**C**onsortium for
**E**lectric
**R**eliability
**T**echnology
**S**olutions

# NERC Frequency Monitoring and Analysis (FMA) Application

# *FUNCTIONAL SPECIFICATION*

***Version 1.7 – For NERC-RS Final Approval***
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***Prepared by:***
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***For:***
***NERC Resources Subcommittee***

North American Electric Reliability Council

CERTS
Consortium for Electric Reliability Technology Solutions

Electric Power Group

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# Executive Summary

For the last three years, NERC, with the assistance of the Department of Energy (DOE) and the Consortium for Electric Reliability Technology Solutions (CERTS), has been developing and deploying various components of the Reliability Monitoring and Compliance Platform (RMCP) block for Wide-Area Monitoring and Compliance. One of the components of the NERC RMCP is the Frequency Monitoring and Analysis application which has been specified as part of NERC responses to some of the August 14, 2003 blackout recommendations, and is being developed to gather, transmit, process, archive, and provide access to Interconnections frequency phasor data to allow NERC Subcommittees and Staff for timely post analysis of frequency abnormalities, frequency response analysis, and to help validate new reliability performance metrics.

The purpose of this document is to define the functional requirements for the NERC Frequency Monitoring and Analysis (FMA) project using the North American Syncro Phasor Initiative (NASPI) phasor infrastructure with TVA serving as host for Eastern interconnection frequency data source, both for real time and for archived phasor frequency data. The document describes the adopted Hardware-Software architectures using Phasor measurements based on requirements specified by NERC Resources Subcommittee. This document also describes requirements for wide area frequency data collection, alarm, event data collection and archiving, data processing and storage, user Interface and visualization requirements.

The proposed research, development, and deployment schedule calls to complete software development and Factory Test (FAT) during 4Q2007, NERC-RS field trial during 4Q2007 and final delivery and training for 4Q2007.

# 1 Introduction

The purpose of this document is to define the functional requirements for the NERC Frequency Monitoring and Analysis (FMA) project using the North American Synchro Phasor Initiatives (NASPI) phasor infrastructure with TVA serving as host for Eastern interconnection frequency data source, both for real time and for archived 1-second phasor frequency data. Section 4 describes the hardware-software architecture agreed between NERC-TVA- CERTS and the target for implementation and for this specification. The remaining sessions define the different requirements such as acceptable location of frequency data sources, data accuracy, data collection periodicity, alarming and events, archiving periods, user interface or visualization, reporting, and system availability and performance requirements.
Both TVA as the phasor frequency data source and NERC-CERTS as developers for the project functional requirements will comply with most of the NERC Resources Subcommittee requirements defined in their 2004 functional specification, and in the Subcommittee decision to integrate NERC 10-second interconnection frequency and NetACE data as backup during their meeting on June 20, 2007 at MISO.

# 2 Background

NERC has been developing and deploying for the last three years with the support and assistance of the Department of Energy (DOE) and the Consortium for Electric Reliability Technology Solutions (CERTS) a Reliability Monitoring and Compliance platform (RMCP) for developing wide area monitoring and compliance tools for NERC Reliability Coordinators and Subcommittees. This platform has evolved from the application of the CERTS performance management concepts and strategy for monitoring and improving reliability performance management. Figure 1 shows the four major categories of NERC Wide Area Real-Time monitoring and compliance applications.

Following are the applications in production or under development for each of the four quadrants:

- First Applications Quadrant - Wide-Area Real-Time Resource Adequacy (ACE-Frequency), and Inadvertent Monitoring
- Second Applications Quadrant: Control Performance Standard (CPS) – Balancing Authority ACE Limit (BAAL) Analysis and Assessment, Area Interchange Error (AIE) Monitoring, and Frequency Monitoring and Analysis using Phasor Measurement Units (PMUs), target of this specification.
- Third Applications Quadrant: Real Time Situational Awareness for Resource Adequacy
- Fourth Applications Quadrant: Situational Awareness for Load-Transmission Adequacy

The NERC-CERTS project team has focused their research and prototyping in wide-area real time monitoring and compliance applications for each of the four applications quadrants shown in Figure 1. During 2005-2006, the CPS-BAAL analysis and assessment tools were developed and released for operation. The NERC frequency monitoring and analysis project will be the second application designed and developed for the analysis and assessment category shown in Figure-1.

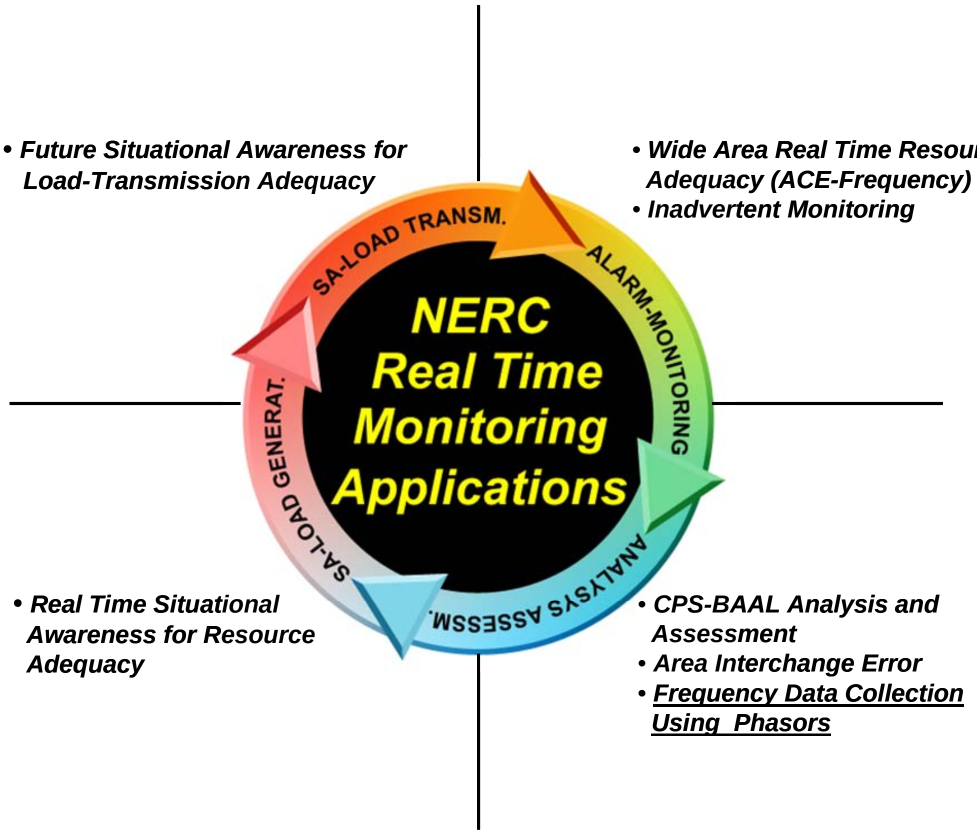


**Figure 1– NERC Reliability Monitoring and Compliance Platform (RMCP)**

# 3 Frequency Monitoring and Analysis Input Data Requirements

3.1 There shall be at least three (3) geographically and electrically separated frequency transducers within each of the Interconnections, Eastern Interconnection, Western Interconnection, ERCOT, and Hydro Quebec (HQ). The intent is to utilize the frequency data supplied to NASPI by installed frequency transducers.

- At least twelve (12) frequency transducers are required.
- The frequency transducers should be physically separated (i.e., cannot be located at the same substation).
- The frequency transducers must be both geographically and electrically dispersed. Electrically the transducers must be separated by at least two major transmission elements (i.e., there must be at least two lines, a line and a transformer or some other set of two or more major active transmission elements between the points monitored by the frequency transducers – closed breakers do not count). Within the Eastern Interconnection, one transducer shall be located within the NPCC or MRO region, one transducer either within the FRCC or SERC region, and one transducer within the SPP or RFC region. Within the Western Interconnection, one transducer shall be located within or near BPA's service area in the NWPP region; one transducer shall be within New Mexico in the AZNM region and one transducer near San Diego or Los Angeles, California. Within ERCOT, the transducers shall be located near Houston, Dallas, and Austin. Within Hydro Quebec, the transducer electrical separation requirements shall apply. Figure 2 below shows the required number and approximate location of the frequency transducers.

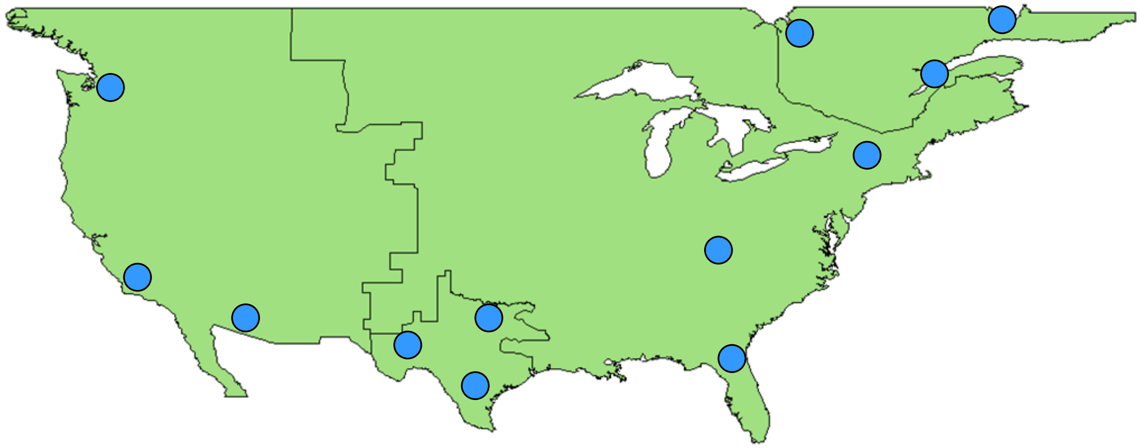

**Figure 2 – Minimum Number and Approximate Location of Frequency Sources**

3.2 These frequency transducers may be the same as those utilized by the local utility, but must communicate independently and must meet the NASPI accuracy and calibration requirements contained below.

3.3 Maintenance of frequency transducers will be coordinated with the NASPI System Administrator. This is to ensure no two transducers in an Interconnection are out of service at the same time.

3.4 Frequency data shall be collected at a minimum scan rate of once per second, for areas where high rate measurements are not currently available, one frequency measure every six seconds can be used in an interim basis.

3.5 Synchronization of the frequency sampling intervals, time stamp information and any other time information1 required should be obtained from sources directly traceable to the NIST time source.

3.6 Frequency data shall be collected to a resolution of at least +/− 0.001 Hertz (three decimal points)

3.7 The time error shall be stored and uploaded to the data warehouse at the same rate as the frequency data.

# 4 System Architecture Overview and Details

Two hardware-software architecture alternatives for the frequency project were presented and discussed during a NERC-CERTS Data Quality review meeting in March 2005. From the two alternatives one combination of the two was agreed as the most feasible and practical by using the Eastern Interconnection Phasor Project (EIPP) phasor infrastructure with TVA serving as the host. This architecture was presented and discussed during a meeting with TVA on April 2005.

During the same meeting, TVA agreed to serve as the host for both the real time and 5-year 1-sec archive frequency data for the Eastern Interconnection. It was also agreed that the project requirements for alarming, events and analysis would be designed and implemented by CERTS and installed in hardware defined and allocated by NERC-CERTS-EPG. Figure 3 and Figure-4 show the architecture to implement the NERC (FMA) prototype using phasor measurements.

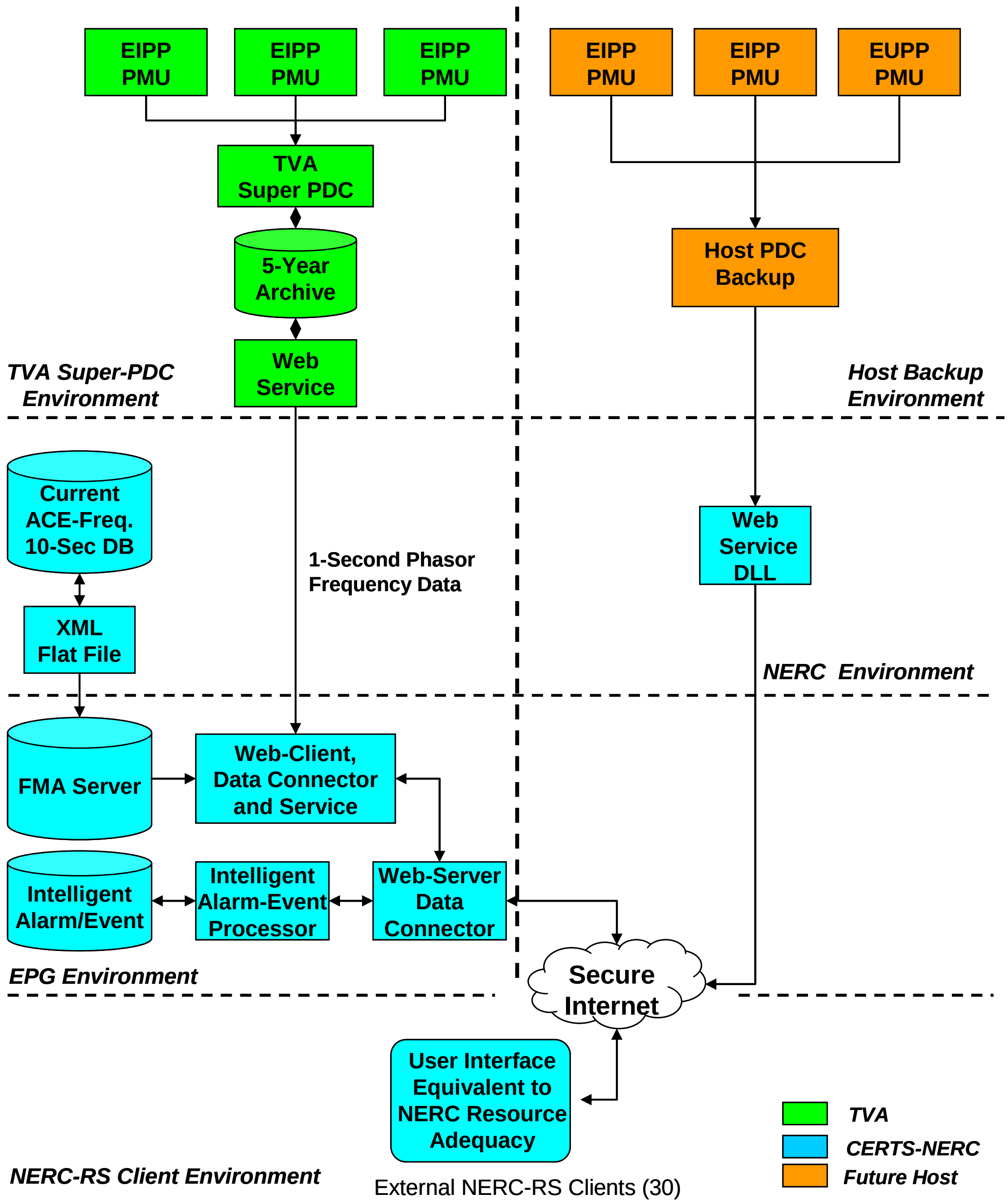


**Figure 3 – Architecture Overview for NERC (FMA) Project**

Following are the major components of the frequency project architecture:

- **Primary and Backup Environments –** The left side from Figure 3 shows the configuration for the primary system using TVA as the host data collector and archives.
- **<u>Level 1</u>** - The left side of the first level shows the main TVA current super PDC environment. 5-years 1-s is available online for NERC from TVA. TVA will provide a secure web service to retrieve data out along with data quality information according to inputs of signal names, resolution flag, timestamps, and/or duration.

