

WinXFM



User's Manual

Software Version
WinXFM-2.22

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1. INTRODUCTION

The program **WinXFM** performs waveform data acquisition, analysis and display with emphasis on electric power systems applications. Data exchange supports the COMTRADE standard (C37.111), the IEEE Synchrophasor Standard (C37.118), Comma Separated Value (CSV) files, as well as a native format (XFM files). The WinXFM program provides the following standard functions:

- Importing and exporting waveform data in COMTRADE Format, as specified in standard C37.111 versions 1991, 1999, and 2013.
- Graphical displays of waveform data.
- Waveform analysis and visualization tools such as phasor and harmonic displays.
- “*Waveform Calculator*” function creates and displays waveforms defined as functions of other waveforms, or user defined functions of time.

In addition to the above standard functions WinXFM can support the following Optional Functions:

- Estimation Based Protection Module.
- Simulation of generic protection functions.
- Merging Unit Sample Value streaming and Data Concentrator Functions.
- Synchrophasor streaming and PMU Functions.
- Interface with several types of data acquisition and waveform generation hardware. Acquired data can be stored, displayed and analyzed. Waveform data can also be transmitted to waveform generation hardware. Supported hardware include several National Instruments platforms and the Pico-Scope platform.

The program is provided with several option levels. The basic program level includes all data file importing/exporting display and analysis features summarized above. Optional features are available as follows:

Option	Description
PXI	Interface with National Instruments PXI data acquisition platform
NID	Interface with National Instruments NiDAQ data acquisition platform
PIC	Interface with PicoScope data acquisition platform
MDC	Merging unit data concentrator using Sample Value Streaming
SPH	Capturing PMU Synchrophasor data streams
GPS	Reception of GPS data from SEL and Trimble GPS receivers
GPF	Generic Protection Function Simulation
EBP	Estimation Based Protection

2. INSTALLATION & SETUP

Before installation, make sure to terminate the existing WinXFM program if already installed and running. You can install WinXFM or update your named user WinXFM license as follows:

1. Go to the site www.ap-concepts.com and navigate to the **XFM Downloads** page. (Note: you can go there directly using the link:

http://www.ap-concepts.com/xfm_downloads.htm

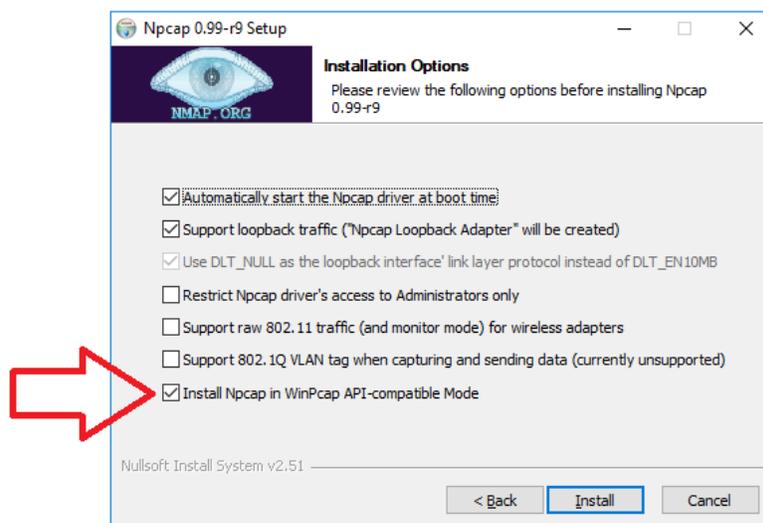
2. Follow the instructions under the title: **For WinXFM Licensees Only**

Specifically:

- Enter your WinXFM Serial number
- Click button to download WinXFM

Once the download is completed run the application installer **WinXFMSetup.exe**. You do not have to uninstall the existing version, if any. Simply install over the existing installation so that any library files the users have previously created are automatically integrated with the updated program.

3. If you have purchased the merging unit sample value streaming and data concentrator functions (MDC), install the NPCAP system by running the installer program named npcap-0.99-r9.exe located in the directory WinXFM\NPCAP\. This directory is created by the WinXFMSetup in Step 2. Make sure you check the option **Install Npcap in WinPcap API-compatible Mode**, as shown below. Leave all other options at their default values.



4. If you have purchased one of the National Instruments hardware interface options (PXI or NID), install the national instruments NI-DAQmx driver. You can download the driver package at:

<https://www.ni.com/en-us/support/downloads/drivers/download.ni-daqmx.html#291870>

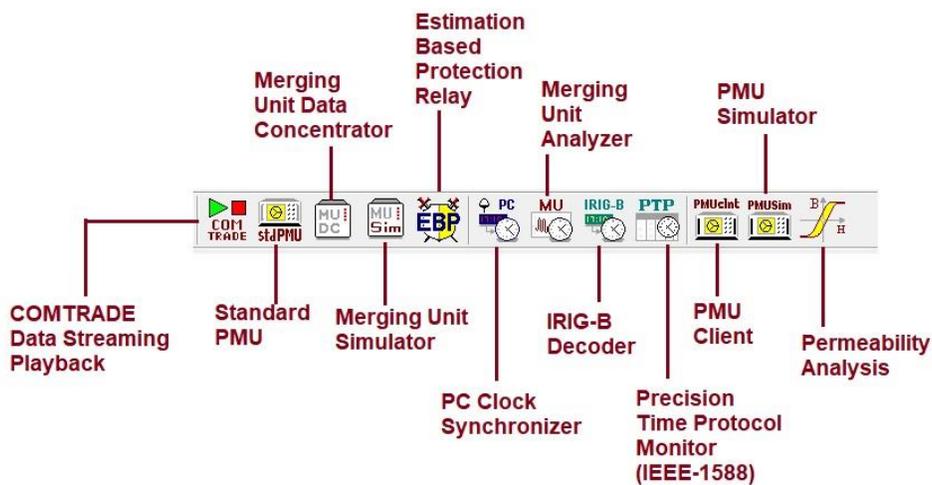
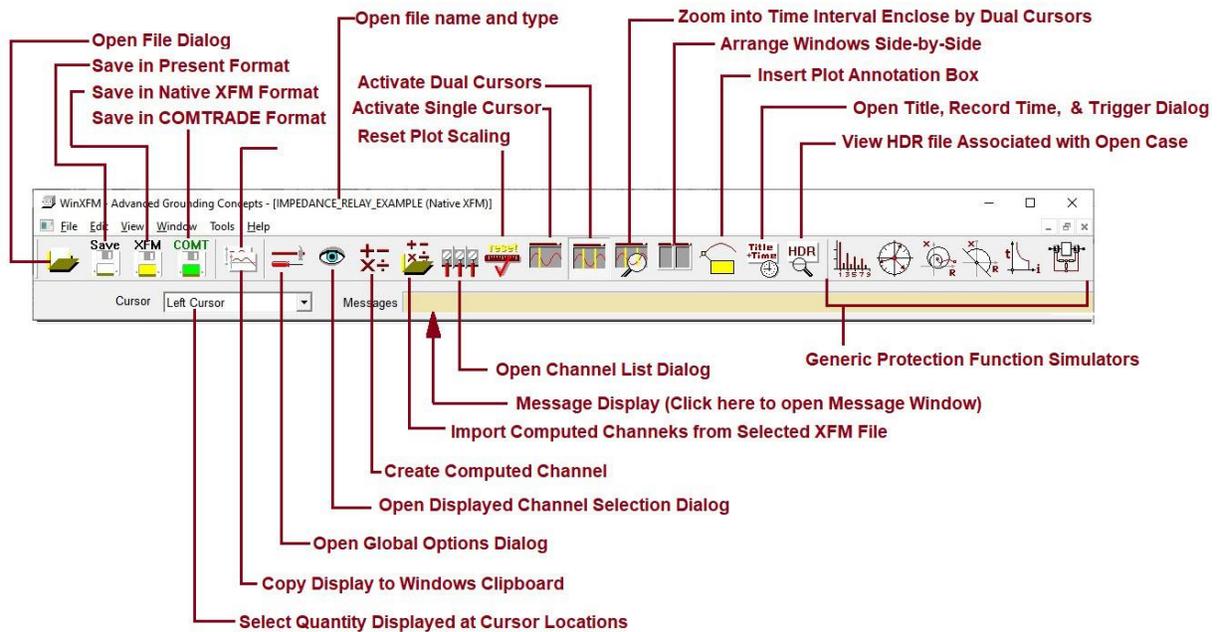
5. If you have purchased the PXI National Instruments hardware interface option, install the national instruments NI-Sync driver in addition to the above mentioned NI-DAQmx driver. You can download the NI-Sync driver package at:

<https://www.ni.com/en-us/support/downloads/drivers/download.ni-sync.html#312046>

3. USING THE PROGRAM

This section describes the fundamental functions of the WinXFM program, including opening waveform data files selecting the waveform display parameters, and performing basic waveform analysis.

WinXFM has a number of commands available via pulldown menus, which are described in detail in Section 8 (Command Reference). A number of frequently used commands are also accessible via toolbar buttons, which are summarized in the Figure below:



3.1 OPENING WAVEFORM FILES

WinXFM supports several waveform file storage formats, including:

- Native WinXFM files
- COMTRADE Files (C37.111, Versions 1991,1999, and 2013)
- Microsoft Excel CSV files
- Synchrophasor Files (C37.118 Format)

Opening and creating the above formats is described next.

NATIVE WINXFM FILES.

This is the default storage format accessible via the **Open, Save, and Save As**, commands of the **File** menu. Native WinXFM files consist of configuration files, ending in .XFM, and waveform data files ending in .XFW. Waveform data files are in binary format, providing compact storage as well as high precision. Waveform samples are stored in 64 bit floating point format. The configuration files preserve all user selected waveform attributes and display parameters. See Appendix 1 for a detailed description of the Native WinXFM file format.

The **Open** and **Save As** commands use a standard windows file dialog (illustrated in Figure 3.1.1) which allows navigating to the desired directory and performing basic directory maintenance operations. The **Open** and **Save** commands can be also executed using the toolbar buttons:



(Open),



(Save)

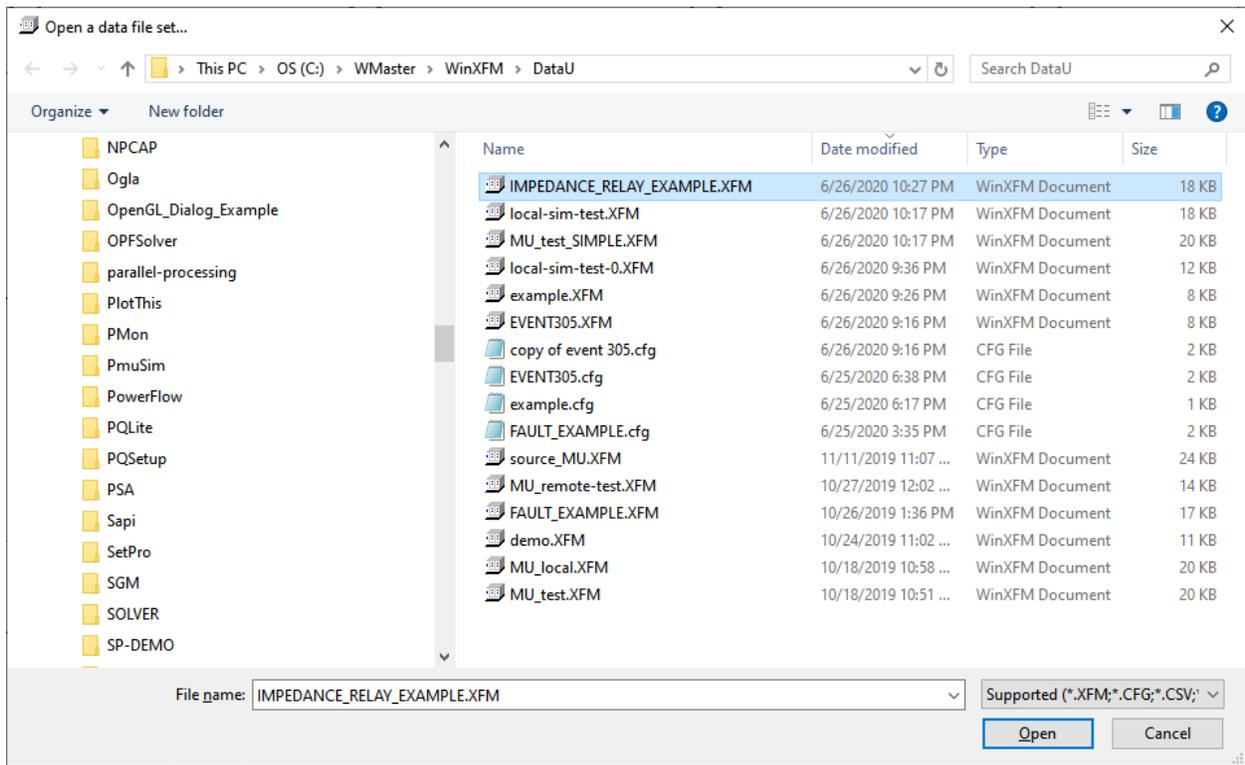


Figure 3.1.1: Native WinXFM File Open Window

COMTRADE FILES

Waveform data stored in COMTRADE format can be imported into WinXFM, as well as exported, using the commands **Open**, **Append COMTRADE File**, and **Save as COMTRADE File**, of the **File** menu. The **Save as COMTRADE File** command can be also issued using the toolbar button:



The COMTRADE format is described in IEEE Standard C37.111 (Common format for Transient Data Exchange for power systems). See also Appendix 2 for a brief description of the COMTRADE file format.

The **Save as COMTRADE File** command uses a standard windows file dialog. Each COMTRADE data set is stored in several file types. C37.111 version 1991 specified three file types with common file name root and different extensions as follows:

- A Configuration file, ending in .CFG, containing channel specifications, sampling rates, time stamps etc.
- A Waveform data file ending in .DAT, containing the waveform samples.
- A Header file ending in .HDR which contains human readable description of the data.

Version 1999 introduced a fourth type of file with the extension .INF which contain additional information related to the waveform data set that specific applications may need to store. INF files are ASCII text format, however unlike HDR files they are meant to be machine readable.

Version 2013 introduced a fourth file type ending in **.CFF**, known as **Combined File Format**, which contains all the information stored in CFG, DAT, INF, and HDR files.

DAT files can be either ASCII or BINARY format. In Standards 1991 and 1999 Binary format each sample was stored as a 16 bit integer. The 2013 Standard introduced two additional binary formats: 32 bit integer, and 32 bit floating point.

The **Save as COMTRADE File** dialog, (illustrated in Figure 3.1.2) allows user selection of all of the above file formats via radio buttons located below the usual file dialog controls. It also allows exporting all channels or only the channels presently displayed (see *Visible Channels Only* radio button).

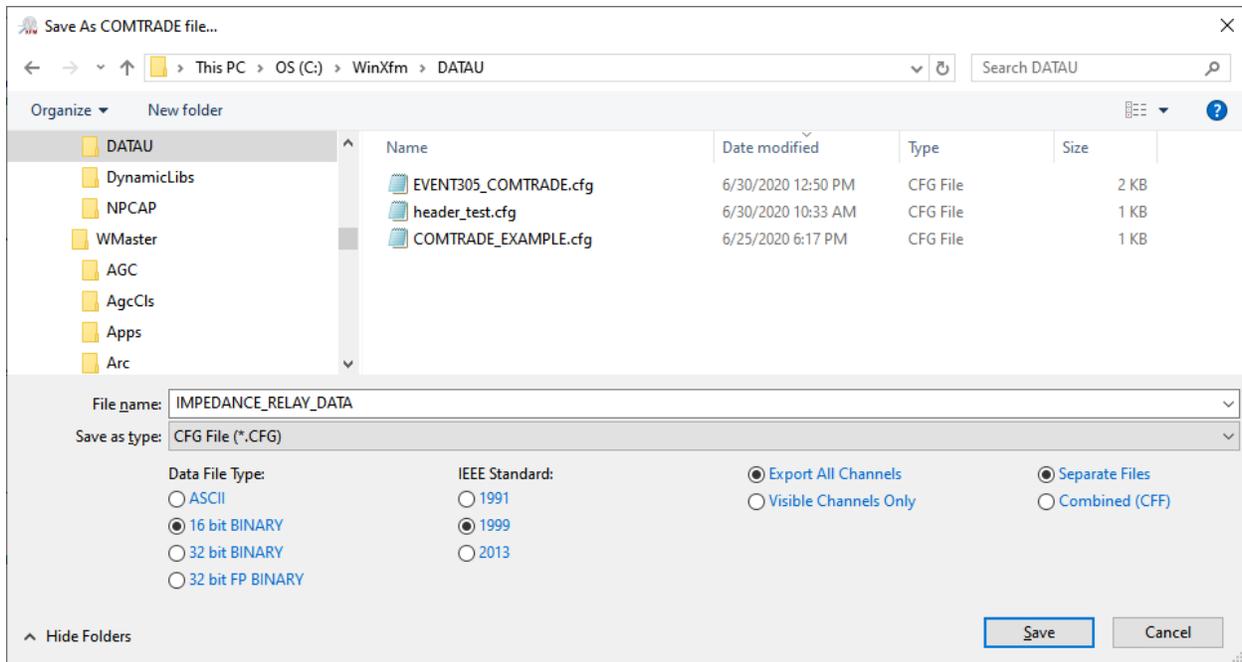


Figure 3.1.2: COMTRADE File Export Window

MICROSOFT EXCEL FILES.

WinXFM can export and import waveform data in Microsoft Excel CSV files. The CSV files generated and read by WinXFM contain the following information:

- Row1: First Sample Time Stamp.
- Row2: Trigger Time Stamp.
- Row3: Time Step.
- Row4: Channel Names, separated by commas.
- Row5: Units, separated by commas.
- Remaining Rows: time index and data values , separated by commas, one row for each sampling instant.

The first few lines of a CSV file example are listed below:

```
03/11/2001 23:44:57.053233
03/11/2001 23:44:57.100000
0.00016700
Time, A_VOLT, B_VOLT, C_VOLT, N_VOLT
microseconds, KV, KV, KV, KV
0, -1.499945e+002, 1.678597e+002, -1.201340e+001
167, -1.552665e+002, 1.617110e+002, -8.760635e-001
```

SYNCHROPHASOR FILES

Synchrophasor files can be imported into WinXFM using the **Open** command of the **File** menu (Note that WinXFM does not export C37.118 files).

This file format is a direct binary file representation of Synchrophasor streaming data as described in the IEEE Standard C37.118-2005. Data are stored in two file types: The first type contains configuration frames, and has a filename ending in .SP1. The second file type contains data frames and its file name ends in .SP2. See Appendix 3 for additional details on the Synchrophasor file format and on importing Synchrophasor files.

3.2 WAVEFORM DISPLAY

The WinXFM waveform display window is illustrated in Figure 3.1. The window displays a user defined number of waveforms which represent data either imported from files or acquired via data acquisition hardware.

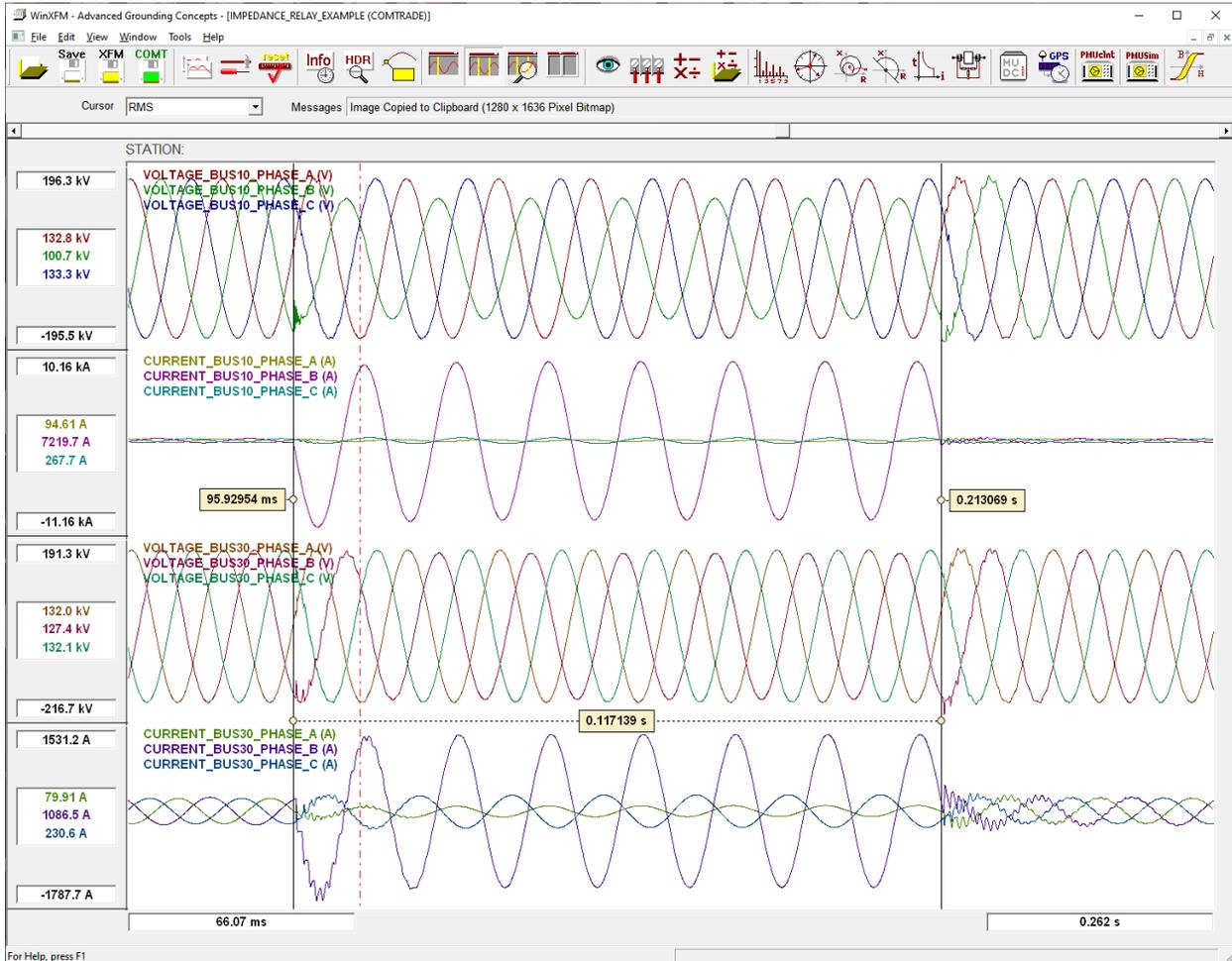


Figure 3.1: User Interface Main Window

The plots are annotated with min/max values along the left side, and time range along the bottom side of the plot view window

The displayed waveforms can be zoomed and scrolled using the mouse, using the right mouse button to zoom, and left mouse button to scroll. The mouse wheel (if available) can also be used for waveform zooming.

The channels to be displayed are selected using the **Select Channels to Display** command of the **View** menu, or the toolbar button: . The command opens a dialog

window illustrated in Figure 3.2. This window displays the names of all available channels on the right side, and the names of the displayed channels on the left side.

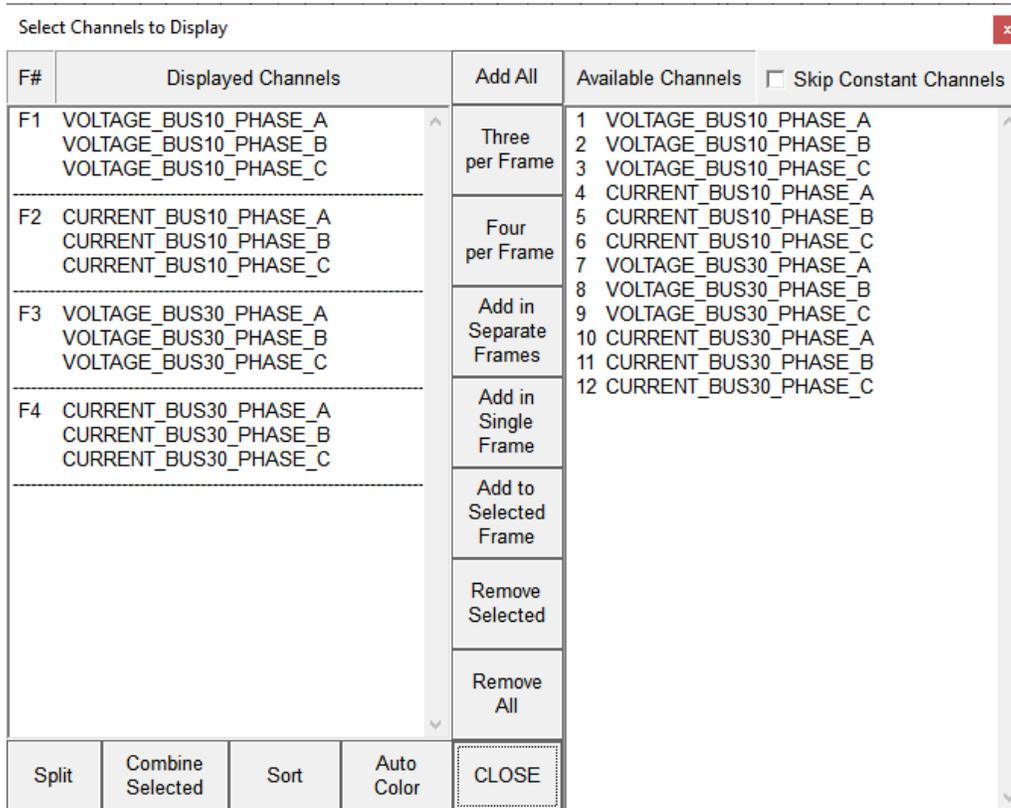


Figure 3.2: Select Channels to Display Window

Channels can be added to the "Displayed Channels" list by double clicking on a channel name in the "Available Channels" list. Channels can be removed from the "Displayed Channels" list by double clicking on a channel name in the "Displayed Channels" list.

Alternatively, the buttons located in the column between the displayed and the available channel lists allow inserting to or removing selected channels from the "Displayed Channels" list.

Each channel selected for display may be plotted on a separate frame, arranged one below the other. Alternatively several channels may be superimposed on each frame. Note that the frame number that each channel is assigned to is listed on the left of the channel names (F1, F2, F3 in Figure 3.2).

Use the buttons below the selected channel list titled **Split** and **Combine Selected** to define how displayed channels are grouped into plot frames.

3.3 CHANNEL TYPES AND PROPERTIES

WinXFM supports four types of channels:

- Waveform Analog Data Channels
- Digital Data Channels
- Computed Channels
- *Data Acquisition Channels (Available only with DAQ options)*

Waveform Data Channels are created when opening data files containing analog waveform data, such as COMTRADE files, Synchrophasor files, as well as native WinXFM files. Similarly, **Digital Data Channels** are created when opening data files containing digital data. **Computed Channels** display waveforms defined by a user entered formula in terms of existing waveform channels, data acquisition or other computed channels. **Data Acquisition Channels** receive data collected by data acquisition hardware controlled by the WinXFM program (NOTE the base WinXFM program does not include any DAQ options, and therefore data acquisition channels are not available).

The available channel list can be edited using the "Edit Channel List" pop-up window. This window is opened using the **Edit Channels** command of the **Edit** Menu or using the

toolbar button . The **Edit Channels** window is illustrated in Figure 3.3

The row of buttons across the top of the window initiate edit operations, as follows:

Edit Button. Click on this button to open the channel properties window corresponding to the channels selected in the edit channel list. Note that multiple channels can be selected with the mouse while holding either the **Ctrl** or the **Shift** key down. This allows to change one or more channel attributes simultaneously on all selected channels.

The contents of the channel properties window depend on the type of channel being edited. Figures 3.4, 3.5, and 3.6 illustrate the channel properties windows for waveform, data acquisition, and computed channels respectively.

The waveform channel properties window (Figure 3.4) includes several user editable parameters, including name, units, bus#, area name, line style, line weight, line color, and description. A number of additional COMTRADE specific parameters are provided which are saved into COMTRADE configuration files.

Figure 3.5 illustrates the properties window of a computed channel. Computed channels display waveforms defined by a formula in terms of existing waveform channels, data acquisition channels or other computed channels. The formula is entered as a standard

mathematical expression which includes constants, variables, operators, and functions. Parentheses are also supported, nested to any level.

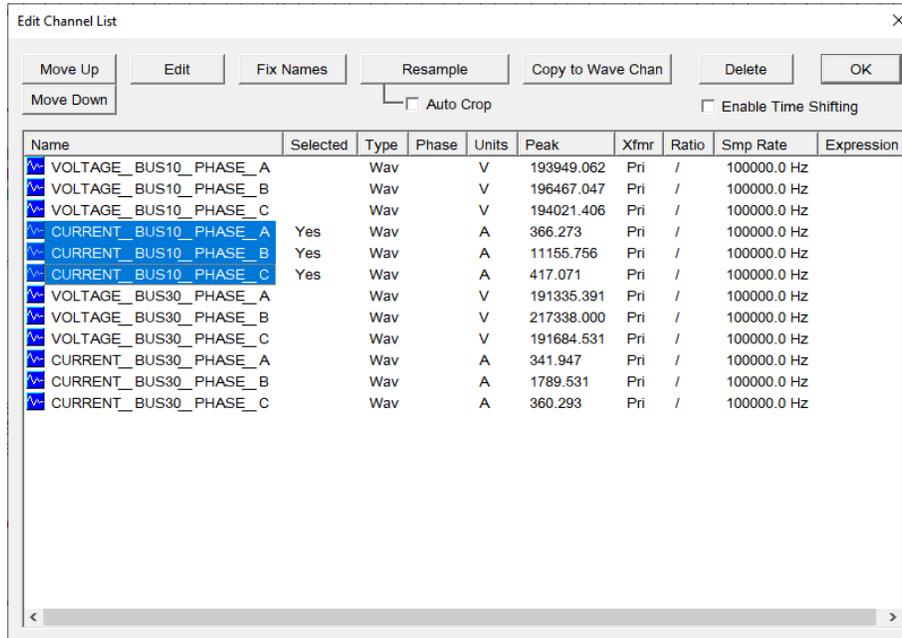


Figure 3.3: Edit Channels Window

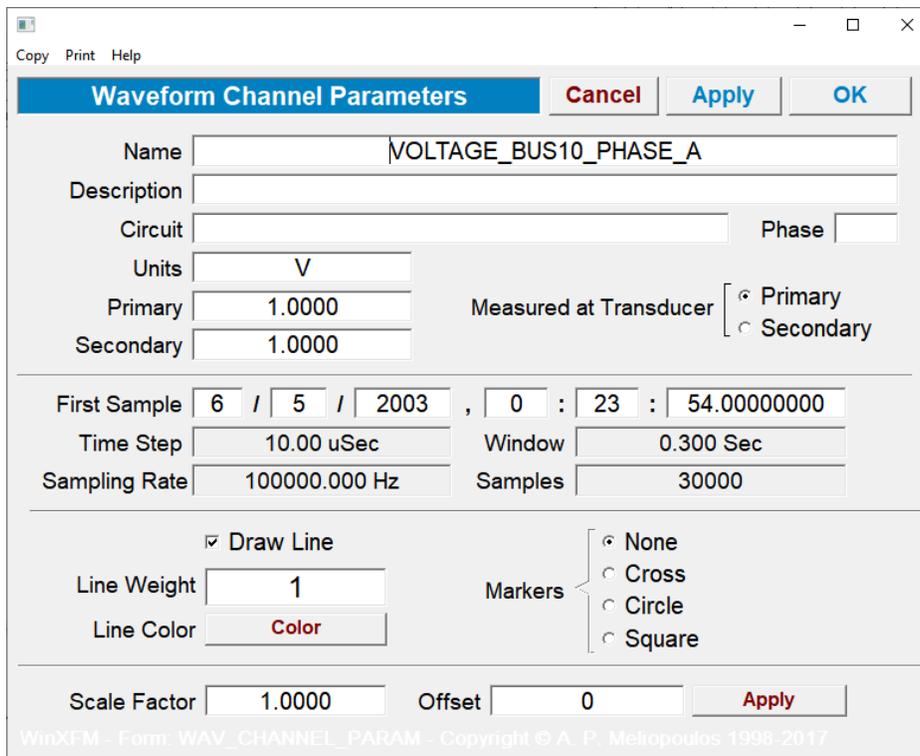


Figure 3.4: Waveform Channel Parameters Window

Constants are expressed using standard floating point or exponential notation (such as 3.14 or 1.23e-7).

