IEEE Transactions on Power Delivery, Vol. 7, No. 4, October 1992.

COMTRADE: A new standard for common format for transient data exchange

Prepared by Working Group H-5 of the
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IEEE Power System Relaying Committee

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ABSTRACT

The paper describes a new IEEE standard developed by the Power System Relaying Committee. It is intended for use by digital computer based devices which generate or collect transient data from electric power systems. The standard should facilitate exchange of the transient data for the purpose of simulation, testing, validation or archival storage. This paper provides an overview of the IEEE Standard, (C37.111) which should be referred to for a full description of the types and structures of the data files. It is expected that the standard will be particularly useful for users of digital relays, digital fault recorders, or digital simulation programs of electrical transient phenomena.

INTRODUCTION

The Standard defines a common format for the exchange of electrical power system transient data files. These files comprise a record of real or simulated power system events. They contain digitized records of voltage and current waveforms, and logical events, such as relay operations, in a time coherent record. The format is intended for use when individuals who use different proprietary recording or simulation systems need to exchange data. COMTRADE provides a common language in which those interested in power system and protection analysis may exchange information, in the form of digital data files, on power system events. The standard provides compatibility with a system recommended by CIGRE working group WG34.01.[1] The present standard is not a standard for communication systems. The working group envisages that all manufacturers involved in the manufacture of recording, analysis and testing systems will provide a bridge between their own proprietary system and COMTRADE. Several manufacturers have already committed to support this standard.

92 WM 201-4 PWRD A paper recommended and approved by the IEEE Power System Relaying Committee of the IEEE Power Engineering Society for presentation at the IEEE/PES 1992 Winter Meeting, New York, New York, January 26 - 30, 1992. Manuscript submitted September 17, 1991; made available for printing November 20, 1991.

Sources of transient data

Sources of Transient data presently in use may be divided into two types: (1) Acquisition devices which record voltage, current and logical signals directly from the power system. These include digital and analog fault recorders, and digital protective relays. (2) Simulation devices which calculate voltage, current and logical signals from a mathematical or physical model of a power system. These include transient simulation programs running on digital or analog computers and analog simulators.

Use of transient data

Transient data files contain detailed information on the conditions of the power system during events such as faults, power swings, loss of generation, energization of equipment, high harmonic loads, etc. Some applications of the transient data files include;

- Analysis and identification of undesirable sources of harmonics and unbalances.
- Analysis and location of power system faults.
- Analysis of events leading to power system instability.
- Use of data in digital form to test digital relaying algorithms.
- Reproduction of data in analog form to test protective relays.

Need for a standard

The need for a common format resulted from the burgeoning interest in analysis of the performance of power systems and their protection subsystems. This led to the proliferation of devices for the acquisition or simulation of power system event data. For

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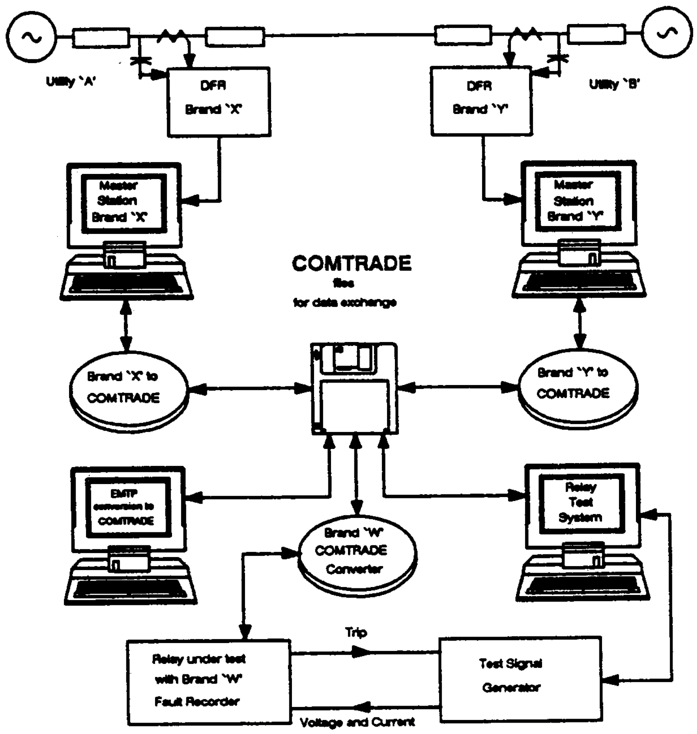


Figure 1. Typical COMTRADE applications.

valid commercial reasons different manufacturers use widely divergent formats and media for data storage. However, we now have situations where interconnected utilities who share a common interconnection but use different manufacturers' equipment or simulation programs cannot exchange data about a common power system event. This standard provides a means of sharing such information.