- **Level 2** - The second level shows the NERC source for 10-second frequency and the XML flat data file that will be created and transmitted daily to the outsource server that will contain 5-years of 10-second frequency data.
- **Level 3** - The third level shows the proposed frequency and the current Intelligent Alarm and data servers. The frequency server shows the connectors and services required to archive 10 second frequency data, and to collect and transfer user requested frequency data. The current Intelligent Alarm server will be expanded to accommodate the new alarm-event FMA requirements.
- **Level 4** - The fourth level shows the NERC geo-graphic multi-view visualization client environment where the frequency data will be collected and presented to end-users with monitoring, tracking, and analysis capabilities residing in each client. Both the user analysis and data collection visualization must be as close as possible to its equivalents in the NERC Resource Adequacy application (ACE-Frequency). Each client will communicate with the NERC and Outsource servers through secure Internet.

Figure 4 shows the 4-level equivalent detail architecture:

- TVA Phasor Data Concentrator
- NERC Resource Adequacy and 10-second frequency data source
- EPG Frequency data and Real Time Intelligent Alarm and Event Servers
- Clients Application PCs

The FMA system architecture and functionality will be designed and implemented to include the following NERC Resources Subcommittee requirements:

- Automatically transmit frequency data from a minimum of three different locations in the Eastern Interconnection, Western Interconnection, ERCOT and HQ.
- Synchronize the frequency sampling intervals, time stamp information and any other time information required (calibrated to sources traceable to the National Institute of Standards and Technology (NIST) time standards).
- Collect and archive frequency data to a resolution of at least +/-0.001 Hertz (one milliHertz).
- Store archived frequency data at a minimum rate of one sample per second or every six seconds in an interim basis, with a resolution no less than the specified accuracy of the associated frequency transducer.
- Maintain on-line archived frequency data for a minimum of five (5) years.
- Support report production and database query capabilities that offer standard periodic reports and event driven reports using archived data.
- Support database query and report writing tools to generate both graphic and tabular format reports.
- Allow only authorized users to view and query the FMA database content
- Integration and online availability of Interconnections 10-second data for frequency and frequency error, and 10-second NetACE validation and analysis purposes.

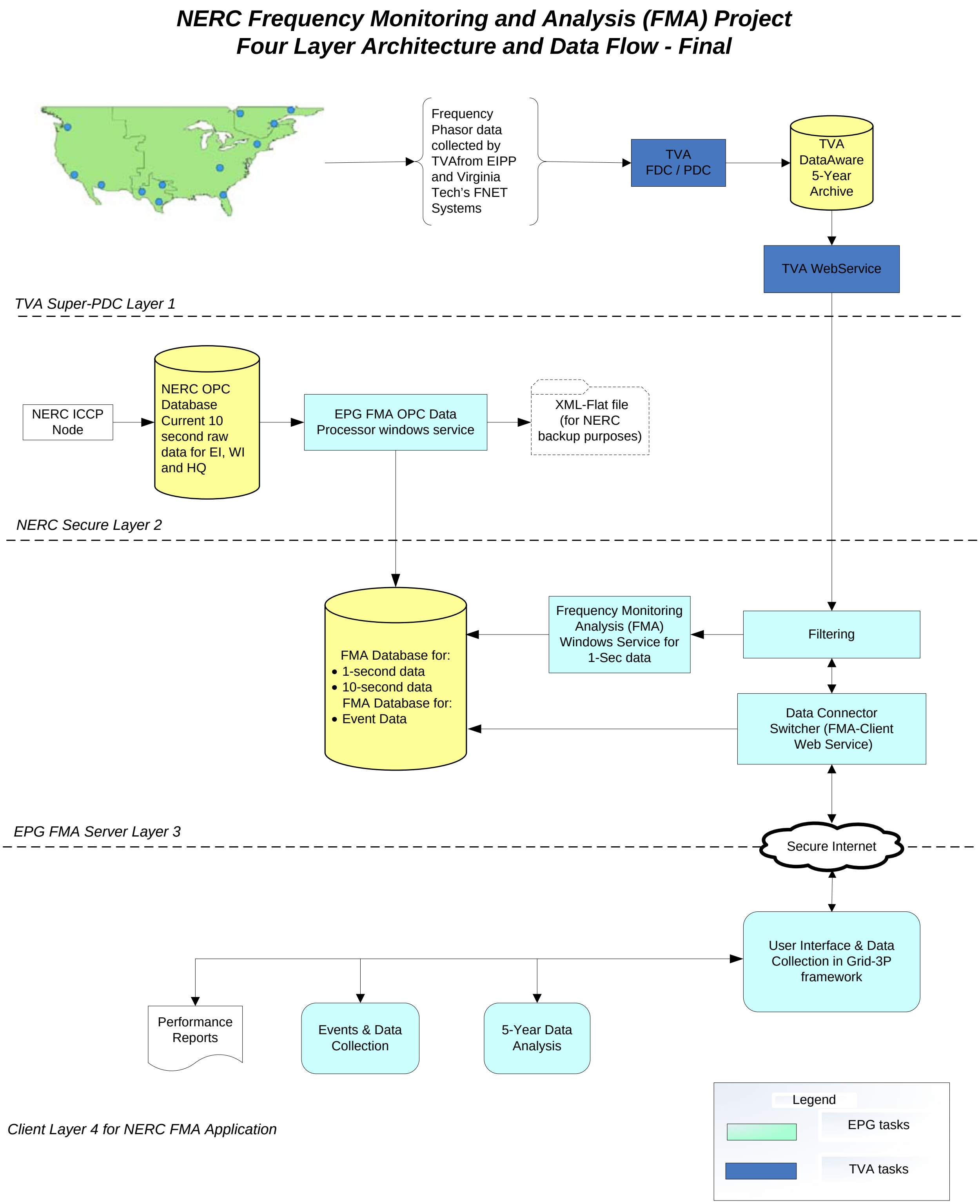


**Figure 4 – 4-Layer Architecture and Data Flow Overview**

# 5 Data Quality and Filtering

Figure 5 shows frequency delta in Hz for 10 different phasor data sources. Graph area circles show abnormal frequency data coming from the PMUs. Data Quality errors as the ones shown in figure 5 need to be filtered to avoid inaccurate frequency monitoring and tracking.

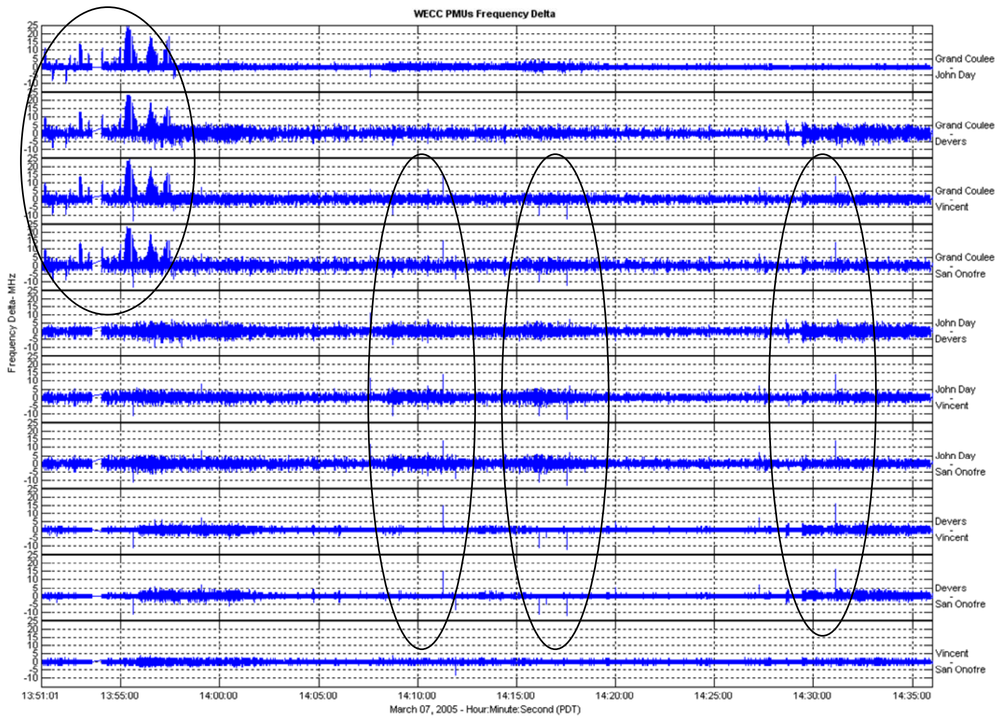


**Figure 5 – WECC Phasor Measurement Units (PMU) Delta Frequency**

The specific requirements for phasor data quality for FMA are:

- Appropriate and effective phasor-data filters warranting high phasor data accuracy, and consequently accurate analysis plots
- Automatic switching to predefined alternate phasor data sources for frequency, when the main phasor data sources become unavailable or data is inaccurate
- Identifiers or flags indicating if FMA phasor data is raw or is filtered data
- Clearly and easily identify what are the time periods the phasor data is missing, have gaps or the accuracy is questionable
- Indicators to clearly show when users need to switch to use the 10-second NERC data, because unavailability or inaccuracies of the phasor data

# 6 Event Data Collection and Archiving Requirements

Collect frequency data from different data sources at scan rates of 1 and 0.1 second (100 milliseconds intervals) following specific trigger conditions will be included. The requirements for this option will meet the following requirements:

6.1 A "first in, first out" (FIFO) buffer of at least six hundred (600) samples collected each 0.1 seconds (100 millisecond samples collected for one minute) shall be populated continuously for each Interconnection.

6.2 Upon the occurrence of one of the trigger conditions (defined below) the FIFO Buffer and at least six thousand (6,000) samples collected each 0.1 seconds (100 millisecond samples collected for ten minutes) shall be archived in a manner similar to standard frequency data for future access.
6.3 Sufficient resources should be allocated to locally store up to one year of triggered events per site.
6.4 Options for increasing the sample period from ten (10) minutes to:
- Fifteen minutes, nine thousand (9,000) samples collected each 0.1 seconds.
- Thirty minutes, eighteen thousand (18,000) samples collected each 0.1 seconds.

6.5 Trigger conditions should be flexible and programmable and are required to be independent for each site. At a minimum the trigger conditions should include the following classes of conditions:
- Frequency magnitude, high and low.
- Frequency rate of change magnitude, positive and negative, over one or more scan cycle.
- Manual request received from NERC Resource Adequacy Real Time Monitoring application.
- Monitoring of measure differences within the Interconnection between instruments to ensure accuracy of measures being stored and quick identification of timing or measurement errors attributable to equipment failure or communications issues.

# 7 Data Processing, Storage and Access

This section lists the technical requirements for the FMA project data processing, storage, access, and system interface.
7.1 Frequency data for each of the sites shall be archived as per the following specifications:
- Frequency data shall be archived from different data sources at resolutions of 1, and 10 seconds.
- Resolution of the archived data shall be to 0.001 Hz (three decimal places).
- On line access to the archived data shall be maintained for a minimum of five (5) years. 1-year archive initially for 10-seconds data.

7.2 Scheduled frequency set point data for the Eastern Interconnection shall be collected from the appropriate Interconnection Time Monitor; time stamped to the nearest 0.01 second and stored concurrently with the frequency data. This data shall be utilized to calculate frequency error as the difference between measured frequency and set point frequency.
7.3 Secure access to archived frequency data will be provided as per the following specifications:
- Data shall be made available to approved personnel via visualization, on line system with very similar graphical visual infrastructure as NERC Real Time monitoring applications.
- Initially NERC Registry User Name and Password will secure the FMA System. Archived frequency data shall be available to approved personnel on 24 hours per day, 7 days per week basis. Data is to be available no later than one hour and fifteen minutes after real time (i.e., data for the previous hour shall be available no later than fifteen minutes after the end of the hour).
- Access security to the frequency data shall be as per best available industry database security technology and shall at a minimum include:
    - Multiple level of access with capability for administrator read/write and read only access.
    - Tools to prevent, detect, and recover from unauthorized access to the database.
    - Periodic reporting of security threats and violations.