Variables are channels represented by the channel name. Any channel can be a variable, including another computed channel as long as it appears before the present computed channel in the channel list.

The word TIME is reserved keyword which represents time in seconds from the beginning of the waveform first sample. A typical application of the TIME variable is in waveform synthesis. For example a 60 Hz sinusoidal waveform can be generated using the formula:

$$\sin(2.0 * \text{PI} * 60.0 * \text{TIME})$$

Supported operators are + (addition), - (subtraction), * (multiplication), / (division), and ^ (exponentiation). Standard operator precedence applies, i.e. exponentiations are evaluated first, followed by multiplications and divisions, followed by additions and subtractions.

A list of supported functions along with a brief description is illustrated in Figure 3.7. A detailed description of supported functions is given in Appendix 6.

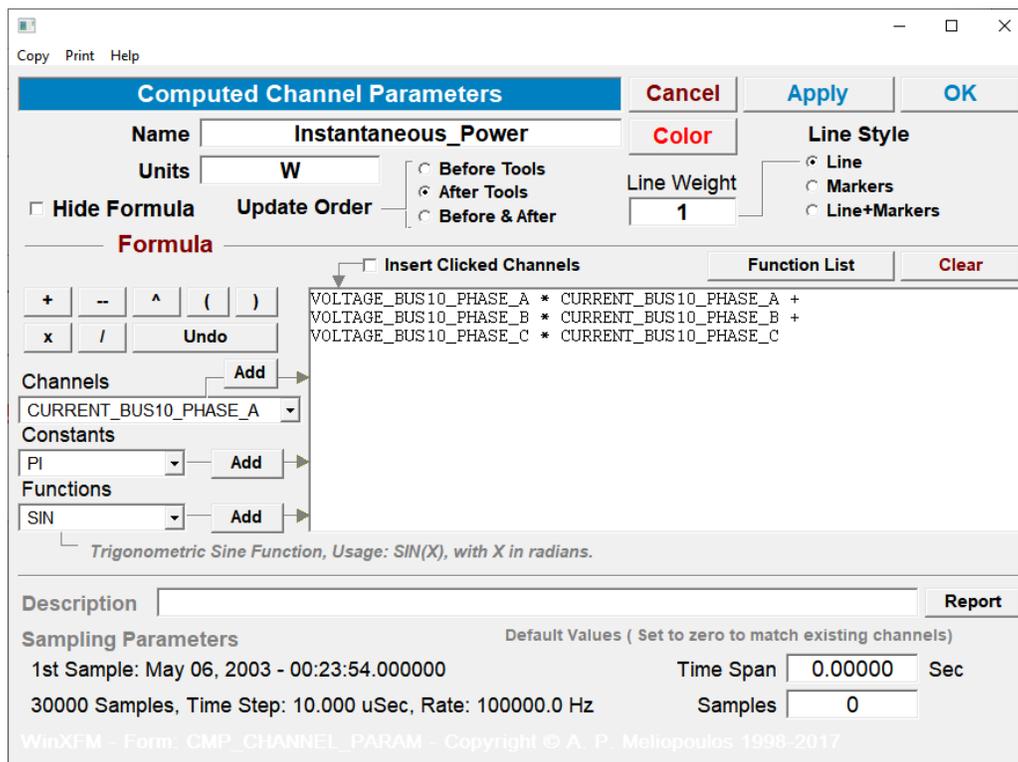


Figure 3.5: Computed Channel Parameters Window

	Name	Args	Description
1	SIN	1	Trigonometric Sine Function,
2	COS	1	Trigonometric Cosine Function,
3	TAN	1	Trigonometric Tangent Function,
4	ASIN	1	Inverse Trigonometric Sine Function,
5	ACOS	1	Inverse Trigonometric Cosine Function,
6	ATAN	1	Inverse Trigonometric Tangent Function,
7	SIGN	1	Returns -1 if argument is negative, +1 otherwise.
8	ABS	1	Returns the absolute value of the argument.
9	SQRT	1	Returns the square root of the argument.
10	LOG	1	Returns the Natural Logarithm of the argument.
11	LOG10	1	Returns the Base 10 Logarithm of the argument.
12	EXP	1	Returns the natural exponential of the argument.
13	INT	1	Returns the closest integer to the argument.
14	MIN	2	Returns the minimum value of two arguments.
15	MAX	2	Returns the maximum value of two arguments.
16	PEAK	1	Returns the maximum absolute value over the entire time span.
17	RMS	2	Computes the RMS value.
18	SON	2	Switches a waveform 'W' on after time 'T'.
19	SOFF	2	Switches a waveform 'W' on after time 'T'.
20	SWIN	3	Switches waveform 'W' on at 'T1' and off at 'T2'.
21	UNWIND	1	Removes phase angle discontinuities.
22	SHIFT	2	Time-Shifts a waveform.
23	FREQ	2	Returns the frequency of a waveform (in Hz).
24	HARM	3	Returns the Harmonic Amplitude.
25	PHASE	3	Returns the Harmonic Phase.
26	THD	2	Computes the Total Harmonic Distortion in %.
27	REAL_POWER	3	Average real power.
28	REACT_POWER	3	Average reactive power.
29	DIST_POWER	3	Distortion power.
30	P_FACTOR_VI	3	Power Factor.
31	P_FACTOR_PQ	2	Power Factor.
32	INTEG	1	Returns the Integral of a Waveform.
33	LP_FILTER	2	Low Pass Filter.
34	GP_FILTER	2	General Purpose Filter.
35	FORECAST	2	Computes Forecast.
36	FORECAST_DEV	2	Computes Forecast Standard Deviation.
37	FORECAST_RES	2	Computes Forecast Residual.
38	SEQ	5	Sequence Component
39	PROG1	5	Impedance Magnitude.
40	PROG2	5	Impedance Phase.

Figure 3.6: Computed Channel Parameters Window

3.4 GLOBAL OPTIONS

This command allows setting of several GUI parameters such as screen colors, update rates, warning sounds, and plot display attributes. The command opens a dialog window (shown below) which contains the corresponding entry fields. The command is also

accessible via the toolbar button: .

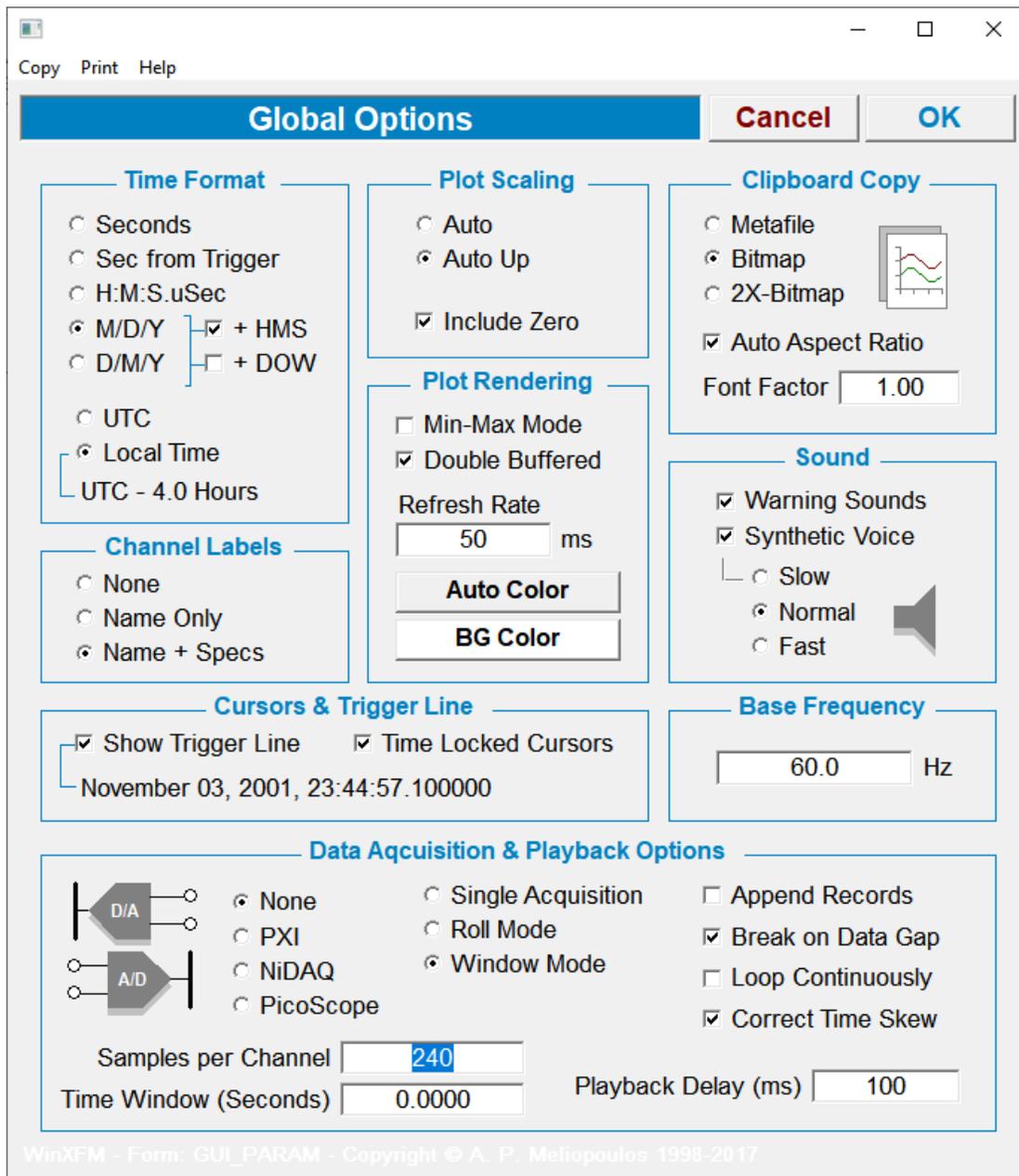


Figure 3.8: Global Parameters Window

Time Format Options. Radio buttons set time annotation format. Time annotation format selection affects horizontal time axis annotations, as well as cursor time annotations, as follows:

- **Seconds:** time annotations in seconds from the beginning of the record.
- **Seconds from Trigger:** Time annotations in seconds from the trigger time instant
- **H:M:S.uSec:** Time annotated with time stamps formatted as hours minutes, seconds and microseconds.
- **M/D/Y:** Time annotated with time stamps formatted as Month, Date, and Year. If the **+HMS** check box is checked, hours minutes and seconds are also displayed. If the **+DOW** check box is checked, the *day-of-the-week* is also displayed.
- **D/M/Y:** Time annotated with time stamps formatted as Date, Month, and Year. If the **+HMS** check box is checked, hours minutes and seconds are also displayed. If the **+DOW** check box is checked, the *day-of-the-week* is also displayed.
- **UTC:** Time is displayed as Universal Coordinated Time.
- **Local:** Time is displayed as local time (note that the local time is defined with respect to hours from UTC below the Local check-box.

Plot Scale Options

- **Auto:** Plot Y axis is automatically selected to match displayed sample range. If the plot display is zoomed in and shifted the Y axis scale is continuously adjusted to match the displayed sample range.
- **Auto-Up:** Plot Y axis is initially automatically selected to match displayed sample range. If the plot display is zoomed in and shifted the Y axis scale is only adjusted if the displayed sample range exceeds the y- axis range
- **Include Zero:** Plot Y axis range includes zero value even if the plotted data range does not.

Clipboard Copy Options

Clipboard options affect the quality and shape of the plot images copied into the Windows Clipboard. Images copied into the Clipboard can be inserted as images into various documents (using other application programs such as *Word, PowerPoint and Excel*).

- **Metafile:** Clipboard image is in “*Windows Metafile*” format. This is a vector based format which is compact but may result in slight image degradation.

- **Bitmap:** Clipboard image is in bitmap format with the same resolution as the screen image. Bitmap images are high quality but are considerably larger than metafiles resulting in larger document files.
- **2x-Bitmap:** Clipboard image is in bitmap format with twice the resolution of the screen image.
- **Auto Aspect Ratio:** If this checkbox is un-checked, the aspect ratio of the image transferred to the clipboard is the same as the view window aspect ratio. If this checkbox is checked the transferred image aspect ratio is automatically selected based on the number of plot frames visible.
- **Font Factor:** modifies the font size used in clipboard transferred images.

Plot Rendering Options

- **Min-Max Mode:** When traces with large number of data points are plotted, sample decimation is used to speedup screen refresh. Turning on Min-Max Mode ensures that short duration spikes and dips are not hidden due to decimation.
- **Double Buffered:** View images are rendered in a background memory buffer resulting in smooth plot zooming, panning and various animations.
- **Refresh Rate:** Time interval between screen refresh (mostly affects animated displays)
- **Auto Color:** automatically assigns colors to plot traces. Multiple traces within one plot frame are assigned different colors. Furthermore, if the selected background color is light, dark colors are assigned to plot traces and vice versa.
- **BG Color:** opens background color selection dialog window

Sound Options

These check boxes and radio buttons control voice message and warning sound generation options. Their operation is self-explanatory.

Cursors and Trigger Line

- **Show Trigger Line:** If this checkbox is checked, the trigger time stamp is indicated on the plot frames by a vertical dotted line.
- **Time Locked Cursors:** If this checkbox is checked, the plot cursors remain at the same absolute time when the plots are zoomed or panned. Otherwise the plot cursors remain at the same screen location.

Base Frequency

Sets the power system base frequency.

Data Acquisition and Playback Options

The controls in this control group are applicable only to data acquisition hardware options. These options are not part of the basic WinXFM program.

3.5 CURSORS AND MEASUREMENT DISPLAYS

The WinXFM plot view provides both single and dual vertical cursors. When the dual cursors are activated (command **Cursors** of the **View** menu), a user selected computed attribute of the displayed waveform segment between the two cursors is displayed on the left panel of the plot view (see Figure below). The plot computed attribute is selected via a pulldown list box located on the horizontal toolbar.

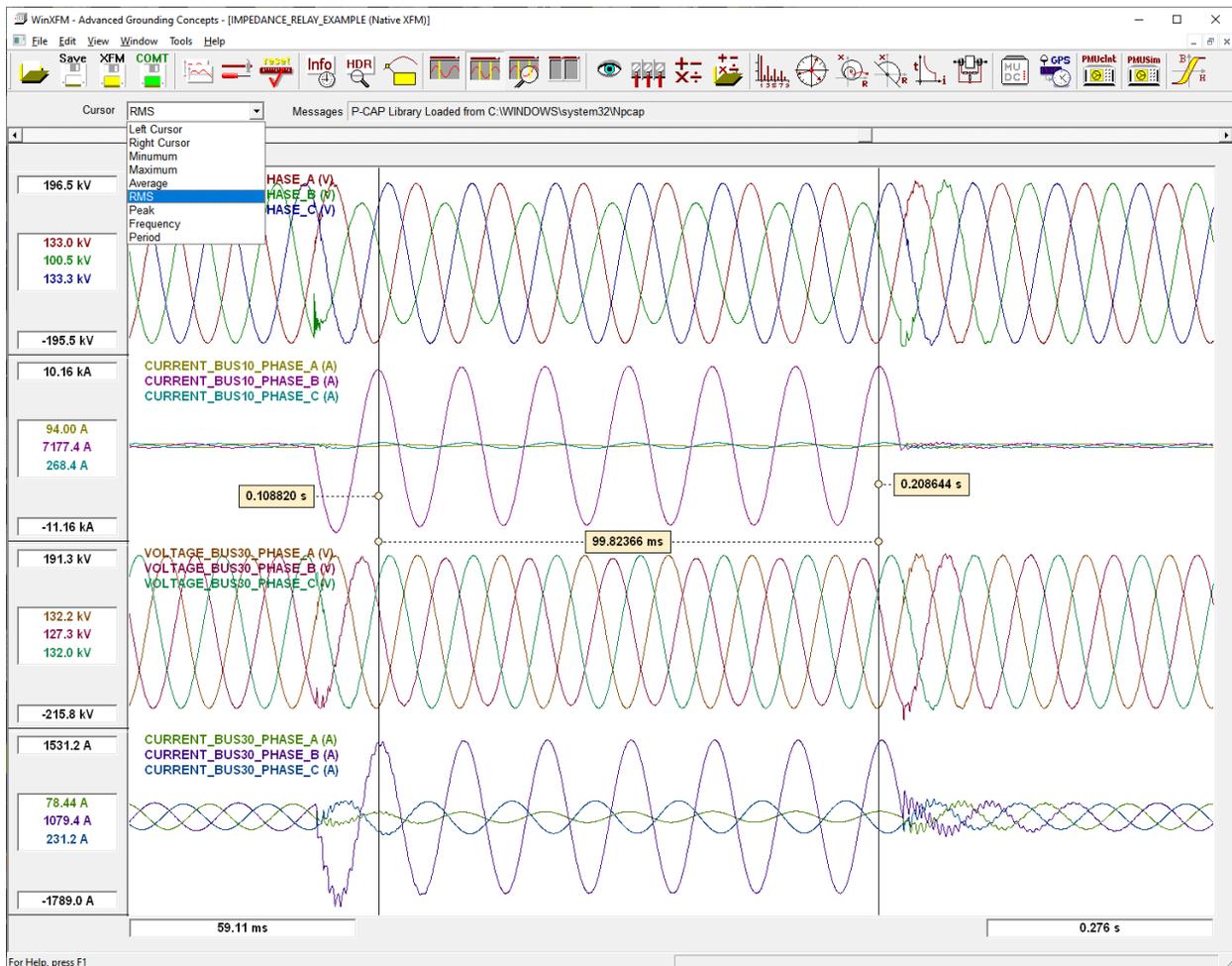
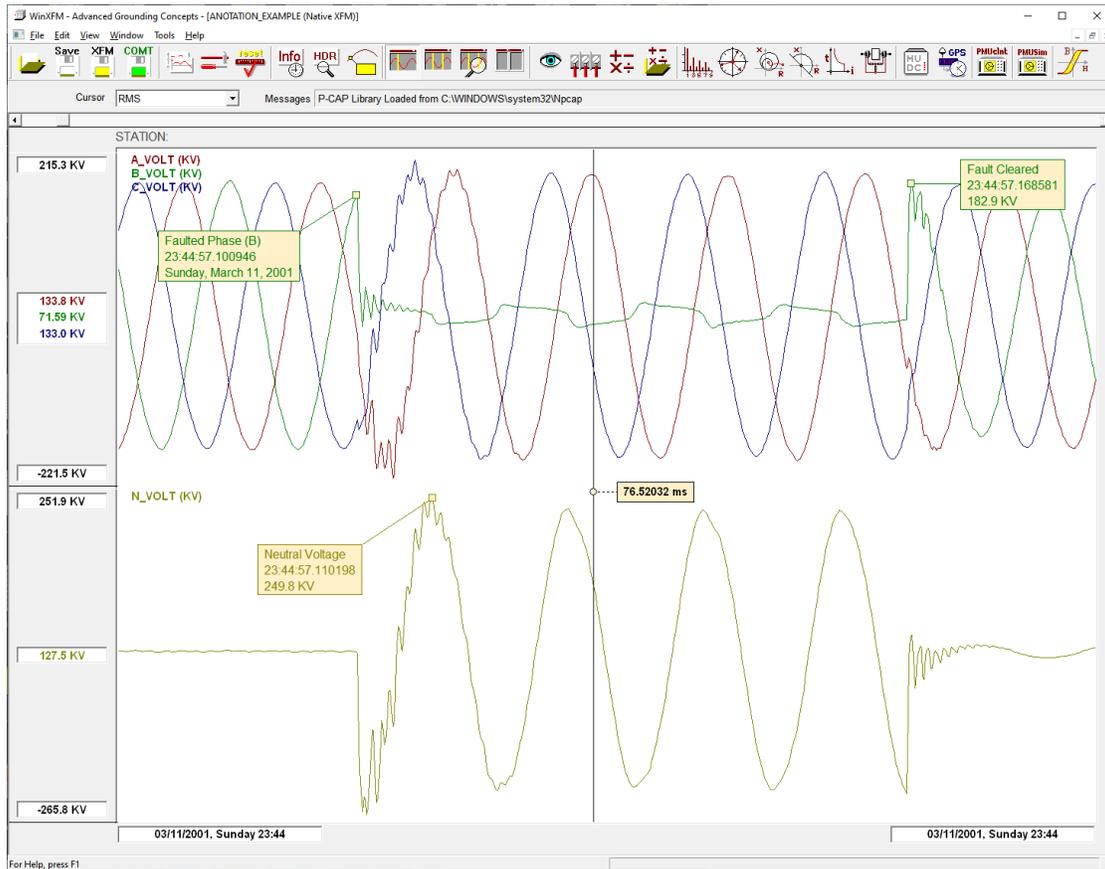


Figure 3.5: Selecting Cursor Numeric Displays

3.6 WAVEFORM ANNOTATIONS

Any number of annotation boxes can be attached to specific points of captured waveforms. Each annotation box can optionally display the time, date, and value at the attached point, as well as user defined text. An example with several annotation boxes is shown in the Figure below.

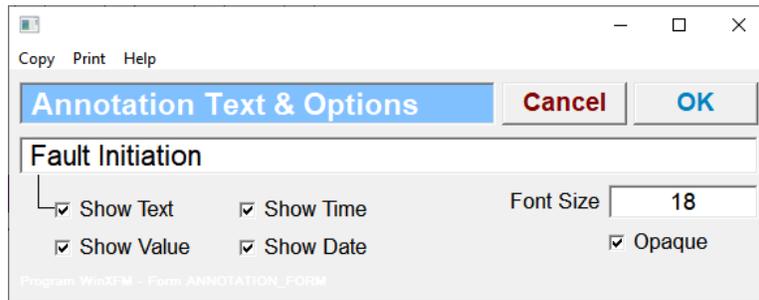


To create an annotation box use the **Insert Annotation** command, located in the **Edit** pull-down menu, or click on the toolbar button:

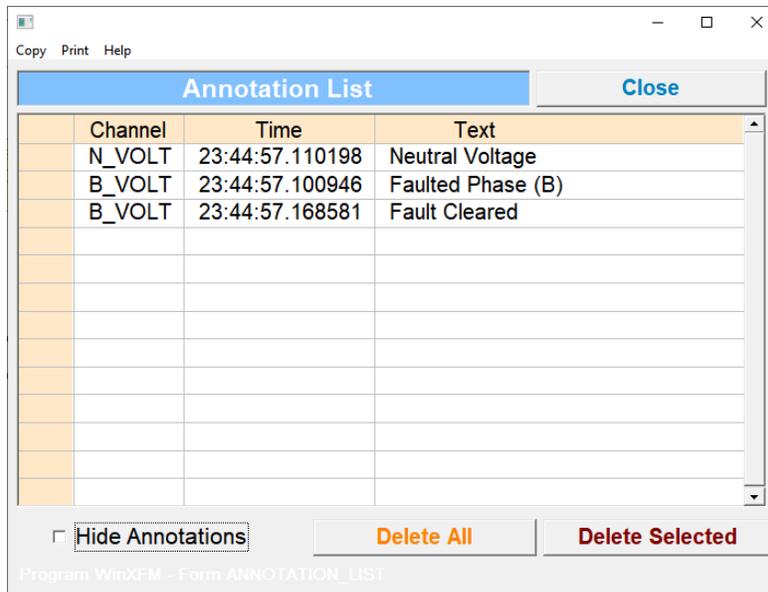


Then click on the location of the waveform where the annotation is to be attached. Note that once inserted annotation boxes can be moved using the mouse. Specifically, you can modify the annotation attachment point by clicking and dragging the annotation pointer. You can also click and move the annotation box as needed without changing the attachment point. You can delete an annotation box by clicking on it to select it and then pressing the delete key. (Selected annotations are identified by double border).

The annotation content can be edited by a left mouse button double click on the annotation body. This action opens a dialog (illustrated below), which allows editing of the annotation text, font size, as well as selecting the additional information displayed, namely the value time and date at the attachment point. Unchecking the Opaque check box draws the annotation text and pointer without the enclosing box (see the right most annotation in the above example, with the text: “Fault Cleared”).



The command **Edit Annotations** of the **Edit** menu opens a dialog window displaying a list of the existing annotations (See Figure below). This dialog provides an alternative method of editing existing annotations. Double clicking on the list entry opens the corresponding Annotation Text and Options dialog. The Hide Annotations check box at the bottom left of the Annotation List dialog hides all existing annotations but without deleting them.



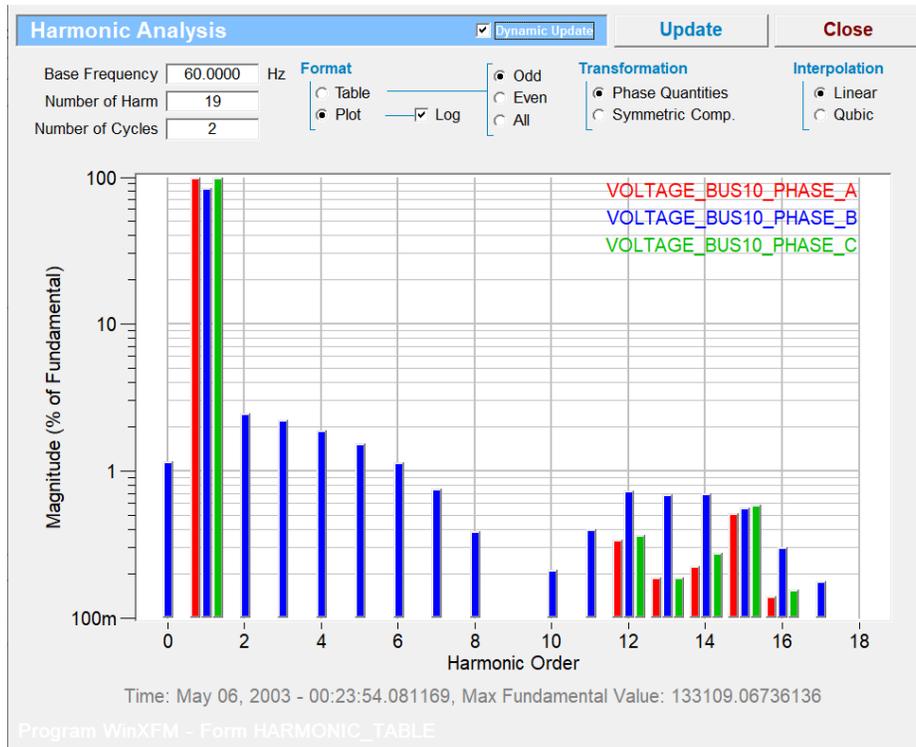
4. BASIC WAVEFORM ANALYSIS TOOLS

The basic WinXFM program includes a number of waveform analysis, manipulation, and visualization tools. These tools are described in this section. The commands for accessing the waveform analysis and visualization tools are located in the WinXFM **Tools** pull-down menu.

4.1 HARMONIC ANALYZER

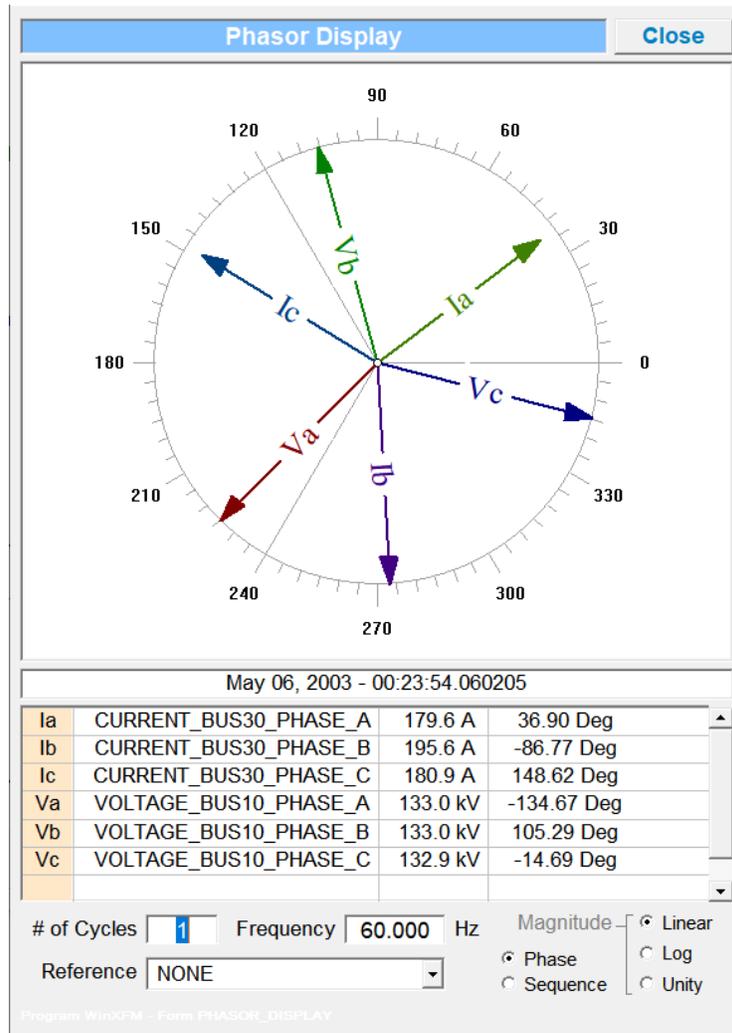
The harmonic analyzer window displays a plot or a table of harmonic components of the currently displayed waveforms. An example of the harmonic analyzer window is shown below. The window includes the following controls:

- Base Frequency,
- Number of harmonics to display,
- Number of cycles of the waveform used to compute the harmonic components.
- Histogram or table display format
- Linear or Logarithmic vertical scale
- Show harmonics of phase quantities or sequence components
- Use linear or cubic interpolation in the harmonic computation algorithm



4.2 PHASOR VIEWER

The phasor viewer window displays the phasors computed from the currently displayed waveforms. An example of the phasor viewer window is shown below. It displays phasors in plot as well as tabular format.



The window includes the following controls:

of Cycles: Number of cycles of the waveform from which phasors are computed. The displayed phasors are computed from a waveform segment starting at the left cursor position, and with duration equal to the user specified number of cycles.

Magnitude (Linear/Logarithmic/Unity): Sets the phasor magnitude plot scale. In **Linear** mode the phasor lengths are proportional to the phasor magnitude. In **Logarithmic** mode, the magnitude scale is logarithmic. Smaller magnitudes are

exaggerated so that the phase angle of smaller phasors can be seen. In Unity mode all phasors are plotted with equal length.

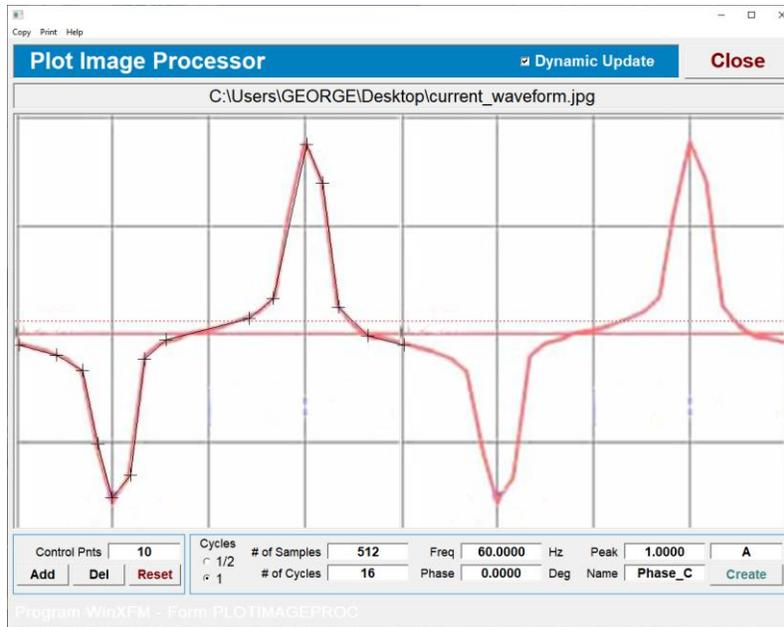
Phase/Sequence: Show phasors as phase quantities or sequence components. This options assumes that the visible phasors are three phase components

Reference pull-down list box. If set to NONE phase angle are computed with the cursor as reference. For example a sinusoidal waveform with maximum value aligned with the cursor has zero phase. If a reference channel is selected then phase angles are computed as phase differences from the selected channel phase.