SUMMARY OF MEDIA AND FILE RECOMMENDATIONS

The Standard recommends the use of removable diskette media such as are commonly used by most personal computers (PCs), and defines a file format for storing waveform, logical event and descriptive data on this medium. The files should conform with Micro-Soft Disk Operating System (MSDOS) files such as used in International Business Machines (IBM) compatible PCs, and are named using the convention for such files. The file names consist of a prefix of up to eight alphanumeric characters, a period, and a three character extension. A set of files for a given event consists of three types of files with the same prefix and the obligatory extensions "HDR", "CFG" and "DAT". Provision is made for multiple files in cases where all of the data will not fit on one diskette.

Header files

The HEADER ("HDR") file is a free form ASCII file containing any textual information the originator wants to convey to the end user. Most word processors can make, read, and print such files. The contents may include information on the recording or simulation system, and the power system location from which the event data was derived. Power system impedances, transformer ratios and similar information may be included. To ensure CIGRE compatibility, information on the data recording format and data file must be included.

Configuration files

The CONFIGURATION ("CFG") file is in a pre-defined fixed format ASCII (alphanumeric) format so that it can be read by a computer program, or a human being. This file contains station name and identification for the record, or simulation and information defining the format of the data ("DAT") file. This includes date and time, sampling rate, frequency, number and type of channels in the data section of the record, and whether the data is stored in BINARY or ASCII format. It provides all of the information necessary to print or make an analog reproduction of the record. The format is fixed so that it can be read by a computer for automated reproduction. This file is not defined in the CIGRÉ system. [1]

Data files

The DATA ("DAT") file contains the actual data samples of the recorded or simulated event. These are digital time tagged samples of the instantaneous values of analog and logical events. Each discrete analog or logical source monitored is called a channel. ***Analog channels*** are commonly voltage and currents. These may have many different values depending upon the resolution of the originating recorder or program, and are represented by integer values. Conversion information for these numbers is contained in the "HDR" and "CFG" files. ***Logical channels*** are typically relay contacts. These have only two states - active or inactive, they are represented by ones and zeroes.

The data file consists of rows and columns. Each row represents a time tagged series of samples. The number of rows in a record depends on the sampling rate and the length of a record. There will be as many rows as there are samples in the record. Each row contains one column for the sample number, one column for the time since the beginning of the record, and one column for each analog or digital channel. Thus a row for an 8 analog and 8 digital channel system will contain 18 columns. The data is stored in ASCII format as defined in the "CFG" file. In ASCII files the data columns are separated by commas and the row is terminated by a "carriage return, line feed", commonly represented as <CR/LF>. Information on the channel number,type and timing is contained in the "HDR" and"CFG" files. The data file must conform exactly to the format defined by the information in the "CFG" file so that it can be read by a computer program.

For each row (complete set of data for one sample period), the storage requirements for the data files are as follows:

The sample number and offset time are each recorded as a ten-integer number, and so will require 10 bytes each; each analog value is stored as a six-integer number, and so will require 6 bytes of storage each; each digital channel is stored as an ASCII zero (0) or one (1) and so will require one byte of storage each. The values for each channel are separated by a comma, requiring one byte of storage. The row is terminated by a carriage return and a line feed character requiring one byte of storage each. An eight analog and eight digital channel record would require 97 bytes of storage per row in this format.

The standard supports ASCII format files. However, it recognizes that binary data files may be useful in some applications. A specification for binary files is included in the standard. To comply with this standard, a binary file must be accompanied by a program which converts the binary file to an ASCII file as defined in this standard.

SAMPLING RATE CONSIDERATIONS

Sampling rate basics

The range of sampling rates of the original data depends on the source of that data, and the exact sample rate used depends upon the equipment used at the source. Therefore, a file generated in one system (recorder or simulator) may have too high or too low a sample rate for application in another system.