7.4 Data quality and database integrity shall be monitored and maintained as per best available industry practices, and shall include, at a minimum:
- Statistical data quality assurance procedures to:
    - Identify, flag, and alarm potential errors induced by malfunctions in communications or database server equipment.
    - Correct recoverable errors via error correction codes, redundant transmittal or other means as deemed necessary and prudent.

- Database integrity and recovery procedures, including:
    - Periodic backup of databases.
    - Off site storage of back up data
    - Redundant equipment
    - Backup site capability

# 8 Data Requirements

Frequency and Time Error Correction (TEC) data should be colleted and archived for all the sources defined in this specification for all four North American interconnections with periodicities of 10, and 1 second for up to 5 years.

**DatAWare and Other Databases Requirement**

5-year 1 second averaged frequency will be available online, and maintained at TVA. Frequency data will be archived in TVA DatAWare software. DatAWare stores data in [timestamp, value, data quality] format. A unique point is assigned to pointer a series of data in above format. In DatAWare, point indices will be created for selected PMUs' frequency signals. For every PMU, if there is new frequency data, the frequency data and its quality along with the timestamp will be archived.

Historic ten second resolution Interconnections frequency and NetACE data will be collected from the NERC ICCP system

Time Error Correction (TEC) data will be available from the NERC Resource Adequacy Outsource Intelligent Alarm and Event processor.

# 9 Data Collection Requirements

For user data collection the user interface should be very similar to the current data collection capability of the NERC Resource Adequacy application and allow setting the data collection independently for each interconnection, for 10-minutes, hourly, daily, monthly, quarterly, yearly or any user selected time period, and for continuous or event data The data collection must allow for user collection of any or all of the PMU data sources, the frequency sensitivities between 2 consecutive seconds, and the equivalent sensitivities for 10-second data together with the interconnection DeltaFreq [mHz]/NetACE[MW] sensitivity.

# 10 Visualization Requirements

The displays and reports should meet the following requirements:

- Individual users will be able to customize their home page to display data in their preferred time zone. This same time zone preference will be used when generating reports.
- User interface system needs to be able to accommodate both 23 and 24 hours days that occur during seasonal time zone conversions.
- The user will have the capability to upload any period of time up to five years and see the selected data on the data collection display.

## 10.1 Visualization Functional Categories

The required visualization will contain the following six functional categories:

- Interconnections Frequency Performance
- Benchmarking Frequency Response
- Frequency Excursion (Events) Review
- Time Error Correction Analysis
- Frequency Trends
- Frequency Events - Disturbances

## 10.2 Displays Sets Definition for Each Functional Category

Table 1 describes the plots distribution for the default two sets of 4-Panel displays for each FMA category.

**Table 1 – Plots Distribution for the Two Default Sets for Each FMA Display Category**

| Plots for 4-panel Display Set 1,2 / FMA Display Categories | Set-1 Displays | | | | Set-2 Displays | | | |
|---|---|---|---|---|---|---|---|---|
| | **Panel-1 Plot** | **Panel-2 Plot** | **Panel-3 Plot** | **Panel-4 Tabular** | **Panel-1 Plot** | **Panel-2 Plot** | **Panel-3 Plot** | **Panel-4 Tabular** |
| Interconnections Frequency Performance | Plot-7 | Plot-8 | Plot-9 | Text | N/A | N/A | N/A | Text |
| Benchmarking Frequency Response | Plot-13 | Plot-14 | Plot-12 | Text | Plot-11 | Plot-13 | Plot-14 | Text |
| Frequency Excursion (Events) Review | Plot-18 | Plot-17 | Plot-19 | Text | Plot-16 | Plot-20 | Plot-15 | Text |
| Time Error Correction Analysis | Plot-21 | Plot-22 | N/A | Text | N/A | N/A | N/A | Text |
| Frequency Trends | Plot-23 | Plot-24 | Plot-25 | Text | N/A | N/A | N/A | Text |
| Future New Category | N/A | N/A | N/A | Text | N/A | N/A | N/A | Text |

## 10.3 Displays Selection and Navigation

Following are basic sequential steps for visualization navigation:

- Select Interconnection
- Define start/end date/time for time-window to display
- Select Display Functional Category
- Select Display Subset from category selected
- Option to select special display configurations

Figure 6 shows an overview of the required visualization navigation.

# VISUALIZATION NAVIGATION

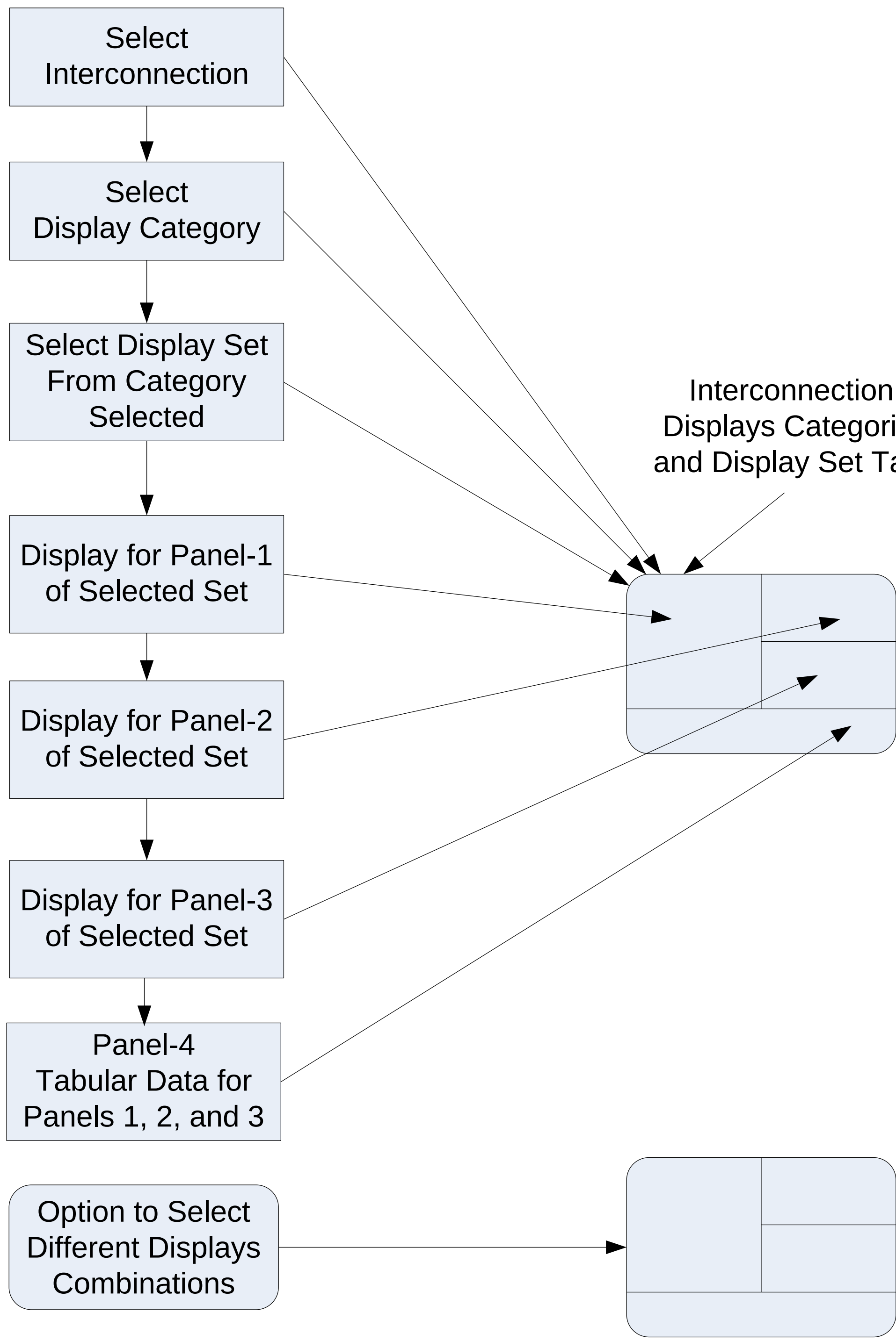


**Figure 6 – Visualization Navigation and Implementation Overview**

## 10.4 Interconnection Frequency Performance Display Metrics Category

Figure 7 and 8 shows 1-minute Daily RMS 1 and Frequency Deviation (Using selected date range and periodicity).

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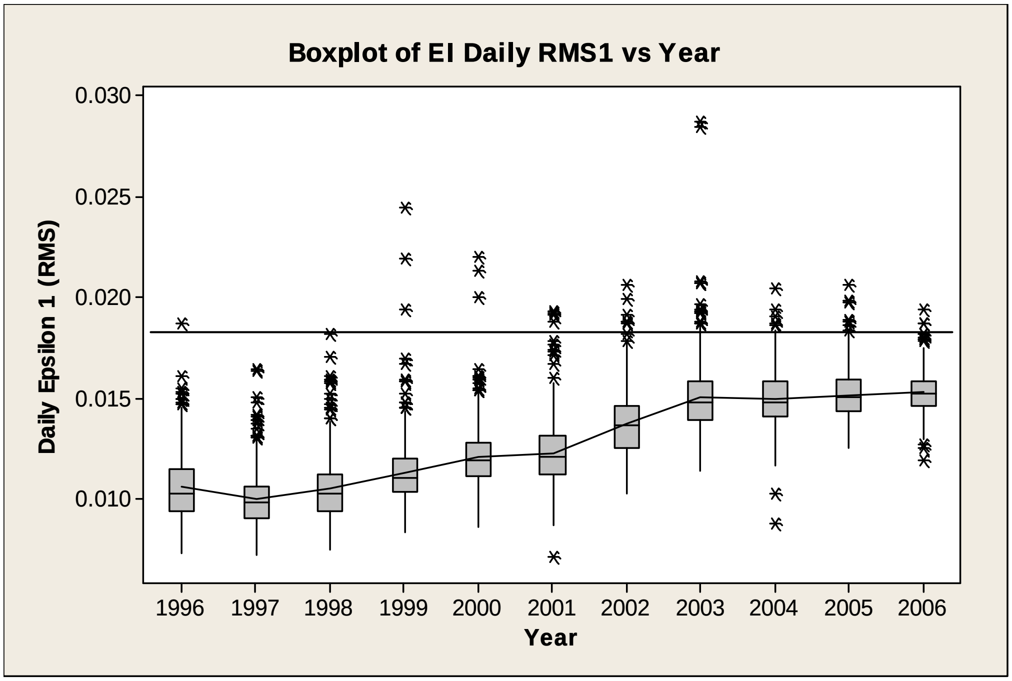


**Figure 7 - RMS 1 (Using Selected Date Range and Periodicity)**

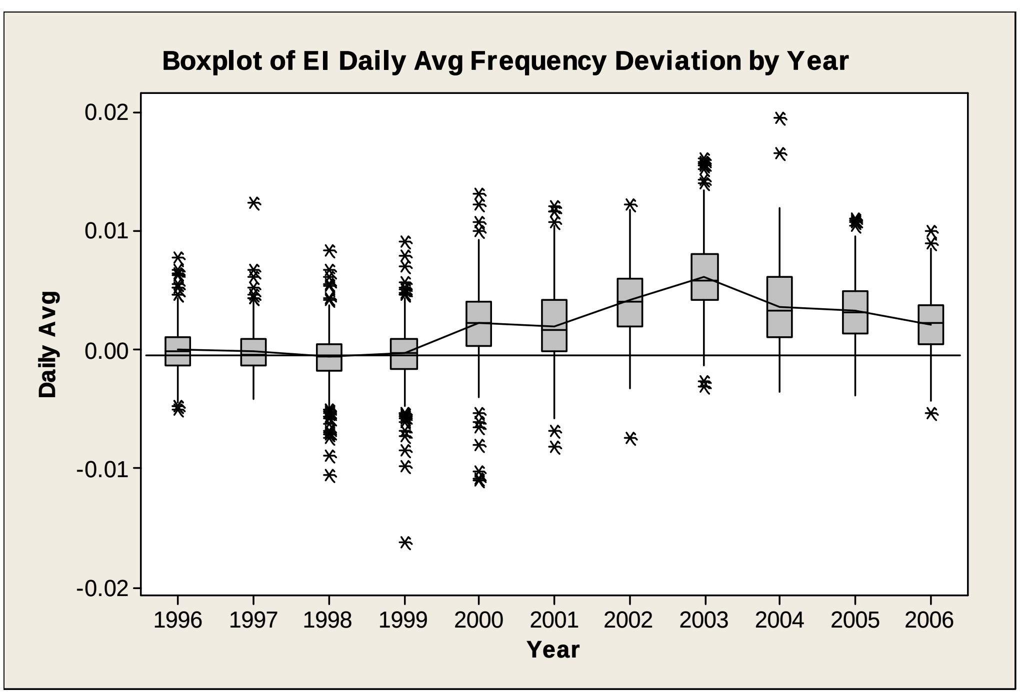


**Figure 8 - Frequency Deviation (Using Selected Date Range and Periodicity)**

Figure 9 show the 1-minute Xbar-R chart (Using selected date range and periodicity). CPS1 is defined in Appendix-C; a sample size of 10000 minutes will give the number of yearly samples shown in Figure 9.