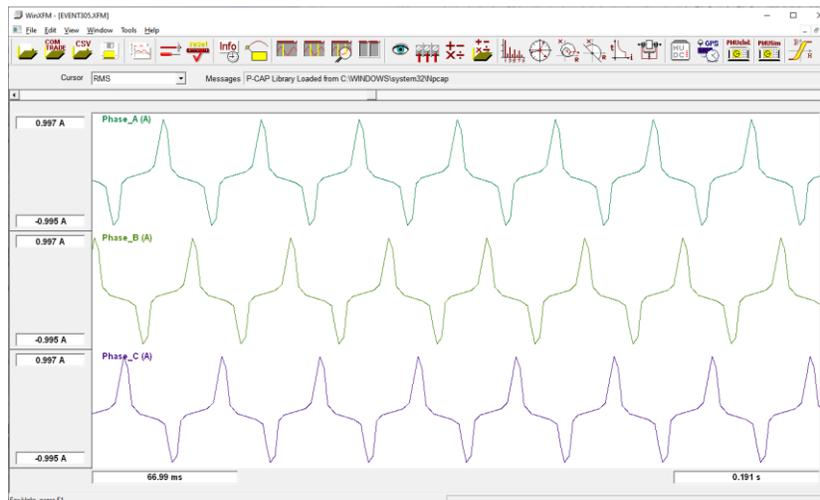
Frequency. Sets the frequency of the computed phasors. Default value is the nominal fundamental frequency of the displayed waveforms. For maximum accuracy, this value should be the actual fundamental frequency of the displayed waveforms.

4.3 PLOT IMAGE IMPORTING

This command opens the Plot Image Processor window (Shown below) which provides a graphical method of generating a waveform by tracing over a plot image. Plot image files in BMP or JPG file format are supported. The plot image processor window contains a user selected number of points indicated by cross symbols (+). These points are manipulated with the mouse so as to match the imported waveform picture (See example Figure below)

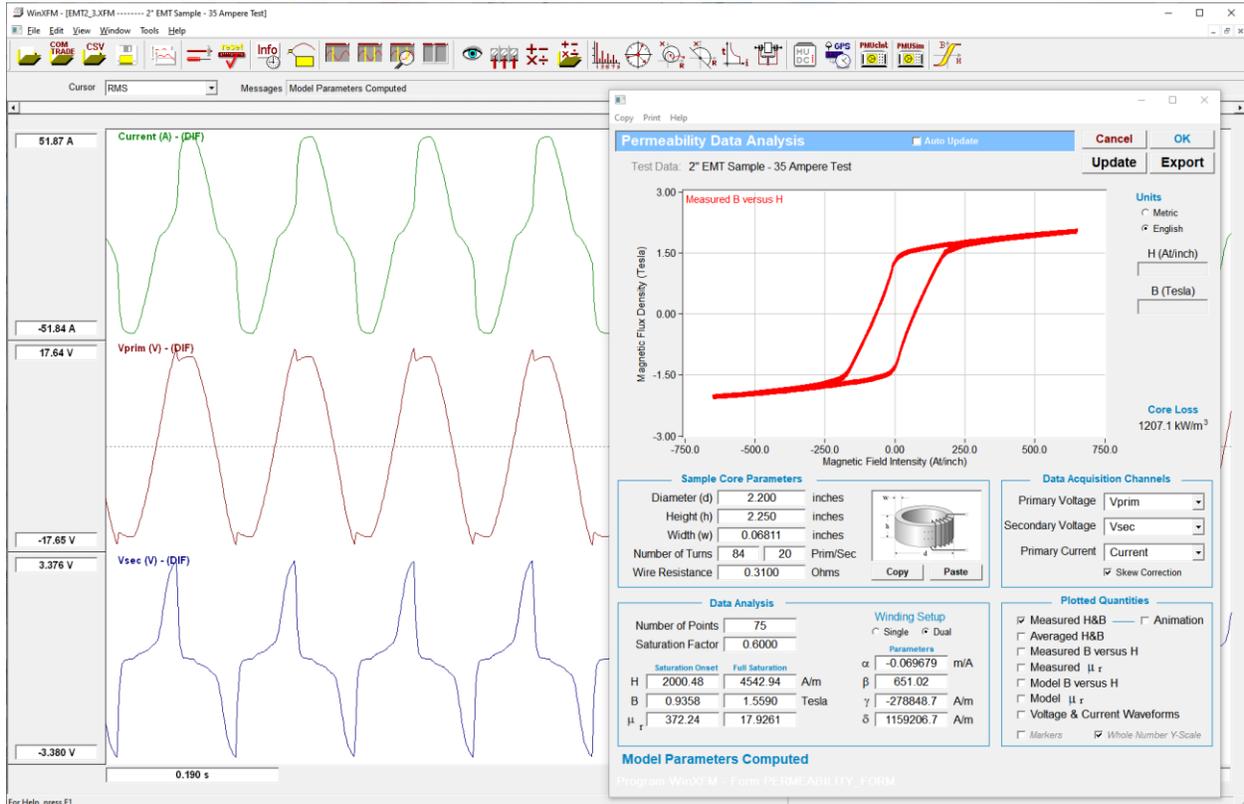


Once the points have been positioned, a waveform can be generated by clicking on the Create button. An example result is shown below:



4.4 PERMEABILITY ANALYSIS

The permeability analysis module computes the B-H curve of a material given voltage and current waveforms obtained from a toroid made of the material under test with two windings. An example is illustrated below. Detailed description of the use of this module is provided in a separate document.



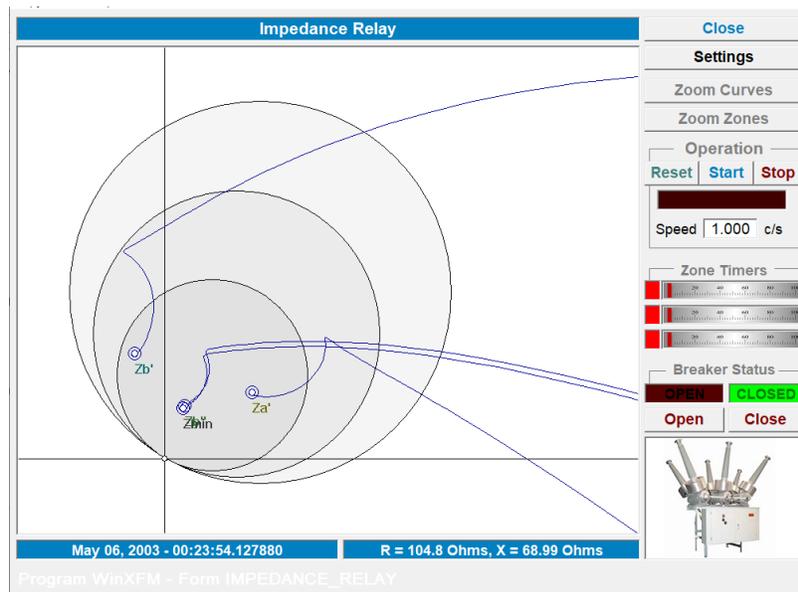
5. GENERIC PROTECTION FUNCTION SIMULATION TOOLS

The WinXFM program provides a number of optional modules which simulate the operation of generic protection functions. These modules are described in this section. The commands for accessing the generic protection functions are located in the WinXFM **Tools** pull-down menu.

*NOTE: The commands and Features presented in this section are not included in the basic WinXFM program, but require the **GPF** (Generic Protection Function Simulation) option.*

5.1 IMPEDANCE RELAY

The impedance relay tool provides an animated visualization of the impedance relay operation. The main impedance relay window is shown below. It contains a plot area where the zone circle diagrams are displayed along with the trajectories of the impedance relay monitored impedances.



The Settings button (near top right area of window) opens the settings dialog (illustrated below), which allows selecting the monitored voltage and current channels, as well as setting the zone characteristics,

Relay Settings **Default** **Apply** **Cancel** **Accept**

Channel Assignment

	Voltage	Current
Phase A	VOLTAGE_BUS10_PHASE_A	CURRENT_BUS10_PHASE_A
Phase B	VOLTAGE_BUS10_PHASE_B	CURRENT_BUS10_PHASE_B
Phase C	VOLTAGE_BUS10_PHASE_C	CURRENT_BUS10_PHASE_C
<input type="checkbox"/> Reference		<input type="checkbox"/> Reverse Current Direction

Zone Parameters

	Z-Magn (Ohms)	Z-Phase (deg)	Delay (cycles)
Zone 1	50.000	60.000	2.000
Zone 2	75.000	60.000	10.000
Zone 3	100.000	60.000	30.000

Compensation Factor (k)

Input Waveforms Secondary Primary Auto-Reclose Debug Mode

Alg. Controls

Phasors / Cycle
Window (Cycles)
 Real Time Data

Display

Minimum
 Va / Ia...
 (Va-Vb) / (Ia-Ib),...
 Va / (Ia-k*Io),...
 All of the Above

Program WinXFM - Form IMPEDANCE_RELAY_SETTINGS

An example file (IMPEDANCE_RELAY_EXAMPLE.XFM) is included in the WinXFM installation directory (c:\xfm\DataU) which can be used to demonstrate the operation of the impedance relay tool.

5.2 DIRECTIONAL OVERCURRENT RELAY

The directional overcurrent relay tool is presently under development.

5.3 TIME OVERCURRENT RELAY

The time overcurrent relay tool is presently under development.

5.4 TRANSFORMER DIFFERENTIAL RELAY

The transformer differential relay tool is presently under development.

5.5 FAULT LOCATOR

The fault locator tool is presently under development.

6. OPTIONAL TOOLS WITH DATA STREAMING CAPTURE

This section describes optional features of the WinXFM program which accept data streaming from external hardware, such as PMUs, Merging Units, and GPS receivers.

NOTE: The commands and Features presented in this section are not included in the basic WinXFM program, but require at least one of the following data acquisition interface options:

MDC	Merging unit data concentrator using Sample Value Streaming
SPH	Capturing PMU Synchrophasor data streams
GPS	Reception of GPS data from SEL and Trimble GPS receivers

6.1 PMU CLIENT

The PMU client tool receives an IEEE-C37.118 synchro-phasor stream. Received data can be plotted within the WinXFM plot view. Any number of PMU client objects can be created and operated simultaneously.

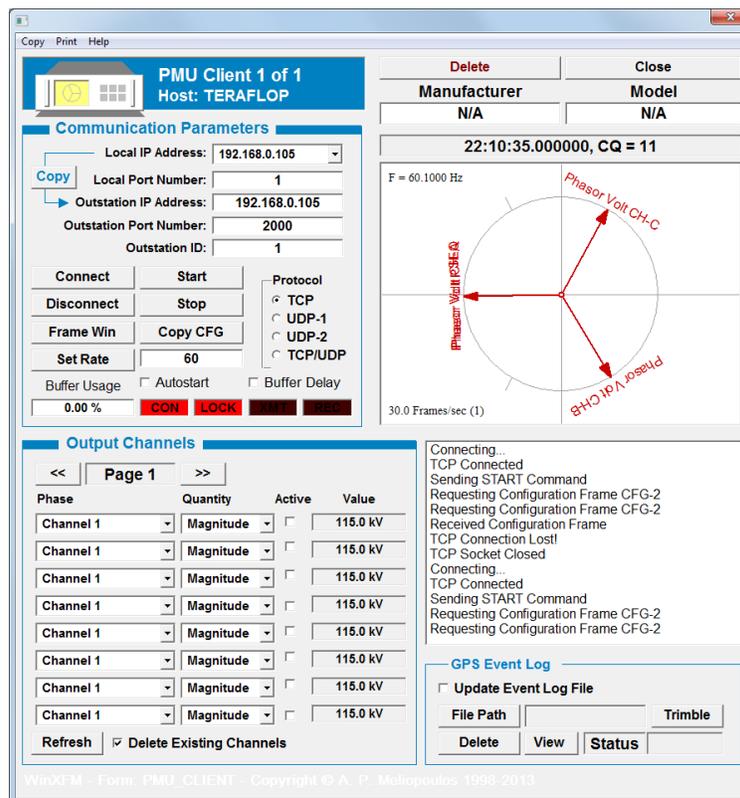


Figure 4.1: PMU Client Control Window

6.2 SIMULATED TEST PMU

The Simulated PMU object generates an IEEE-C37.118 synchro-phasor stream. The synchro-phasors are created based on a set of user selected parameters, such as frequency, voltage and current magnitude and phase angle, etc. The purpose of this object is for testing various IEEE-C37.118 applications, such as PMU clients or evaluating network hardware performance in the presence of Synchrophasor streams

The simulated test PMU command opens the dialog window (shown below) displaying the controls of a simulated PMU. Any number of simulated PMU instances can be created and operated simultaneously.

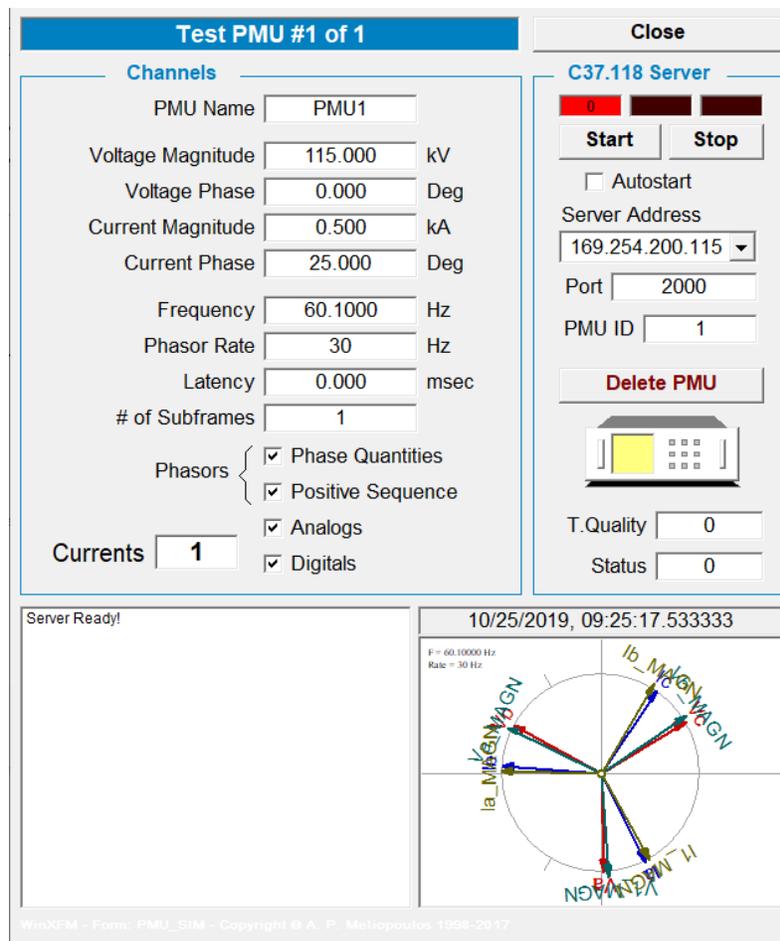


Figure 4.1: Simulated Test PMU Window

6.3 MERGING UNIT DATA CONCENTRATOR

The MU data concentrator receives sample value (SV) data transmitted via a local area network **Link Layer**. The SV protocol is described in the IEC 61850.9-2 standard. The main MU concentrator window is shown below. It includes several controls for setting the concentrator parameters, starting and stopping the concentrator, as well as displaying system performance data. Furthermore, it includes a virtual Phasor Measurement Unit (vPMU), which processes the incoming point-of-time data, and computes the corresponding phasors. The computed phasors can be plotted in the WinXFM main plot view, and/or transmitted to PMU client applications via an IEEE C37.118 stream.

Merging Unit Data Concentrator [Close]

Concentrator Settings

Sampling Rate	4800	Hz
Base Frequency	60.00	Hz
Max Local Latency	400.0	ms
Max Remote Latency	2000.0	ms
Max Analysis Latency	100.0	ms

Plot Raw Data
 Packet Reports
 Error Reports
 TCP/IP Reports
 Stop on Error
 Completeness

Auto Start MUDC

Synchronphasors

10/25/19 - 10:18:32.600000

F = 60.01000 Hz

V = 115068.01 V

Add Phase Shift

C37.118 Server

REC XMT
 Stop Start

Addr: 169.254.200.1
 Port: 2000
 PMU ID: 1
 Name:

Plot PMU Output

Performance

Max Local Latency (%) 7.26 ms

Max Remote Latency (%) 0.00 ms

Buffer Usage (%)

Buffer Size: 10080
 SV Reception Rate: 1.172 Mb/sec
 TCP Reception Rate: 0.000 Mb/sec

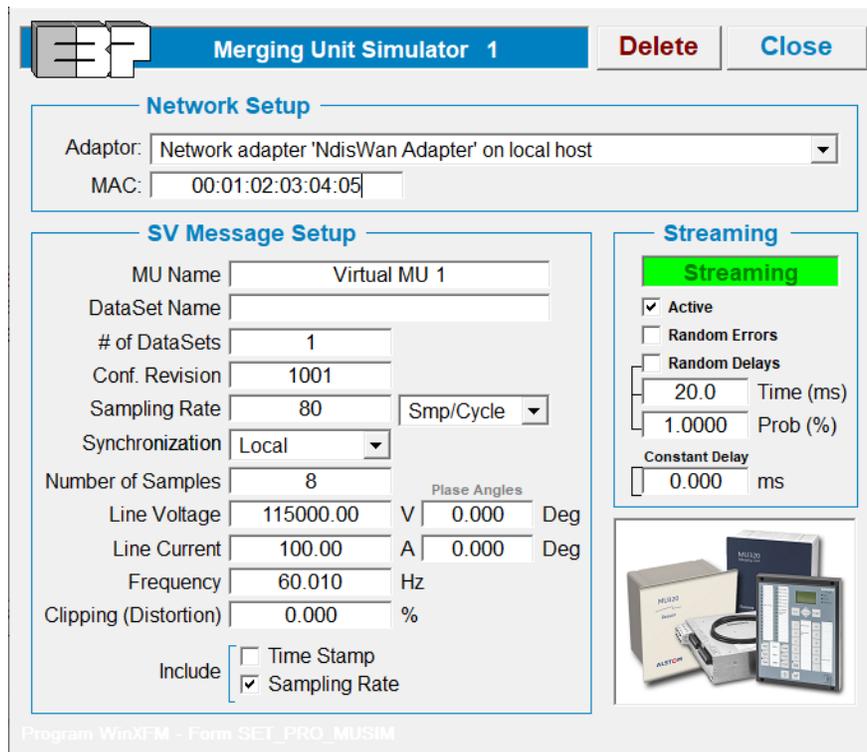
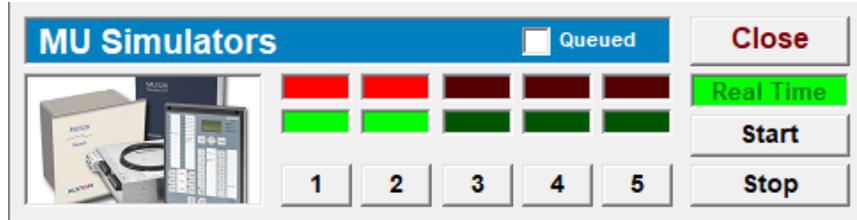
Error Counts

Too Late	0	TCP/IP Xmit	0
Too Early	0	Bad SV Data	0
Out of Seq	0	Bad TCP Data	0

Program WinXFM - Form SET_PRO_MUCOM_FORM

6.4 MERGING UNIT SIMULATORS

The merging unit simulator tools create Sample Value (SV) streams as defined in the IEC 61850.9-2 standard for the purpose of testing various merging unit applications. The main control window of the MU simulators is shown below. It contains 5 buttons labeled 1 through 5, which open the setup windows of up to five MU simulators (second Figure below). The start and stop buttons initiate and terminate the SV data streams.



6.5 GPS MONITOR (SEL-2407)

The SEL GPS monitor window displays information transmitted by SEL-2407 GPS clocks, including:

- Time and date
- Several GPS receiver status flags
- Latitude, Longitude and Elevation at the receiver location
- The signal strength of the received satellite signals
- The settings of the front panel switches

The GPS monitor window is shown below. Use of this tool requires a connection to the GPS receiver via RS-232 port.

SEL GPS Clock Monitor Close

Connection

Port: [Dropdown]
 Baud Rate: 9600 [Dropdown]
 Password: patates
 Connect Run
 Terminal

Time & Status

Time: [Text]
 Date: [Text]
 GPS Status: [Text]
 Almanac: [Text]

Receiver Location Reset Zoom

Location

Latitude: [Text]
 Longitude: [Text]
 Elevation: [Text]

Self Test

RTL: Display: Antenna:
 Flash: Battery: GPS:
 SDRAM:

Satellite Signal Strength

12 signal strength bars (0-100 scale)

Front Panel Switch Settings

Switch	Function	Setting
1		
2		
3-4		
5		
20		
6-7		
8-9		
10-11		
12-17		
18		
19		

Program WinXFM - Form GPSMONITOR_SEL

6.6 GPS MONITOR (TRIMBLE THUNDERBOLT)

The Trimble Thunderbolt GPS monitor window displays information transmitted by Thunderbolt-E GPS receiver, including:

- Several GPS receiver status variables
- The trajectory, location and signal strength of the received satellite signals, plotted over a world map image

The GPS monitor window is shown below. This tool can collect data over a time period and generate reports of satellite availability over time. Use of this tool requires a connection to the GPS receiver via RS-232 port.

The screenshot displays the 'GPS Monitor' software interface. The main window is titled 'Satellite Locations' and shows a world map with several GPS satellites (numbered 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30) plotted over the map. The map is titled 'Saturday, July 04, 2009 10:48:07'. The interface includes several control panels on the left:

- Connection:** A 'Connect' checkbox, a 'Port' dropdown menu, and a 'Baud Rate' dropdown menu set to '9600'.
- GPS Status:** A list of status variables with input fields: SV Fix, Survey, Activity, Latitude, Longitude, Altitude, Time, PPS Error, OSC Error, and OvenTemp.
- Graphical Reports:** A list of checkboxes: 'Elev.Mask' (checked, value 10.000), 'Plot Trajectories' (checked), 'Animation' (checked, value Pause), and 'DataLog' (unchecked). A 'Plot Reports' button is also present.
- Packet Reports:** A list of checkboxes: 'Raw Packet Data', 'Primary Timing Packet', 'Suppl. Timing Packet', 'Satellite Tracking', and 'Ephemeris'.

At the bottom of the window, the text 'Program WinXFM - Form GPSMONITOR_TRIMBLE' is visible.

6.7 GPS CLOCK SYNCHRONIZER

The Clock Synchronizer module adjust the PC clock using timing signal from a SEL-2407 GPS receiver or a merging unit. The setup window of the clock synchronizer module is shown below.

Clock Synchronization [Update Now] [Apply] [Close]

Sync Source
 None
 Merging Unit
 SEL-2404

Update Every minutes
 Announce Sync

Clock Offset Seconds

Local Time
Corrected Time
 Announce Seconds

Synchronization Interval: 15.00 minutes

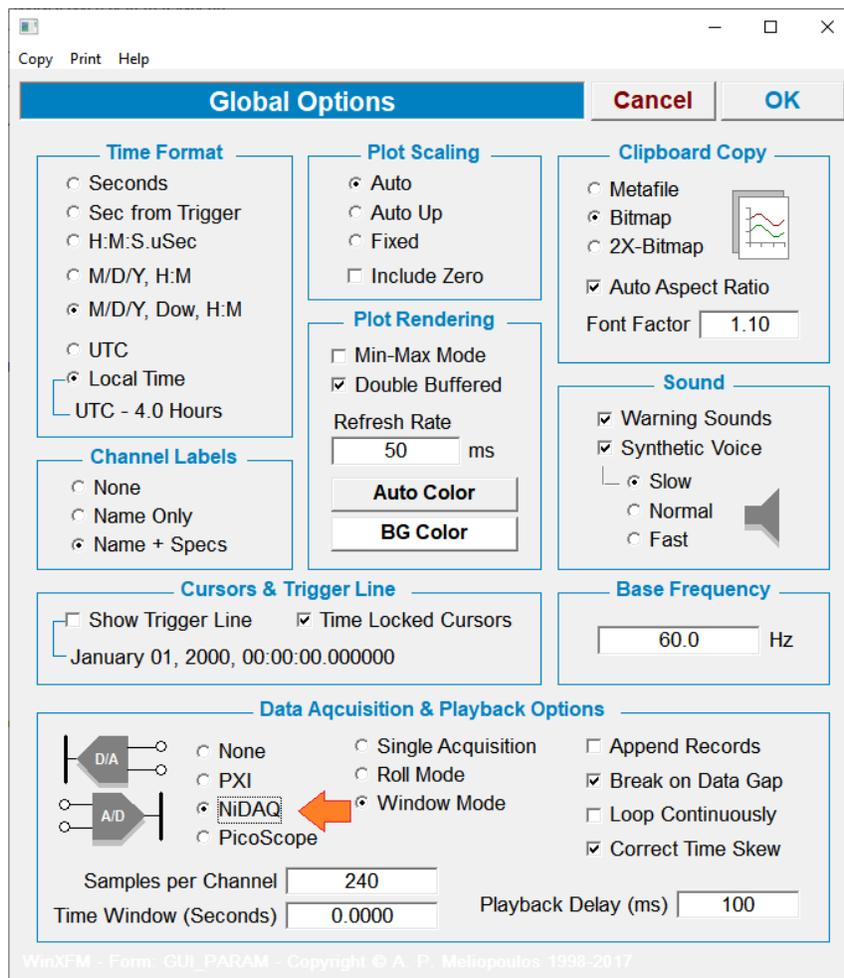
Program WinXFM - Form GPSCLOCKSYNC_SEL

Key Merging Unit ASDU
Virtual MU 1
Latency No Active MU

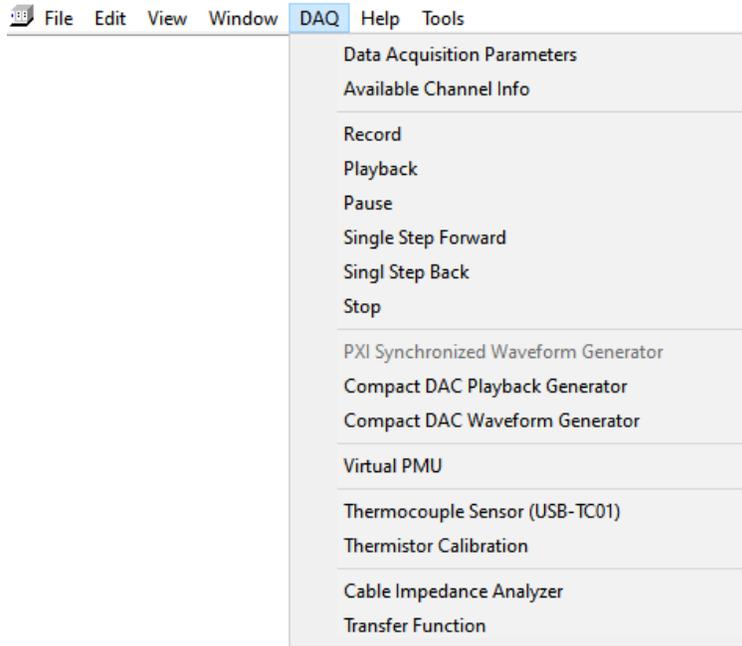
SEL-2407
Serial Port
Baud Rate 9600
Port Activity
Synchronize
GPS Time Local UTC

7. OPTIONAL TOOLS FOR DATA ACQUISITION AND GENERATION DEVICES

The WinXFM program can optionally interface with several types of data acquisition and waveform generation hardware. The specific hardware platform to be used is selected via the Global Options command located in the Edit pull-down menu (also accessible via the toolbar button: ). The command opens the dialog window shown below, which contains the DAQ hardware selection radio buttons. *Note that changing the DAQ Hardware selection takes effect after exiting and restarting the WinXFM program, so that the appropriate dynamic-link-libraries for the selected hardware can be loaded.*



Acquired data can be stored, displayed and analyzed. Furthermore, waveform data can be transmitted to waveform generation hardware. Supported hardware include several National Instruments platforms and the Pico-Scope platform. The WinXFM commands related to data acquisition and generation functions are located under the DAQ pull-down menu (shown below), and are described in this section.



NOTE: The commands and Features presented in this section are not included in the basic WinXFM program, but require at least one of the following data acquisition interface options:

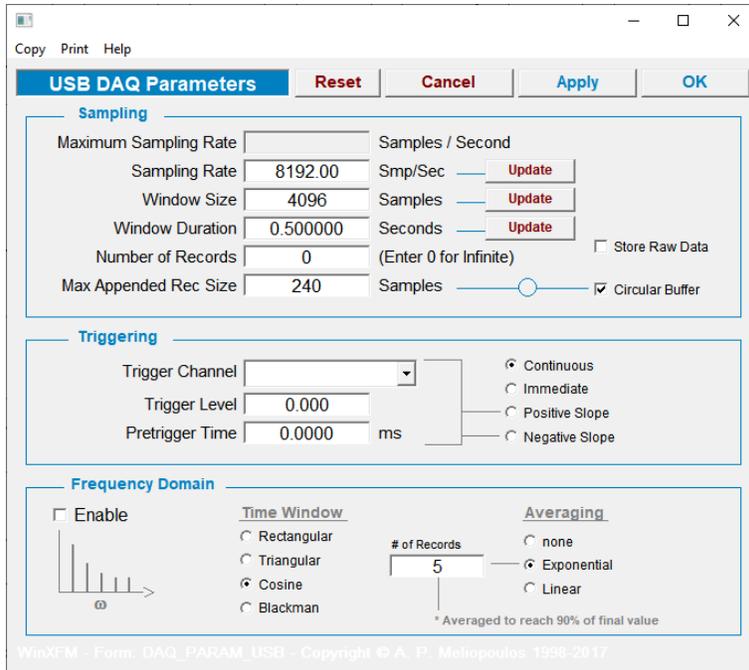
PXI	Interface with National Instruments PXI data acquisition platform
NID	Interface with National Instruments NiDAQ data acquisition platform
PIC	Interface with PicoScope data acquisition platform

7.1 DATA ACQUISITION PARAMETERS

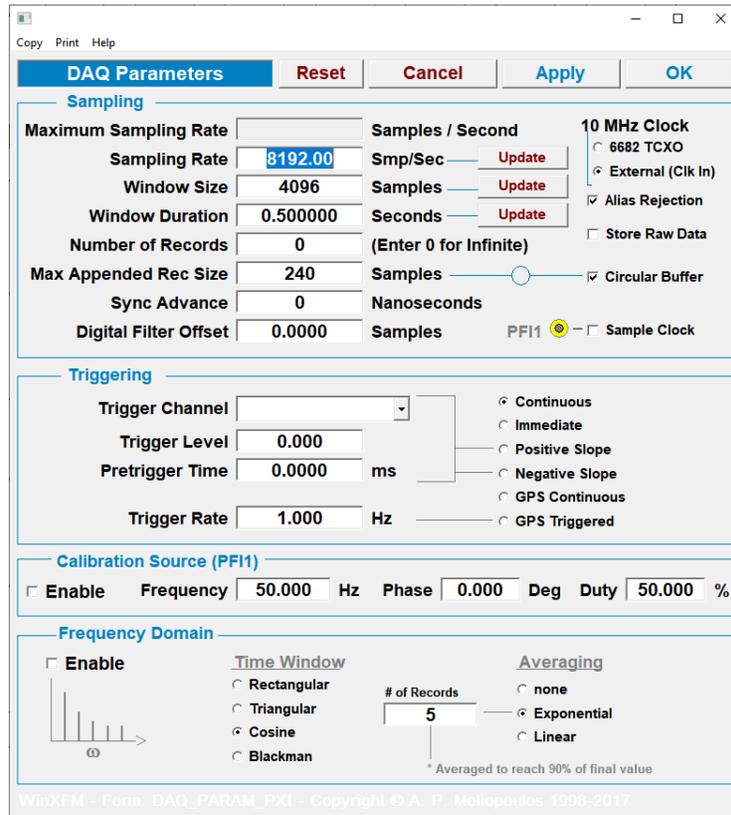
This command is located in the DAQ menu and can also be accessed via the toolbar button:



The Data Acquisition Parameters command opens the dialog window, which allows selection of the sampling and triggering parameters. The sampling and triggering parameters displayed depend on the selected hardware platform. The two Figures below show the controls for the NI-DAQmx, and PXI platforms respectively.



