial issue, but it is not. The COMTRADE standard defines a format for storing transient data. This data can be used for fault analysis, maintenance, settings, testing, and historical archiving [6]. COMTRADE analysis tools are built to read and analyze this data. When conformance errors exist, these tools may not be able to find the data they need, or in some cases may not be able to access the data at all. As stated in the abstract conformance errors can be placed into three different categories, formatting errors, interpretation errors, and designation errors.

i) Formatting Errors can be broken into two categories, critical and non-critical. Critical formatting errors render COMTRADE records unreadable or unusable and can only be remedied by finding and correcting the error(s). Some common critical formatting errors are listed below.

1. Missing or extra data separators in analog or digital channel definitions.
2. Including carriage return/line feed characters in binary, binary32, or float32 DAT files.
3. The number of analog or digital channels in the second line of the CFG file does not match the number of channels listed.
4. The file type specified in the CFG file does not match the data listed in the DAT file.
5. Critical information is missing such as the line frequency or sampling rate.
6. End sample listed in the CFG file does not correspond with the last sample recorded in the DAT file.
7. Analog channel definition fields not listed in the correct order.
8. Sampling rate specified in the CFG file does not correspond with the sampling rate used in the DAT file (time stamp field).

Figure 1 shows an example of a critical formatting error in a 1999 CFG file. Figure 2 shows an example of a COMTRADE analysis tool attempting to open the file.

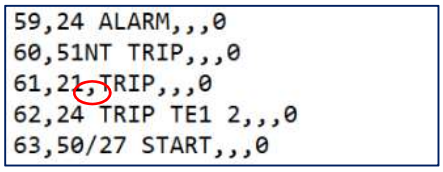

Figure 1

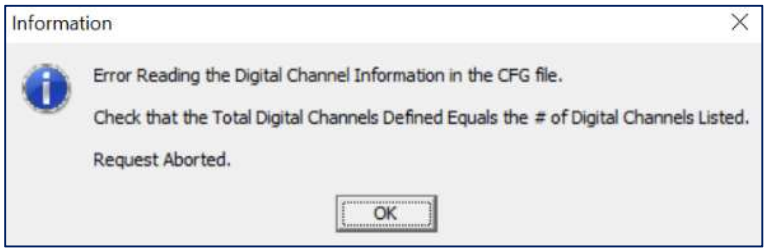

Figure 2

The file shown in Figure 1 contains hundreds of analog and digital channels and just one extra data separator rendered it unreadable. Without an application that can quickly detect this error, manually attempting to find it could take hours.

Most critical formatting errors render records unreadable but there are some formatting errors that do not and may lead to data corruption or misrepresentation. An example would be the sampling rate listed in the CFG file does not match the sampling rate used in the DAT file. This would cause data corruption but would not prevent the file from being opened. In this case it is important for analysis engineers to check CFG file information to confirm it corresponds with what the analysis tool displays.

Non-critical formatting errors are deviations from the standard that do not render records unreadable or unusable. Some common non-critical formatting errors are listed below.

1. Using more than the maximum number of characters allowed for channel identifiers.
2. Not including the substation or device identifier fields.
3. Analog or digital channel counts on the second line do not end with an A or D.
4. Time Stamp Multiplication field not listed.
5. Missing time zone field in a 2013 record.
6. Missing time quality field in a 2013 record.
7. Missing control feed/line returns in a CFG file.
8. Extra bytes in a binary DAT file.

Any non-critical field that exceeds its maximum or does not meet its minimum character count can also be considered a non-critical error as long as it does not affect opening or reading the record. An example of a non-critical formatting error is missing time code fields in a 2013 COMTRADE record. These fields are used to identify the time zone that the record was created in. While this formatting error can affect time synchronization issues with other COMTRADE records it will not affect the ability to open and analyze the record.

The classification of some errors as non-critical may lead readers to believe that these errors can be left as is. This is not the case. While these errors do not directly affect readability, the combination of non-critical errors with critical errors can compound issues. An example of this is missing carriage returns or line feeds in the CFG file. Alone this error will not prevent a record from being opened or analyzed, but if

an extra data separator also exists in the record preventing it from being opened, then the missing carriage returns or line feeds will make it almost impossible to find the extra data separator.

The three revision years share the same critical formatting errors, but do not share the same non-critical formatting errors. This is because the 1999 revision year added new fields and strict requirements to existing fields, therefore creating more potential formatting errors. Examples include the maximum and minimum character restrictions on channel, substation, and device identifiers. This is also true for the 2013 revision which added new fields to the format as well. Examples include missing time zone and time quality fields.

ii) Interpretation Errors arise when data is formatted correctly, but the data itself is incorrect. Like formatting errors some interpretation errors render COMTRADE records unreadable while others do not. Unlike formatting errors all interpretation errors regardless of this distinction are considered critical errors. This is because interpretation errors on average lead to incorrect data values more commonly then formatting errors. If a COMTRADE analysis tool is able to open and display a COMTRADE record with interpretation errors, then most probably the data values displayed are incorrect. Some common interpretation errors are listed below.