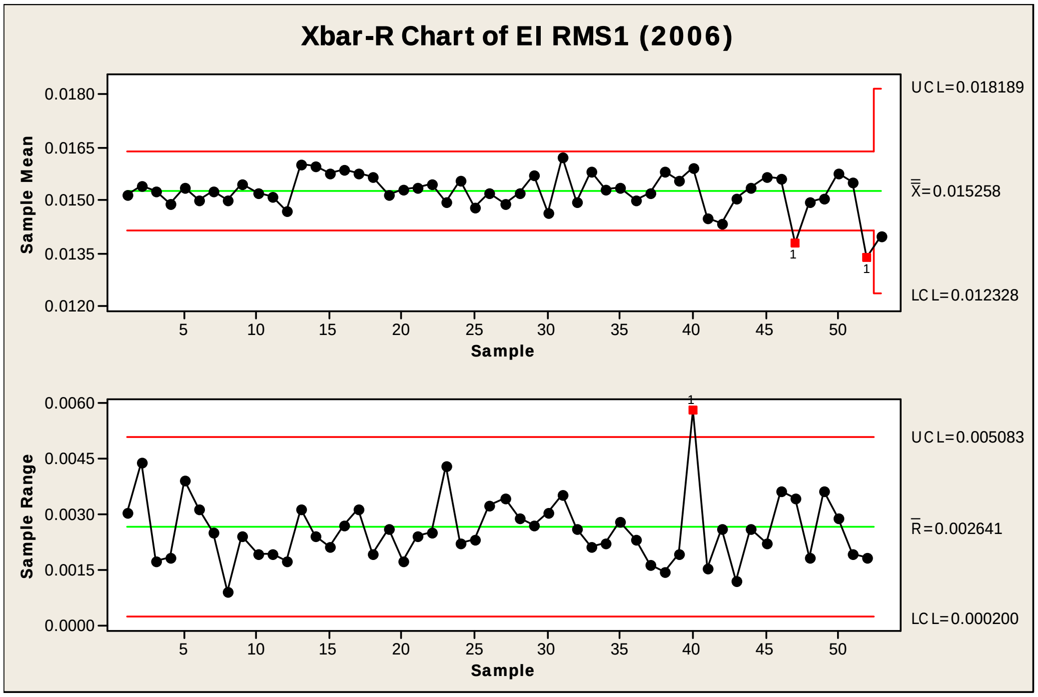


**Figure 9 – Xbar-R Chart (Using Selected Date Range and Periodicity)**

Figure 10 shows the table for the five nosiest days (Using selected date range and periodicity) for each year using the RMS1 as the criteria

| Month | Day | Year | Daily Avg | StDev | RMS1 |
|---|---|---|---|---|---|
| 7 | 23 | 1999 | -0.0073 | 0.0206 | 0.0219 |
| 7 | 29 | 1999 | -0.0162 | 0.0183 | 0.0244 |
| 4 | 17 | 2000 | 0.0123 | 0.0158 | 0.0200 |
| 5 | 9 | 2000 | 0.0131 | 0.0168 | 0.0213 |
| 11 | 15 | 2000 | 0.0037 | 0.0217 | 0.0220 |
| 7 | 15 | 2002 | 0.0103 | 0.0178 | 0.0206 |
| 12 | 15 | 2002 | 0.0116 | 0.0162 | 0.0199 |
| 8 | 2 | 2003 | 0.0158 | 0.0134 | 0.0207 |
| 8 | 3 | 2003 | 0.0152 | 0.0142 | 0.0208 |
| 8 | 7 | 2003 | 0.0143 | 0.0134 | 0.0196 |
| 8 | 14 | 2003 | 0.0157 | 0.0240 | 0.0287 |
| 8 | 15 | 2003 | 0.0161 | 0.0235 | 0.0284 |
| 8 | 16 | 2003 | 0.0065 | 0.0183 | 0.0194 |
| 11 | 24 | 2003 | 0.0089 | 0.0187 | 0.0207 |
| 2 | 9 | 2004 | 0.0108 | 0.0162 | 0.0194 |

**Figure 10 – Nosiest Days (Using Selected Date Range and Periodicity)**

## 10.5 Benchmarking Frequency Response Category

Figure 11 shows the historical interconnection Beta and the Current Interconnection Beta (Using selected date range and periodicity). Attachment-A describes the first method required to calculate interconnections frequency response. The second method will use a combination of dynamic data collected by this application and static data entered by NERC-RS via the date entry display.

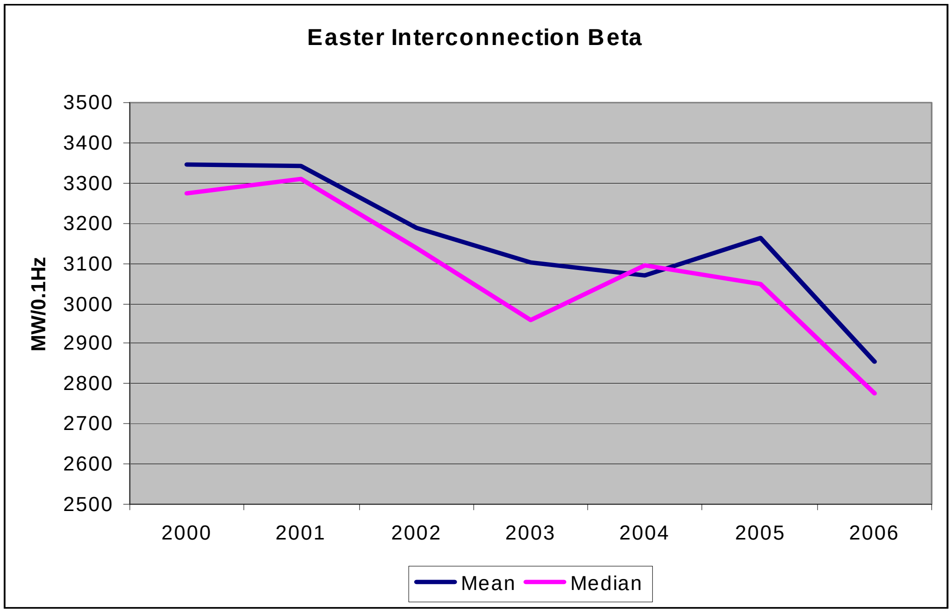


**Figure 11 – Interconnection Current Beta (Using Selected Date Range and Periodicity)**

Figure 12 and 13 shows the interconnection Frequency response and the MW/0.10 Hz vs. Minimum frequency charts (Point-C, Using selected date range). The Matlab produce equivalent Descriptive Statistics is acceptable.

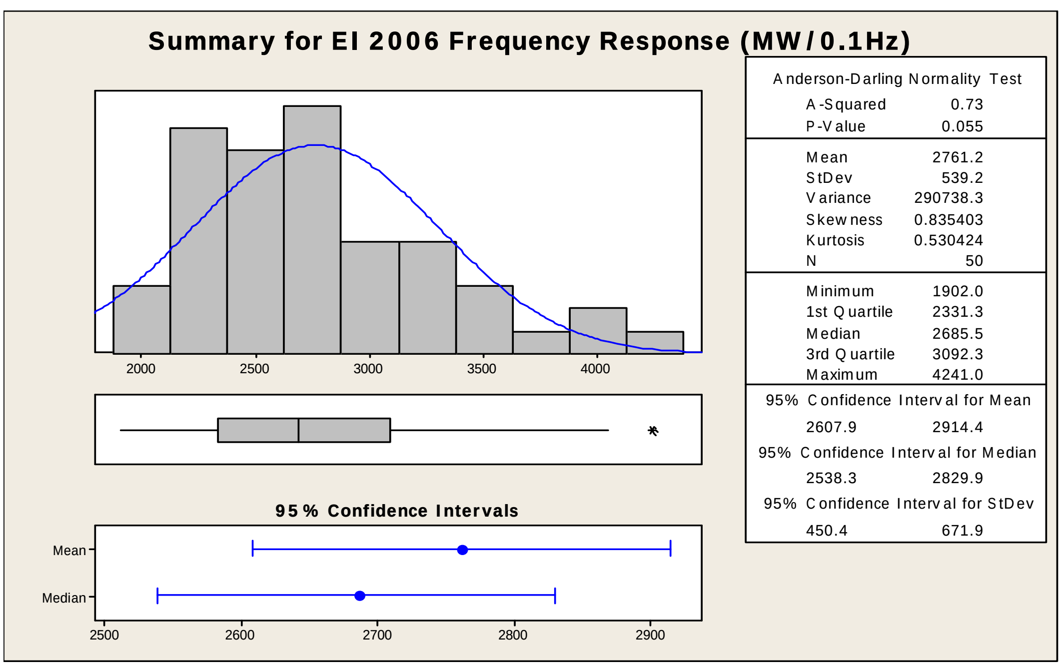


**Figure 12 – Interconnection Frequency Response Point C (Using Selected Date Range)**

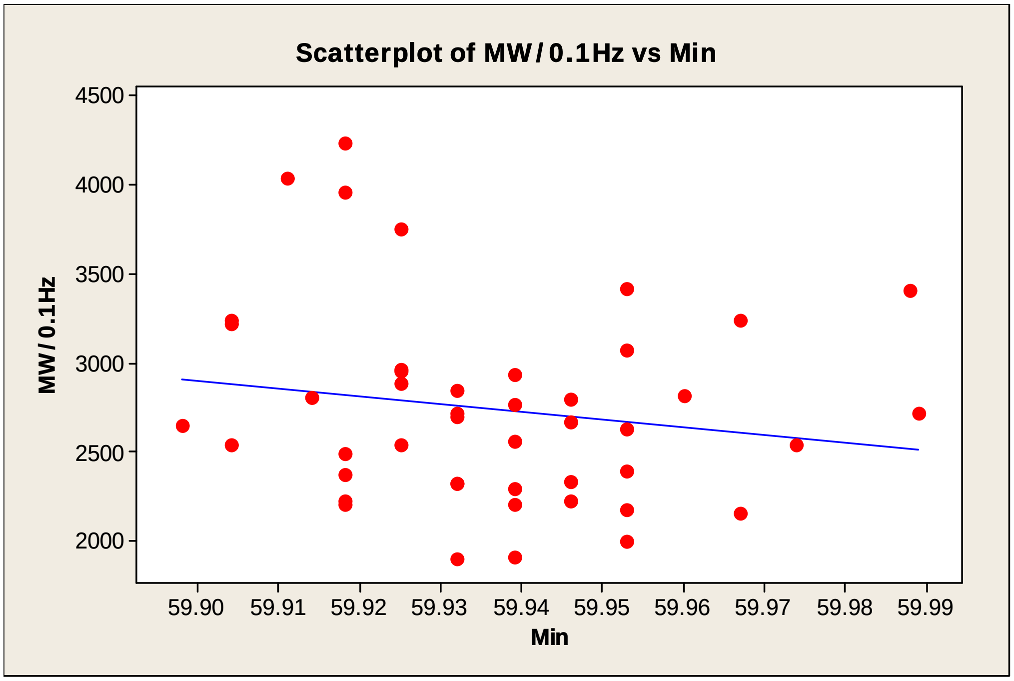


**Figure 13 – Interconnection MW/0.1 Hz vs. Minimum Frequency (Point-C, Using Date Range)**

Figure 14 shows the MW/0.1 HZ vs. Size of Resource loss (Using selected date range).

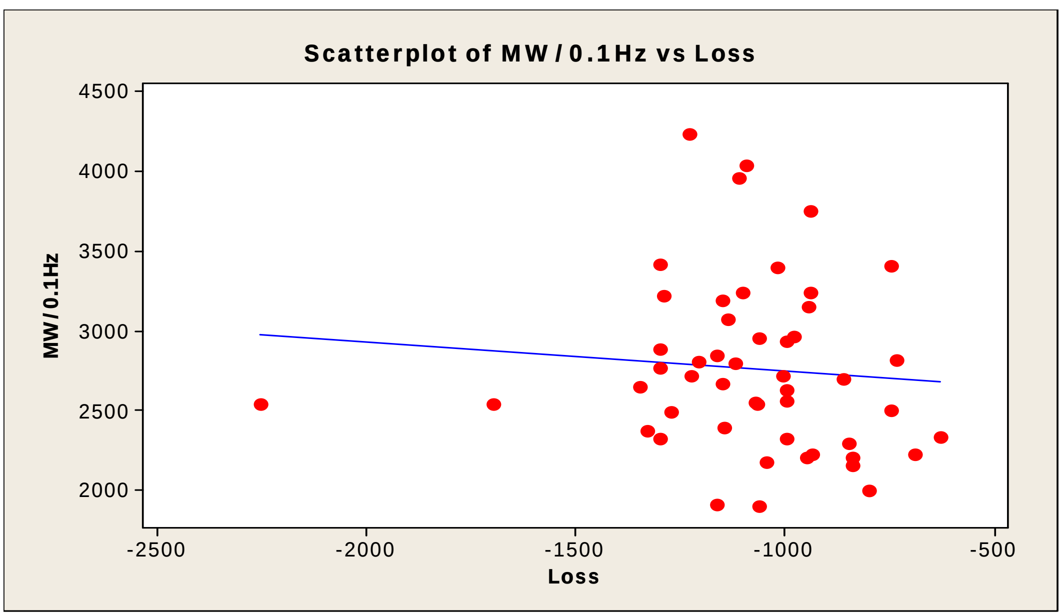


**Figure 14 – Interconnection MW/0.1 Hz vs. Size of Resource Loss (Using Selected Date Range)**

### 10.6 Frequency Excursion (Events) Review Category

Figure 15 and 16 show a Typical Frequency Event, and the counts of events (Using selected date range and periodicity). Negative bars represent the count of events whose frequency deviation is LT -50 mHz.