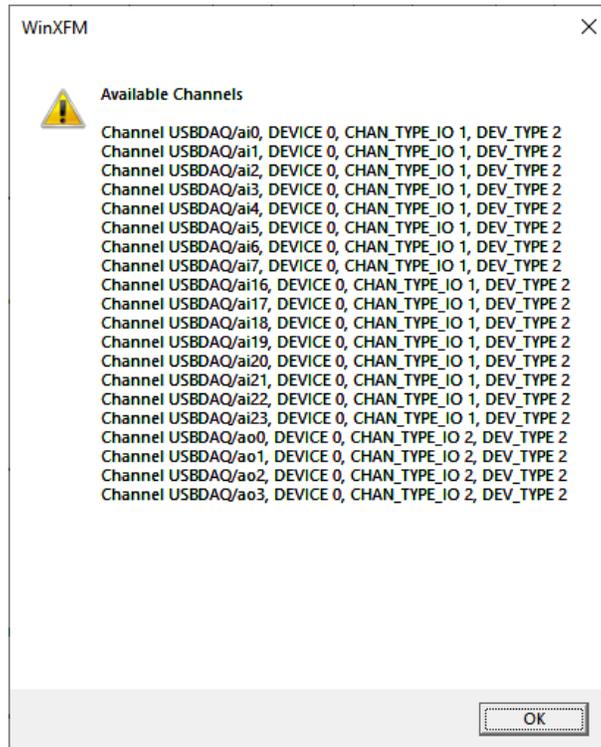
NI-DAQmx Data Acquisition Parameters Dialog



PXI Data Acquisition Parameters Dialog

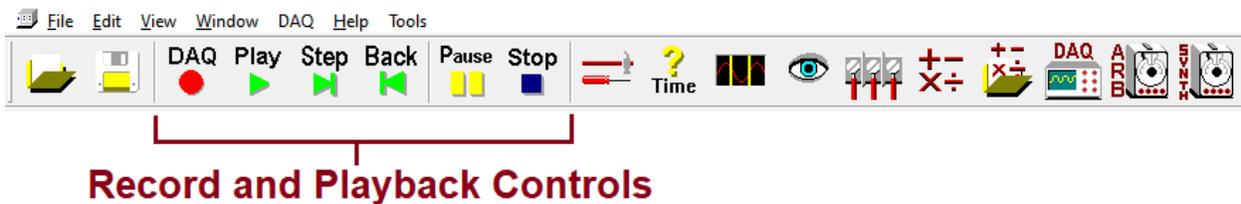
7.2 AVAILABLE CHANNEL INFO

This command displays the list of available data acquisition channels of the presently connected data acquisition hardware. An example of the command result is shown below:



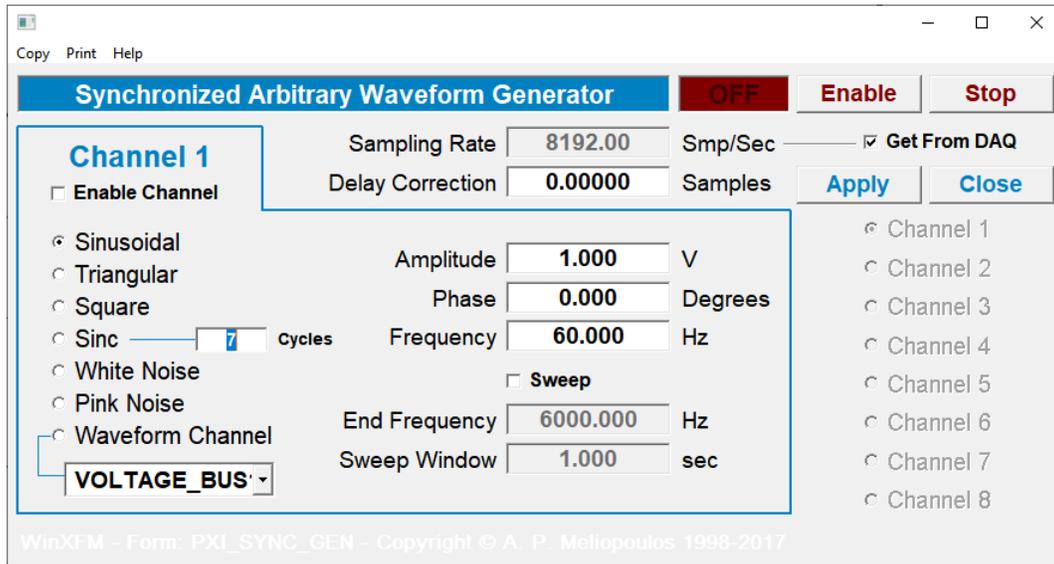
7.3 RECORD, PLAYBACK, PAUSE, STOP, AND SINGLE STEP COMMANDS

These commands control the data acquisition and playback process. They are located in the DAQ pull-down menu, and are also accessible via the toolbar buttons illustrated below.



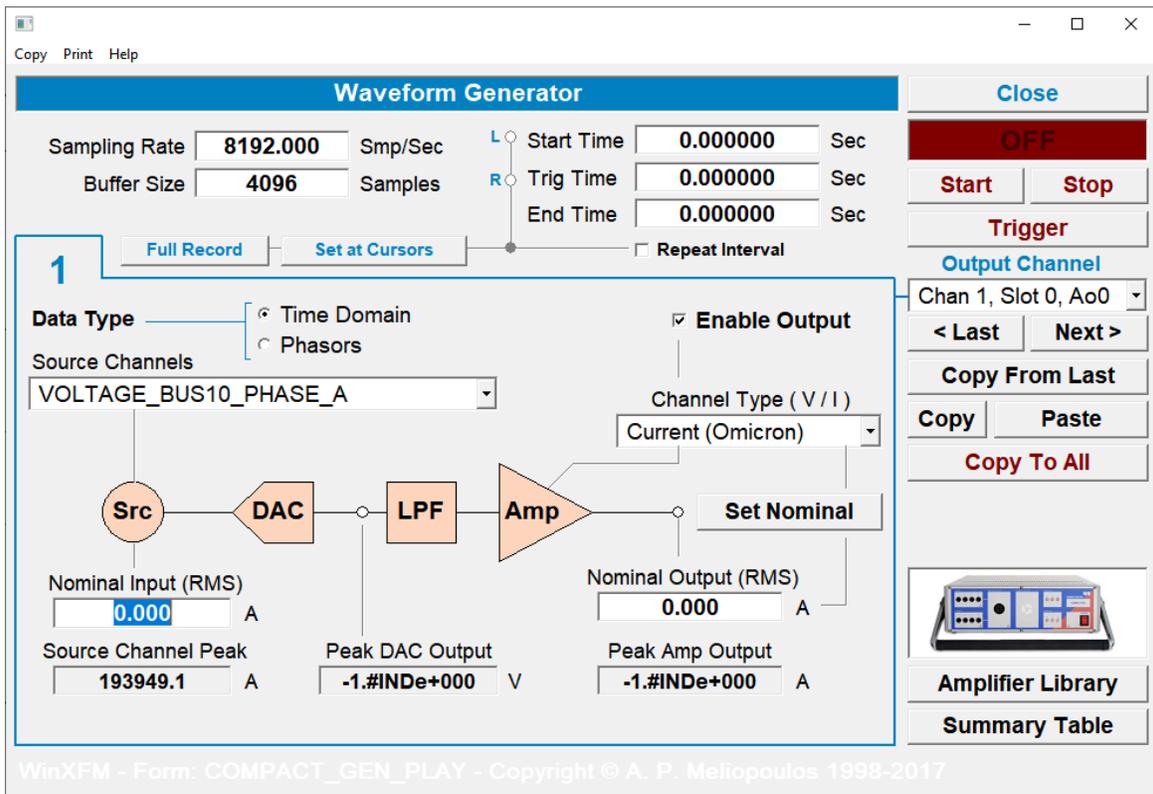
7.4 PXI SYNCHRONIZED WAVEFORM GENERATOR

This command opens the dialog window (shown below) containing setup parameters for the signal generators of the National Instruments PXI platform PXI-4661 modules. The PXI DAQ .



7.5 COMPACT DAC PLAYBACK GENERATOR

This command opens a setup dialog window for the Playback Waveform Generator. Using this feature selected waveforms can be reproduced as analog signals. Waveform reproduction can start and stop at user selected times. Waveforms can be scaled as needed by specifying nominal input and nominal output values. This module supports the National Instruments Compact DAC platform D/A converters.



7.6 COMPACT DAC WAVEFORM GENERATOR

This command opens a setup dialog window for the Synthesized Waveform Generator. This module generates sinusoidal, triangular, square as well as noise waveforms. Waveforms can be modified in several ways by specifying amplitude frequency and phase angle parameters. This module supports the National Instruments Compact DAC platform D/A converters.

Compact DAQ Synthesized Waveform Generator

Copy Print Help

Close OFF

Chan 1, Slot 0, Ao0

Sampling Rate **8192.000** Smp/Sec

Buffer Size **4096** Samples

Enable Channel

Connected to Current Amp.
Current (Omicron)

Sinusoidal
 Triangular
 Square
 White Noise
 Pink Noise

* **Amplitude** **2.000** A Fixed
 End Amplitude **2.500** A Ramp
 Ampl Ramp Time **5.000** sec Step
 Repeat

Frequency **60.000** Hz Fixed
 End Frequency **61.000** Hz Ramp
 Freq Ramp Time **5.000** sec Step
 Repeat

Phase **0.000** Degrees

Total Harmonic Distortion **0.000** %

Harmonic Orders **3, 5, 7, 9**

Start

Stop

Apply

< Last Next >

Copy From Last

Copy Last +120

Copy To All

Amplifier Library

Summary Table

** Amplitude specified as peak value at amplifier output*

WinXFM - Form: COMPACT_GEN_SYNTN - Copyright © A. P. Meliopoulos 1998-2017

7.7 VIRTUAL PMU

The virtual PMU command opens the setup dialog for the WinXFM virtual PMU module (See Figure below). The virtual PMU computes phasors from point of time signals captured from a data acquisition devices connected to the WinXFM computer.

The screenshot displays the 'Virtual PMU' software interface. At the top, it shows 'PMU #1 of 1' and 'PMU_1' with 'Delete PMU', 'Stop', 'Start', and 'Close' buttons. The interface is divided into several sections:

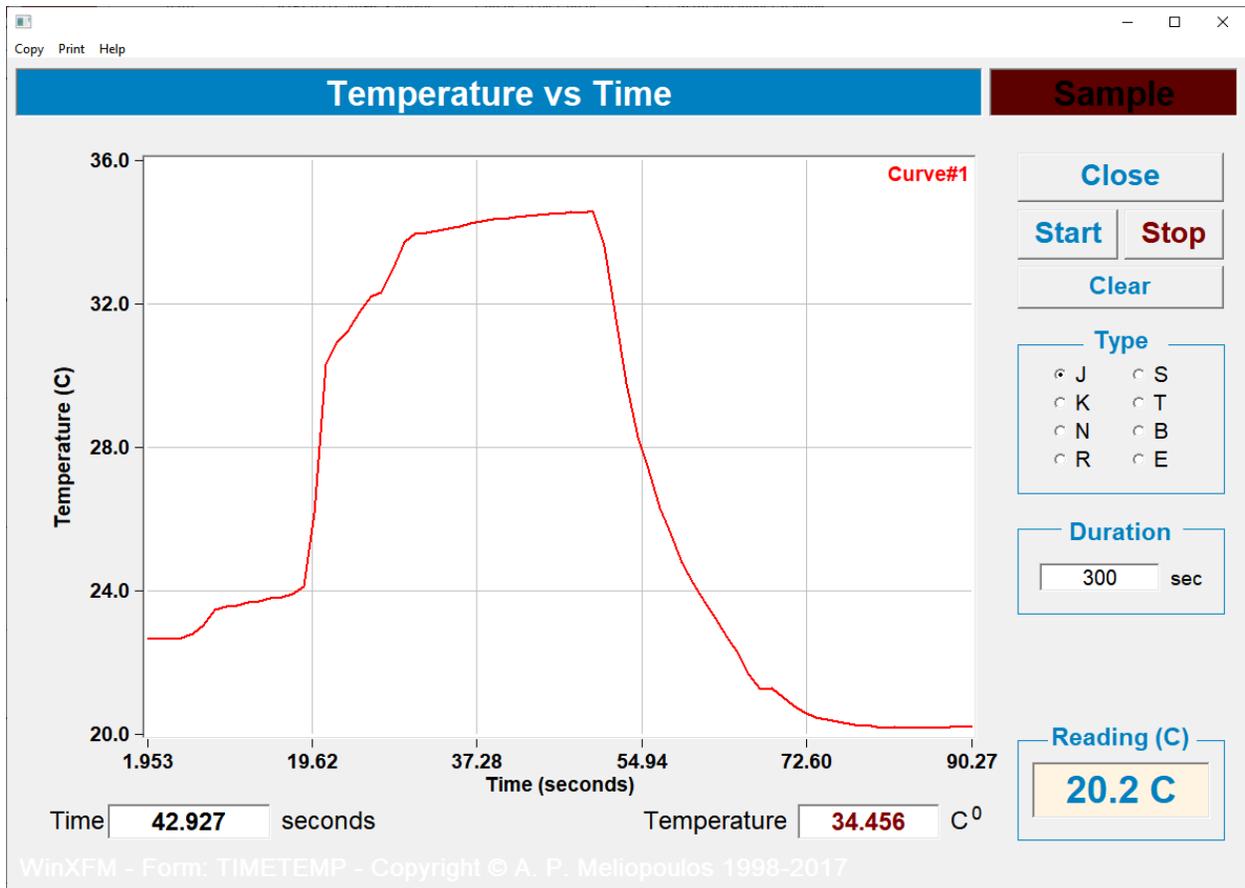
- Input Channels:** Source is set to 'Local Data Acquisition'. Phases A, B, and C are all set to 'VOLTAGE_BUS10_PI'. The Neutral is set to 'CURRENT_BUS10_P'. Nominal is 5.000 and Offset is 0.000 Hr.
- C37.118 Server:** Server Address is 169.254.178.72, Port is 2000, and PMU ID is 1. There are 'Start' and 'Stop' buttons.
- Phasor Algorithm:** 'Settings' button is present. The algorithm is set to 'Recursive Estimation'.
- Output Channels:** A table lists output channels for Phase_A, with quantities Magnitude, Angle, Frequency, and dFdT. All are currently inactive.
- Results:** A vertical list shows four zeros (0).
- Phasor Plot:** A circular plot with a red dot at the center. Text above the plot reads 'F = 0.00000 Hz' and 'DF/DT = 0.00000 Hz/sec'. A timestamp 'January 01, 2000 - 00:00:00.000000' is displayed above the plot.

At the bottom, there is a copyright notice: 'WinXFM - Form: PMU_MAIN - Copyright © A. P. Meliopoulos 1998-2017'.

The Virtual PMU module computes phasors using the “Standard PMU” algorithm, which is described in Appendix 4 of this document.

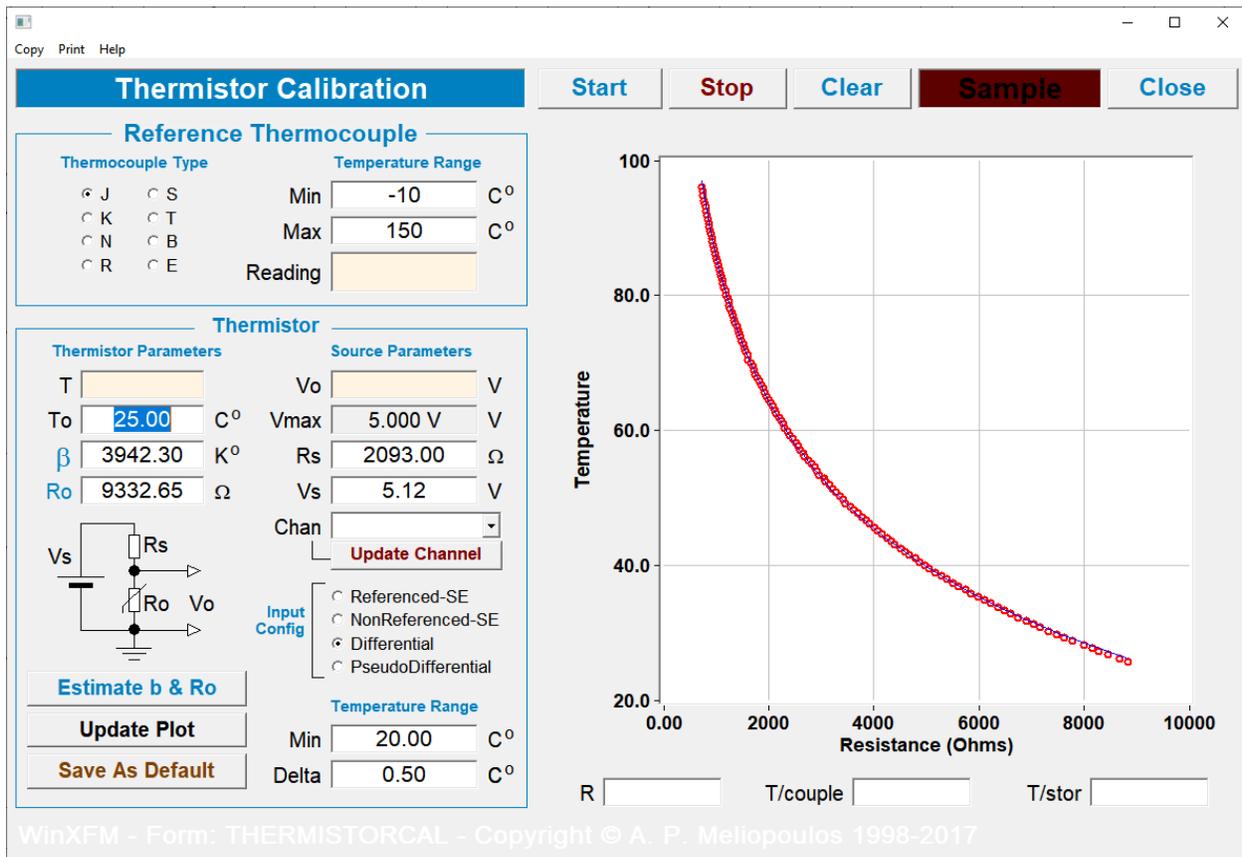
7.8 THERMOCOUPLE SENSOR (USB-TC01)

This command opens the dialog window shown below, which displays temperature versus time plots. The plotted data are captured from a National Instruments thermocouple module USB-TC01, which must be connected to the WinXFM computer via USB.



7.9 THERMISTOR CALIBRATION

This command opens the dialog window shown below, which can be used to calibrate thermistor temperature sensors. The calibration is performed by comparing the thermistor reading to the reading obtained from a National Instruments thermocouple module USB-TC01. The USB-TC01 must be connected to the WinXFM computer via USB, while the thermistor voltage is monitored by a data acquisition device also connected to the WinXFM computer. It is recommended that both thermistor and reference thermocouple are immersed in hot water (near the boiling point), and allow the system to capture data as the water cools to room temperature. Required input data are the voltage (V_s) and series resistance (R_s) of the source driving the thermistor and the computed results are the thermistor β and R_o parameters.



7.10 CABLE IMPEDANCE ANALYZER

This command opens the dialog window shown below, which can be used to evaluate the impedance of a cable. An AC current is passed through a cable sample, while the current and voltage across the cable sample is monitored by a data acquisition device connected to the WinXFM computer. Optionally, the cable sample temperature is monitored with up to four thermistors, also monitored by the same data acquisition device. The current through the cable is slowly varied and a plot of impedance versus current is generated.

The cable impedance is computed using coherence analysis averaging which provides high accuracy, by rejecting external noise.

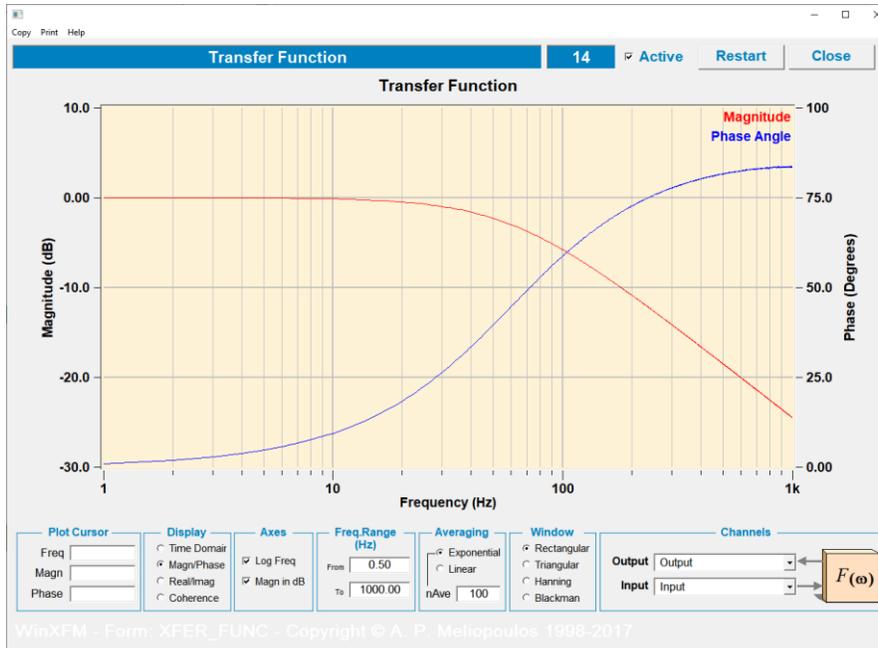
The screenshot shows a software dialog box titled "Impedance vs Current Coherence Analysis". The window has a standard Windows-style title bar with "Copy", "Print", and "Help" menus. The main area is divided into several sections:

- Analysis Parameters:** Includes fields for "Analysis Frequency" (60.000 Hz), "Sampling Rate" (8192.0 Hz), "Window Size" (4096), "Records Averaged" (10), "Channel Skew" (7.629 usec), "Window Time" (0.500 sec), "Cable Length" (10.00 feet), and "Temp. Coef." (0.0039 Ohms/C). There is a checkbox for "Correct for Temperature".
- Instrumentation Channels:** A section with a blue header containing dropdown menus for "Voltage" (V_02), "Current" (V_01), and "Impedance". It also includes four "Temperature" fields (Temperature 1-4) with "N/A" dropdowns.
- Acquire Point:** A section with a red header and buttons for "Auto" (checked), "Sort", "Table", and "Clear". It also has input fields for "Voltage", "Current", and "Impedance".
- Data Display:** A large empty plot area with the text "No plot data defined..." centered at the top.
- Footer:** Includes a row of radio buttons for "Symbols", "MP", "RX", and "RL", followed by "Current:" and "Impedance:" labels with corresponding input fields.

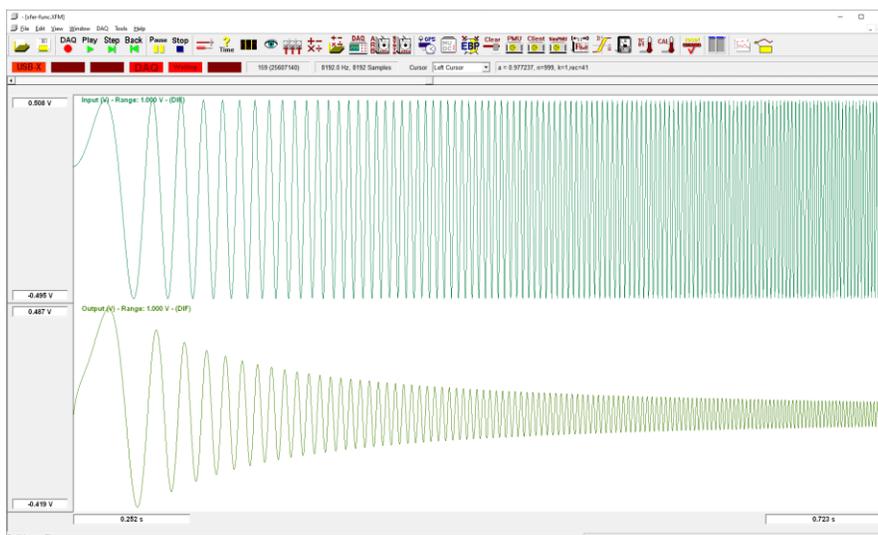
At the bottom of the window, the text "WinXFM - Form: IMPEDANCE_VS_CURRENT - Copyright © A. P. Meliopoulos 1998-2017" is displayed.

7.11 TRANSFER FUNCTION

This command opens the transfer function measurement dialog window, shown below. This tool can be used to measure the frequency response of a single-input single-output linear system, while the input and output waveforms are monitored via data acquisition hardware. The transfer function is computed using coherence analysis with frequency domain averaging.



The result shown above is the frequency response of a first order low pass filter, with a swept frequency sinusoidal input signal. The input and output signals are shown below



8: COMMAND REFERENCE

This section provides a brief description of the WinXFM commands. The WinXFM commands are accessible via six pull-down menus, named: File, Edit, View, Window, Tools, and Help.

8.1 FILE MENU COMMANDS

NEW

Creates a new empty WinXFM document View. An empty document can be used to generate waveforms based on formulas (See also: [Channel Types and Properties](#)).

OPEN

Toolbar Button



Opens waveform data files. Supported file formats are:

- Native WinXFM files (file names ending in XFM and XFW),
- COMTRADE files (file names ending in CFG, DAT and HRD)
- Excel comma separated value files (file names ending in CSV)
- Synchronphasor data files (file names ending in SP! and SP2)

APPEND COMTRADE FILE

Adds waveform data from user selected COMTRADE files to the waveforms displayed. This command can be used to combine data from multiple COMTRADE files into a single COMTRADE file. Note that the combined files must have the same sampling rate and cover time periods that are at least partially overlapping.

OPEN MULTIPLE SP FILES

Opens one or multiple synchronphasor data files. Synchronphasor data files are generated by state estimator applications implemented in the WinXFM and WinIGS programs.

SAVE

Toolbar Button



Saves Waveform data in the same format they were opened, namely:

- Native WinXFM files (file names ending in XFM and XFW),
- COMTRADE files (file names ending in CFG, DAT and HRD)
- Excel comma separated value files (file names ending in CSV)

An exception to the above is that waveform data read from synchrophasor files are saved in native WinXFM format.

SAVE &AS XFM FILE

Toolbar Button



Saves Waveform data in Native WinXFM file format under a user selected file name and folder

SAVE AS COMTRADE FILE

Toolbar Button



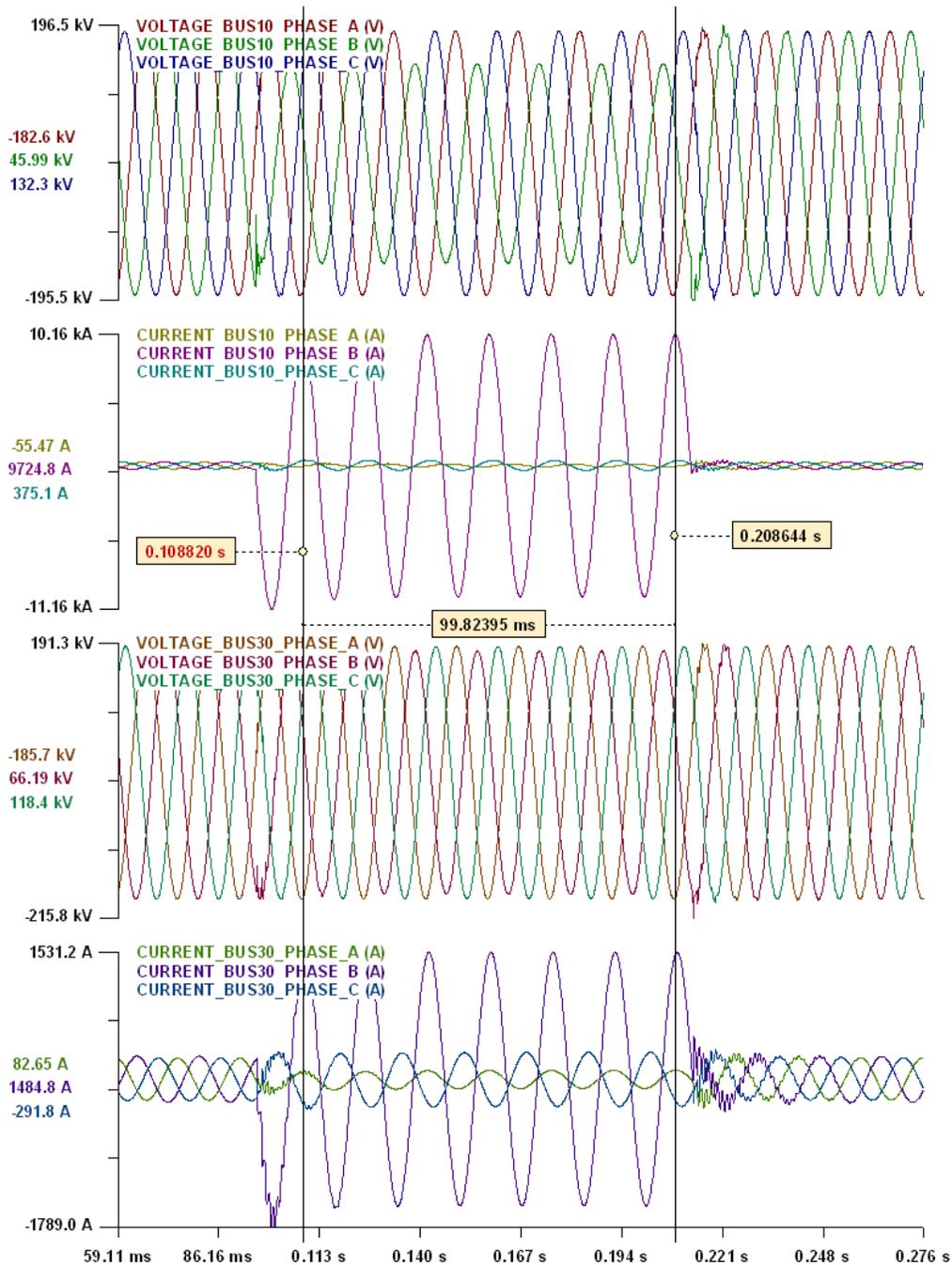
Saves Waveform data in COMTRADE file format under a user selected file name and folder

SAVE AS CSV FILE

Saves Waveform data in Excel CSV file format under a user selected file name and folder

PRINT

Prints the presently displayed waveforms to a user selected printer. Note that the printed format and layout is optimized for printing aspect ratio of 8.5 x 11 " page, in either portrait or landscape mode. An example of printed formatting is illustrated below:



PRINT PREVIEW

Displays how the currently displayed waveforms will appear when printed.

PRINT SETUP

Allows selection of printer and printer options such as paper size and page orientation.

CLOSE CASE

Closes the currently selected view document

EXIT

Terminates the WinXFM program execution.