1. Analog channel units not listed.
2. Analog multiplier, offset, time skew, range minimum, or range maximum contains non-numeric characters.
3. Primary and secondary values not included or incorrectly specified in post 1991 revision years.
4. Fault date and time tag is indiscernible.
5. Fault date month and day tags are reversed.
6. Line frequency listed in the CFG file does not correspond with the data in the DAT file.
7. Float32 or Binary32 data types used in pre-2013 revisions.
8. Incorrect time zone field.

Interpretation errors tend to create more issues than formatting errors. These issues can include sending restoration crews to the wrong fault location or providing relay technicians with the wrong settings. Interpretation issues can also be difficult to correct. While the process of correcting formatting errors can be time consuming, many interpretation errors are unfixable. An interpretation error is deemed unfixable if the information in the CFG file cannot be used to correct the error. Figure 3 shows an example of a 1999 CFG file with an unfixable interpretation error that renders the file unreadable. Figure 4 shows an example of a COMTRADE analysis tool attempting to open the record.

```
20,VBV,B,,kV,0.022714,0,0,-32767,32767,2000.0,1,P
21,VCV,C,,kV,0.022714,0,0,-32767,32767,2000.0,1,P
22,VAZ,A,,kV,nan,0,0,-32767,32767,2000.0,1,P
23,VBZ,B,,kV,nan,0,0,-32767,32767,2000.0,1,P
24,VCZ,C,,kV,nan,0,0,-32767,32767,2000.0,1,P
25,VDC,,,V,0.011182,0.719017,0,-32767,32767,1,1,P
```

Figure 3

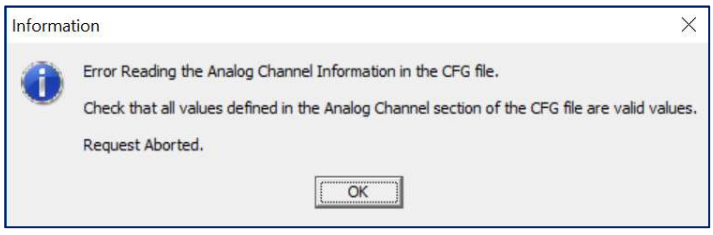

Figure 4

The term “nan” in the analog multiplier field renders this record unreadable. This can be considered an interpretation error because it can be assumed that “nan” stands for not available. In the event that an analog multiplier field contains “nan” or is left blank, then the field can be filled with the numeric value “1” to make the file readable. Yet with no way to confirm that the channel multiplier should be “1” this may lead to a misrepresentation of the data, therefore making this an unfixable error.

A more serious interpretation error that does not render a record unreadable is primary and secondary values specified incorrectly. This will cause COMTRADE analysis tools to display primary values as secondary values or vice versa. To catch this error without a software tool engineers can compare displayed voltage level to the actual voltage level of the line.

iii) Designation Errors arise when the data itself is correct, but the labeling information associated with it is incorrect. Unlike formatting and interpretation errors, designation errors rarely if ever prevent a COMTRADE record from being opened. Designation errors arise from mislabeling of critical data fields. Some common designation errors are listed below.

1. Digital channels in DAT file listed in a different order than specified in the CFG file.
2. Analog channel identifier not associated with the correct channel.

These errors can be considered critical because similar to interpretation errors they lead to incorrect values. An example of this is shown in Figure 5 where the analog channel identifiers “IC” and “IB” are flipped. Figure 6 shows how this error affects the COMTRADE analysis tool.

```
12,6A,6D
1,VA,,,kVolts,0.001000000000,0.0,0.0,-305100,3051
2,VC,,,kVolts,0.001000000000,0.0,0.0,-303300,3025
3,VB,,,kVolts,0.001000000000,0.0,0.0,-300399,3003
4,IA,,, Amps,0.001000000000,0.0,0.0,-7802000,7812
5,IB,,, Amps,0.001000000000,0.0,0.0,-452000,45200
6,IC,,, Amps,0.001000000000,0.0,0.0,-514000,51600
```