For instance, EMTP [2] simulations may need to sample at a very high rate to maintain accuracy. The time resolution of samples resulting from such a study is much more detailed than would be useful in any plotting or reproduction system (other than another EMTP program). The sampling rate, and therefore the number of samples, would normally be reduced before exchange or cross application of this data. It must be realized that reduction of the sample rate ***by any method*** means loss of frequency response. Also, once the data is converted to a low sampling rate there is no way to restore the loss of frequency response by reconverting back to the original data. Simple decimation of the sample rate by throwing away every second, or second and third, data point is not a valid method of sample rate conversion. This method leads to generation of large artificial frequency components in the data.

Similarly, while digital fault recorders from different manufacturers have a similar range of sampling frequencies, they do not all have a common base frequency. These sampling rates are similar to the ranges of sampling frequency used in analog reproduction systems for relay testing. However, in both cases the data sampling frequency may have to be modified for a cross application. The range of sampling frequencies in the current generation of digital relays which store fault data is lower than that commonly used in digital fault recorders and reproduction systems. Therefore, the sampling rate of data from digital fault recorders will probably need to be changed for a digital relaying application. Recorders or relays usually have anti-aliasing filters in the sampling circuit to limit the frequency components of the input signal. These filters prevent the generation of spurious frequency components in the data caused by the interaction of the sampling frequency and the high order frequency components of the original signal (aliasing). Conversion to a higher sampling rate is relatively simple, but the effect of the anti-aliasing filter in the original recording system cannot be removed. Therefore, increasing the sampling rate will not restore the high frequency components that were removed by this filter.

The standard suggests methods suitable for conversion between one sampling rate and another.

Conversion between sampling rates via digital signal processing (DSP) techniques

If the sampling rate of the available data and the desired sampling rate are numerically related, then a DSP solution is possible. The rates must be related such that there is a number, the least common multiple, of which both rates are factors. So that Lfs = Mfo = fLCM; where F is an integer, M is an integer, fs is the desired sampling rate, fo is the original sampling rate, and fLCM is the least common multiple of fs and fo.

A mathematical description of a suitable filter with a cut-off frequency $1/2f_s$ is required. The standard discusses the application of filters. A sample FORTRAN program for the conversion and a FORTRAN file describing a sample filter are provided in Appendix B of the standard. This process is shown schematically in Figure 2.

Application of these techniques will cause some phase shift

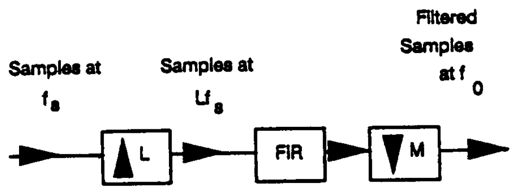


Figure 2. DSP Solution.

between the input and output file data. Also, because the input is discontinuous at the beginning (there are no samples before the first sample) it will take several samples before the filter output tracks the input data correctly. Sufficient pre-fault data should be provided so that this tracking time remains in a benign area of the file. If necessary, artificial data can be supplied to extend the pre-fault period. However, since all channels are manipulated with the same filter, discrepancies should not cause major problems. Figure 3 shows data originally sampled at 4320 Hz and the resultant data after conversion to 720 Hz.

Use of sampling rates with common base

The procedure outlined above would be simplified if the original sampling frequency and the conversion sampling frequency were chosen from a list of frequencies with a least common multiple. In this case, only one filter description would be needed. Unfortunately, because of the range of frequencies in use this is not possible. However it seems as though most of the

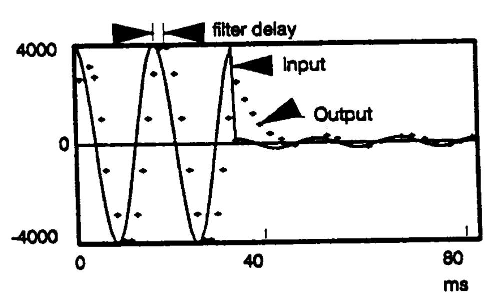


Figure 3. Example of Sample Rate Conversion.

common sampling frequencies can be covered by two least common multiples. Table 1 shows frequencies corresponding to a least common multiple of 384 and 3200 times the nominal system frequency (50 or 60 Hz). Conversion between numbers not on these lists would require that the least common multiple be calculated.