8.2 EDIT MENU COMMANDS

COPY IMAGE

Toolbar Button



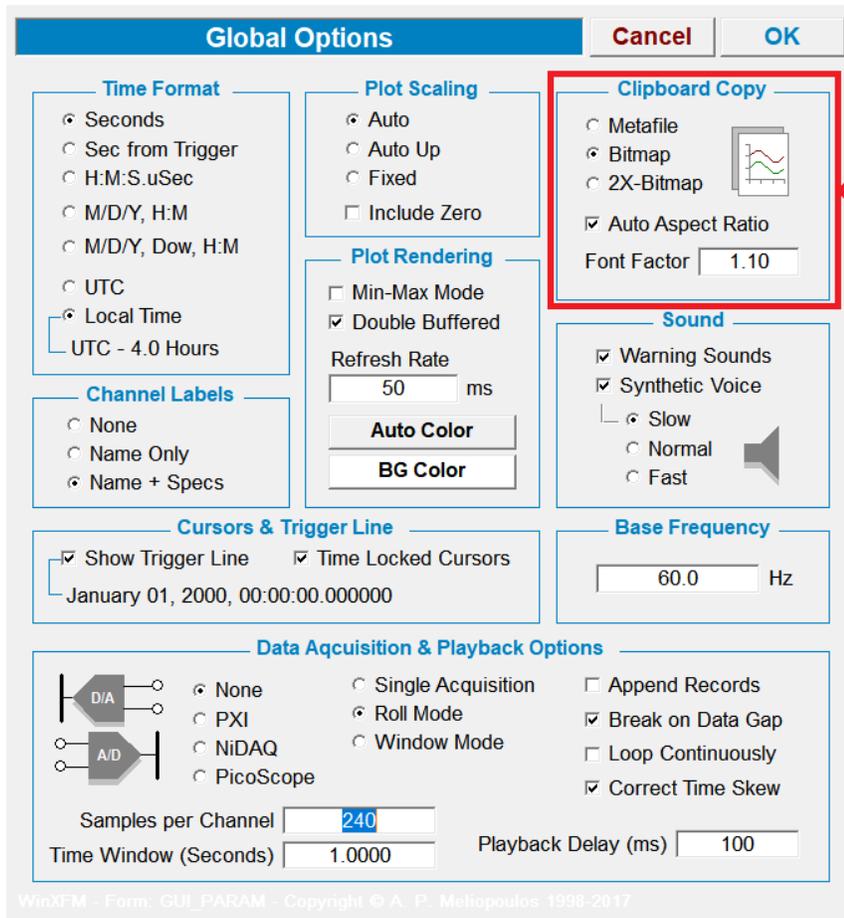
Creates an image of the presently displayed waveforms and copies it into the Windows Clipboard. Clipboard images can be subsequently pasted in word-processing and image processing applications. The image sent to the Windows clipboard is either in **Bitmap** format or **Windows Enhanced Metafile** format. The bitmap format provides high image quality but results in large file size, while the enhanced metafile format is significantly more compact with somewhat reduced image quality. The image formatting option is selected by opening the Global Option dialog (illustrated below) using the “**Global Options**” command of the Edit menu or the toolbar button:



Note that there are two bitmap options (Bitmap and 2X-Bitmap). The Bitmap option generates an image with 1280 pixels along the horizontal direction, while the 2X-Bitmap has 2560 pixels. The 1280 pixel option is recommended for most applications.

Checking the **Auto Aspect Ratio** button allows the program to determine the aspect ratio of the generated clipboard image, based on the number of plot frames displayed on the screen. If the **Auto Aspect Ratio** button is unchecked, the clipboard image aspect ratio is made the same as the screen image aspect ratio.

The **Font Factor** entry allows adjustment of the text size appearing in the generated clipboard image.

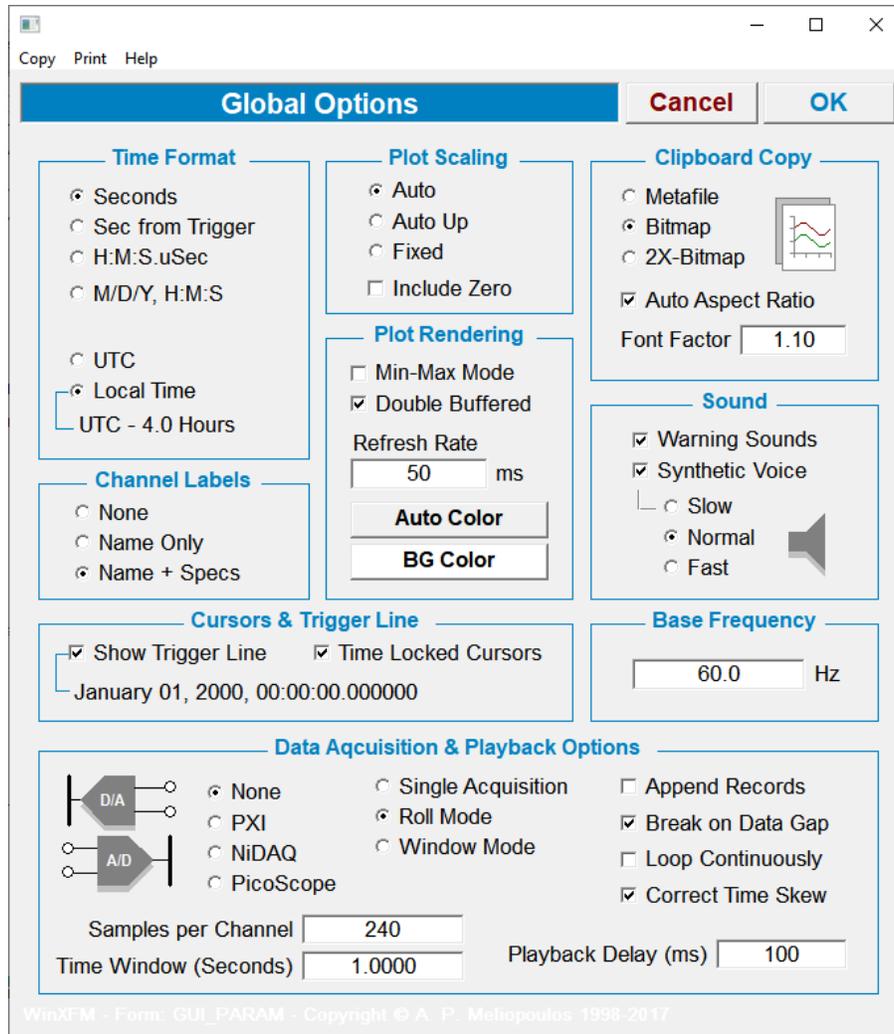


GLOBAL OPTIONS

Toolbar Button



The “**Global Options**” command of the Edit menu opens the dialog form illustrated below which allows modification of a number of program settings related to the appearance of waveform screen and other user interface parameters, as well as a number of parameters related to the data acquisition hardware accessed by the WinXFM program. A brief description of the settings included in this dialog follows:



Time Format

Selects the time axis and cursor time annotation formatting. Available options are to display time in seconds from the start of the recording, seconds from the trigger time, as well as display of date (M/D/Y) and time in hours, minutes, and seconds. Furthermore, time can be displayed as local or UTC time. (Note that the 1991 and 1999 versions of the COMTRADE standard does not specify whether the recording start and trigger times are stored as local or UTC times. WinIGS assumes that the time stamps stored in 1991 & 1999 COMTRADE files are local times).

Plot Scaling

Selects the method with which the program selected the vertical axis scaling. The **Auto** option matches the extent of the y axis to the range of the displayed waveforms. During Zooming, the scale is continuously adjusted based on the range of the displayed waveform segment. In **Auto-Up** mode the scaling is automatically adjusted only if the

range of the displayed waveform segments exceeds the range of the vertical axes. In Fixed Mode, the vertical axis scaling is not automatically adjusted. In the **Include Zero** checkbox is checked, the Y axes are forced to include zero, even if the waveform data may be all positive or all negative.

Channel Labels

Selects whether the channel names (and for computed channels the defining formulas) are displayed on the plot areas. Note that the channel names and specifications are shown in the same color as the corresponding curves

Plot Rendering

Selects parameters affecting the plot trace quality and appearance. Checking the **Min-Max** mode ensures that extreme waveform values (such as spikes and dips) are not hidden at any zoom level. Checking the **Double Buffered** check box provides smooth redraw and animation during zooming and panning. The **refresh rate** sets the rate at which the dynamic displays are updated (The refresh rate option affects only hardware driven functions, where the waveform data may be changing in real time). The **Auto Color** button automatically assigns different colors on displayed waveforms. The **BG Color** button opens a color selection dialog in order to set the plot area background color.

Clipboard Copy

Selects the type and quality of the images copied into the Windows clipboard. Images copied into the Windows clipboard can be subsequently pasted into other applications. See also [Copy Image](#) command for more details.

Sound

Allows selection of voice and warning sound options. The WinXFM program uses sound effects and voice prompts to indicate some error conditions or completion of computational processes. Sound and voice options can be turned off by un-checking the corresponding check boxes.

Base Frequency

Sets the power system base frequency value, which is used in several analysis algorithms, such as the computation of harmonics.

Data Acquisition and Playback Options

WinXFM supports a number of data acquisition platforms from National Instruments and PicoScope. If one of the data acquisition option (radio buttons titled: PXI, NiDAQ or PicoScope) is selected, WinXFM will attempt to load the necessary Dynamic-Link Libraries (DLL's) in order to enable the interface between WinXFM and the selected DAQ hardware. Note that this option requires the installation of the driver software specific to the DAQ hardware to be used.

The “Data Acquisition and Playback Options” group contains a number of controls related to the reception and display of data received from data acquisition hardware, namely:

“**Single Acquisition/Roll Mode/Window Mode**” radio buttons. This setting determines the way acquired data are displayed. In **Single Acquisition** mode, WinXFM receives data samples until the number of samples received matches the entry in the **Samples per Channel** field, then the data acquisition is terminated, and the entire set of data received is displayed. In **Roll** mode, WinXFM receives data samples continuously, and always displays the latest N samples received, where N is the entry in the **Samples per Channel** field, or the number of samples acquired over the time interval specified in the **Time Window** field (whichever is greatest). In **Window** mode, WinXFM receives data samples continuously, and updates the display each time an additional set of N samples are received.

If the **Append Records** checkbox is checked each set of N samples acquired is appended to the plot buffers, otherwise, each set of N samples acquired replaces the samples in the plot buffers.

The **Break on Data Gap** option terminates the data acquisition process if missing samples are detected.

The **Loop Continuously** option forces acquired data to be played back in an endless loop. (This option affects only the Playback process).

The **Correct Time Skew** option is applicable to Data acquisition devices that use multiplexed A/D converters. This option applies a time skew correction among sequentially sampled channels.

The **Playback Delay** entry sets the rate at which multiple stored records are sequentially displayed. This option affects only the playback of data stored during the data acquisition process.

EDIT CHANNELS

Toolbar Button



This command creates opens the channel list dialog illustrated below. The dialog shows a list of the existing channels along with several channel properties:

Selected: Indicates if a channel has been selected.

Type: Channel type, (one of the following *Wave, Computed, DAQ, Digital*)

Phase: COMTRADE channel phase specification

Units: Channel quantity units

Peak: Maximum absolute value of channel waveform

Xfmr: Instrument transformer side (Primary or Secondary)

Ratio: Instrument transformer transformation ratio

Edit Channel List ×

Auto Crop
 Enable Time Shifting

Name	Selected	Type	Phase	Units	Peak	Xfmr	Ratio	Smp Rate	Expression
VOLTAGE_BUS10_PHASE_A		Wav		V	193949.062	Pri	/	100000.0 Hz	
VOLTAGE_BUS10_PHASE_B		Wav		V	196467.047	Pri	/	100000.0 Hz	
VOLTAGE_BUS10_PHASE_C		Wav		V	194021.406	Pri	/	100000.0 Hz	
CURRENT_BUS10_PHASE_A	Yes	Wav		A	366.273	Pri	/	100000.0 Hz	
CURRENT_BUS10_PHASE_B	Yes	Wav		A	11155.756	Pri	/	100000.0 Hz	
CURRENT_BUS10_PHASE_C	Yes	Wav		A	417.071	Pri	/	100000.0 Hz	
VOLTAGE_BUS30_PHASE_A		Wav		V	191335.391	Pri	/	100000.0 Hz	
VOLTAGE_BUS30_PHASE_B		Wav		V	217338.000	Pri	/	100000.0 Hz	
VOLTAGE_BUS30_PHASE_C		Wav		V	191684.531	Pri	/	100000.0 Hz	
CURRENT_BUS30_PHASE_A		Wav		A	341.947	Pri	/	100000.0 Hz	
CURRENT_BUS30_PHASE_B		Wav		A	1789.531	Pri	/	100000.0 Hz	
CURRENT_BUS30_PHASE_C		Wav		A	360.293	Pri	/	100000.0 Hz	

Smp Rate: Channel sampling rate. Note that in COMTRADE files all channels have the same sampling rate. However WinXFM can simultaneously display waveforms with different sampling rates, allowing the option of opening and displaying multiple COMTRADE files which may have different sampling rates.

Expression: Applies to computed channels only – The user specified formula defining the channel waveform.

The buttons located along the top side of the dialog window perform several editing operations. These operations are generally applied on selected channels. Channels can be selected by clicking on the channel names (first list column). Multiple channels can be simultaneously selected using the **Ctrl** and **Shift** keys. A short description of the dialog button functions follows:

Move Up & Move Down: Change the selected channel order within the list.

Edit: Opens the selected channel properties dialog. Note that if multiple channels are selected, any changes made are applied to all selected channels.

Fix Names: Modifies all channel names to comply with WinXFM recommended naming requirements. Specifically it is recommended that channel names do not contain spaces, parentheses, or numeric operators such as (=, +, -, *, /, ^)

Resample: Resamples all channels with the sampling rate of the selected (*reference*) channel. Also ensures that all channel samples are synchronized with the samples of the reference channel. Resampling permits saving channels with different original sampling rates into a single COMTRADE file set.

Copy to Wave Chan: Creates a copy of the selected channel. Note that if the selected channel is a computed channel the created copy is a wave channel.

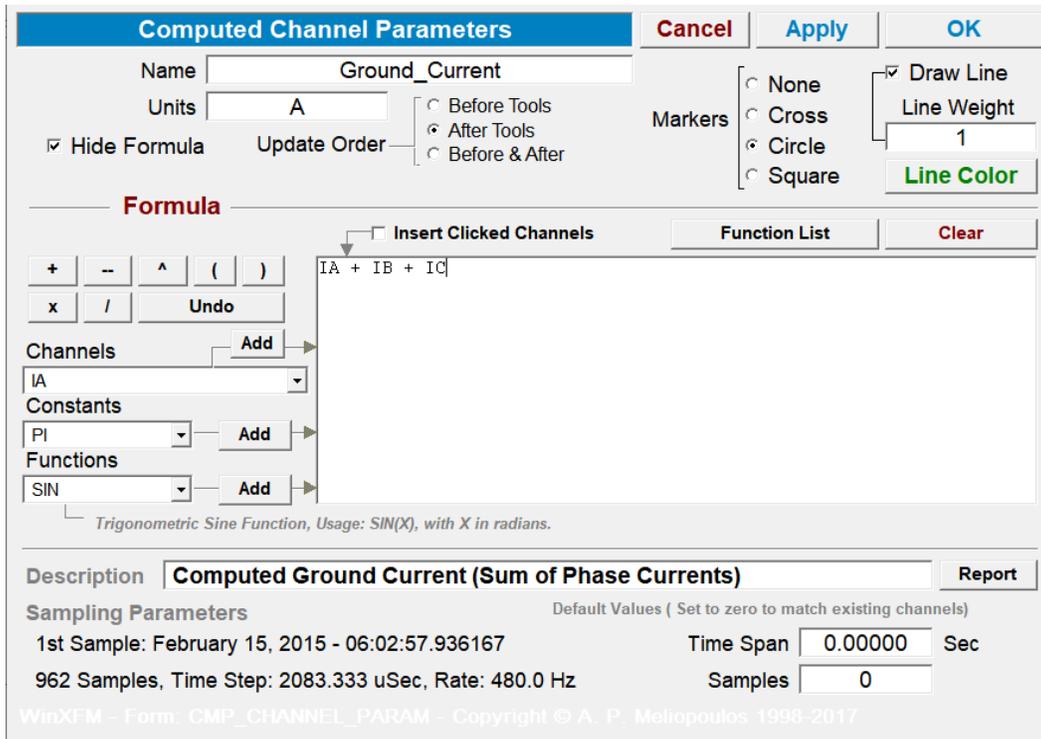
Delete: Deletes selected channels.

Enable Time Shifting. This check box enables time shifting the selected channels using the mouse. Specifically, by left button clicking and dragging the mouse horizontally, while holding down the Ctrl key, the selected channels are time shifted proportionally to the mouse pointer movement. The purpose of this feature is to visually align waveforms that originate from different non-synchronized data acquisition devices.

Auto Crop. If this check box is checked, the resampling operation is automatically followed by cropping all channels to a common time interval. This results in a set of waveforms with identical sampling rates, starting time, and number of samples, which can be saved in a single COMTRADE file set.



This command creates a computed channel, which contains a waveform defined with a mathematical function. The function arguments can be any other waveform (including other existing computed waveforms). The command opens the computed channel parameters dialog window, illustrated below, in which the function defining the computed waveform is written.



The computed channel parameters window controls are described below:

Name The name of the computed channel. Channel names must be alphanumeric strings without spaces and without any characters reserved for delimiter use or arithmetic operators, such as [] { } () * ^ % + - /. Furthermore they should not be any of the function names supported by WinXFM. Note that channel names are NOT case sensitive.

Units The units of the function value.

Hide Formula Check this checkbox to prevent the function formula from being displayed on the plot frame next to the channel name.

Update Order	Radio buttons setting the evaluation time of the channel function as before, after or both before and after computations performed by WinXFM tools such as protective relay simulators. The default setting “After Tools” works for most cases, unless the value of the computed channel is used by a certain WinXFM tool.
Markers	Selects the marker symbols indicating the computed sample values of the channel waveform.
Draw Line	Uncheck this checkbox to suppress drawing a continuous line through the waveform computed sample values.
Line Weight	Sets the thickness of the waveform plotted line. The weight values of 0 and 1 correspond to the “Hairline” setting i.e. the thinnest possible setting. Values of 2 and above result in proportionally thicker line.
Line Color	Opens a color selection dialog for setting the plot line color.
Formula	The area below the title “Formula” contains a multiline edit box in which the expression defining the waveform function is entered. To the left of the expression editing box are a number of buttons which insert mathematical operators into the expression edit box, as well as three pull-down controls from which the existing channel names, constants, and function names can be selected and inserted into the edit box. The waveform expression can also be edited directly by typing into the expression edit box. Furthermore, if the Insert Clicked Channels checkbox is checked, then clicking on a waveform trace automatically adds the channel name at the expression edit box cursor location.
Function List	Opens a dialog displaying a list of the supported functions along with brief description and argument list.
Clear	Deletes the entire contents of the expression edit box.
Description	User defined description text (Optional Field)
Report	Button reserved for future use
Time Span	Time span for which the computed channel waveform is calculated. (Only used if no other channels exist and the waveform is defined in terms of mathematical functions of time only).

Samples Number of samples computed (Only used if no other channels exist and the waveform is defined in terms of mathematical functions of time only).

IMPORT COMPUTED CHANNELS

Toolbar Button



This command copies all computed channels from a user selected file to the presently open file. See also command [Add Computed Channel](#) for details about computed channels.

CROP TO CURSORS

This command deletes all waveform samples outside the present time interval indicated by the view window cursors. Note that the command has no effect unless the Dual Cursors are activated

LEFT CURSOR TRIM

This command deletes all waveform samples at times before the present location of the left cursor. Note that the command has no effect unless the Single or Dual Cursors are activated

RIGHT CURSOR TRIM

This command deletes all waveform samples at times after the present location of the right cursor. Note that the command has no effect unless the Dual Cursors are activated.

FILL MISSING DATA

This command inserts linearly interpolated values at time instances where samples are missing.



This command opens a dialog window (illustrated below) showing the station name, data acquisition device identifier, first sample and trigger time stamps, as well as user editable case description text. The information shown in this dialog can be optionally included in images transferred to the windows clipboard, as illustrated in the example below.

Configuration Data
Cancel
OK

Station Name

DAQ Device ID

Include Station && Device ID in Reports

Additional Text

Include Above Text in Reports

Include Acquisition && Trigger Times in Reports

Acquisition Time Stamp:

Trigger Time Stamp:

Sampling Rate: Frequency:

IED Offset: Local Offset:

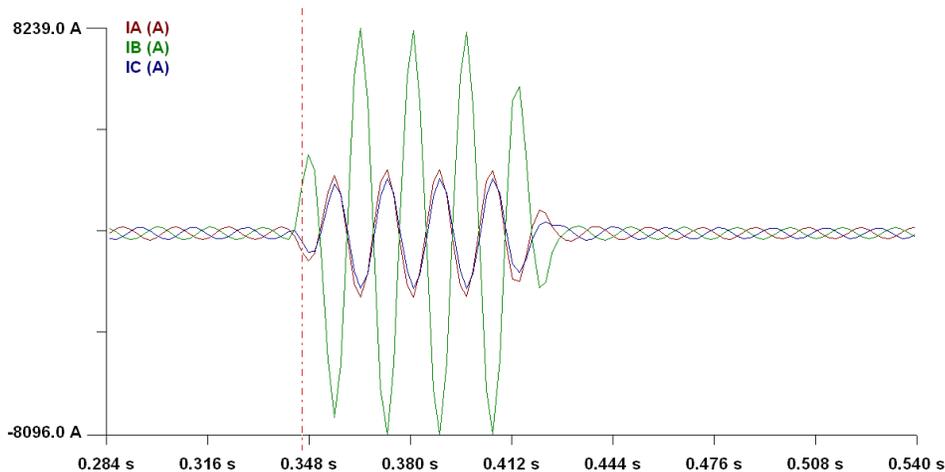
Time Quality Code: Leap Second:

COMTRADE File Type:

WinXFM - Form: CASE_DESCRIPTION - Copyright © A. P. Melopoulos 1998-2017

Station: Station XYZ

IED: Event Recorder 1001
 Recording Start: February 15, 2015 - 06:02:57.936167
 Trigger Time: February 15, 2015 - 06:02:58.282000
 Optional Descriptive Text

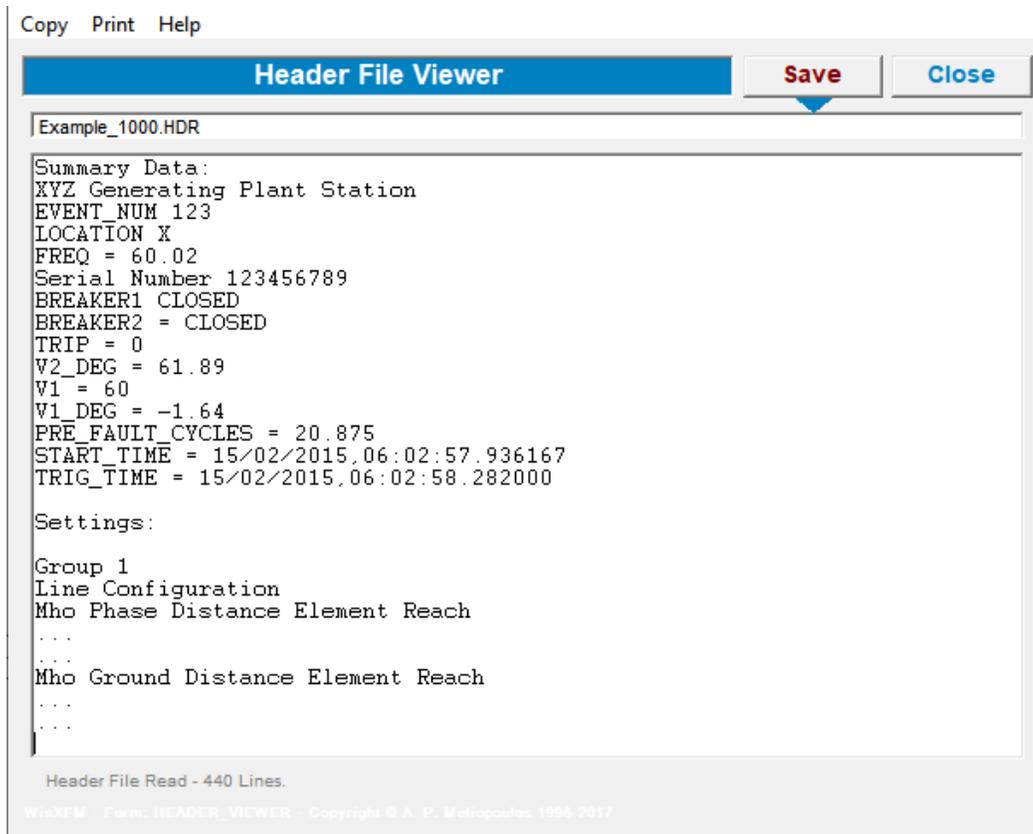


HEADER FILE

Toolbar Button



This command opens a dialog window (illustrated below) showing the contents of the header file associated with the open COMTRADE file set.



INSERT ANNOTATION

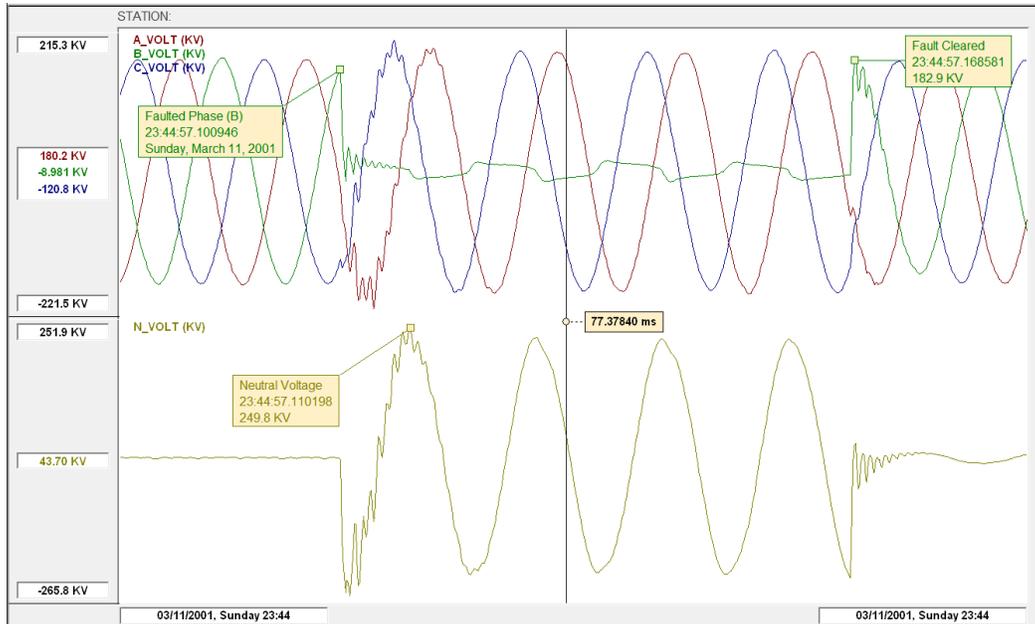
Toolbar Button



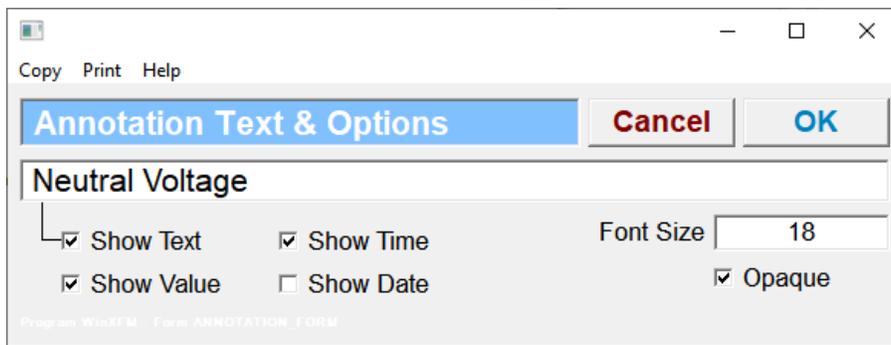
This command inserts a plot annotation object, linked to a user selected plot trace. Once the command is executed click on the desired point of a plot trace to locate and display the annotation object. An example containing several annotation objects is illustrated below.

Once the annotation object is created in can be relocated along the plot trace it is attached by left-clicking and moving the annotation object anchor. The annotation box can also be repositioned relative to the anchor by clicking on and dragging the annotation box.

Furthermore, the annotation text and display options can be edited by a left double click on the annotation box.



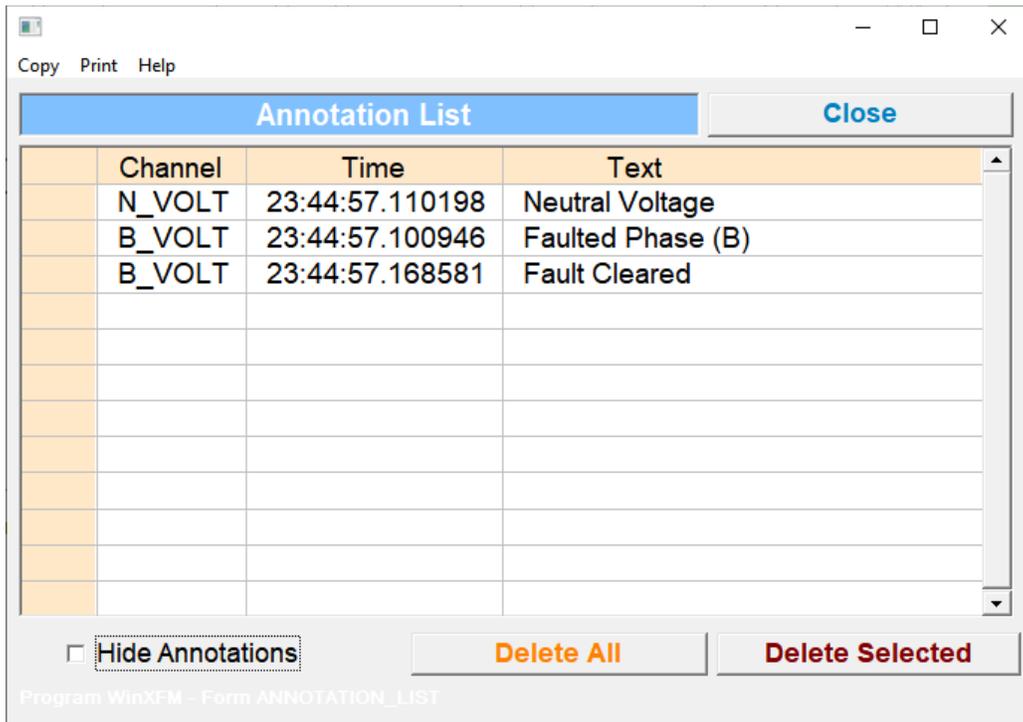
A left double click on the annotation box opens the dialog illustrated below:



An annotation box selected by left-button mouse click can be deleted by clicking on the Delete key. See also commands [Edit Annotations](#), and section [Waveform Annotations](#).

EDIT ANNOTATIONS

This command opens a dialog window displaying a list of the existing annotations (See Figure below). This dialog provides allows editing existing annotations. Double clicking on the list entry opens the corresponding **Annotation Text and Options** dialog. See also section [Waveform Annotations](#).



DELETE SELECTED ANNOTATION

This command deletes the selected plot annotation object. Annotations are selected by a mouse left-button click on the annotation box. A selected annotation is highlighted by a double box perimeter line.

The command is also executed using the keyboard **Del** key.

8.3 VIEW MENU COMMANDS

TOOLBAR

Hides or Shows the WinXFM Toolbar.

STATUS BAR

Hides or Shows the WinXFM Status Bar.

Add All	Adds all available channels in the displayed channel list, one per frame
Three per Frame	Adds selected analog channels in the displayed channel list, three per frame. This option is intended for cases where the available list contains channels arranged in sequential three phase triplets. Multiple channels can be selected within the Available Channels list using the Ctrl and Shift keys. If no selection is made, then all available channels are used.
Four per Frame	Adds selected analog channels in the displayed channel list, four per frame. This option is intended for cases where the available list contains channels arranged in sequential quadruplets (for example A,B,C,N). Multiple channels can be selected within the Available Channels list using the Ctrl and Shift keys. If no selection is made, then all available channels are used.
Add in Separate Frames	Adds selected channels into the displayed channel list, one per frame. Multiple channels can be selected within the Available Channels list using the Ctrl and Shift keys.
Add in Single Frame	Adds selected channels into the displayed channel list in a single plot frame. Multiple channels can be selected within the Available Channels list using the Ctrl and Shift keys.
Add to Selected Frame	Adds selected channels into the selected frame in the displayed channel list. Multiple channels can be selected within the Available Channels list using the Ctrl and Shift keys.
Remove Selected	Removes selected channels from the Displayed Channels list. Multiple channels can be selected within the Displayed Channels list using the Ctrl and Shift keys.
Remove All	Removes all channels from the Displayed Channels list.