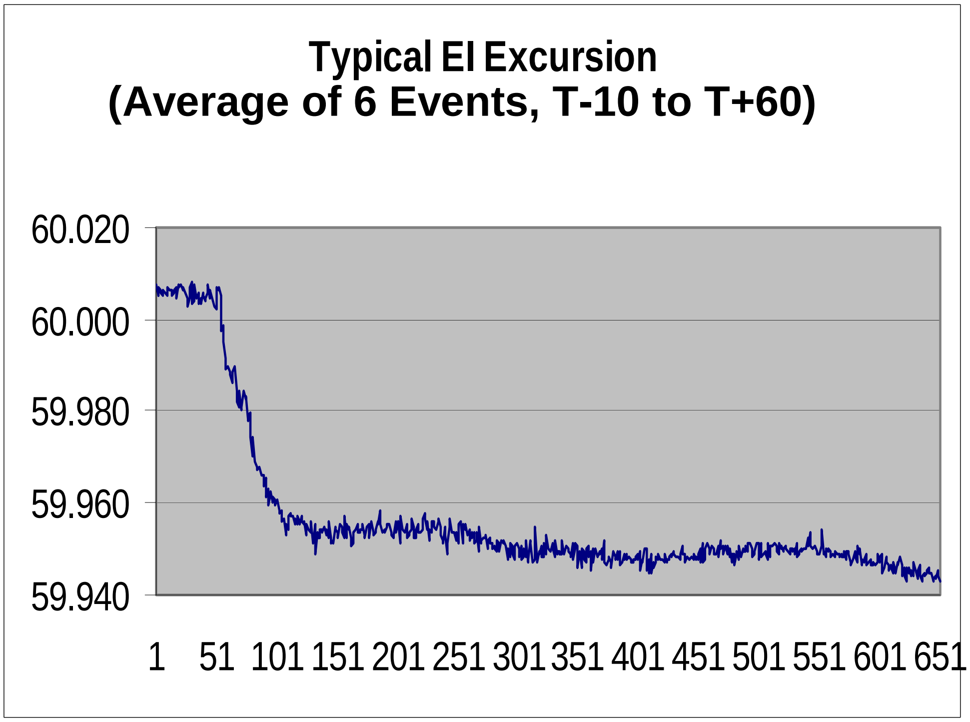


**Figure 15 – Interconnection Typical Low Frequency Event**

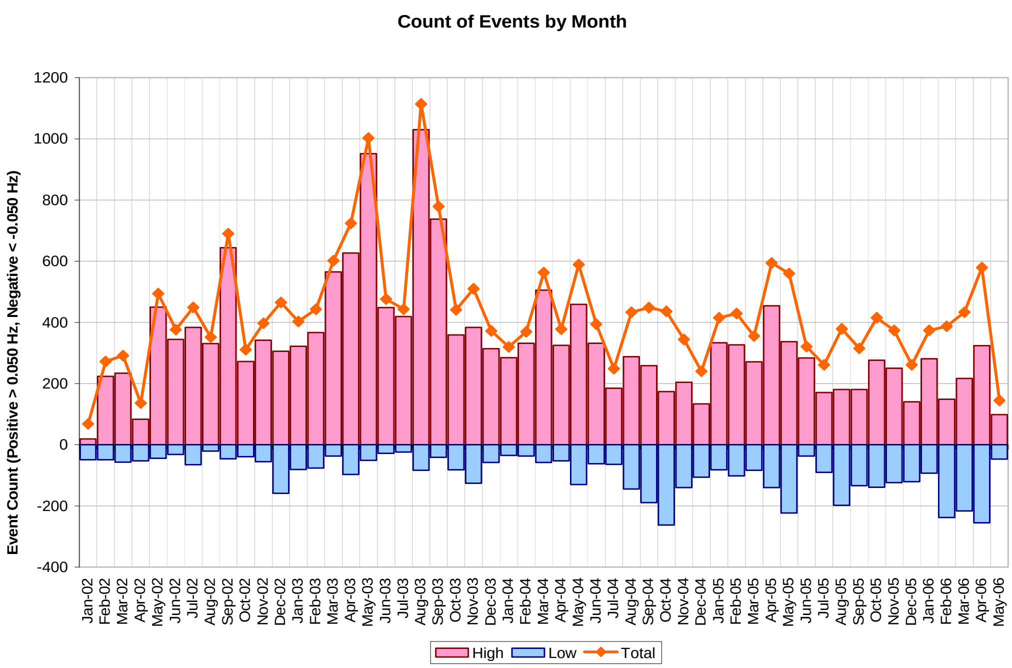


**Figure 16 – Count of Events (Using Selected Date Range and Periodicity)**

Figure 17 and 18 show the probability of Frequency of Events and the count of frequency disturbances (Using selected date range and periodicity), and Figure 19 shows the average duration length charts.

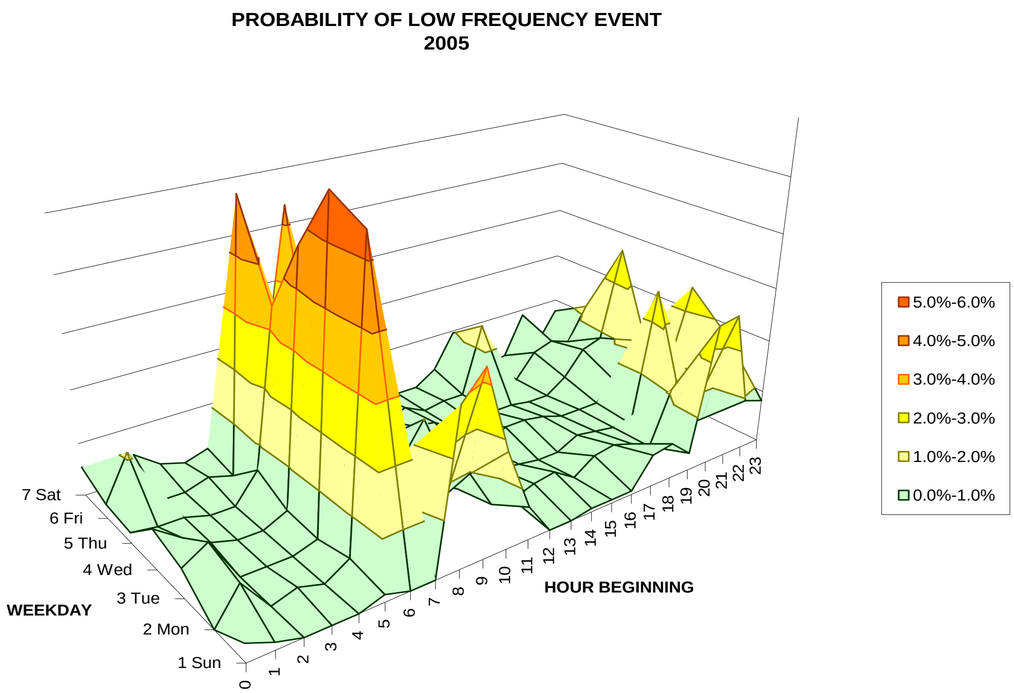


**Figure 17 – Probability of Frequency of Events (Using Selected Date Range and Periodicity)**

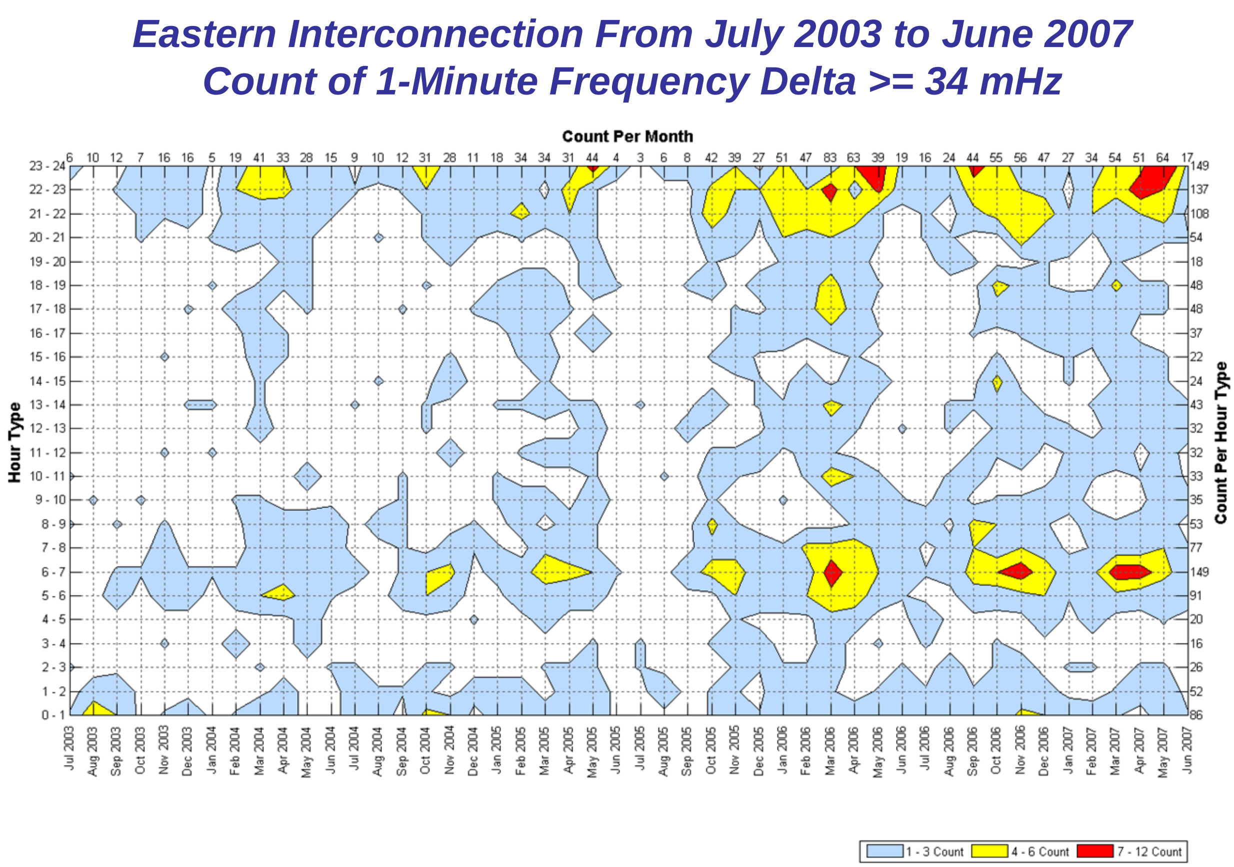


**Figure 18 – Count of Frequency Disturbances (Using Selected Date Range and Periodicity)**

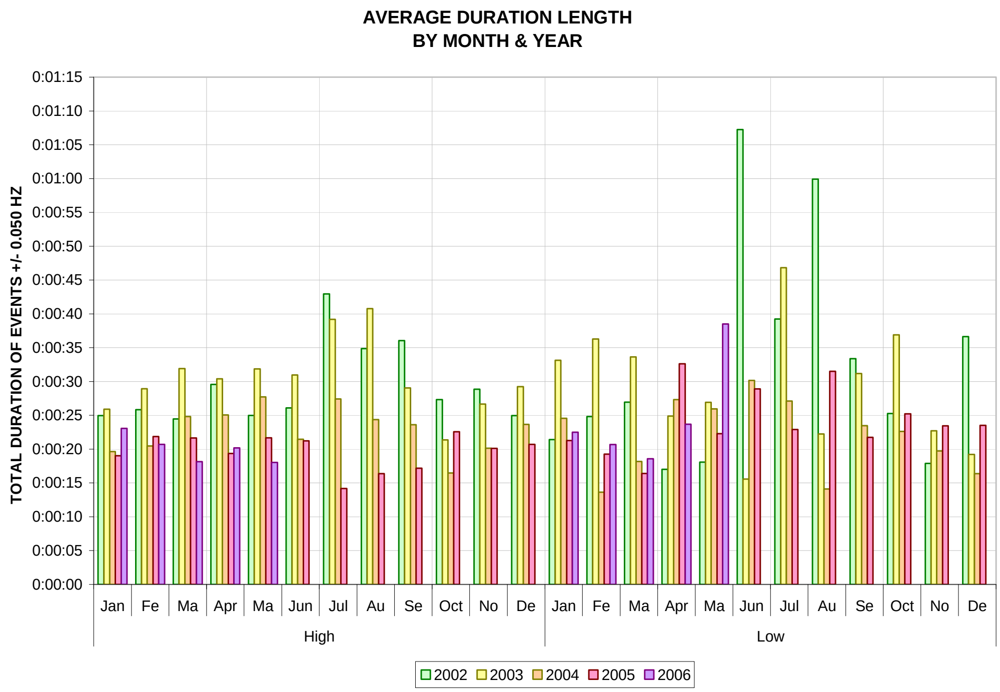


**Figure 19 – Average Duration Length**

Figure 20 shows the count of events grouped by duration - (Still waiting for WECC definition)

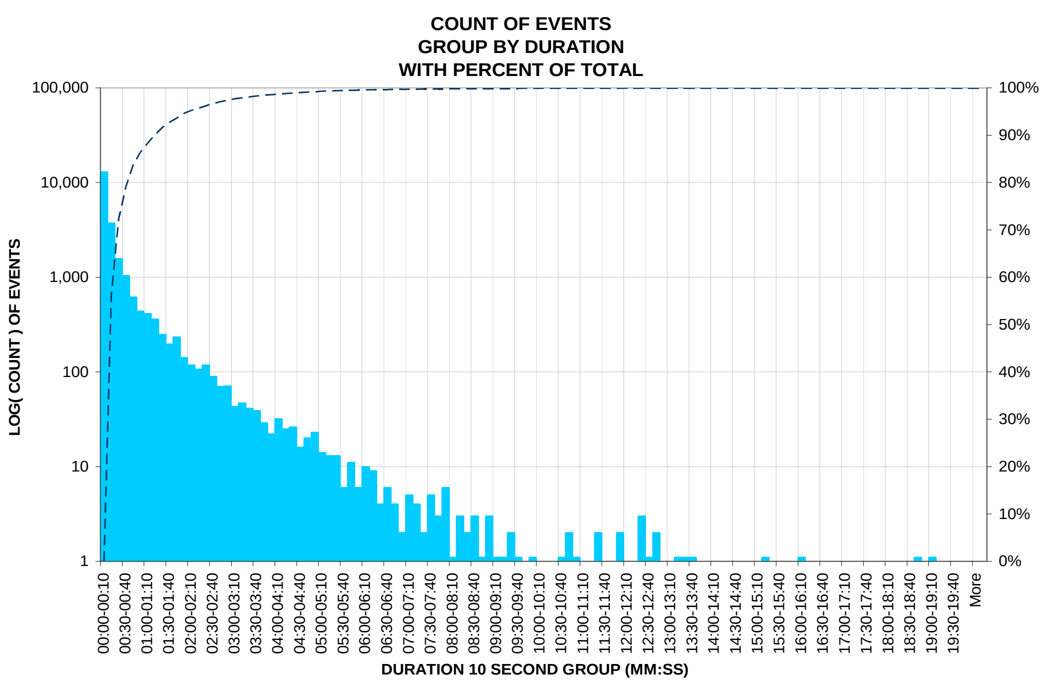


**Figure 20 – Count of Events Grouped by Duration**

## 10.7 Time Error Correction Analysis Category

Figure 21 shows an example of the Time Error Summary chart (Using selected date range and periodicity). Figure 22 shows the time error vs. the average frequency error with all manual TEC excluded (Using selected date range and periodicity).