TABLE 1A Frequencies Corresponding to $f_{LCM} = 384 \times f_{base}$ samples/cycle

samples/cycle	f for 60 Hz.	f for 50 Hz.
384	23040	19200
192	11520	9600
128	7680	6400
96	5760	4800
64	3840	3200
48	2880	2400
32	1920	1600
24	1440	1200
16	960	800
12	720	600
8	480	400
6	360	300
4	240	200

Table 1B Frequencies Corresponding to $f_{LCM} = 3200 \times f_{base}$ samples/cycle

samples/cycle	f for 60 Hz.	f for 50 Hz.
3200	192000	160000
1600	96000	80000
800	48000	40000
640	38400	32000
400	24000	20000
320	19200	16000
200	12000	10000
160	9600	8000
128	7680	6400
100	6000	5000
80	4800	4000
64	3840	3200
50	3000	2500
40	2400	2000
32	1920	1600
20	1200	1000
16	960	800
10	600	500
8	480	400
4	240	200

SUMMARY AND CONCLUSIONS

The COMTRADE standard originated from the Power System Relaying Committee of the IEEE and specifies a common format for transient data exchange. This format will be used by people needing to send power system transient data originating in one format to someone else who uses a different format. This process is currently very difficult and the adoption of this standard should bring a universal language to the world of transient data exchange. However, COMTRADE is not intended to be a communication standard.

Each party must have the means of converting to and from his own format to COMTRADE. It is anticipated that such conversion programs will be provided by manufacturers who use their own proprietary formats. All manufacturers cooperating in the preparation of this standard have agreed to provide such conversion programs, and several manufacturers already have provided such conversion programs to their customers.

The Standard discusses sources and application of transient data, problems and solutions in dealing with systems that sample data at different rates, and provides sample transient files as well as an example data rate conversion program.

It is hoped that the Standard will simplify communication between protection engineers and facilitate the dissemination of power system transient data.

References

[1] Final report, CIGRE Working Group 34.01, A.G. Phadke (Convener), "Digital Protection Techniques and Substation Functions", Paris, France, June 1989.

[2] H. W. Dommel, "Digital Computer Solution of Electromagnetic Transients in Single and Multi-Phase Systems", IEEE Trans. of PAS, Vol. PAS-88, No. 4, April 1969, pp. 388-399.

Discussion

L. Amikam, R. Gustin, and **R. Rawlins,** (Schlumberger Industries): The members of Working Group H-5 are to be commended for their efforts in both the timeliness and expediency by which this standard has reached the power industry. With the proliferation of solid state recording technologies, personal computers, multimedia electronic file transfer capabilities, and the need to optimize power system operations, control, and protection, it has become apparent that a vast opportunity for exchange of critical transient event data has evolved for the power systems engineer. As a manufacturer of fault and disturbance analysis equipment, Schlumberger Industries intends to support this standard in its entirety. Towards this effort, clarification of the following points is requested.

Section 6.2.3.2 defines the number and type of channels in a fixed format with only two digits (TT, nn), thereby implying a maximum number of 99 channels. High end fault recorder applications for both utility and some industrial applications may exceed this number. How should transfer of the analog data be accomplished?

It is inevitable that data format and definition will change over time. Common practice is to provide the current version number and/or date of the software or data format in the code, thereby assuring downward compatibility for future file transfers. It would be prudent to require the current standard number and date in the header file.

Section 6.2.3.3 describes a conversion factor to convert raw sample data to their proper units using the equation "Ax + B", where A and B are defined as real numbers in a fixed format. What is the precision of these numbers?

The configuration file format assumes the sampling rate to be the same for both analog and digital inputs within the record. Solid state recording devices are available today that provide variable sampling rates for analog inputs, with a fixed rate for digital inputs. Some form of interpolation will be required to generate event data that corresponds to each analog sample upon exportation.

In light of present efforts by IEEE PES working groups and a task force in the areas of synchronized sampling and phasor measurement, future drafts of this standard may require additional data formats for the interchange of transient disturbance data based on complex numbers, such as phasor quantities.

Rochester Instrument Systems, (Rochester, NY): To provide maximum utilization of transient recorder data Rochester Instrument Systems, Inc. has supported and continues to support the efforts to develop a standard exchange format.

Since early 1990, Rochester Instrument Systems, in conjunction with Macrodyne, has been supporting the preliminary COMTRADE data exchange formats. That original program and 2 subsequent versions are available to any RiS or Macrodyne customer upon request, free of charge. The RiS/Macrodyne COMTRADE convert program is a separate disk program that is executed external to our base Master Station program. This program can convert from our binary format to the COMTRADE formats (binary or ASCII) and also from COMTRADE formats to our binary format. The latest version, supporting the final approved format, will be available to any RiS or Macrodyne customer free of charge.