The checkbox titled **Skip Constant Channels** hides digital channels which have a constant value over the entire record.

The controls along the bottom of the Displayed Channels list perform the following functions:

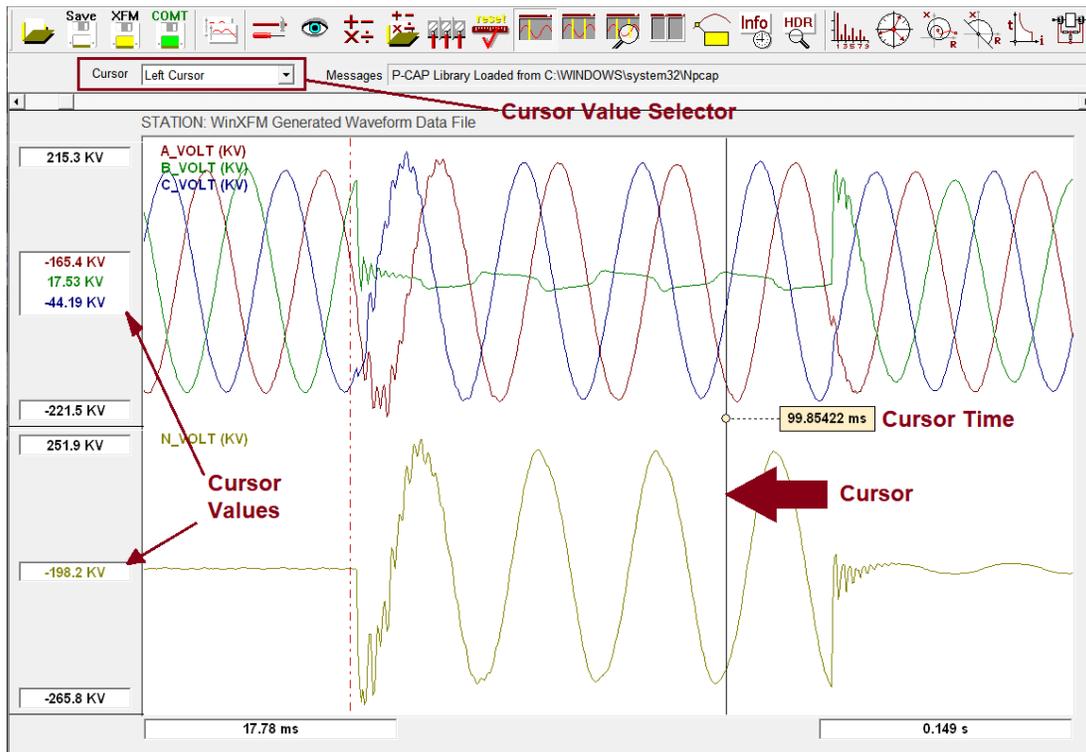
Split	Rearranges the channels listed in the Displayed Channels list so that they are plotted in separate plot frames.
Combine Selected	Combines the selected channels in the Displayed Channels list so that they are plotted in a single common plot frame.
Sort	Alphabetically sorts the channels in the Displayed Channels list.
Auto Color	Automatically assigns different plot trace colors on the displayed channels

SINGLE CURSOR

Toolbar Button



This command activates the single cursor mode. The cursor is displayed as a vertical line over the plot frames (See Figure below), and can be moved using the left mouse button.



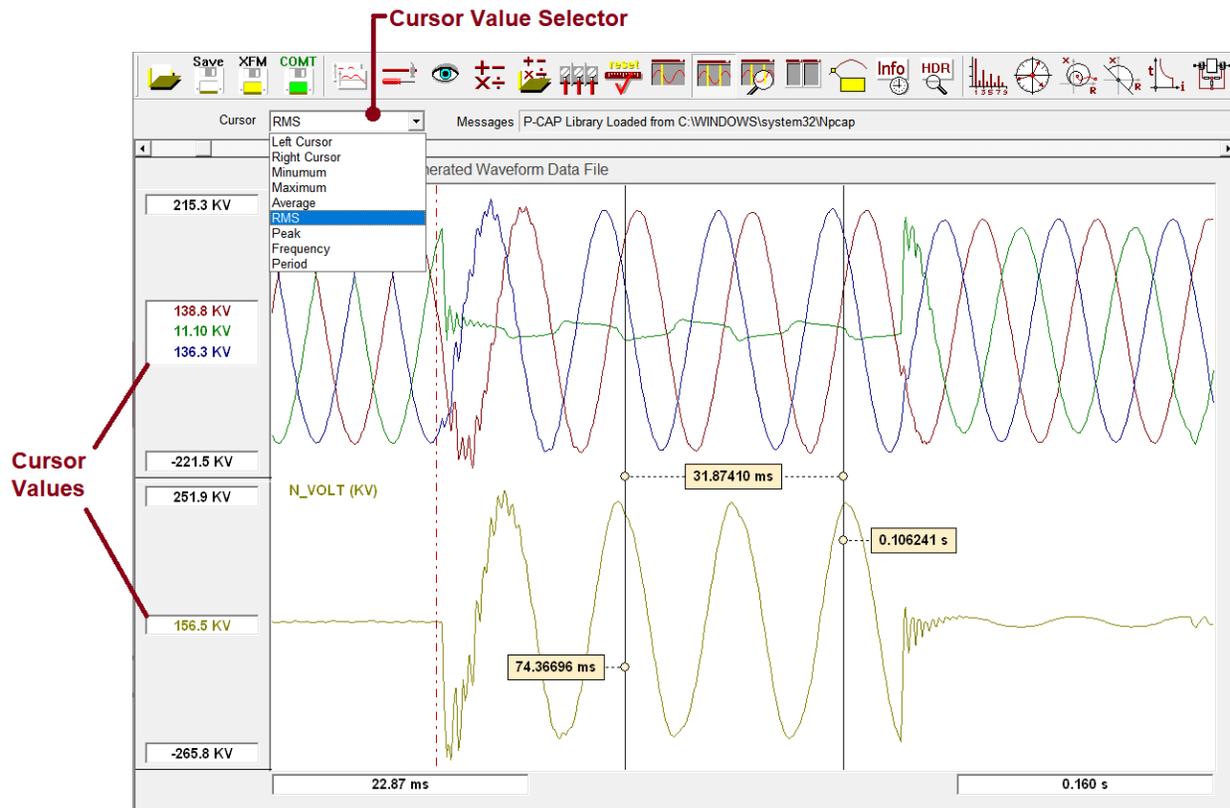
The trace values at the cursor location are displayed on the left side of the plot frames. Note that the box showing the cursor time can be relocated as needed using the mouse.

DUAL CURSORS

Toolbar Button



This command activates the dual cursor mode. The cursors are displayed as two vertical lines over the plot frames (See Figure below), and can be independently moved using the left mouse button, or moved together using the right mouse button.



The trace values at the cursor location are displayed on the left side of the plot frames. Note that the boxes showing the cursor times as well as the time difference between the two cursors can be relocated as needed using the mouse.

The cursor value selector provides the following options:

Left Cursor	Instantaneous value at the left cursor location
Right Cursor	Instantaneous value at the right cursor location
Minimum	Minimum value of the waveform segment between cursors
Maximum	Maximum value of the waveform segment between cursors
RMS	RMS value of the waveform segment between cursors
Peak	Peak value of the waveform segment between cursors
Frequency	Average Frequency of the waveform segment between cursors
Period	Average Period of the waveform segment between cursors

ZOOM TO CURSORS

Toolbar Button



This command rescales the plot time axis so that the time interval between the two cursors occupies the entire plot frame width. The command has no effect unless in Dual Cursor mode.

RESET PLOT SCALING

Toolbar Button



This command rescales the plot vertical axes so that the range of the waveform segment presently displayed on each plot frame occupies the entire plot frame height. The command has no effect if the **Plot Scaling** mode is set to **Auto**, since in Auto mode the plot frames are always automatically rescaled (See also [Global Options](#) command)

TIME DOMAIN

Displays waveforms as functions of time. (This is the default WinXFM Setting).

FREQUENCY DOMAIN

Displays waveform spectra with linear vertical scales. (This option is only available when a data-acquisition hardware mode is activated).

FREQUENCY DOMAIN (LOG SCALE)

Displays waveform spectra with logarithmic vertical scales. (This option is only available when a data-acquisition hardware mode is activated).

8.4 WINDOW MENU COMMANDS

PLOT WINDOW

This command opens additional plot-frame view windows.

MESSAGE WINDOW

This command opens the WinXFM message window. This window displays a list of progress, warning, and error messages generated by WinXFM. This window can also be opened by clicking on the Messages area of the program toolbar, which displays the latest message.

CASCADE

This command rearranges view windows in cascaded formation.

TILE

Toolbar Button



This command rearranges view windows in tiled formation.

8.5 TOOLS MENU COMMANDS

PHASOR VIEWER

Toolbar Button



This command opens the phasor viewer tool, which displays the fundamental frequency phasors computed from the currently displayed waveforms. For detailed description for the Phasor Viewer tool see section [Phasor Viewer](#).

HARMONIC ANALYZER

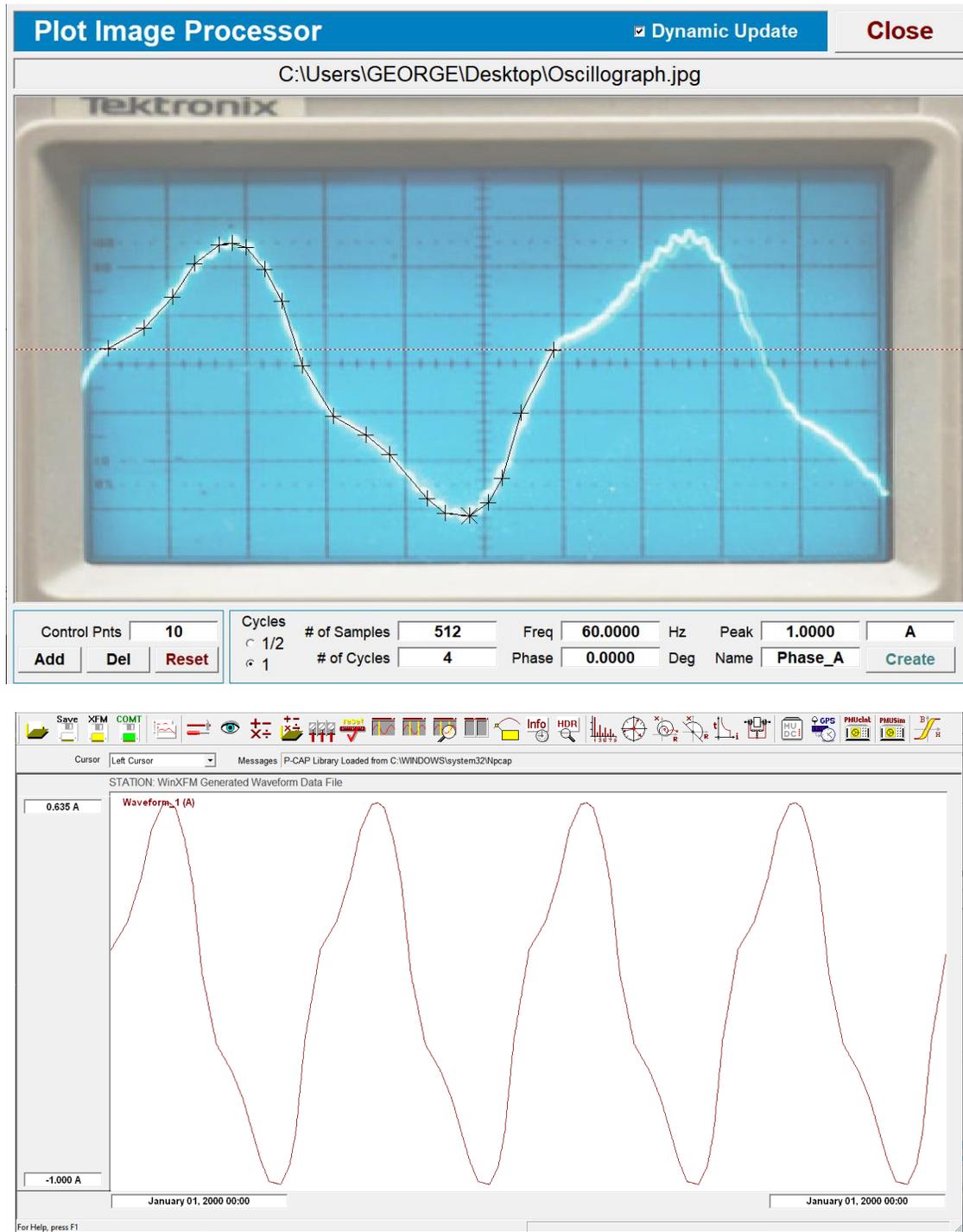
Toolbar Button



This command opens the harmonic analyzer tool, which displays a plot or a table of harmonic components of the currently displayed waveforms. For detailed description for the Phasor Viewer tool see section [Harmonic Analyzer](#).

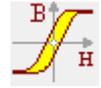
IMPORT PLOT IMAGE

This command opens the plot image processor window illustrated below. This window displays a user selected image of a waveform, and allows tracing over the plot image so that the waveform can be reproduced as a WinXFM channel (See example below).



PERMEABILITY ANALYSIS

Toolbar Button



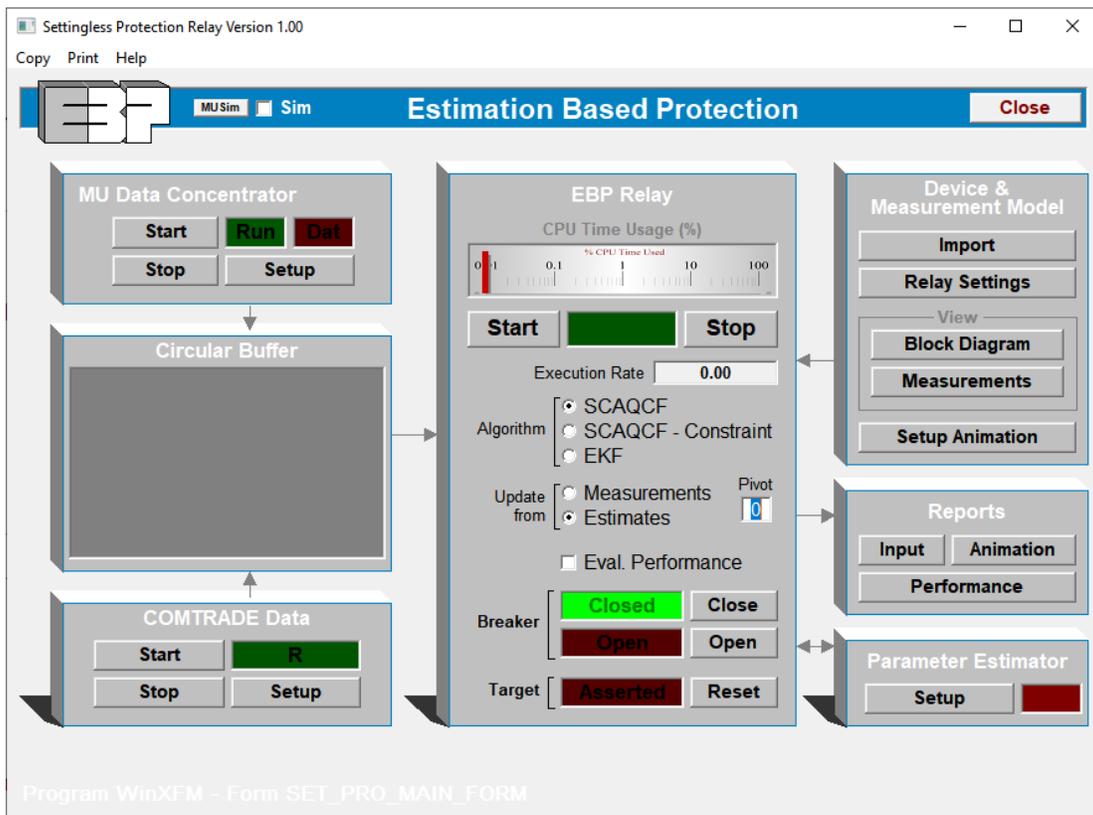
This command opens the permeability analysis module, which computes the B-H curve of a material given voltage and current waveforms obtained from a toroid made of the material under test with two windings (See also section [Permeability Analysis](#)). Detailed description of the use of this module is provided in a separate document.

ESTIMATION BASED PROTECTION RELAY

Toolbar Button

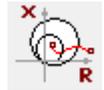


This command opens the estimation based protection (EBP) relay window, illustrated below. The EBP relay is an implementation of a power system protective relay based on state estimation. Detailed description of the use of this module is provided in a separate document.



IMPEDANCE RELAY

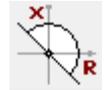
Toolbar Button



This function is presently under development

DIRECTIONAL OVERCURRENT RELAY

Toolbar Button



This function is presently under development

TIME OVERCURRENT RELAY

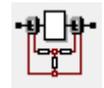
Toolbar Button



This function is presently under development

TRANSFORMER DIFFERENTIAL RELAY

Toolbar Button



This function is presently under development.

FAULT LOCATOR

This function is presently under development.



This command opens a PMU client window, illustrated below. The PMU client module receives an IEEE-C37.118 synchro-phasor stream. Received data are transferred into a WinXFM channel, and therefore, can be plotted within the WinXFM plot view. Any number of PMU client objects can be created and operated simultaneously.

PMU Client 1 of 1
Host: TERAFL0P

Communication Parameters

Local IP Address: 192.168.0.105
Local Port Number: 1
Outstation IP Address: 192.168.0.105
Outstation Port Number: 2000
Outstation ID: 1

Buttons: Connect, Start, Disconnect, Stop, Frame Win, Copy CFG, Set Rate, Buffer Usage (0.00%), Autostart, Buffer Delay

Protocol: TCP, UDP-1, UDP-2, TCP/UDP

Output Channels

Phase	Quantity	Active	Value
Channel 1	Magnitude	<input type="checkbox"/>	115.0 kV
Channel 1	Magnitude	<input type="checkbox"/>	115.0 kV
Channel 1	Magnitude	<input type="checkbox"/>	115.0 kV
Channel 1	Magnitude	<input type="checkbox"/>	115.0 kV
Channel 1	Magnitude	<input type="checkbox"/>	115.0 kV
Channel 1	Magnitude	<input type="checkbox"/>	115.0 kV
Channel 1	Magnitude	<input type="checkbox"/>	115.0 kV
Channel 1	Magnitude	<input type="checkbox"/>	115.0 kV

Buttons: Refresh, Delete Existing Channels

Phasor Plot
F = 60.1000 Hz
30.0 Frames/sec (1)
Labels: Phasor Volt CH-C, Phasor Volt CHB, Phasor Volt CHA

Log Window
Connecting...
TCP Connected
Sending START Command
Requesting Configuration Frame CFG-2
Requesting Configuration Frame CFG-2
Received Configuration Frame
TCP Connection Lost!
TCP Socket Closed
Connecting...
TCP Connected
Sending START Command
Requesting Configuration Frame CFG-2
Requesting Configuration Frame CFG-2

GPS Event Log
 Update Event Log File
File Path: [] Trimble
Buttons: Delete, View, Status

WinXFM - Form: PMU_CLIENT - Copyright © A. P. Meliopoulos 1998-2013



This command opens a Simulated PMU setup window (shown below). The Simulated PMU generates an IEEE-C37.118 synchro-phasor stream. The synchro-phasors are created based on a set of user selected parameters, such as frequency, voltage and current magnitude and phase angle, etc. The purpose of this object is for testing various IEEE-C37.118 applications, such as PMU clients or evaluating network hardware performance in the presence of Synchrophasor streams. Any number of simulated PMU instances can be created and operated simultaneously.

Test PMU #1 of 1
Close

Channels

PMU Name

Voltage Magnitude kV

Voltage Phase Deg

Current Magnitude kA

Current Phase Deg

Frequency Hz

Phasor Rate Hz

Latency msec

of Subframes

Phasors {
 Phase Quantities
 Positive Sequence
 Analogs
 Digitals

Currents

C37.118 Server

0
0

Autostart

Server Address

Port

PMU ID

Delete PMU

T.Quality

Status

Server Ready!

10/25/2019, 09:25:17.533333

F = 60.10000 Hz
Rate = 30 Hz

WinXFM - Form: PMU_SIM - Copyright © A. P. Mellopoulos 1998-2017

MERGING UNIT DATA CONCENTRATOR

Toolbar Button



This command opens the Merging Unit (MU) data concentrator setup window. The MU Data concentrator receives sample value (SV) data transmitted via a local area network **Link Layer**. The SV protocol is described in the IEC 61850.9-2 standard. The main MU concentrator window is shown below. It includes several controls for setting the concentrator parameters, starting and stopping the concentrator, as well as displaying system performance data. Furthermore, it includes a virtual Phasor Measurement Unit (vPMU), which processes the incoming point-of-time data, and computes the corresponding phasors. The computed phasors can be plotted in the WinXFM main plot view, and/or transmitted to PMU client applications via an IEEE C37.118 stream.

Merging Unit Data Concentrator

Concentrator Settings

Sampling Rate	4800	Hz
Base Frequency	60.00	Hz
Max Local Latency	400.0	ms
Max Remote Latency	2000.0	ms
Max Analysis Latency	100.0	ms

Synchronphasors

10/25/19 - 10:18:32.600000

F = 60.01000 Hz

V = 115000.01 V

C37.118 Server

Addr: 169.254.200.1

Port: 2000

PMU ID: 1

Name:

Performance

Max Local Latency (%): 7.26 ms

Max Remote Latency (%): 0.00 ms

Buffer Usage (%):

Buffer Size: 10080

SV Reception Rate: 1.172 Mb/sec

TCP Reception Rate: 0.000 Mb/sec

Error Counts

Too Late: 0

Too Early: 0

Out of Seq: 0

TCP/IP Xmit: 0

Bad SV Data: 0

Bad TCP Data: 0

Program WinXFM - Form SET_PRO_MUCOM_FORM

MERGING UNIT SIMULATORS

This command opens the merging unit simulator setup window, which creates Sample Value (SV) streams as defined in the IEC 61850.9-2 standard for the purpose of testing various merging unit applications. The main control window of the MU simulators is shown below. It contains 5 buttons labeled 1 through 5, which open the setup windows of up to five MU simulators (second Figure below). The start and stop buttons initiate and terminate the SV data streams.

The image shows two screenshots of the MU Simulators software interface.

The top screenshot is the main control window titled "MU Simulators". It features a "Queued" checkbox, a "Close" button, and a "Real Time" indicator. Below these are five colored buttons labeled 1 through 5, and "Start" and "Stop" buttons. An image of the hardware is shown on the left.

The bottom screenshot is the setup window for "Merging Unit Simulator 1". It includes a "Delete" and "Close" button. The "Network Setup" section shows the adaptor as "Network adapter 'NdisWan Adapter' on local host" and the MAC address as "00:01:02:03:04:05". The "SV Message Setup" section includes fields for MU Name (Virtual MU 1), DataSet Name, # of DataSets (1), Conf. Revision (1001), Sampling Rate (80 Smp/Cycle), Synchronization (Local), Number of Samples (8), Line Voltage (115000.00 V), Line Current (100.00 A), Frequency (60.010 Hz), and Clipping (Distortion) (0.000 %). The "Streaming" section has a "Streaming" indicator, "Active" checked, "Random Errors" and "Random Delays" unchecked, "Time (ms)" set to 20.0, "Prob (%)" set to 1.0000, and "Constant Delay" set to 0.000 ms. The "Include" section has "Time Stamp" unchecked and "Sampling Rate" checked. An image of the hardware is shown at the bottom right.

Program WinXFM - Form SET_PRO_MUSIM



This command opens the SEL GPS monitor window, which displays information transmitted by SEL-2407 GPS clocks, including:

- Time and date
- Several GPS receiver status flags
- Latitude, Longitude and Elevation at the receiver location
- The signal strength of the received satellite signals
- The settings of the front panel switches

The GPS monitor window is shown below. Use of this tool requires a connection to the GPS receiver via RS-232 port.

SEL GPS Clock Monitor [Close]

Connection

Port: [Dropdown]
 Baud Rate: 9600 [Dropdown]
 Password: potatoes [Text]
 Connect Run
 [Terminal]

Time & Status

Time: [Text]
 Date: [Text]
 GPS Status: [Text]
 Almanac: [Text]

Receiver Location [Reset Zoom]

[World Map]

Location

Latitude: [Text]
 Longitude: [Text]
 Elevation: [Text]

Satellite Signal Strength

0	20	40	60	80	100
0	20	40	60	80	100
0	20	40	60	80	100
0	20	40	60	80	100
0	20	40	60	80	100
0	20	40	60	80	100
0	20	40	60	80	100
0	20	40	60	80	100
0	20	40	60	80	100
0	20	40	60	80	100

Self Test

RTL Display Antenna
 Flash Battery GPS
 SDRAM

Front Panel Switch Settings

Switch	Function	Setting
1		
2		
3-4		
5		
20		
6-7		
8-9		
10-11		
12-17		
18		
19		

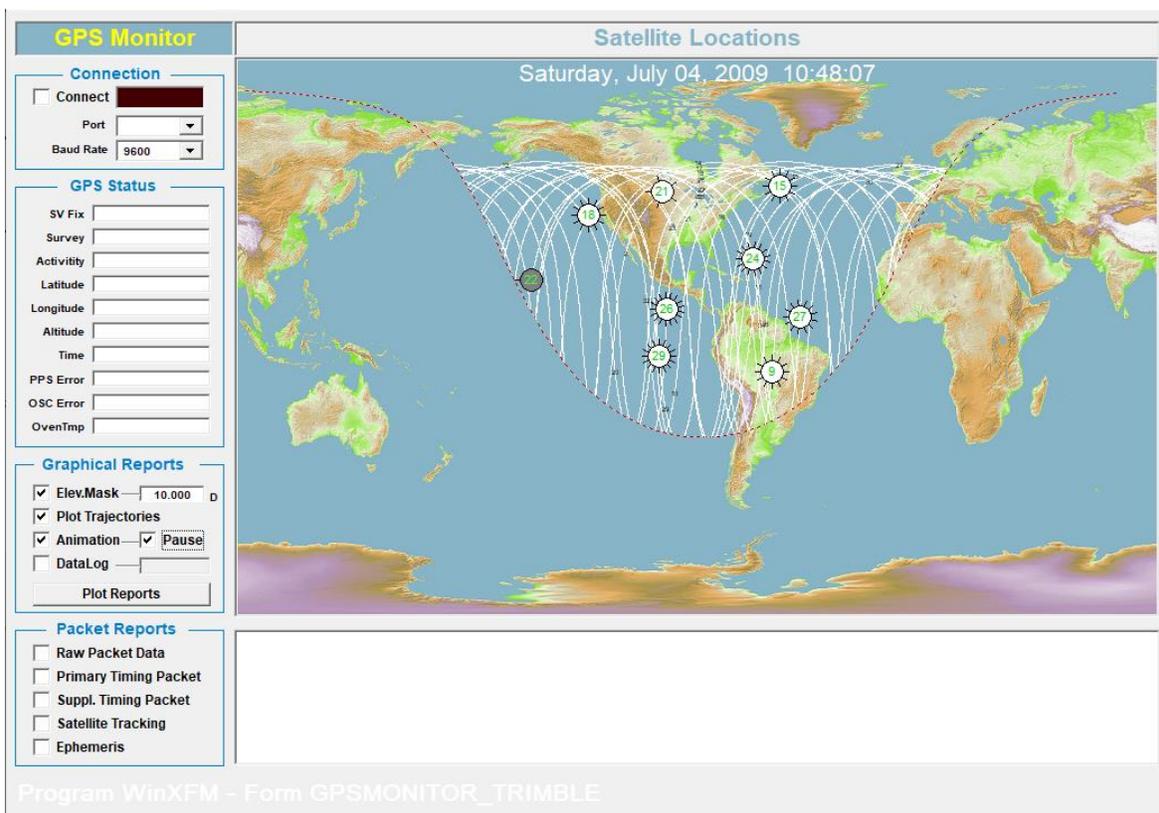
Program WinXFM - Form GPSMONITOR_SEL

GPS MONITOR (TRIMBLE THUNDERBOLT)

This command opens the Trimble Thunderbolt GPS monitor window, which displays information transmitted by Thunderbolt-E GPS receiver, including:

- Several GPS receiver status variables
- The trajectory, location and signal strength of the received satellite signals, plotted over a world map image

The GPS monitor window is shown below. This tool can collect data over a time period and generate reports of satellite availability over time. Use of this tool requires a connection to the GPS receiver via RS-232 port.



GPS CLOCK SYNCH

The Clock Synchronizer module adjust the PC clock using timing signal from a SEL-2407 GPS receiver or a merging unit. The setup window of the clock synchronizer module is shown below.

Clock Synchronization [Update Now] [Apply] [Close]

Sync Source
 None
 Merging Unit
 SEL-2404

Update Every minutes
 Announce Sync

Clock Offset Seconds

Local Time
Corrected Time
 Announce Seconds

Synchronization Interval: 15.00 minutes

Program WinXFM - Form GPSCLOCKSYNC_SEL

Key Merging Unit ASDU
Virtual MU 1
Latency No Active MU

SEL-2407
Serial Port
Baud Rate 9600
Port Activity
Synchronize
GPS Time Local UTC

RESERVED FUNCTION

This command is reserved for development use.

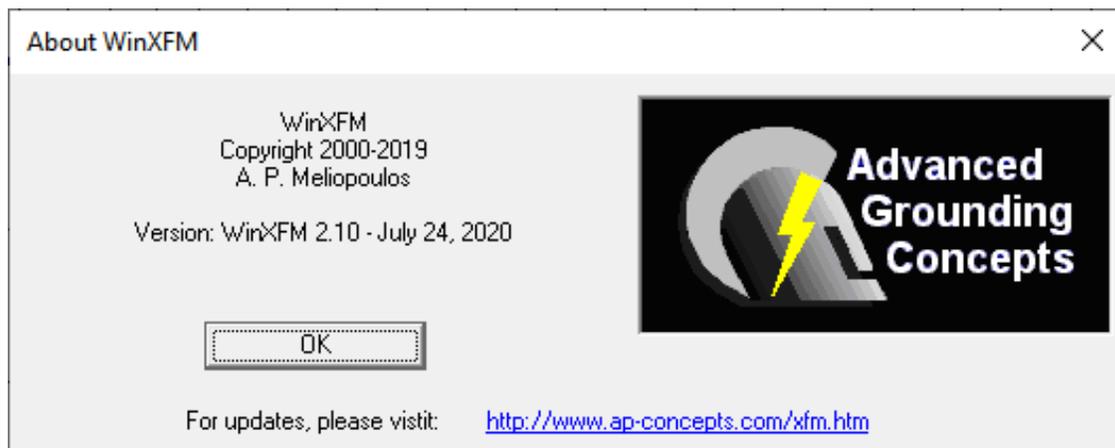
8.6 HELP MENU COMMANDS:

HELP TOPICS

This command displays this document.

ABOUT WINXFM

This command opens a dialog showing the version and copyright information of the WinXFM program (See example below).



AUTHENTICATION

This command opens the WinXFM authentication window (Shown below). This dialog window accepts the WinXFM user serial number and provides program registration and license expiration information.



The image shows a Windows-style dialog box titled "WinXFM Authentication". At the top, there is a menu bar with "Copy", "Print", and "Help". Below the title bar, a blue header contains the text "WinXFM Authentication". The main content area has a red message: "Serial Number Validated. Please Check Agree Box, and then click on Accept button to continue...". Below this, there is a "WinXFM Serial # :" label followed by a text input field containing "xxxxxxxxxx" and a "Validate" button. Further down, the following information is displayed in blue text: "Organization : Advanced Grounding Concepts", "Expiration : Tuesday, March 02, 2055", and "Version : WinXFM 2.09 - July 10, 2020". A section titled "Named User License" contains a "Site:" label with a dropdown menu. Below it is a table labeled "Authorized Users:" with a scrollable area containing several empty rows. At the bottom of this section, there is a red message: "This license authorizes only the above named users. No other persons are allowed to use this license." followed by an unchecked checkbox and the word "Agree". At the very bottom of the dialog are two buttons: "Cancel" and "Accept".