Figure 5

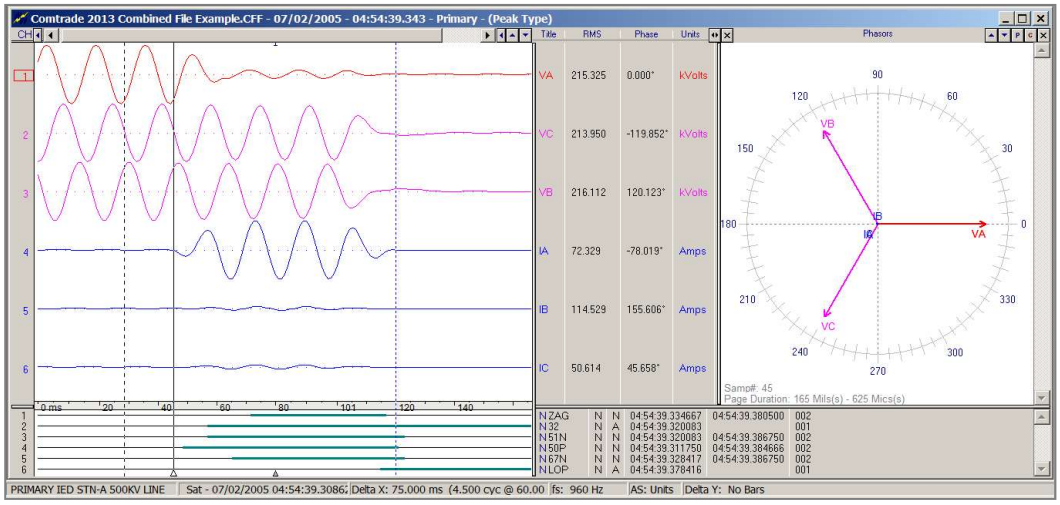

Figure 6

For this example, any COMTRADE analysis tool would show a rotation of ACB instead of ABC which is the correct rotation for this case. These types of errors can lead analysts to act on the wrong phase which can compound issues instead of correcting them. Since all three revision years classify the channel count and identifier fields as critical, all three revisions share the same potential designation errors.

III – The Experiment

The good news is that in recent years IEEE has taken a proactive role in developing potential solutions for conformance errors in COMTRADE records. In 2013 a task force of COMTRADE experts was formed at the Power Systems Relay Committee (PSRC) to analyze the possibility of conformance errors in the 2013 revision of the COMTRADE standard. A report titled “2013 COMTRADE Conformity Test Plan” was released in 2015. This report was the first PSRC effort to define potential errors in a COM standard. By 2022 COMSET and perhaps a new revision of COMTRADE will be released [8]. To ensure proper standard adoption, the creation of a conformance error report should become part of the standard creation process for all COM standards.

In the winter of 2017 the ICAP COMTRADE Conformity Assessment Steering Committee (CCASC), a committee of COMTRADE experts was formed. Since its formation this committee has worked to create a process for evaluating COMTRADE standard conformance tools (CSCT). A CSCT is a software application that can detect conformance errors in COMTRADE records. The process of evaluation created by the CCASC can be replicated for other COM standard such as the COMNAME, COMFEDE, and COMDEV standards.

To be considered for evaluation by the CCASC, a CSCT must have the ability to detect all of the conformance errors outlined in the 2013 COMTRADE Conformity Report. As of July 2019, two CSCTs have been submitted to the CCASC for evaluation. To test these CSCTs members of the CCASC collected 100 COMTRADE records from ten power utilities and manufactories. Below is a statistical breakdown of the records collected.

- The records were separated and tested by revision year with 18 records in the 2013 revision, 54 records in the 1999 revision, and 28 records in the 1991 revision.
- 18 out of the 28 (64%) 1991 records collected contained conformance errors, with the most common errors being an incorrect revision year, and missing unit values for analog channel definitions.
- 34 out of the 54 (62%) 1999 records collected contained conformance errors. While the type of conformance error varied more for the 1999 records than the 1991 records, the most common errors were missing control feed/line returns between fields, and incorrectly formatted date and time fields.
- 6 out of the 18 (33%) 2013 records collected contained conformance errors, with the most common errors being missing or not properly formatted time code fields. While all the 2013 records collected came from various manufacturers, all were created using the same COMTRADE analysis tool. Therefore, the testing of these 2013 records is not a good indication of the frequency with which conformance errors can be found in 2013 records within the industry. This issue was caused by a lack of 2013 records being used in the industry upon the time of this testing.

While 100 records can be considered a relatively small sample size, the number of different sources that provided records indicate conformance errors in COMTRADE records are a prevalent issue in our industry.

In the previous section interpretation errors were classified as either fixable or non-fixable. The passing of the COMDEV standard in 2018 changes the classification of many non-fixable errors to fixable. An example of this is missing analog channel units. COMDEV standardizes device name fields in COM and other standards. In the COMTRADE standard it standardizes the naming of the substation name, device name, and the analog and digital channel identifiers fields. According to COMDEV analog channels with amps as the unit must have the channel identifier as one of the following depending on the channels phase, IA, IB, IC or IN. This allows users to use the channel identifier to determine the channels units in the case that they are not listed.