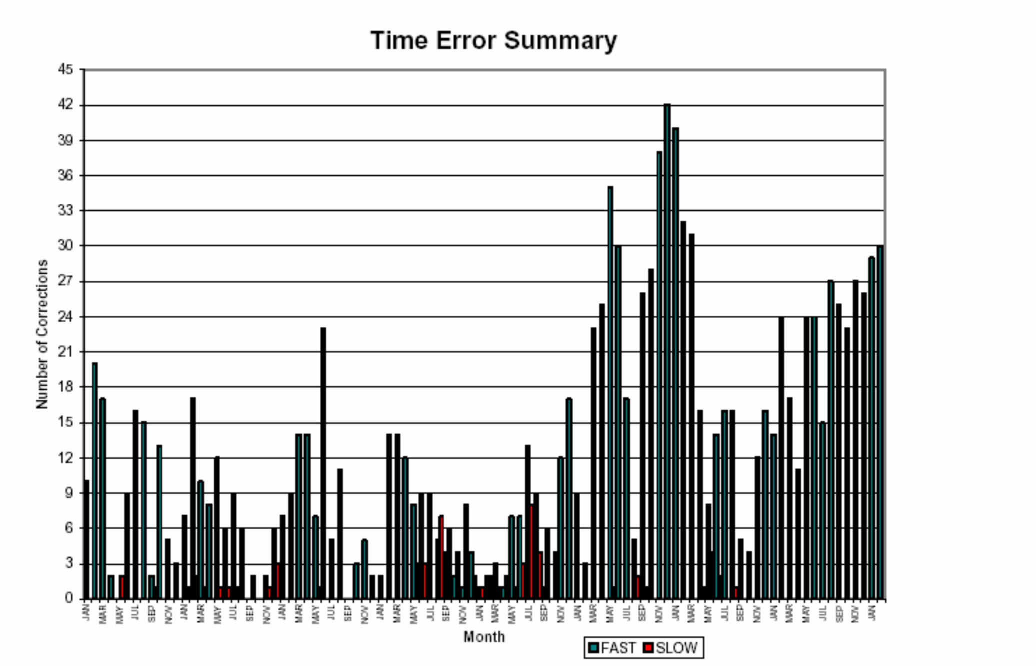


**Figure 21 – Time Error Summary (Using Selected Date Range and Periodicity)**

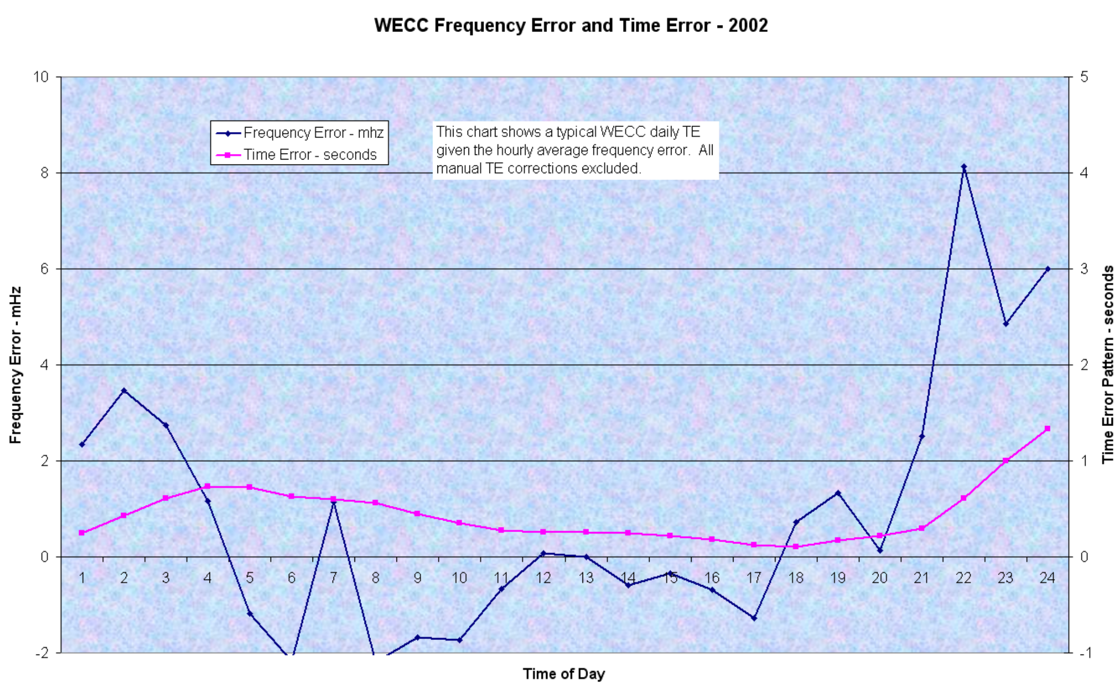


**Figure 22 –Time Error vs. Average Frequency Error (Using Selected Date Range and Periodicity)**

## 10.8 Frequency Trends Category

Figure 23 shows the frequency trends (Using selected date range and periodicity). This chart shows how the frequency profile in the 1, 5, 10, 20, 30, 45 and 60 minute time frames has changed since 1998. The standard profile, dark blue-line (133. 28, 23.08, 10.32, 7.30, 5.16, 4.21, 3.44, 2.98) has one observed data point, the 10 minute frequency profile. The other points are derived from the 10- minute frequency observations. All the other lines should be actual data from the different years. Figure 24 shows the

Frequency Rolling Trend (Using selected date range and periodicity).Figure 25 shows the Frequency Error from the Mean (Using selected date range and periodicity).

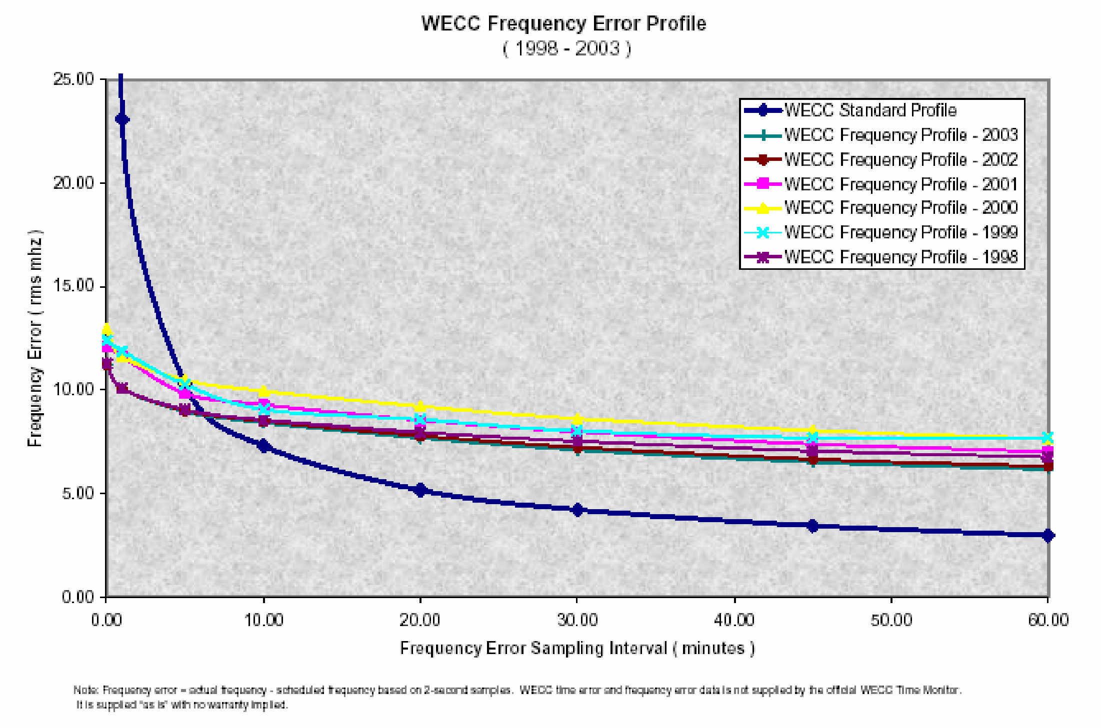


**Figure 23 –Frequency Trend (Using selected date range and periodicity)**

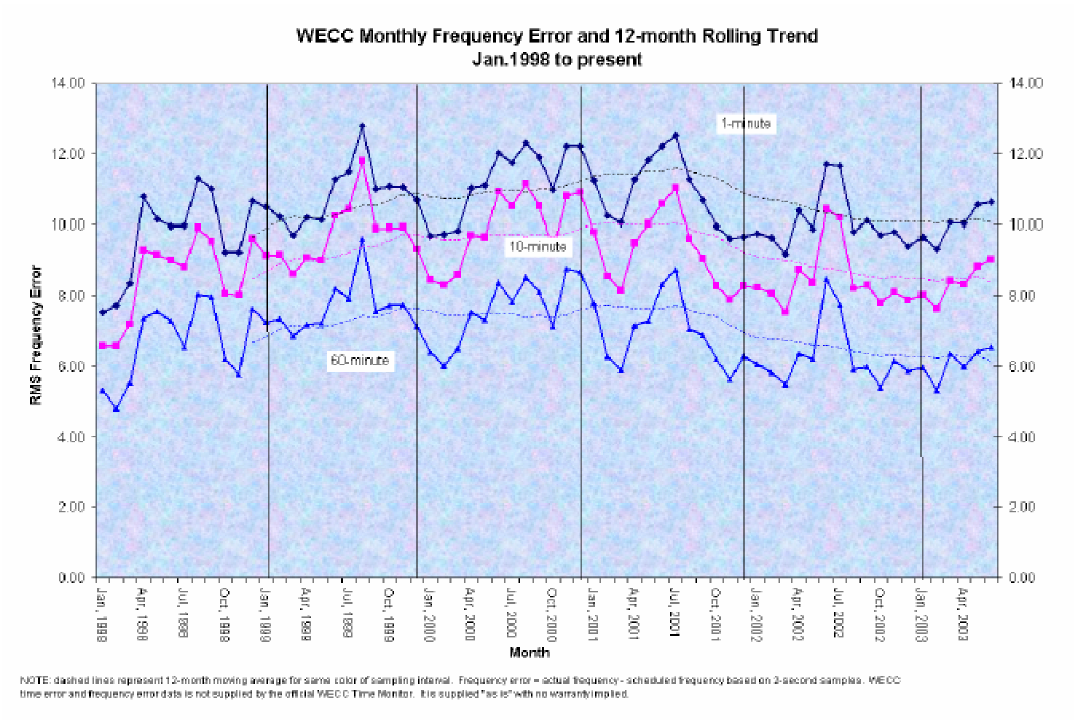


**Figure 24 –Frequency Rolling Trend (Using selected date range and periodicity)**

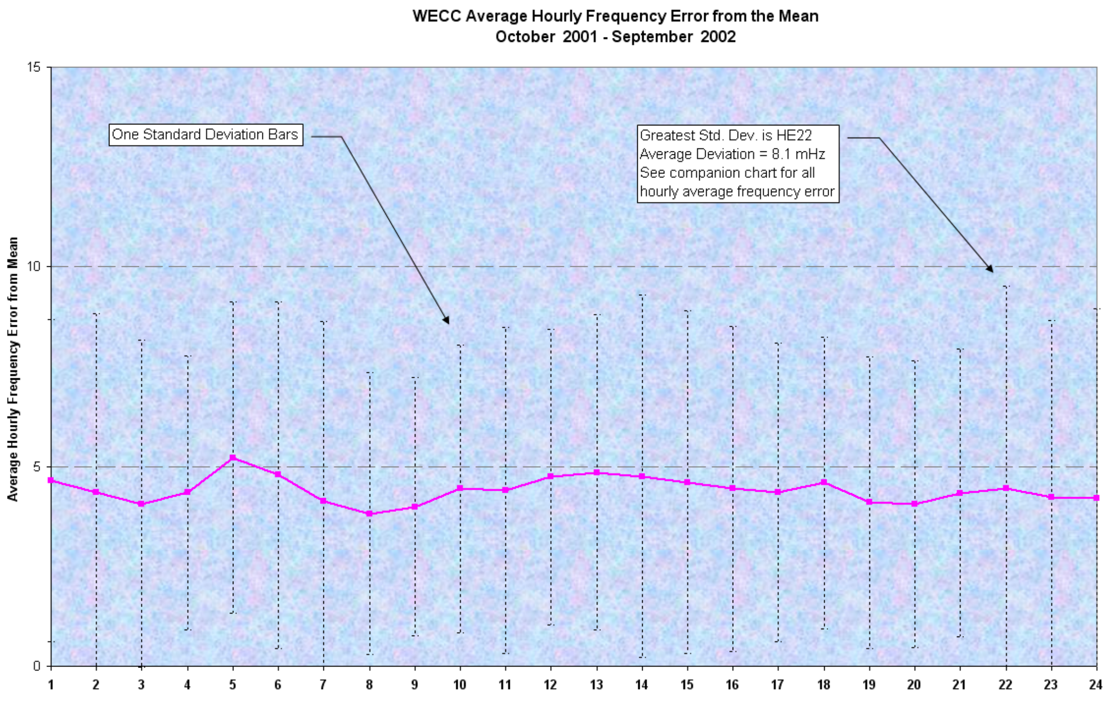


**Figure 25 –Frequency Error from the Mean (Using Selected Date Range and Periodicity)**

# 11 Reporting Requirements

11.1 Periodic and on-demand display and reports on data quality and database integrity with alarm notification shall include at a minimum:

- Error reporting, including NASPI communications errors, database errors and web access errors.
- Approved user list sorted alphabetically, by access authority, by company, by control area and by region.
- Access activity including number of queries and size of queries.
- Database and hardware performance reporting, including communication utilization, processor utilization, maximum, minimum and average query times and maximum, minimum and average user wait times.