Copy Print Help

WinXFM Authentication

Serial Number Validated. Please Check Agree Box,
and then click on Accept button to continue...

WinXFM Serial # :

Organization : Advanced Grounding Concepts
Expiration : Tuesday, March 02, 2055
Version : WinXFM 2.09 - July 10, 2020

Named User License

Site:

Authorized Users:

This license authorizes only the above named users.
No other persons are allowed to use this license. Agree

Program WinXFM - Form XFM_SERIAL_NUM

APPENDIX 1 – WINXFM FILE FORMAT

The native WinXFM program waveform storage files consist of two types of files with common root name and ending in .XFM and .XFW respectively. The .XFM file is in ASCII format and contains a number of parameters related to user selected display options, annotation data, various analysis module user selected settings, etc. The .XFW files are binary format and contain the waveform sample data.

Figure A1.1 shows partial listing of a native WinXFM configuration file. It is an ASCII where each line starts with a reserved keyword followed by one or more related values. Groups of such lines contained in bracketed sections contain settings for specific WinXFM functions, such as cable impedance tool parameters, annotations, impedance relay simulation parameters, etc. This organization allows addition of new features without loss of backward compatibility.

The configuration file also contains a bracketed section for each analog waveform channel, digital channel, or computed channel. An example of the waveform section is given in Figure A.1.2

The WinXFM waveform data file (filename.XFW) is a binary file organized as illustrated in Table A.1.1

```

!WinXFM Setup Parameter File
!Last Update: 06/28/2020 22:53:39
!-----
STORAGE_PATH c:\wmaster\WinXfm\datau\
PRINT_FONT_MAGNIF 1.1000
PLOT_BK_COLOR 16777215
SCALING_MODE 0
TIME_AXIS_ANNOT 1
TIME_DISPLAY_OFFSET 1
SHOW_CHAN_SPECS 2
REFRESH_DELAY 50
PLAYBACK_DELAY 100
INCLUDE_ZERO 0
CORRECT_TIME_SKEW 1
CLIP_COPY_INCLUDE 1 1
DAQ_TIME_STAMP -3617008641903833651
PLOT_FRAME 3 4 5
ZVC_DATA
{
    ZVC_NAVERAGES 10
    ZVC_CURRENT_CHAN -1
    ZVC_VOLTAGE_CHAN -1
    ZVC_TEMPERATURE_CHAN 0 0 0 0
    ZVC_PLOT_MODE 0
    ZVC_AUTOSORT 1
    ZVC_ANAL_FREQ 60.000000
    ZVC_CABLE_LENGTH 10.000000
    ZVC_REPORT_LENGTH 5278.871391
    ZVC_LENGTH_FACTOR 1.000000
    ZVC_TEMP_COEF 0.003900
    ZVC_TEMP_CORRECT 0
}
ANNOTATION_DATA
{
    ANNOT_TEXT Fault Initiation
    ANNOT_PARAM 56635711928053808 4 -258 80 1 1 1 1 1 18
    ANNOT_TEXT Peak Current
    ANNOT_PARAM 56635711930375128 4 -205 -132 1 0 1 1 1 18
    ANNOT_TEXT Fault Cleared
    ANNOT_PARAM 56635711991104480 4 47 35 1 0 1 0 0 18
}
IMPEDANCE_RELAY_DATA
{
    RELAY_BOOLEAN_SET 0 0 0
    RELAY_INTEGER_SET 80 0 1 1
    RELAY_REAL_SET 0.15000 1.00000
    ZONE_IMPEDANCE_MAGN 50.0000 75.0000 100.0000
    ZONE_IMPEDANCE_ANGLES 60.0000 60.0000 60.0000
    ZONE_DELAY_CYCLES 2.0000 10.0000 30.0000
    VOLTAGE_CHANNELS
    CURRENT_CHANNELS
}
. . .

```

Figure A1.1: WinXFM Configuration File Example (filename.XFM)

```

. . .
. . .
WAVE_DAO_DATA
{
    SAMPLING_RATE 8192.00000
    BUFFER_SIZE 4096 4096
    TOTAL_RECORDS 0
    DECIMATION_MODE 0
    DECIMATION_FACTOR 0
    SYNC_ADVANCE 0
    ALIAS_REJECTION 1
    GPS_TRIGGER_RATE 1.000000
    PRETRIGGER 0.000000 0
    TRIGGER_LEVEL 0.000000
    TRIGGER_MODE 0 0
    TRIGGER_DELAY 0.000000
    TRIG_CHAN -1
    STORE_TO_FILE 0
    PLAYBACK_APPEND 0
    BREAK_ON_DATA_GAP 1
    PLAYBACK_LOOP 0
    MAX_APPEND_SIZE 240 0.000000
    APPEND_METHOD 2
    CLOCK_SOURCE 1
    EXPOSE_DAO_CLOCK 0
    SQUARE_WAVE_SRC_STATUS 0
    SQUARE_WAVE_SRC_FREQ 50.000000
    SQUARE_WAVE_SRC_PHASE 0.000000
    SQUARE_WAVE_SRC_DUTY 50.000000
    AVERAGING_MODE 1
    WINDOW_TYPE 2
    EXP_AVE_NUM_REC 5
    ENABLE_FD_COMP 0
    WAV_CHANNEL
    {
        NAME VOLTAGE_BUS10_PHASE_A
        BUS_NUMBER
        NETWORK_AREA
        DESCRIPTION
        COLOR 128
        UNITS V
        TIME_STAMP 56635711876497408
        DAQ_TIME_STEP 1.0000000000000000e-005
        DAQ_TIME_SKEW 0.0000000000000000e+000
        PLOT_SYMBOLS 0
        LINE_WEIGHT 1
        COMTRADE_PRISEC 0
        COMTRADE_CIRCUIT
        COMTRADE_MAX 32767
        COMTRADE_MIN -32767
        COMTRADE_PHASE
        COMTRADE_PRIMARY 1.0000
        COMTRADE_SECONDARY 1.0000
        PATTERN_NUMBER 0
    }
    WAV_CHANNEL
. . .

```

Figure A1.2: Configuration File Waveform Data Section Fragment (filename.XFM)

Table A.1: Organization of WinXFM native waveform data files

Item	Data Type	Bytes	Description
1	integer	4	Channel Type (1-DAQ, 2=Waveform, 3=Computed)
2	integer	4	Channel Index (0,1,2,...)
3	integer	4	Number of Samples in Waveform Data
4	double	8	Waveform Samples 64 bit floating point format
Repeat items 1 through 4 for each waveform in file			

APPENDIX 2 – COMTRADE FILE FORMAT

The WinXFM program presently reads and writes COMTRADE configuration (CFG) and data (DAT) files as described in the IEEE standard C37.111, Versions 1991, 1999, and 2013.

The Configuration File contains the following information:

1	Station Name, Recorder ID, Revision
2	Number of Channels, Number of Analog Channels, Number of Digital Channels
3	Analog Channel Parameters (repeated for every analog channel)*
4	Digital Channel Parameters (repeated for every Digital channel)**
5	Nominal Power Frequency
6	Number of Sampling Rates
7	Sampling Rate, End Sample Number (Repeated for each sampling rate)
8	First sample Time Stamp***
9	Trigger Time Stamp***
10	Data file type (ASCII or BINARY)
11	Time Index Multiplier (C37.111-1999, and C37.111-2013)
12	UTC Offset Codes (C37.111-2013 Only)
13	Time Quality Codes (C37.111-2013 Only)

* The Analog channel parameters are as follows:

- Channel Index Number
- Channel Identifier
- Phase Identifier
- Circuit Name
- Units
- Multiplier
- Offset
- Skew
- Minimum Raw Data Value
- Maximum Raw Value
- Instrument Transformer Primary Rating

- Instrument Transformer Secondary Rating
- P or S indicating data are primary or secondary value

**The Digital channel parameters are as follows:

- Channel Index Number
- Channel Identifier
- Normal State (0 or 1)

***According to the 1999 and 2013 COMTRADE standards, the first sample and trigger time-stamps are formatted as follows:

dd/mm/yyyy, HH:MM:SS.SSSSSS

where dd the day of the month (valid range: 1-31), mm the month number (valid range: 1-12), yyyy the year (valid range: 1970-9999)

Note that in the 1991 COMTRADE standard the time stamps are as follows:

mm/dd/yy, HH:MM:SS.SSSSSS

i.e: the month and day order are reversed and the year is expressed with only the last two digits. Both formats are supported by WinXFM.

APPENDIX 3 – IMPORTING SYNCHROPHASOR FILES

Synchrophasor data are transmitted using two types of TCP-IP frames, namely **configuration** and **data** frames. The data in these frames are defined in the IEEE Standard C37.118 version 2005. Configuration frames contain channel name and attribute information, while data frames contain time and phasor values. The configuration and data frame structures are described in Table 9 and Table 7 respectively of the IEEE Std C37.118™-2005, and are repeated in this document for convenience (see Tables A3.1 and A3.2). For more details please refer to IEEE Std C37.118™-2005.

WinXFM can receive synchrophasor data streams, display the data in plot format, as well as store and retrieve the data. These data are stored in a sequence a sequence of binary file pairs as follows:

- A Synchrophasor Configuration File (ending in .SP1), and
- A Synchrophasor Data File (ending in .SP2)

These files contain **synchrophasor** configuration and data frames as defined in the IEEE Standard C37.118 version 2005. The synchrophasor data file names consist of a user defined name followed by a time code corresponding to the time the files were created. For example in the file names:

EXAMPLE_1362175321.SP1, EXAMPLE _1362175321.SP2

The number 1362175321 is the time code known as “Second of Century” and is equal to the number of seconds since midnight of January 1, 1970. The synchrophasor frames are written into these files with some additional indexing data that facilitate frame reading and associating the appropriate configuration frame to each data frame. Specifically, the configuration and data frame file structures are defined in Tables A3.3 and A3.4, respectively.

Importing Synchrophasor Files

The command **Import C37.118 files** opens a dialog window illustrated in Figure A3.1. This window allows for opening multiple Synchrophasor files and combining the data into contiguous plots. The first task is to select the Synchrophasor files to be imported. For this purpose click on the **Select Files** button to open the file selection dialog. This is a standard windows file open dialog which allows navigating to the desired directory and selecting multiple files. Hold down the **Shift** key and click on the first and last file of interest to select sequential multiple files.

Table A3.1: C37.118 Configuration Frame Format (From IEEE Std C37.118™-2005 - Table 9)

No.	Field	Size (bytes)	Short Description
1	SYNC	2	Sync byte followed by frame type and version number.
2	FRAMESIZE	2	Number of bytes in frame, defined in 6.2.
3	IDCODE	2	PMU/DC ID number, 16-bit integer, defined in 6.2.
4	SOC	4	SOC time stamp, defined in 6.2.
5	FRACSEC	4	Fraction of Second and Time Quality, defined in 6.2.
6	TIME_BASE	4	Resolution of fraction-of-second time stamp.
7	NUM_PMU	2	The number of PMUs included in the data frame.
8	STN	16	Station Name—16 bytes in ASCII format.
9	IDCODE	2	PMU ID number as above, identifies source of each data block.
10	FORMAT	2	Data format within the data frame.
11	PHNMR	2	Number of phasors—2-byte integer (0 to 32 767).
12	ANNMR	2	Number of analog values—2-byte integer.
13	DGNMR	2	Number of digital status words—2-byte integer.
14	CHNAM	16 × (PHNMR + ANNMNR + 16 × DGNMR)	Phasor and channel names—16 bytes for each phasor, analog, and each digital channel (16 channels in each digital word) in ASCII format in the same order as they are transmitted. For digital channels, the channel name order will be from the least significant to the most significant. (The first name is for Bit 0 of the first 16-bit status word, the second is for Bit 1, etc., up to Bit 15. If there is more than 1 digital status, the next name will apply to Bit 0 of the 2nd word and so on).
15	PHUNIT	4 × PHNMR	Conversion factor for phasor channels.
16	ANUNIT	4 × ANNMNR	Conversion factor for analog channels.
17	DIGUNIT	4 × DGNMR	Mask words for digital status words.
18	FNOM	2	Nominal line frequency code and flags.
19	CFGCNT	2	Configuration change count.
	Repeat 8–19		Fields 8–18, repeated for as many PMUs as in field 7 (NUM_PMU).
20+	DATA_RATE	2	Rate of data transmissions.
21+	CHK	2	CRC-CCITT

Table A3.2: C37.118 Data Frame Format (From IEEE Std C37.118™-2005 - Table 7)

No.	Field	Size (bytes)	Comment
1	SYNC	2	Sync byte followed by frame type and version number.
2	FRAMESIZE	2	Number of bytes in frame, defined in 6.2.
3	IDCODE	2	PMU/DC ID number, 16-bit integer, defined in 6.2.
4	SOC	4	SOC time stamp, defined in 6.2, for all measurements in frame.
5	FRACSEC	4	Fraction of Second and Time Quality, defined in 6.2, for all measurements in frame.
6	STAT	2	Bitmapped flags.
7	PHASORS	4 × PHNMR or 8 × PHNMR	Phasor estimates as defined in Clause 5. May be single-phase or 3-phase positive, negative, or zero sequence. Values are 4 or 8 bytes each depending on the fixed 16-bit or floating-point format used, as indicated by the configuration frame.
8	FREQ	2 / 4	Frequency (fixed or floating point).
9	DFREQ	2 / 4	Rate of change of frequency (fixed or floating point).
10	ANALOG	2 × ANNMR or 4 × ANNMR	Analog data, 2 or 4 bytes per value depending on fixed- or floating-point format used, as indicated by the configuration frame.
11	DIGITAL	2 × DGNMR	Digital data, usually representing 16 digital status points (channels).
	Repeat 6–11		Fields 6–11 are repeated for as many PMUs as in NUM_PMU field in configuration frame.
12+	CHK	2	CRC-CCITT

Table A3.3: Structure of Configuration Frame Files (xxx.SP1)

Item	Type	Size (Bytes)	Description
1	Integer	4	Frame Count Number
2	Integer	4	Number of Bytes of Following Configuration Frame (N)
3	Mixed	N	Configuration Frame Data (See Table 3)
Repeat items 1, 2, and 3 for each configuration frame			

Table A3.4: Structure of Data Frame Files (xxx.SP2)

Item	Type	Size (Bytes)	Description
1	Integer	4	Frame Count Number
2	Unsigned Integer	8	Configuration Frame Offset. Location of the configuration frame in the SP1 file, corresponding to the data frame to follow in this file. Specifically this number is the offset (in bytes) from the beginning of the configuration file (.SP1) of the configuration frame count number .
3	Integer	4	Number of Bytes of data frame to follow (M)
4	Mixed	M	Data frame (See Table 4)
Repeat items 1, 2, 3, and 4 for each data frame			

Note that the number of files that can simultaneously be opened is a function of the available computer random access memory. For this purpose the dialog provides memory information (available / required memory) for a user selected number of files to open. It also provides the option of decimating the data so that long time spans of data can be opened and viewed, in spite of memory limitations. Decimation is determined by the **Factor** field. For example, a factor of 5 results in one sample being added to each channel plot buffer for every 5 consecutive Synchrophasor frames. The radio buttons titled **Sample, Average, Min/Max** determine how the decimated samples are computed. Specifically for a decimation factor of 5 each sample added to the plot buffers is obtained as follows:

Sample: One out of every 5 consecutive values is kept and the rest are discarded.

Average: Each sample is the average of the last 5 values.

Min/Max: Minimum and Maximum of the last 5 values. Note that this option creates two plot channels for every channel contained in the synchrophasor files.

The field below the decimation factor (titled Samples/Ch) shows the resulting number of samples per channel after decimation.

Each phasor channel stored in the selected Synchrophasor files is converted into two plot traces. The radio buttons in the **Phasors** control group determine the conversion method. Specifically the **Polar(Radians)** radio button generates a magnitude channel and a phase angle channel in radians. The **Polar(Degrees)** radio button generates a magnitude

channel and a phase angle channel in degrees. The **Rectangular** radio button generates a real and imaginary part channel.

In addition to phasor, analog and digital channels, Synchrophasor frames contain samples of the power frequency, rate of change of frequency (ROCOF), and several status channels related to the state of the GPS receiver and the Data Acquisition Clock. These channels can be optionally converted to plot traces by checking the corresponding radio buttons located in the **Include** control group. The **PMU Clock Lock** signal takes the value of 0 indicating that the data acquisition clock is locked to UTC time, while a value of 1 indicates the opposite. The Clock Quality indicates the GPS receiver clock accuracy. It ranges from a value of Zero, indicating normal operation (GPS clock locked), to a value of 15 indicating a GPS clock fault.

Once the files to import, the channels, and the decimation parameters have been selected, click on the **Import** button to open the selected files. Note that if the selected parameters result in exceeding the available memory, an error message will be generated. This error condition can be corrected by either decreasing the number of files to import or by increasing the decimation factor.

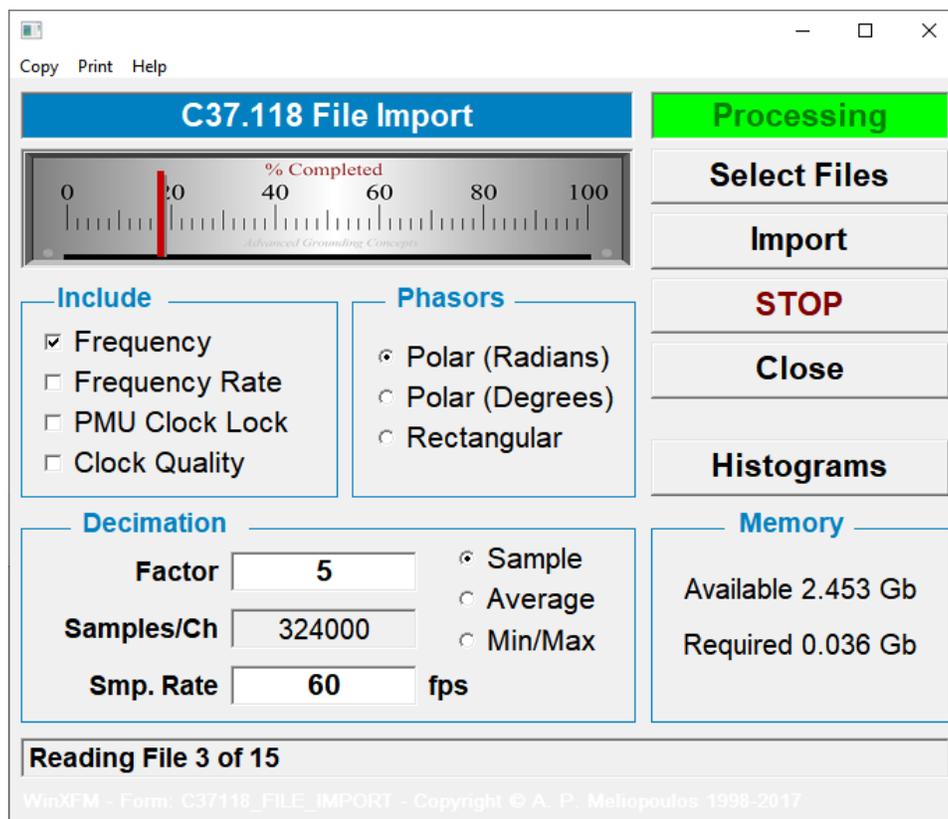


Figure A3.1: Synchrophasor File Import Window

An alternative option for examining large numbers of Synchrophasor files is by generating histograms of selected variables. Click on the **Histograms** button of the **Synchrophasor File Import** dialog to open the **Synchrophasor File Histograms** dialog window, illustrated in Figure A3.2.

Histograms are generated by reading a user selected number of Synchrophasor files and dynamically updating the counts that a user selected variable falls within a set of user defined discrete intervals. The discrete intervals (bins) are defined by specifying the minimum and maximum value and the number of bins. In the example illustrated in Figure 3.1.4 the selected variable is the power frequency (**Select Channel** group) the min/max values are 59.9 to 60.1 Hz, and the number of bins is set to 71 (**X-Axis Range** control group).

To generate the histogram plot, first click on the **Select C37.118 Files** button to select which files to use, then click on the **Update from C37.118 Files** to proceed. Note that since Synchrophasor data are simply counted and not copied into plot buffer memory, this number of files to be processed is practically not limited by random access memory availability.

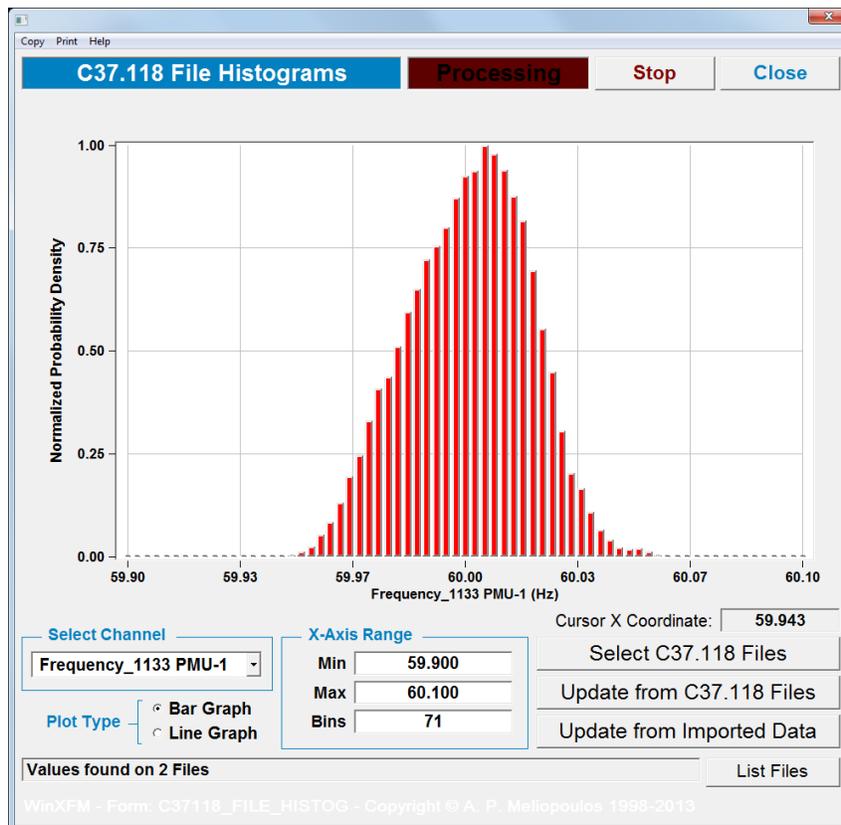


Figure A3.2: Synchrophasor File Histogram Window

APPENDIX 4 – THE STANDARD PMU

This appendix describes the fundamentals of the "Standard PMU" implementation including fractional sample numerical integration method and the theoretical analysis of phase angle computation from sampled waveform data where the sampling rate is not an integer multiple of the base frequency.

The standard PMU implementation achieves accurate phasor amplitude and phase computation, as well as accurate frequency and ROCOF estimation in the presence of distortion and transients using by computing the Fourier integral of the waveform using fractional sample numerical integration. Two variants of the method were implemented, the first based on trapezoidal integration and the second based on quadratic integration. These methods are described in the next two sections.

A4.1 – FRACTIONAL SAMPLE TRAPEZOIDAL INTEGRATION.

This section presents the derivation and resulting equations for the implementation of trapezoidal integration of a uniformly sampled function over an interval with endpoints not necessarily coincident with sampling instances. The method is cast into a recursive algorithm over a moving window, requiring a relatively small number of operations.

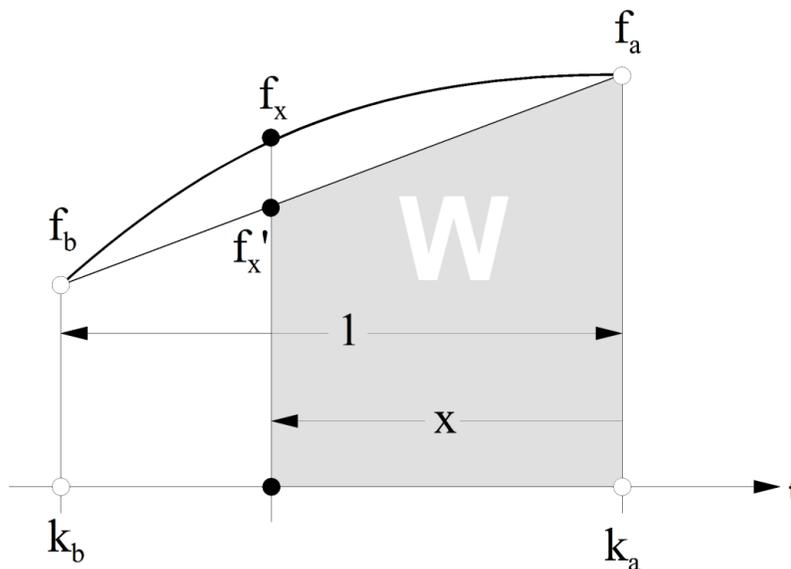


Figure A4.1

Refer to Figure A4.1 and consider the sampled function f_k for which we are evaluating the integral using the Trapezoidal integration method. The area of the end trapezoidal is

computed by first linearly interpolating the waveform at the end point x and then computing the area W as

$$W = (f_a + f_x) x / 2$$

The linearly interpolated f_x is:

$$f_x = (1 - x) f_a + x f_b$$

Substituting:

$$W = (f_a + (1 - x) f_a + x f_b) x / 2 = (x - \frac{1}{2} x^2) f_a + \frac{1}{2} x^2 f_b$$

Or:
$$W = A f_a + B f_b$$

Where:
$$A = x - \frac{1}{2} x^2 \quad \text{and} \quad B = \frac{1}{2} x^2$$

Since the sample f_a also contributes to the next trapezoid a value of $(\frac{1}{2} f_a)$ the total contribution of sample f_a is obtained by setting $A = \frac{1}{2} + x - \frac{1}{2} x^2$

RECURSIVE ALGORITHM IMPLEMENTATION

Using the above result, a recursive algorithm for the computation of a Discrete Fourier Transform (DFT) of a uniformly sampled waveform f_k . Note that the algorithm must track the fundamental frequency of the waveform f_k and thus the period T over which the interval is computed may vary, although it is expected the variation from step to step will be small.

The recursive algorithm is developed by considering two snapshots $k-1$ and k of consecutive time instances differing by one sample period. The integration time window length is T_{k-1} in the first instant and T_k in the second instant, where $T_k = 2\pi / \omega_{Bk}$ (and ω_{Bk} is the waveform tracked base frequency at time instant k).

Figure A4.2 illustrates the weighted samples that must be summed in each of the time instances to yield the corresponding phasor values:

$$\vec{V}_k = \sum_{k=k_1}^{k_2} a_k \cos(\omega k \Delta t) v_k - i \sum_{k=k_1}^{k_2} a_k \sin(\omega k \Delta t) v_k$$

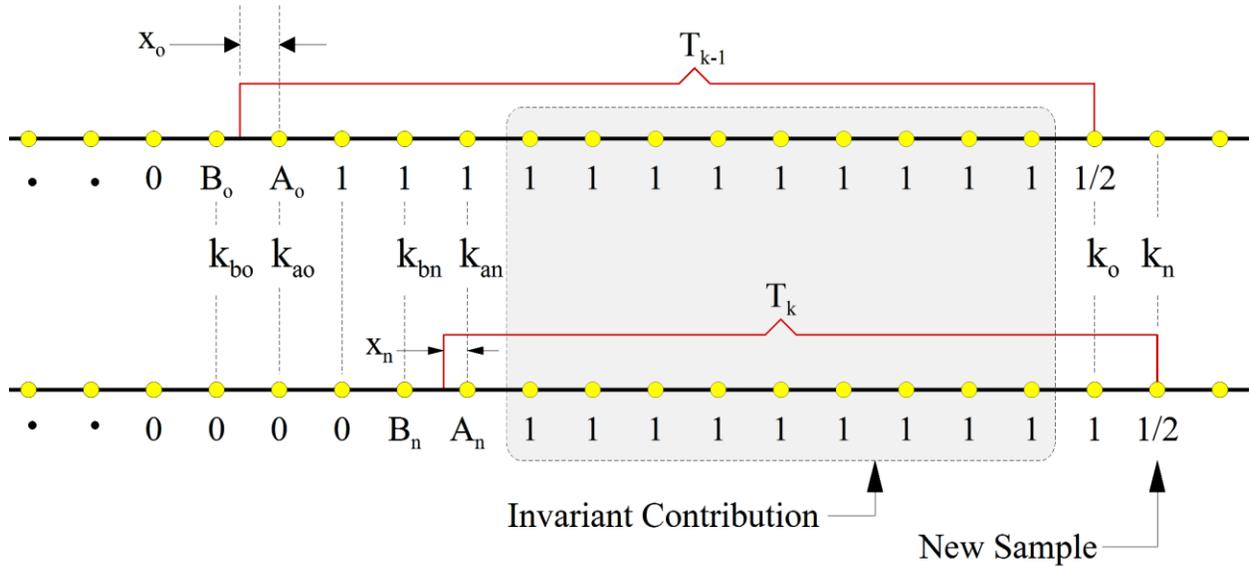


Figure A4.2: Two Consecutive Snapshots of the Integration Window

The Figure shows the factors a_k to be multiplied by the $v_k \sin(\omega k \Delta T)$ and $v_k \cos(\omega k \Delta T)$ terms. In the following treatment we refer to both these terms as f_k . The number of terms (n) in these summed sequences, and the values of x_0 and x_n depend of the waveform base frequency (ω) as follows:

$$T = 2\pi/\omega$$

$$n = \text{int}\{ T / \Delta t \} + 2, \text{ and}$$

$$x = T / \Delta t - \text{int}\{ T / \Delta t \}$$

The frequency w is periodically estimated (typically every cycle) and thus the above values are adjusted accordingly. (The frequency estimation is presented in the next section).

Recall that from the trapezoidal integration of the fractional time interval:

$$A_0 = \frac{1}{2} + x_0 - \frac{1}{2} x_0^2, \quad B_0 = \frac{1}{2} x_0^2$$

$$A_n = \frac{1}{2} + x_n - \frac{1}{2} x_n^2, \quad B_n = \frac{1}{2} x_n^2$$

Where x_0, x_n the fraction of the first interval contained in the time window of the *old* and *new* instances respectively. Note that the samples enclosed in the gray rectangle have the same coefficients and thus the sum of these terms is the same for both instances. Thus, the recurrence formula is as follows:

$$V_{kn} = V_{ko} + 1/2f_{ko} + 1/2f_{kn} - B_0 f_{kbo} - A_0 f_{kao} + B_n f_{kbn} + A_n f_{kan} + S$$

Where: f_k represents the terms $v_k \sin(\omega k \Delta T)$ or $v_k \cos(\omega k \Delta T)$, and

$$S = - \sum_{k=k_{ao}+1}^{k_{an}} f_k \quad \text{if } k_{ao} < k_{an}, \text{ and}$$

$$S = \sum_{k=k_{an}+1}^{k_{ao}} f_k \quad \text{if } k_{ao} > k_{an}$$

and, $S = 0$ if $k_{an} = k_{ao}$.

Note that if the sampled waveform base frequency does not change between the two consecutive time instants, then $k_{an} = k_{ao} + 1$, and the term S is simply $-f_{k_{an}}$.

PHASE CORRECTION

The algorithm presented in the previous section computes the phasor of a sampled waveform using a DFT where the frequency of the kernel functions $\sin(a)$ and $\cos(a)$ is continuously adjusted to match the base frequency of the sampled waveform. The raw phase angle of the computed phasor (P_{RAW}) is therefore referenced to the phase of the kernel function phase and thus must be adjusted to achieve phase reference with respect to UTC. The phase adjustment is simply the negative of the phase angle of the kernel function at the time instant of interest (t_{UTC}), namely the UTC 1PPS mark + an integer multiple of the phasor reporting period (for example the period will be 16.6666 ms for 60 phasors per second on a 60 Hz system). Thus the phasor referenced to UTC (P_{UTC}) is evaluated as follows:

$$P_{UTC} = P_{RAW} \times e^{-ja}$$

Where $a = a_k - \omega_k (t_k - t_{UTC})$

T is the

And a_k the phase angle of the DFT kernel functions at time t_k

ω_k the radian frequency of the DFT kernel functions at time t_k

Note that t_k is selected so that the middle of the phasor computational window is as close as possible to the phasor reporting time (t_{UTC}). Since the algorithm always places the end of the window (t_k) exactly aligned with a sample, t_{UTC} is generally not coincident with a

sampling instant. However this does not introduce any additional error. Figure A4.3 illustrates this procedure pictorially.