It is RiS' plan to provide conversion from RiS binary event data to the COMTRADE formats within the Master Station program in the future.

S. J. Henk, (Macrodyne, Inc., Clifton Park, NY): The Macrodyne COMTRADE conversion programs support both Macrodyne and Rochester Instrument Systems equipment. The programs were written during the development of the COMTRADE standard and, thus, have evolved with the standard. The first Macrodyne conversion programs

As a result of this problem, Macrodyne has chosen an order where the analog channels are followed by the digital channels. This interpretation is based on section 6.2.3 where it is stated that the information in the configuration file must be listed in the exact order and fixed-order format shown in sections 6.2.3.1–6.2.3.6, and based also on section 6.2.3.3 where the digital channels are shown to be following the analog information.

Additionally, section 6.2.3.2 of the standard reads: "This statement contains the number and type of channels as they occur in each data record in the data file." Macrodyne has chosen to interpret this to mean the exact order in which they occur in each data record. Subsequently, Macrodyne uses this section of the standard to determine the type of each data value in the COMTRADE data file. (Another method of determining data types would be to examine the number of items in each line of channel information in the configuration file.) Also, the provision for exactly three items in this section implies that all analog channels must be grouped together, and, likewise, all digital channels. The provision, at some time, for additional entries for channel types in section 6.2.3.2 would allow a more general channel format and easier implementation of the standard.

Lastly, it should be noted that the data file example in section 7 of the standard does not meet the specifications for integer format as described in section 6.3.6.

I. Introduction

Information describing power system disturbances in the COMTRADE format controls a Test System, which is used for assessing protective relay performance.

The System generates test waveforms which represent in frequency spectrum, magnitude and duration the CT and PT secondary quantities used as relay input signals. When using modelled information (from EMTP/ATP-etc.) the simulation quality is limited only by the computational precision of the model. When actual disturbance information is used, simulation quality is limited by the dynamic range and accuracy of the D.F.R. measurements.

This System approach provides realistic, repeatable test signals which are used to establish protection system response, in the field or lab. As a result of their intrinsic design, these Test Systems may also be externally synchronized via GPS satellite for on-site end-to-end tests, drastically reducing the need for staged faults.

II. System Configuration

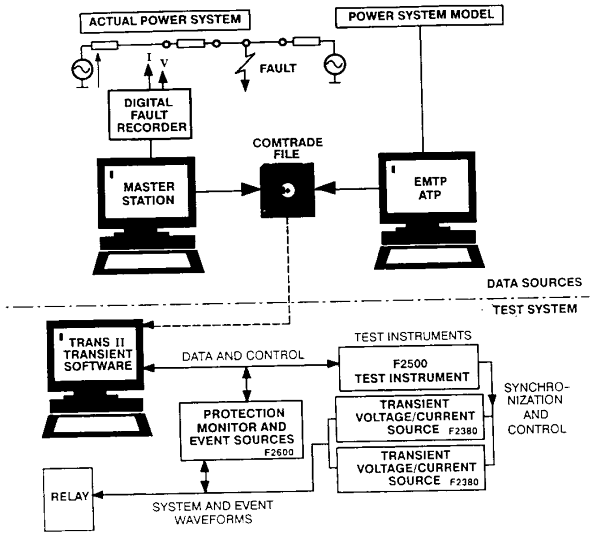
System elements include:

- test instruments for both power system and event waveform generation, and synchronization
- unconditionally stable, high power d.c. coupled transient voltage and current sources
- a Software System for waveform manipulation, instrument control and test result storage, running on an MS-DOS P.C..

Using COMTRADE files, Doble's TRANS II™ software graphically displays all waveforms for selection, combining, normalizing sample rates, scaling, pre-fault extension and test file generation. Test files defining power system waveforms and events are downloaded to F2000 Instrument memory which accommodates up to 256 k, 16 bit waveform coefficients per channel. Test instruments synchronously address waveform memory (for up to 12 sources) provide D/A conversion, and programmable anti-aliasing filters. The resulting analog signals are amplified by modular, d.c. coupled transient amplifiers to provide high level test signals. Up to 12 kVA peak power is available, accommodating all relay types from high burden electromechanical to the newest microcomputer designs.

III. Reported Applications

- A United Kingdom protection manufacturer used the system to investigate misoperation of a relay in South Africa. The fault data



differential relays that cannot be tested using traditional sinusoidal quantities.