11.2 The system shall automatically and periodically prepare routine reports. Where hourly data is displayed, the hours are to be displayed in the user-defined time zone. Each report shall clearly designate at the top where the data is from, and the date and time.

- Graphic output of archived data shall be available in hourly, daily, weekly and monthly standard formats.
- Event driven displays and report shall be available on a per-site basis in both graphic and tabular format for at least the following events:
  - Single sample frequency or frequency error exceeding pre-defined maximum or minimum. Report shall cover period within plus or minus a selected time period of the specified event.
  - Difference between two samples of frequency or frequency error exceeding pre-defined maximum. Report shall cover period within plus or minus a selected time period of the event.
  - Rate of change for any selected number (from two to thirty) successive frequency or frequency error samples exceeding pre-defined maximum. Report shall cover period within plus or minus a selected time period of the event.

  - Ten-minute average frequency or frequency error exceeding pre-defined maximum or minimum. Report shall cover period within plus or minus a selected time period of the ten-minute period.
  - One Hour average frequency error exceeding pre-defined maximum. The report shall cover period within plus or minus a selected time period of the subject hour.
- Database query and report writing tools shall be provided to generate both graphic and tabular format report. Specific capability shall include at a minimum the ability to:
  - Select and report on any selected individual time or date for each site.
  - Select and report on any selected range of times or dates for each site.
  - Select and report on any selected individual frequency or frequency range for each site.
  - Select and report on any selected individual frequency error or range of frequency errors for each site.
  - Select and report on any selected individual sites.
- All data should be exportable to a spreadsheet or database program and graphs should be exportable as either a jpeg or pic file.

11.3 Report generation system needs to be able to accommodate both 23 and 24 hours days that occur during seasonal time zone conversions.

11.4 Predefined queries that would generate tabular reports should be available to all users. The user must have the ability to save these queries and export the data into a spreadsheet or database program.

11.5 Users will be able to create, save, edit, and delete user-defined reports. For user-defined reports, an interface will be developed. This will allow a user to select a wide range of times, data, and values to be calculated and displayed.

11.6 Database query and report writing tools shall be provided to generate tabular format reports. The user needs to be able to save, edit, edit and delete these queries and reports. This function shall be as flexible as possible. Requests shall be enterable fields with a drop down menu for the statistical functions referenced below. Specific capability shall include at a minimum the ability to:

- Select and report on any selected individual time or date for each site.
- Select and report on any selected range of times or dates for each site.
- Select and report on any selected individual frequency or frequency range for each site.
- Select and report on any selected individual frequency error or range of frequency errors for each site.
- Select and report on any selected individual sites.
- Request any of the following types of reports for the above enterable periods and sites.
- Calculate any of the statistical functions listed below for the selected period, and site: RMS, Mean, Median, Mode, Std Deviation, RMS One Minute, RMS Ten Minutes, RMS 60 Minutes, Correlation, Frequency, Min, Max, Variance, Probability

The following reports shall be automatically generated, displayed and saved for the periods and frequencies specified within each report description.

**Daily Reports**

Within fifteen minutes of the receipt of the frequency data a statistical report, containing the information shown in table 2 below shall be prepared and displayed for each site and for the Eastern Interconnection, Western Interconnection, ERCOT, and HQ. Data used will be the data that has passed error checking and has been flagged as valid data. The table shall be updated as each hour is received. Data used in preparing the report shall be the average of the data from three transducer locations in each interconnection. Each daily table shall be retained until the third day of the following month.

The data indicated by asterisks shall be displayed graphically as line charts. Those with the same number of asterisks shall be displayed on the same graph. The graphs shall be updated at the same time as the table.

**Table 2 – Daily Report**

Site or Interconnection
Month, Day and Year

| Hour (GMT) | * Mode | * Median frequency deviation from schedule | * Mean frequency deviation from schedule | Minimum frequency recorded within the hour with Site & Time Stamp | Maximum Frequency recorded within the hour with Site & Time Stamp | ** RMS 1 min | ** RMS 10 minute | ** RMS 60 min | * Std Deviation of frequency deviation |
|---|---|---|---|---|---|---|---|---|---|
| 0100 | | | | | | | | | |
| 0200 | | | | | | | | | |
| 0300 | | | | | | | | | |
| 0400 | | | | | | | | | |
| 0500 | | | | | | | | | |
| 0600 | | | | | | | | | |
| ------ | | | | | | | | | |
| 2200 | | | | | | | | | |
| 2300 | | | | | | | | | |
| 2400 | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

**Monthly Reports**

Within fifteen minutes of the receipt of the frequency data a statistical report, containing the information shown in table 3 below shall be prepared and displayed for each site and for the Eastern Interconnection, Western Interconnection, ERCOT, and HQ. Data used will be the data that has passed error checking and has been flagged as valid data. The table shall be updated as each hour is received. Data used in preparing the report shall be the average of the data from three transducer locations in each interconnection. Once completed Monthly reports shall be retained for a rolling twelve-month period.

Interconnection time error reporting shall be calculated based on each interconnection's scheduled frequency and actual frequency.

The hourly statistical data will be for that specific hour for all days of the given month. Therefore statistical calculations for hour 0300 will be based on the 0300-hour of every day of the selected month.

The data indicated by asterisks shall be displayed graphically as line charts. Those with the same number of asterisks shall be displayed on the same graph. The graphs shall be updated at the same time as the table.

**Table 3 – Monthly Report**

Site or Interconnection
Month/Year

| Hour (GMT) | * Mode | * Median frequency deviation from schedule | * Mean frequency deviation from schedule | Minimum frequency recorded within the hour with Site & Time Stamp | Maximum Frequency recorded within the hour with Site & Time Stamp | ** RMS 1 min | ** RMS 10 minute | ** RMS 60 min | * Std Deviation of frequency deviation |
|---|---|---|---|---|---|---|---|---|---|
| 0100 | | | | | | | | | |
| 0200 | | | | | | | | | |
| 0300 | | | | | | | | | |
| 0400 | | | | | | | | | |
| 0500 | | | | | | | | | |
| 0600 | | | | | | | | | |
| ------ | | | | | | | | | |
| 2200 | | | | | | | | | |
| 2300 | | | | | | | | | |
| 2400 | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

**Daily RMS 1 by Year - Report**

Table 4 below shows a Daily RMS 1 by year report. The table gives the mean, standard deviation, median and maximum for each year.

**Table 4 – Daily RMS by year Report**

| Year | Mean | StDev | Median | Maximum |
|---|---|---|---|---|
| 1996 | 0.0105 | 0.0017 | 0.0102 | 0.0187 |
| 1997 | 0.0100 | 0.0014 | 0.0098 | 0.0164 |
| 1998 | 0.0105 | 0.0016 | 0.0102 | 0.0182 |
| 1999 | 0.0113 | 0.0017 | 0.0110 | 0.0244 |
| 2000 | 0.0121 | 0.0016 | 0.0119 | 0.0220 |
| 2001 | 0.0123 | 0.0017 | 0.0121 | 0.0193 |
| 2002 | 0.0137 | 0.0017 | 0.0136 | 0.0206 |
| 2003 | 0.0150 | 0.0019 | 0.0148 | 0.0287 |
| 2004 | 0.0149 | 0.0014 | 0.0148 | 0.0204 |
| 2005 | 0.0154 | 0.0014 | 0.0153 | 0.0198 |

**On Demand Reports**
(See Appendix-B for data and format sample for this type of on demand report)

## 12 System Security and User Level Assignment

The Frequency Monitoring and Analysis System Administrator will provide user administration functionality for managing users and user rights. This function will provide for user definitions of update and view privileges as well as general security.

## 13 System Availability and Performance Requirements

At least one PMU frequency phasor site in each Interconnection must be in service at all times. The Frequency project is a high availability system. Therefore, the NASPI central storage facilities must have suitable redundancy and UPS. High availability also requires staff support to be available on short notice in order to minimize frequency data collection and analysis downtime for the duration of the system outages. Back-up and disaster recovery shall be fully integrated into the overall design of the system.
To support the high user availability required, the System will support communications access by two separate means:

- The public Internet (initial).
- NERCnet (when approved).

The System will accommodate 30 users simultaneously logged-in with a longest response time for a query or report generation of one minute.

## 14 User Options

Following are the options and application thresholds users can change on the options display.

- Selection of plots for the sets of displays for each visualization category.
- Selection of primary, secondary, and tertiary for 1 and 10 second frequency data sources.
- Selection of each interconnection epsilon reference for RMS plots (defaults: Eastern=18, Western = 12, HQ =7, ERCOT = 10).
- Selection of each Interconnection frequency threshold for the count of frequency disturbances (default: 34 mHz for all Interconnections).

## 15 Testing Process

A Factory Test (FAT) will be provided for NERC's approval at least four weeks prior to the start of any part of the acceptance testing. NERC shall have the right to incorporate additional tests, change the sequence of test, or modify the steps within any test sequence as it sees fit. Acceptance of the System will not take place until successful completion of the steps described in the testing plan. Should the system fail any part of the initial acceptance test, NERC reserves the right at its sole discretion to retest only the system that failed, any parts of the test plan that it deems necessary to ensure that changes have not impacted other parts of the system, or the entire test plan.

## 16 Documentation to Deliver

The following documentation will be delivered as part of the project.

- This Functional Specification
- Testing Plan
- Maintenance Documentation and Database Schema
- User Manual
- Database schema
- On line User Instructions
- Training Instructions – Ability to download, reproduce, and distribute data and images of the each Interconnection frequency display for training and operational purposes.

# 17 System Acceptance

Final system acceptance shall be made in writing by NERC after successful completion of all contractual obligations and technical specifications. Under no circumstances shall the warranty period begin or final payment be made prior to NERC's final acceptance of both, the Data Collection and Transmittal and the Data Processing, Storage, Access and System Interface.

# 18 Implementation Tasks, Schedule and Ownership

| MAJOR TASKS | RESPONSIBLE | COMPLETION DATE |
|---|---|---|
| Meeting with CERTS to define project feasibility using EIPP Phasor Data | Carlos | March 2005 |
| Meeting with TVA to define project requirements and Phasor-Based Architectures | TVA, Bob Cummings and Carlos | April 2005 |
| CERTS create Functional Specification version 0.5 | Carlos | October 2005 |
| Review Functional Specification Version 1.0 | Carlos | January 22 2007 |
| Review Functional Specification Version 1.6 | Carlos | June 30, 2007 |
| Design Specification Version 1.0 | Simon | July 6, 2007 |
| Data Interface, Definition, Coordination and Development with TVA | Thirumaran | July 12, 2007 |
| Application Development | Thirumaran | August 20, 2007 |
| Internal Testing (plan development, bug resolution) – EPG.B, Thirumaran | Thirumaran | August 24 2007 |
| Detail Factory Test Plan, Execution. Pasadena | Simon | September, 24 2007 |
| Random Final Factory Test | Carlos | October 19 2007 |
| NERC-RS Field Trial – NERC-RS | NERC-RS | November 23, 2007 |
| Corrections from Field Trial Final, detail and random FATs After Field Trial | Simon, Carlos | December 7, 2007 |
| Delivery and Training - Frank | Frank | December 20, 2007 |

# Attachment A

**DEFINITIONS:**

**1. Average (Meab), Median, Mode, RMS** (See Wikipedia for Detail Definitions)**:**

The arithmetic mean is defined as

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

The standard deviation of the sample is defined as

$$s = \sqrt{\frac{1}{(n-1)}\left(\sum x_i^2 - n\left(\sum x_i\right)^2\right)}$$

Median = The median is the value such that 50% of the sample cases lie below the value and 50% of the cases above

Mode means the most frequent value assumed by a variable

RMS = Square Root of the square of the mean plus the square of the standard deviation

**2. ACE, ACE components, Unexplained ACE and CPS1:**

*At the Balancing Authority Level:*

$$ACE_{BA} = (ActualInterchange_{BA} - ScheduledInterchange_{BA}) - 10 \times FrequencyBias_{BA} \times (ActualFrequency - ScheduledFrequency)$$

*At the Interconnection Level:*

$$ACE_{Interconnection} = \sum ACE_{BAs} = -10 \times \sum FrequencyBias_{BAs}(ActualFrequency - ScheduledFrequency)$$

*Defining:*

$$ActualACE_{Interconnection} = \sum ACE_{BAs}$$

$$EstimatedACE_{Interconnection} = -10 \times \sum FrequencyBias_{BAs} \times (ActualFrequency - ScheduledFrequency)$$

*Then At The Interconnection Level*

$$ActualACE_{Interconnection} - EstimatedACE_{Interconnection} = 0$$

*Non-Zero Values in the Above Difference*
*Between Interconnection Actual and Estimated ACE Is The*
***Unexplained or Missing ACE***
*Due to Incorrect Schedule Frequency, Missing Schedules, Bad Ties,*
*Wrong Dynamic Schedules, Meter Errors or Inadequate Frequency Response*

## CPS1 Calculation

CPS1 (%) = 100*(2 – (frequency error*ACE)) / k

The constant (k) is based on the size of the control area and an interconnection target variation of the one-minute averages of frequency error.