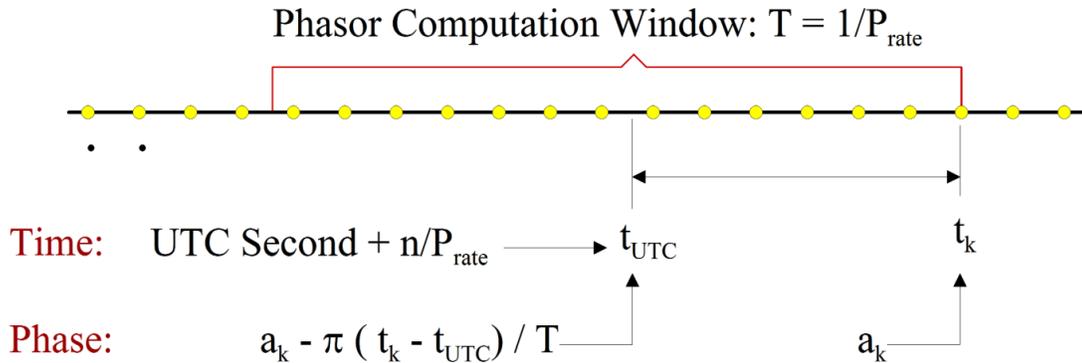


Figure A4.3: Phase Adjustment

BASE FREQUENCY TRACKING

The sampled waveform base frequency is tracked using the rate of change of the computed phasor phase angle. The frequency adjustment is typically performed once every cycle of the nominal system frequency. Specifically, let the computed phasor angles at time T_k and T_{k+1} are a_1 and a_2 respectively, then ω is updated as follows:

$$\omega_{k+1} = \omega_k + (a_k - a_{k-1}) / \Delta T$$

or:

$$f_{k+1} = f_k + (a_k - a_{k-1}) / (2 \pi \Delta T)$$

where:

$$\Delta T = T_{k+1} - T_k$$

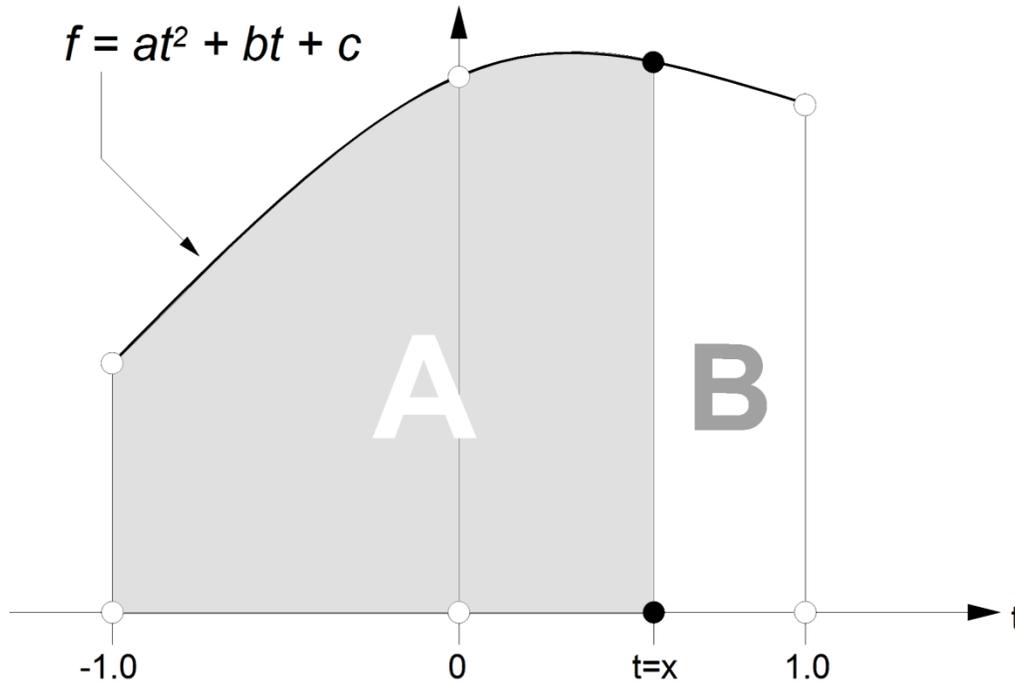
In order to improve the frequency tracking characteristics the above frequency adjustment can be modified using *proportional* and *integral* feedback terms. Specifically the frequency increment term $E_k = (a_k - a_{k-1}) / (2 \pi \Delta T)$ can be considered as an error signal based on which the frequency is adjusted. This is consistent with the fact that if the kernel frequency matches the sampled waveform base frequency then the computed phases a_k and a_{k-1} will be identical and the error signal E will be zero. The following frequency adjustment formula may thus be used:

$$f_{k+1} = f_k + A E_k + B \sum_{i=0}^k E_i$$

Where A and B are constants to be determined by experiment. One observation is that a positive term B helps improve the frequency tracking in cases where the frequency increases or decreases at a constant rate (frequency ramping). Also, setting the term A to a value less than one, reduces the frequency overshoot that occurs during a step frequency change.

A4.2 - FRACTIONAL SAMPLE QUADRATIC INTEGRATION.

This appendix presents the derivation and resulting equations for the implementation of quadratic integration of a uniformly sampled function over an interval with endpoints located between samples. The method is based on extending Simpson's rule to integration of arbitrary intervals.



Let $f_{1,2,3}$ be three consecutive samples of a uniformly sampled sequence taken at $t = -1$, $t = 0$ and $t = 1$. Assuming f is given by a quadratic equation with coefficient a , b , c , yields:

$$f_1 = f(-1) = a - b + c$$

$$f_2 = f(0) = c$$

$$f_3 = f(1) = a + b + c$$

solving for the coefficients a , b , c yields:

$$c = f_2$$

$$a = f_1/2 - f_2 + f_3/2$$

$$b = a + c - f_1 = f_1/2 + f_3/2 - f_2 + f_2 - f_1 = f_3/2 - f_1/2$$

The area is computed by integrating the above from -1 to x:

$$A = [at^3/3 + bt^2/2 + ct]_{-1}^x = ax^3/3 + bx^2/2 + cx + a/3 - b/2 + c$$

Or:

$$A = a(x^3 + 1)/3 + b(x^2 - 1)/2 + c(x + 1)$$

Summarizing:

$$a = (f_3 + f_1)/2 - f_2$$

$$b = (f_3 - f_1)/2$$

$$c = f_2$$

$$A = a (x^3 + 1)/3 + b (x^2 - 1)/2 + c (x + 1)$$

And in terms of the sample values f_1, f_2, f_3 :

$$A = ((f_3 + f_1)/2 - f_2) (x^3 + 1)/3 + (f_3 - f_1)(x^2 - 1)/4 + f_2 (x + 1)$$

$$A = (f_1) (x^3/6 - x^2/4 + 5/12)$$

$$+ (f_2) (-x^3/3 + x + 2/3)$$

$$+ (f_3) (x^3/6 + x^2/4 - 1/12)$$

The remaining area (B) can be deduced by symmetry, by exchanging f_1 and f_3 , and replacing x with $-x$, which yields:

$$B = (f_1) (-x^3/6 + x^2/4 - 1/12)$$

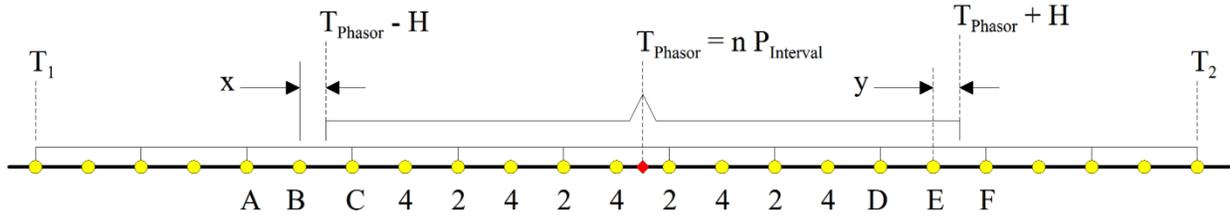
$$+ (f_2) (x^3/3 - x + 2/3)$$

$$+ (f_3) (-x^3/6 - x^2/4 + 5/12)$$

Note that as expected the sum $A + B$ is independent of x , specifically:

$$A + B = (f_1) (1/3) + (f_2) (4/3) + (f_3) (1/3)$$

APPLICATION OVER PHASOR WINDOW



Given circular buffer extend T1 to T2, Phasor widow 2H, the Phasor at time ($n \cdot P_{\text{interval}}$) is computed as follows:

$$\vec{V} = \sum_{k=k_1}^{k_2} a_k \cos(\omega k \Delta t) v_k - i \sum_{k=k_1}^{k_2} a_k \sin(\omega k \Delta t) v_k$$

Where v_k are the raw data samples at time $k \Delta T$, ω is the estimated power frequency, and a_k are coefficients defined as follows:

$$\text{for } k = k_1 \quad a_k = -x^3/6 + x^2/4 - 1/12$$

$$\text{for } k = k_1+1 \quad a_k = x^3/3 - x + 2/3$$

$$\text{for } k = k_1+2 \quad a_k = -x^3/6 - x^2/4 + 3/4$$

$$\text{for } k = k_1+3 \quad a_k = 4/3$$

$$\text{for } k = k_1+4 \quad a_k = 1/3$$

$$\text{for } k = k_1+5 \quad a_k = 4/3$$

...

$$\text{for } k = k_2 - 4 \quad a_k = 1/3$$

$$\text{for } k = k_2 - 3 \quad a_k = 4/3$$

$$\text{for } k = k_2 - 2 \quad a_k = y^3/6 - y^2/4 + 3/4$$

$$\text{for } k = k_2 - 1 \quad a_k = -y^3/3 + y + 2/3$$

for $k = k_2$ $a_k = y^3/6 + y^2/4 - 1/12$

Note that $k_2 - k_1$ must always be even. Specifically they are computed as follows:

$$k_1 = \begin{cases} \lfloor (T_{\text{phasor}} - H - T_1) / \Delta T, & \text{if } (k_2 - k_1) \text{ is even,} \\ \lfloor (T_{\text{phasor}} - H - T_1) / \Delta T - 1, & \text{otherwise} \end{cases}$$

$$k_2 = \lceil (T_{\text{phasor}} + H - T_1) / \Delta T, \rceil$$

the variables x and y are:

$$x = (T_{\text{phasor}} - H - T_1) / \Delta T - (k_1 + 1) \quad x \text{ is always in } (-1,1)$$

$$y = (T_{\text{phasor}} + H - T_1) / \Delta T - (k_2 - 1) \quad y \text{ is always in } (0,1)$$

A4.3 - FRACTIONAL SAMPLE INTEGRATION ERROR ANALYSIS

Figure A4.4 illustrates the maximum phase angle error (in milli-degrees) versus sampling frequency for base frequency of 60 Hz for three computational methods:

- Rectangular integration without fractional sample correction (Red Trace).
- Trapezoidal integration with fractional sample correction (Blue Trace).
- Quadratic integration with fractional sample correction (Green Trace).

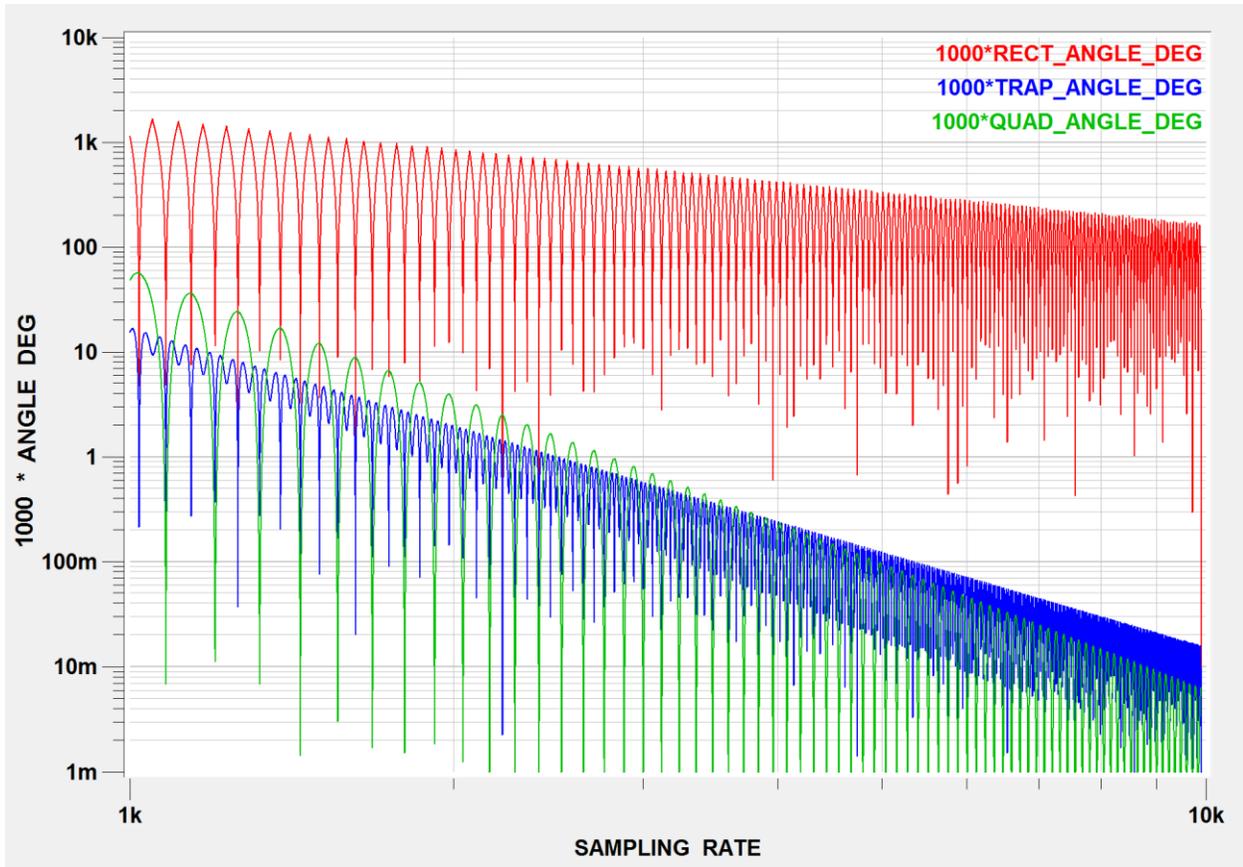


Figure A4.4

Note that for sampling frequencies below about 4 kHz, the trapezoidal integration performs better than the quadratic, and vice-versa. Figures A4.5 and A4.6 show zoomed-in views of the trapezoidal and quadratic methods illustrating that when the sampling frequency is within 0.5% of an integer multiple of **twice** the base frequency (120 Hz) the quadratic integration performs substantially better than the trapezoidal.

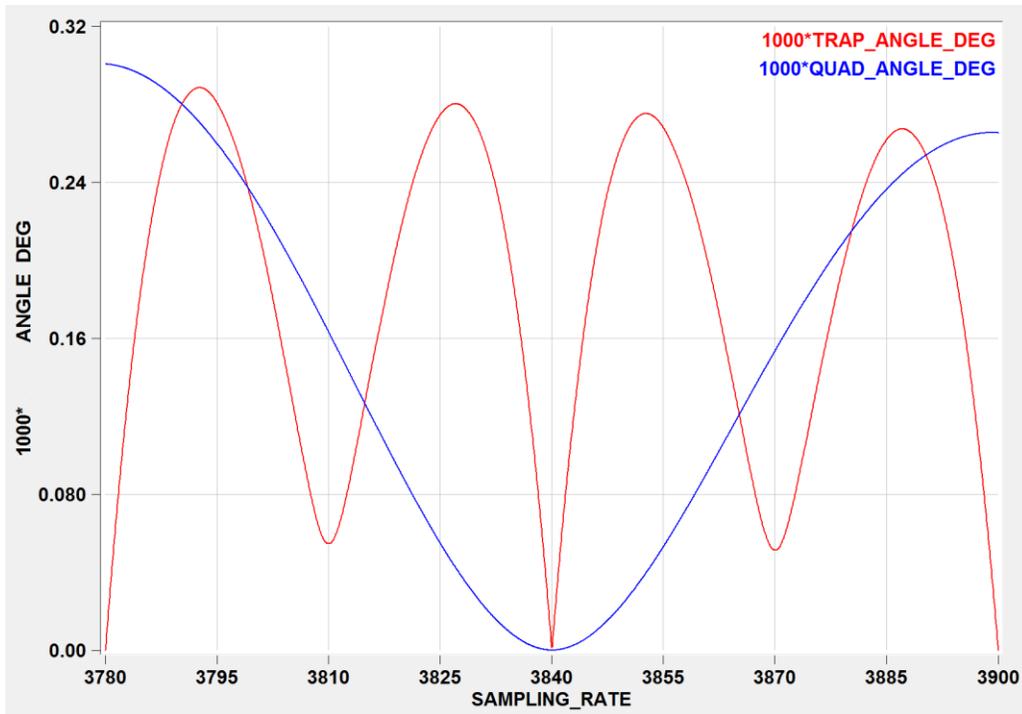


Figure A-4.5 – Trapezoidal (Red) and Quadratic (Blue) Methods near 3840 Hz

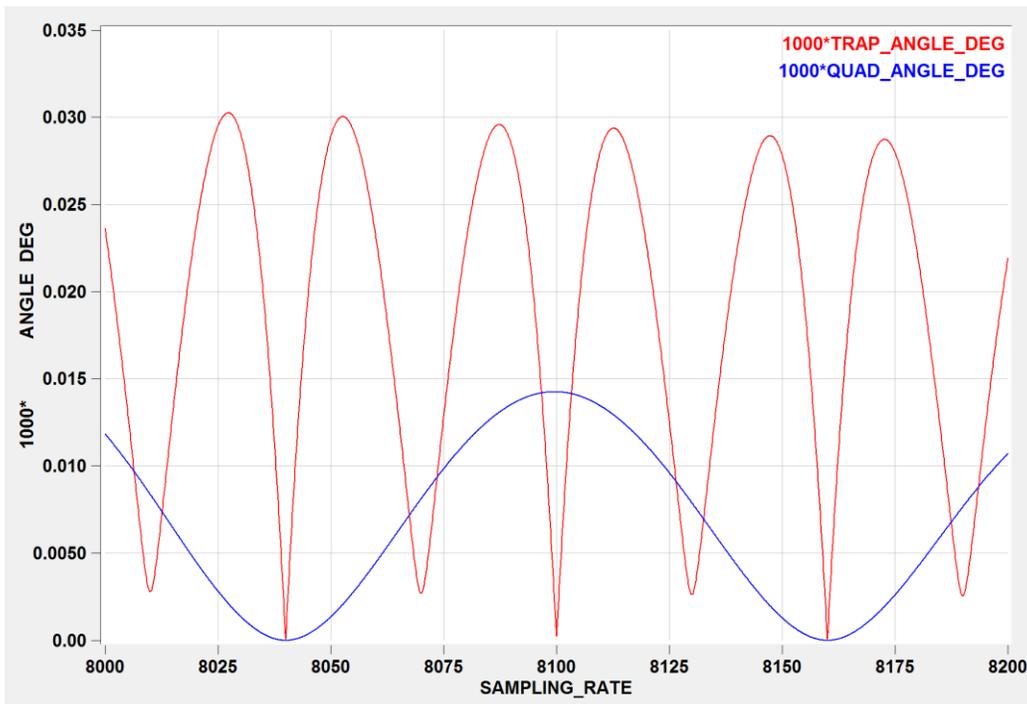


Figure A-4.6 – Trapezoidal (Red) and Quadratic (Blue) Methods near 8040 and 8160 Hz

APPENDIX 5 – SUPPORTED COMPUTED CHANNEL FUNCTIONS

The WinXFM waveform calculator generates computed channels which are defined as functions of time and/or other existing waveform or computed channels. This appendix describes the function usage.

A5.1 SIN FUNCTION

Trigonometric Sine Function, Usage: $\text{SIN}(X)$, with X in radians

A5.2 COS FUNCTION

Trigonometric Cosine Function, Usage: $\text{COS}(X)$, with X in radians.

A5.3 TAN FUNCTION

Trigonometric Tangent Function, Usage: $\text{TAN}(X)$, with X in radians.

A5.4 ASIN FUNCTION

Inverse Trigonometric Sine Function, Usage: $\text{ASIN}(X)$. Result in radians.

A5.5 ACOS FUNCTION

Inverse Trigonometric Cosine Function, Usage: $\text{ACOS}(X)$. Result in radians.

A5.6 ATAN FUNCTION

Inverse Trigonometric Tangent Function, Usage: $\text{ATAN}(X)$. Result in radians.

A5.7 SIGN FUNCTION

Returns -1 if argument is negative, +1 otherwise. Usage: $\text{SIGN}(X)$

A5.1 ABS FUNCTION

Returns the absolute value of the argument. Usage: $\text{ABS}(X)$.

A5.8 SQRT FUNCTION

Returns the square root of the argument. Usage: $\text{SQRT}(X)$.

A5.9 LOG FUNCTION

Returns the Natural Logarithm of the argument. Usage: $\text{LOG}(X)$.

A5.10 LOG10 FUNCTION

Returns the Base 10 Logarithm of the argument. Usage: LOG10(X).

A5.11 EXP FUNCTION

Returns the natural exponential of the argument. Usage: EXP(X).

A5.12 INT FUNCTION

Returns the closest integer to the argument. Usage: INT(X).

A5.13 MIN FUNCTION

Returns the minimum value of two arguments. Usage: MIN(X1,X2).

A5.14 MAX FUNCTION

Returns the maximum value of two arguments. Usage: MAX(X1,X2).

A5.15 PEAK FUNCTION

Returns the maximum absolute value over the entire time span. Usage: PEAK(X).

A5.16 RMS FUNCTION

Computes the RMS value. Usage: RMS(w,f), where w: waveform, f: nominal frequency(Hz).

A5.12 SON FUNCTION

Switches a waveform 'W' on after time 'T'. Usage: SON(W,T) with 'T' in seconds

A5.17 SOFF FUNCTION

Switches a waveform 'W' on after time 'T'. Usage: SOFF(W,T) with 'T' in seconds

A5.18 SWIN FUNCTION

Switches waveform 'W' on at 'T1' and off at 'T2'. Usage: SWIN(W,T1,T2) with T2, T2 in seconds.

A5.19 UNWIND FUNCTION

Removes phase angle discontinuities. Usage: UNWIND(w), w: waveform.

A5.20 INTEG FUNCTION

Returns the Integral of a Waveform. Usage: INTEG(w), w: waveform.

A5.12 SHIFT FUNCTION

Time-Shifts a waveform. Usage: SHIFT(w,t), where w: waveform, t: Time Shift (sec)

A5.21 FREQ FUNCTION

Returns the frequency of a waveform (in Hz). Usage: FREQ(V,Fn), where V: waveform, Fn: Nominal Frequency(Hz)

A5.22 HARM FUNCTION

Returns the Harmonic Amplitude. Usage: HARM(w,f,n), w: waveform, f: base frequency (Hz), n: harmonic order.

A5.23 PHASE FUNCTION

Returns the Harmonic Phase. Usage: PHASE(w,f,n), w: waveform, f: base frequency (Hz), n: harmonic order.

A5.12 THD FUNCTION

Computes the Total Harmonic Distortion in %. Usage: THD(w,f), where w: waveform, f: nominal frequency(Hz).

A5.24 REAL_POWER FUNCTION

Average real power. Usage: REAL_POWER(v,c,f), v: voltage waveform, c: current waveform, f: base frequency (Hz).

A5.25 REACT_POWER FUNCTION

Average reactive power. Usage: REACT_POWER(v,c,f), v: voltage waveform, c: current waveform, f: base frequency (Hz).

A5.26 DIST_POWER FUNCTION

Distortion power. Usage: DIST_POWER(v,c,f), v: voltage waveform, c: current waveform, f: base frequency (Hz)

A5.27 P_FACTOR_VI FUNCTION

Power Factor. Usage: P_FACTOR_VI(v,c,f), v: voltage waveform, c: current waveform, f: base frequency (Hz)

A5.28 P_FACTOR_PQ FUNCTION

Power Factor. Usage: P_FACTOR_PQ(p,q), p: real power waveform, q: reactive power waveform.

A5.29 LP_FILTER FUNCTION

Low Pass Filter. Usage: LP_FILTER(w,f), Where w: Waveform, f: Filter Cutoff Frequency (Hz).

A5.30 FILTER FUNCTION

General Purpose Filter. Usage: FILTER(w,k), Where w: Waveform, k: Coefficient File Number

A5.31 FORECAST FUNCTION

Computes Forecast. Usage: FORECAST(w,n), Where w: Waveform, n: Filter Cutoff Frequency (Hz).

A5.32 FORECAST_DEV FUNCTION

Computes Forecast Standard Deviation. Usage: FORECAST_DEV(w,n), Where w: Waveform, n: Filter Cutoff Frequency (Hz).

A5.33 FORECAST_RES FUNCTION

Computes Forecast Residual. Usage: FORECAST_RES(w,n), Where w: Waveform, n: Filter Cutoff Frequency (Hz).

A5.34 SEQ FUNCTION

Sequence Component Usage: SEQ(Va,Vb,Vc,Freq,iSeq), where iSeq=0,1,2.

A5.35 PROG1 FUNCTION

Impedance Magnitude. Usage: PROG1(Vm,Va,Im,Ia,T).

A5.36 PROG2 FUNCTION

Impedance Phase. Usage: `PROG1(Vm,Va,Im,Ia,T)`;

APPENDIX 6: THE VIRTUAL IP MERGING UNIT DATA FORMAT

The WinXFM EBP (Estimation Based Protection) option is required to activate the virtual IP Merging Unit (vIP-MU). The vIP-MU transmits sample values using the network layer of the OSI communications standard, using the TCP-IP Protocol. This approach provides access to sample value data from remote locations given that the transmitting and receiving device have access to a common **Wide Area Network**. Note that merging-unit sample-value packets are confined within a single **Local Area Network**, since they are normally blocked by network routers and switches.

Using this module an EBP application operating in Substation 1 can use measurements captured by merging units in Substation 2 as illustrated in Figure A6.1.

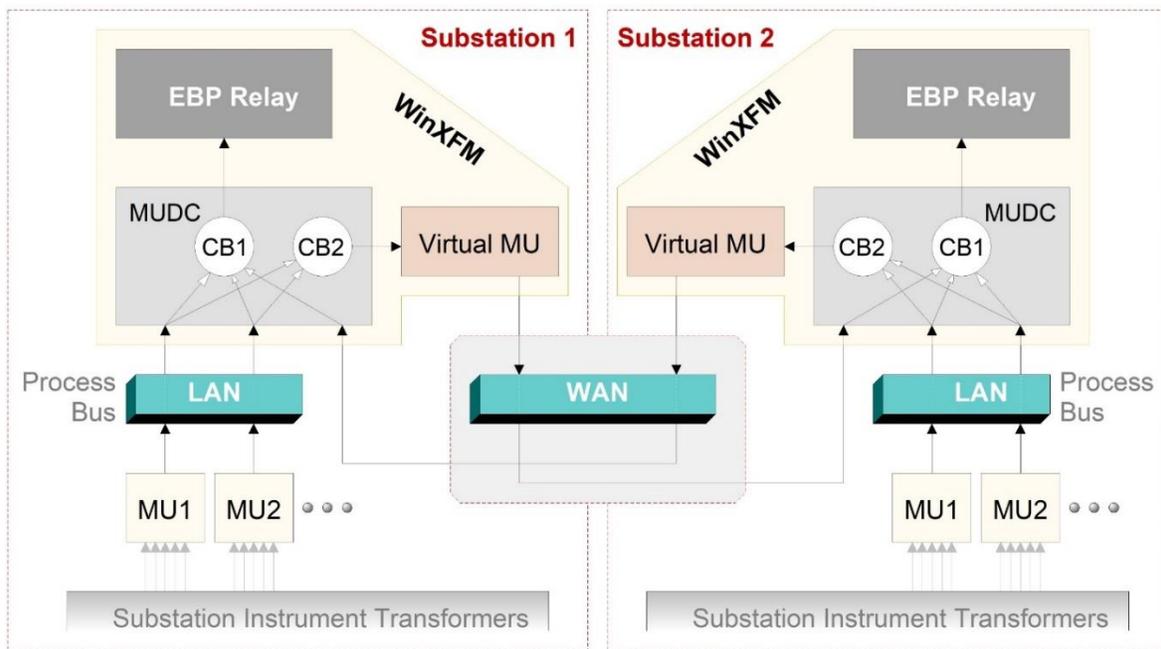


Figure A6.1: Block Diagram of EBP relay Using Virtual-IP Merging Units.

The virtual IP merging unit (vIP-MU) transmits sample value data packed in a TCP-IP packet. In order to achieve low header overhead, each packet includes data from multiple time instances. The payload organization of the TCP data packet is described in Table A6.2. Note that the total number of bytes in the frame payload is given by the following expression:

$$nFrameBufferBytes = 42 + 16 * nAsdus + 4 * nSamplesPerAsdu * nAsdus * nSamplesPerFrame;$$

Table A6.1: vIP-MU TCP Configuration Packet Payload Organization

#	Name	Type	Bytes	Description
1	ID & Type	char	8	The 8 byte string: vIPMU _{nnn} , where _{nnn} is a 3 character string indicating packet type vIPMUCFG for configuration packet
2	Frame Length	DWORD	4	Total number of BYTES in frame
3	Samples per Second	WORD	2	Merging unit sampling rate in samples per second (typically 4800 for 60 Hz systems)
4	Samples per ASDU	WORD	2	Number of samples in each ASDU (typically 8)
5	Samples per Frame	WORD	2	Number of consecutive samples included in the packet frame (user selected – default value 80)
6	Number of source ASDUs	WORD	2	Number of source ASDUs included. Each ASDU typically includes 8 channels (4 currents + 4 voltages)
7	N _{char}	char	1	Integer indicating length of following string (0-255)
8	vIP-MU Name	char	N _{char}	virtual IP MU alphanumeric identifier (N _{char} bytes)
9	N _{char}	char	1	Integer indicating length of following string (0-255)
10	ASDU Name 1	char	N _{char}	1 st source merging-unit alphanumeric ID (N _{char} bytes)
...				
Repeat above 2 items for each of the remaining source merging-unit ASDUs				
...				

Total Bytes: 20 + alphanumeric data size...

Table A6.2: vIP-MU TCP Sample Data Packet Payload Organization

#	Name	Type	Bytes	Description
1	ID & Type	char	8	The 8 byte string: vIPMU _{nnn} , where _{nnn} is a 3 character string indicating packet type: vIPMUDAT for uncompressed data packet
2	Frame Length	DWORD	4	Total number of BYTES in frame
2	Time Stamp	QWORD	8	8-byte integer containing the first sample time stamp. The time stamp is defined as follows: $t = s \times n + i$, where: s: second of century (number of seconds since 1/1/1970) n: sampling rate (samples per second) i: sample count (0-4799 for 60 Hz Systems)
3	Synch Code	DWORD	4	Synchronization type, 2 bits for each ASDU transmitted (0=none, 1=local, 2=global). Lowest order bit pair corresponds to first ASDU in frame.
4	nSamp	DWORD	4	Total number of samples following $nSamp = n_{spa} \times n_{asdu} \times n_{spf}$ n_{spa} : number of samples per ASDU (typically 8) n_{asdu} : number of ASDUs n_{spf} : number of samples per frame
5	Sample Values	int	4 x nSamp	Sample values from each ASDU repeated for each of n_{spf} time instants

Total Bytes: $28 + 4 \times n_{spa} \times n_{asdu} \times n_{spf}$