IV. Test System Status

Since June 1991, a Beta version of the TRANS I software system supporting this application has been distributed to 50 utilities and manufacturers.

F2000 Instruments, transient firmware and hardware options, transient current and voltage sources are currently standard production items. The TRANS II software system is being released in March, '92.

DFR manufacturers are moving to provide utility programs for format conversion of their output files to COMTRADE. Conversion utility programs will support this valuable COMTRADE application. Doble has received preliminary copies of two conversion programs; each needs modification to comply with the Standard.

M. Kezunović, (Texas A & M University, College Station, Texas, U.S.A.): This discussion is related to potential application of the COMTRADE Standard in digital simulators for relay testing.

Texas A & M University (TAMU) has been involved in research and development activities related to digital simulators for relay testing for a number of years [1, 2]. One of the main requirements regarding digital simulator applications is to be able to transfer both Electromagnetic Transient Program (EMTP) and Digital Fault Recorder (DFR) files to the waveform replay subsystem of the simulator. This transfer requires format conversion from the source file (EMTP or DFR) to the file used by the waveform replay system. Simulator application studies carried out at Texas A & M University have required, so far, the use of test waveforms generated by three different EMTPs and three different DFRs [3]. As a result, conversion software for each type of the EMTP and DFR data formats had to be written. As the COMTRADE format was introduced, the approach taken by TAMU has been to convert the files coming from any of the mentioned sources into the COMTRADE standard format. After that, a conversion software has been written to convert the COMTRADE file format into the file format of the waveform replay subsystem.

This approach significantly simplifies future use of data files provided by other users since a standard format is available for the data file exchange. Future TAMU simulator application study will be related to extensive relay testing and the existence of the standard data file format is going to be quite useful. A large number of relay test files are to be generated through various means and/or obtained from various users. They are to be used to generate relay test waveforms on the TAMU's simulator. Due to the existence of the standard, almost all of the DFR manufacturers have committed to providing their recorded files in the COMTRADE format. The EMTP files can easily be converted to a COMTRADE format as well. Under the circumstances, the data files to be used for relay testing may directly be generated in the standard format. This makes their use in relay testing straightforward since only the conversion from the COMTRADE format to the waveform replay subsystem format needs to take place regardless of how many different sources of the data file have been used.

TAMU intends to report further experiences coming from using the COMTRADE standard for the simulator applications so that future revisions of the standards can be utilized to accommodate any additional requirements that may be coming from this application.

References

[1] M. Kezunović, et al., "DYNA-TEST Simulator for Relay Testing, Part I: Design Characteristics," *IEEE Trans. on Power Delivery,* Vol. 6, No. 4, October 1991.

[2] M. Kezunović, et al., "DYNA-TEST Simulator for Relay Testing, Part II: Performance Evaluation," *IEEE PES Winter Meeting,* Paper No. 91 WM 250-3-PWRD, New York, February 1991.

[3] M. Kezunović, et al., "Use of Digital Recorder Files for Protective Relay Evaluations," *Fault Disturbances Conference,* College Station, April 1991.

The Working Group appreciates the comments of the discussers. Regarding the comments of Mr. Henk, section 6.2.3.2 defines the order in which the data is provided through the data type identifier 't'. The examples in section 6.2.4 and 7.2 clearly show how this is to be implemented and interpreted. The interpretation that all channels of one type are to be grouped together is correct.

The example in section 7.3 contains columns 1 and 2 of the data in I1 format, whereas section 6.3 defines an I10 format. This is an oversight, and will be corrected in future revisions of the standard. The intent of the standard is to use the I10 format.

A comment was made during the oral discussion that PT and CT ratios are no longer included in the COMTRADE format. This is not strictly true. They can be (and perhaps should be) included in the header file. On the other hand, the configuration file does provide an overall multiplication factor, which converts the sample values to engineering units. This multiplication factor includes, among other ratios, the CT and PT ratios.

Regarding the questions raised by Messrs. Amikam, Gustin, and Rawlins, we are indeed currently limiting the number of channels to 99. Should this prove to be a hindrance, we will take it up in the next revision. Also, the working group expects that the fields provided for the constants A and B will prove to be adequate. Should this turn out to be sufficient, we will consider a change in a future revision.

It is our hope that this standard will be of use to the industry, and the Power System Relaying Committee would like to receive any comments on the standard that the users may have.