CPS1 will equal 200% any time frequency is exactly on schedule or control area ACE is zero. Since the constant is based on a target RMS frequency noise roughly 70% greater than historic frequency performance, most control areas score a CPS1 around 160% to 180%.

Minimum acceptable performance is 100% for a rolling 12-month period.

There are two primary problems with CPS1:

1. CPS1 is the average of all the one-minute scores for the past 12 months. A control area can be deficient by a thousand or more Megawatts for several hours and still get an acceptable 12-month rolling score. System disturbances and blackouts are caused by large, short-term problems.

2. Performance is self-calculated and self-reported to NERC.

For the Eastern Interconnection:

CPS1 = (2 - (ACE*(ACTUAL_FREQ - **SCHED_FREQ**)) / (-10*BIAS*0.018*0.018))*100

## Correlation – Use Matlab corresponding commads and programs as reference

For a series of n measurements of X and Y written as $x_i$ and $y_i$ where i = 1, 2, ..., n, then the Pearson product-moment correlation coefficient can be used to estimate the correlation of X and Y . The Pearson coefficient is also known as the "sample correlation coefficient". The Pearson correlation coefficient is then the best estimate of the correlation of X and Y. The Pearson correlation coefficient is defined as:

$$r_{xy} = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{(n-1)s_x s_y}$$

where $\bar{x}$ and $\bar{y}$ are the sample means of $x_i$ and $y_i$ , $s_x$ and $s_y$ are the sample standard deviations of $x_i$ and $y_i$ and the sum is from i = 1 to n.

## Linear Regression – Use Matlab corresponding commands and programs as reference

For linear regression

$$y = \alpha + \beta x + \varepsilon$$

To calculate Alpha and Beta, we sum the observations, the squares of the Ys and Xs and the products XY to obtain the following quantities.

$$S_X = x_1 + x_2 + \cdots + x_n$$

and $S_Y$ similarly.

$$S_{XX} = x_1^2 + x_2^2 + \cdots + x_n^2$$

and $S_{YY}$ similarly.

$$S_{XY} = x_1 y_1 + x_2 y_2 + \cdots + x_n y_n.$$

We use the summary statistics above to calculate $\widehat{\beta}$, the estimate of β.

$$\widehat{\beta} = \frac{nS_{XY} - S_X S_Y}{nS_{XX} - S_X S_X}.$$

We use the estimate of β and the other statistics to estimate α by:

$$\widehat{\alpha} = \frac{S_Y - \widehat{\beta} S_X}{n}.$$

A consequence of this estimate is that the regression line will always pass through the "center"

$$(\bar{x}, \bar{y}) = (S_X/n, S_Y/n).$$

**Time Error Accumulation**

The time error accumulated by a deviation of frequency from normal is given by

$$t = 60(f)(m)/F$$

where *t* is the time error in seconds, *f* is the average frequency deviation in hertz, *m* is the time during which frequency deviation *f* has persisted in minutes, and *F* is schedule system frequency in hertz. Thus, an 0.02-Hz average deviation that persists for 50 min will cause accumulation of a 1-s time error.

## 3. Frequency Response Calculation Using 1-Second Data

### Identification of Frequency Response Curve Points A, B, and C Using 1-Second Data:

An approximate method for defining the three frequency response points is: C= point and minimum event frequency, A=frequency at 2 seconds before the event minimum frequency, and B= frequency after 3 seconds after event minimum frequency – See chart below

Figure 1 shows a trace of an Interconnection's frequency resulting from a generating unit trip ("unit trip" is a term meaning a sudden complete loss of a generator).

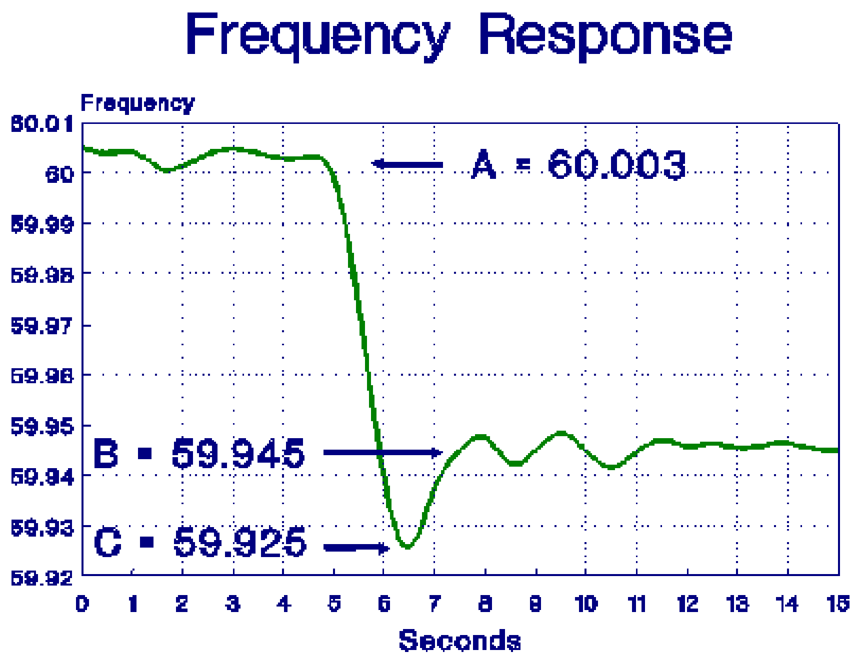


**Figure 1 Typical Frequency Excursion**

NERC references three key events to describe such a disturbance. Point A is the pre-disturbance frequency, typically close to 60 Hz. Point C is the maximum excursion point, while point B is the settling frequency of the Interconnection's frequency.

**Interconnection Frequency Response Calculation Method Using 1-Second Data:**

With 1-second data - With the frequency Points A, B, and C determined, the following table shows the steps 2 to 8 that should be followed to calculate frequency response. The MW for steps 2 and 3 will be the interconnection Net ACETies for 1-minute before point-C and the interconnection Net ACETies for 1-minute after point-C respectively. The MW loss for step-5 will be the difference between the Net ACE Total MW between steps 2 and 3. The MW for steps 2, 3 and 5 should be editable and will be manually edited by End Users.

| AREA FREQUENCY RESPONSE CALCULATION | | | |
|---|---|---|---|
| 2: Actual Net Interchange Immediately Before Disturbance (Point A)* | | | MW |
| 3: Actual Net Interchange Immediately After Disturbance (Point B)* | | | MW |
| 4: Change in Net Interchange | | | MW Line 3 – Line 2 |
| 5: Load (+) or Generation (□) Lost Causing the Disturbance | | | MW |
| 6. Control Area Response | | | MW Line 4 – Line 5 |
| 7. Change in Interconnection Frequency from Point A to Point B | | | Hz (–) for frequency decrease; (+) for frequency increase |
| 8. Frequency Response Characteristic | | | MW/0.1 Hz Line 6 /(Line 7 x 10.0) |
| OTHER INFORMATION | | | |
| 9. Frequency Bias Setting | | | MW/0.1 Hz |
| 10. Net System Demand Immediately Before Disturbance (Point A) | | | MW |
| 11. Synchronized Capacity Immediately Before Disturbance (Point A) | | | MW |
| 12. From your charts | Frequency at Point A | | Hz |
| 13. From your charts | Frequency at Point B | | Hz |
| 14. From your charts | Frequency at Point C | | Hz |

## 4. Interconnection Frequency Response Calculation Method Using 10-Second Data

The following Interconnection Frequency Response formula should be applied for 10-Second and 1-Minute data.

$$\textbf{Frequency Response}_{\textbf{interc}} = \textbf{Bias}_{\textbf{interc}} + (\textbf{Delta NetACE/10 * Delta Frequency})$$

$Bias_{interc}$ = Yearly Interconnection frequency bias;
NetACE = Aggregate of the ACE from all the Balancing Authorities in the interconnection;
Delta NetACE = NetACE change between two consecutive 10-second samples;
Delta Frequency = Frequency change between two consecutive 10-second samples.

# Attachment B

The rank, the loss (MW), the generation location, and the data source columns shown in the table below will be data users will be entering manually in a specific section of the requested static data entry display.

A report with the same format and data is required in addition to the reports described in section

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Please setup your time zone in the red box | | | | | | | | | | | | | | | | | |
| Dalight/Standard | | | | | | | | Your Correction | ------> | See | ------> | ------> | >>>------> >>>---- | ------> | Atlantic | 0 | |
| ^ | YEAR | | 2006 | | | Averages | | 1 | | | | | | Est Loss @ | Eastern | 1 | |
| ^ | mm | dd | hhmm | | | (-5>-1) | (15>20) | | | | MW | | | 28500 | Central | 2 | |
| ^ | | | Atl | Max | Min | Pre | Post | Your Date/Time | DelFreq | Rank | Loss | MW/Hz | Location and Unit(s) | MW / Hz | Mountain | 3 | **Data Sou** |
| S | 1 | 2 | 2409 | | | | | 2006Jan01 23:09 | -0.024 | 42 | | - | gen | 684 | | | NYISO |
| S | 1 | 2 | 1726 | | | | | 2006Jan02 16:26 | -0.023 | 45 | -566 | 24609 | Amos U2 | 656 | | | NYISO |
| S | 1 | 2 | 2245 | | | | | 2006Jan02 21:45 | -0.042 | 8 | -1072 | 25524 | Mt. Storm U2 and U3 | 1197 | | | NYISO |
| S | 1 | 7 | 857 | | | | | 2006Jan07 07:57 | -0.016 | 73 | | - | gen | 456 | | | NYISO |
| S | 1 | 8 | 1859 | | | | | 2006Jan08 17:59 | -0.024 | 42 | -700 | 29167 | Amos U1 | 684 | | | NYISO |
| S | 1 | 10 | 1126 | | | | | 2006Jan10 10:26 | -0.021 | 54 | | - | gen | 599 | | | NYISO |
| S | 1 | 10 | 1656 | | | | | 2006Jan10 15:56 | -0.031 | 20 | -800 | 25806 | Mitchel | 884 | | | NYISO |
| S | 1 | 10 | 1926 | | | | | 2006Jan10 18:26 | -0.019 | 66 | | - | gen | 542 | | | NYISO |
| S | 1 | 15 | 127 | | | | | 2006Jan15 00:27 | | #N/A | -1300 | - | Zimmer | 0 | | | MISO - S |
| S | 1 | 15 | 326 | | | | | 2006Jan15 02:26 | -0.047 | 3 | -1300 | 27660 | Zimmer | 1340 | | | NYISO |
| S | 1 | 16 | 924 | | | | | 2006Jan16 08:24 | -0.027 | 27 | | - | gen | 770 | | | NYISO |
| S | 1 | 20 | 1024 | | | | | 2006Jan20 09:24 | -0.020 | 62 | | - | gen | 570 | | | NYISO |
| S | 1 | 21 | 255 | | | | | 2006Jan21 01:55 | -0.027 | 27 | | - | gen | 770 | | | NYISO |
| S | 1 | 21 | 1556 | | | | | 2006Jan21 14:56 | -0.025 | 37 | | - | gen | 713 | | | NYISO |
| S | 1 | 23 | 513 | | | | | 2006Jan23 04:13 | -0.020 | 62 | | - | gen | 570 | | | NYISO |
| S | 1 | 26 | 1441 | | | | | 2006Jan26 13:41 | -0.022 | 50 | | - | gen | 627 | | | NYISO |
| S | 1 | 29 | 917 | | | | | 2006Jan29 08:17 | -0.030 | 22 | -674 | 22467 | Homer City U3 | 855 | | | NYISO |
| S | 1 | 31 | 1809 | | | | | 2006Jan31 17:09 | -0.021 | 54 | | - | gen | 599 | | | NYISO |
| | | | | | | | | | | | | | | | | | |
| S | 2 | 9 | 901 | | | | | 2006Feb09 08:01 | -0.020 | 62 | | - | gen | 570 | | | NYISO |
| S | 2 | 13 | 1716 | | | | | 2006Feb13 16:16 | -0.021 | 54 | -636 | 30286 | phase 2 | 599 | | | NYISO |
| S | 2 | 16 | 2436 | | | | | 2006Feb15 23:36 | -0.021 | 54 | | - | | 599 | | | NYISO |
| S | 2 | 17 | 227 | | | | | 2006Feb17 01:27 | -0.025 | 37 | | - | | 713 | | | NYISO |
| S | 2 | 18 | 2025 | | | | | 2006Feb18 19:25 | -0.015 | 74 | -601 | 40067 | Astoria 1 | 428 | | | NYISO |
| S | 2 | 19 | 1708 | | | | | 2006Feb19 16:08 | -0.044 | 6 | -1300 | 29545 | Zimmer | 1254 | | | NYISO |
| S | 2 | 22 | 323 | | | | | 2006Feb22 02:23 | -0.025 | 37 | | - | gen | 713 | | | NYISO |
| S | 2 | 23 | 1113 | | | | | 2006Feb23 10:13 | -0.028 | 24 | -940 | 33571 | Millstone U2 | 798 | | | NYISO |