IV – Conclusion

Conformance errors in COMTRADE records are small errors that can create large problems. For years these errors were handled inefficiently by sending unreadable or misinterpreted records back to vendors for analysis. As stated above this is a time-consuming process, fortunately many industry experts have worked to change this process in the last decade. The creation of a conformance report along with formation of the CCASC encourages the industry to create CSCTs and also creates an easily replicable process for other COM standards. Testing done by the CCASC shows that a CSCT can reduce the average time needed to find conformance errors in COMTRADE records from hours to seconds. In conclusion, while conformance errors have been a persistent problem since the release of the first COMTRADE revision, recent efforts have laid a foundation for handling these errors in COMTRADE and other active COM standards.

V – Background Information on COMTRADE History

In the late 1980s digital fault recorder (DFR) providers had their own proprietary formats and software tools for storing transient data [1]. The number of proprietary formats used in the industry made the exchange of transient data a cumbersome task which required software tools to convert from one format to another. This deficiency in transient data exchange led IEEE to develop the COMTRADE standard, which serves as a “Common Format for Transient Data Exchange in Power Systems” [2]. The first revision of the COMTRADE standard was released in 1991 under the name IEEE C37.111.1991.

The 1991 COMTRADE format consists of three files, a CFG file, DAT file and HDR file. The HDR file is optional and used for additional information. The CFG and DAT files are mandatory; the DAT file stores the data while the CFG file lays out the data’s configuration. The format within each file uses commas and carriage return/line feeds as delimiters between fields. All fields are classified as either critical, which means the field is mandatory, or non-critical which means the field is optional [3].

As the 1990s progressed new digital relays with the ability to record transient data were created. This opened the field of transient data recording to a large number of new providers which in turn led to the introduction of a large number of new operating nuances. IEEE monitored these changes throughout the decade and in 1999 a new revision of the COMTRADE standard, C37.111.1999 was released. A few major differences between the two revisions are listed below:

1. A new optional file INF was added increasing the total file count to four [4].
2. More explicit restrictions were placed on critical fields (such as character minimums and maximums).
3. A new binary format was specified and the requirement for a user-supplied conversion program was eliminated.
4. New fields were added to the analog channel definition to support primary to secondary conversions and vice-versa.
5. New fields were added to the digital channel definition to match the level of definition in the analog channels.
6. Support for event triggered data was added with the addition of a new mode for Sampling Rate Information when the sampling rate is variable.

In 2004 the North American Electric Reliability Corporation (NERC) launched an investigation into the root cause of the 2003 northeast blackout. To perform this investigation a large number of transient data files were collected and studied. While COMTRADE was vital to this investigation, it also uncovered a number of weaknesses in the standard. Some of which include, the lack of a field specifying the time zone the record was created in, and the lack of a field specifying time tag synchronization. These discoveries led IEEE to develop another revision of the COMTRADE standard, C37.111.2013, which was released in 2013. A few major differences between the 2013 and 1999 revisions are listed below:

1. The 2013 revision defines an optional single file format (CFF) which combines the four files (INF, HDR, CFG, DAT) into one. The CFF file is separated into four sections, one for each file in a record, only the CFG and DAT sections are critical [5].
2. For the DAT file binary32 and float32 formats are now supported along with binary and ASCII.
3. New fields were added to the CFG file to specify time zones and data quality.
4. The use of Unicode UTF-8 characters was added.
5. A number of the fields in the CFG file that were listed as non-critical in 1999 were changed to critical.

VI – References

[1] IEEE PES PSRC H4 Working Group. “Summary of the Proposed Revisions to IEEE Standard C37.111-1999, COMTRADE Common Format for Transient Data Exchange”. Western Protective Relay Conference. October 2009

[2] Tierney, Dennis. Gosalia, Jay. “Tutorial: Using COMTRADE Files for Relay Testing”. Western Protective Relay Conference. October 1998

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[4] IEEE Std. C37.111-1999, IEEE Standard Format for Transient Data Exchange.

[5] IEEE Std. C37.111-2013, IEEE Standard Format for Transient Data Exchange.

[6] Ukil, A. Zivanovic, R. “Automated analysis of power systems disturbance records: smart grid big data perspective”. IEEE Innovative Smart Grid Technical Conference., ISGT ASIA 2014. Kuala Lumpur, Malaysia. 2014

[7] IEEE PES PSRC H26 Working Group. “COMTRADE 2013 Conformity Test Plan”. Report to the PSRC Main Committee May 2015.

[8] IEEE PES PSRC H23 Working Group. “Summary Paper of IEEE Standard C37.248-2017”. Report to the PSRC Main Committee January 2019.