**C**onsortium for
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Real Time
Wide-Area
Monitoring,
Control and
Protection

# PHASOR DATA REQUIREMENTS FOR

## Real Time Wide-Area Monitoring, Control and Protection Applications

## White Paper – Final Draft

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# 1. INTRODUCTION

Competitive markets, aging transmission lines, lack of transmission expansion and environmental constraints among other things are forcing power systems to operate closer to their limits and to utilize the existing assets more efficiently. To operate under these constraints and still maintain high reliability is a very challenging task requiring new real time wide-area tools using phasor technologies and multi-view visualization solutions.

Real Time Wide-Area Monitoring, Control and Protection systems, as complements to SCADA and EMS systems, have been proposed by the Consortium for Electricity Reliability Solutions (CERTS) and other organizations during the last couple of years, and are now emerging worldwide. Phasor technologies, ranging from new hardware, data communications, application software, and new real time risk based monitoring paradigms are being researched and prototyped to respond to the challenging operational mission. In North America some of these systems are already being used by Reliability Coordinators whose charter and responsibility is to monitor and maintain system reliability within their jurisdictions that usually include different controls areas in a wide geographical area [1], [2].

Phasor measurements have been developed both in the lab and in the field and have been used over the last 20 years. The resulting end-measurement device is the Phasor Measurement Unit (PMU). Its capabilities for high precision, speed of response and time synchronization make PMUs very appropriate for wide area steady-state and stability monitoring for Reliability Coordinators as well as for protection and control. An additional device, the Phasor Data Concentrator (PDC) has been under development for about 10 years, and is a multi-CPU device that allows for the collection, concentration, correlation, and synchronization of phasor data from different PMUs and from other PDCs. Recent computer-based architectures interconnected via wide area networks utilizing PMU data and archiving databases are becoming new cost-effective solutions and are now commercially available.

The objective of this white paper is to, first review the progress and evolution of phasor technology in different parts of the world and, second to identify and describe the functional requirements of those real time wide-area applications that have been found to respond the best for Real Time Wide-Area Monitoring, Control and Protection tasks. And third, using the functional requirements identified, to describe and summarize the phasor data requirements for each application in the tools portfolio for wide area monitoring, control and protection.

# 2. BACKGROUND

During the last five years research, development and applications of phasor measurement systems have been reported in public documents by other countries. The following review summarizes the major phasor-based application developments in those countries that have the most experience with the application of phasor technologies in wide area monitoring, analysis, control and protection. [3], [4], [5], [6], [7], [8].

## 2.1 Phasor Technology - World Wide Research, Development, and Applications

**North America**

A commercial monitor for making synchronized measurements in the form of phasors evolved from a research effort funded by the Department of Energy (DOE) in the mid 1980s. The first digital version was developed at Virginia Tech. Later, Macrodyne designed and built a commercial unit around the original concept developed at Virginia Tech. These initial monitors could filter and digitize the power system's frequency variations and instantaneous voltage and current, up to a sample rate of 2880 samples per second or 48 samples per cycle. Furthermore real and reactive power could be then calculated based on the voltage and current phasor measurement values.

Two major projects demonstrated the utilization of GPS synchronized power system measurements in North America. In 1992, the Electric Power Research Institute's (EPRI) sponsored a Phasor Measurements Project using a commercially available Phasor Measurements Unit (PMU) to collect GPS-synchronized measurements for analyzing power system problems. In 1995, Bonneville Power Administration (BPA) and Western Area Power Administration (WAPA) under DOE's and EPRI"s sponsorship launched the Wide Area Measurements (WAMS) project. WAMS demonstrated the use of GPS-synchronized measurements over a large area of their power networks and demonstrated the networking of GPS-based measurement systems in BPA and WAPA. The project was timely in that real time measurements were taken during both July 2$^{nd}$ and August 10$^{th}$ power system breakups and blackouts that occurred in the western U.S. interconnection during 1996. Since then phasor measurements have been used for blackouts post analysis and assessment, including the August, 2003 blackout.

Currently, there are more than twenty North American utilities that have PMUs installed in their substations. However, the current levels of development of these experiences are not the same. While several of the Eastern Interconnection utilities are in the initial stages of implementing and networking PMUs, utilities in the Western Interconnection, stimulated by the WAMS project, have already developed a wide area phasor network in conjunction with monitoring and post-disturbance tools that are based on phasor measurements. Plans are in place to specify and deploy prototypes for wide area real time control systems using their phasor technology infrastructures.

**France**

The French system EdF ("Electricite de France") utilizes protection schemes to avoid collapse situations or to limit their effect when they occur. The development of a coordinated protection scheme was carried out based on the centralized comparison of the voltage angles of the system obtained from the PMUs.

**Scandinavia**

There is a great potential for phasor measurement applications in Scandinavia, mainly due to the long distance power transmission and limited transmission capacity expansion possibilities. Smart control, based on phasor measurements, can be used as an alternative to adding new transmission lines by increasing power transmission capacity.

Just like in North America, the Scandinavian countries that constitute Nordel, have gone through a deregulation process. Although not yet concluded, this process has forced utilities to decide about strategic points that affect the future operation of the electric system.

During the year 2000 a study was carried out, with the support of Lunds Universitet, to verify the applicability of the technologies employed by the WAMS project for monitoring the reliability of the Nordic systems. This document contains much information on the WAMS project including its origin, constitution, applications and the current degree of development. Based on this study, it was recommended to introduce the technology reported in the WAMS project into the Nordel system. Three years after its publication, there are reports about the installation of few PMUs in substations in Denmark and Iceland that have been, used for tests carried out by ABB together with the grid operators of those countries. In Denmark phasor measurements have been considered for the improvements of system models, as well as the development of analysis tools for operation monitoring.

**Spain**

Sevillana de Electricidad (CSE) has added phasor measurements to its SCADA system and together with Siemens performed the necessary modifications in their state estimator function to enable it to support processing of phasor measurements.  They also conducted an extensive test program to establish the robustness, accuracy requirements and effectiveness of phasor measurements. Because of the experience gained from this test program their state estimator was modified to process phasor measurements, and upon successful fulfillment of the test program, the modified state estimator was installed at CSE and is currently operational.

**Italy**
Phasor data has been used for blackouts post disturbance analysis and evaluations including their August 2003 blackout. Wide Area WAMS type systems have been specified and will be developed in the near future for real time monitoring and preventive, adaptive protection.

**China**
The China State Grid will have about 150 PMUs installed nation-wide by the end of 2004. Most of them still do the dynamic monitoring and try to do the model validation. One provincial installation has modified their state estimator to use PMU measurements.

The investigation on the GPS-based synchronized phasor measurement (SPM) and its application in power systems in China were started in 1994. Until 2002 there were more than four PMS systems in operation and a lot of similar systems are under development. After several phasor measurement systems have been installed in Chinese Grids, researchers in China are now putting more emphasis in how to make use of the measured phasor information to improve the system's security and reliability.

**Korea**
Korea's primary goal for synchronized phasor data use has been to monitor the system dynamics and to build a database for validating the simulation models. In Korea National Control Center they monitor the system conditions at the sampling rate of 10 times per second. For archiving purposes the phasor data is kept for two minutes in normal condition. When a major disturbance occurs, data for eighteen minutes after the disturbance, plus two minutes before, are stored permanently for later analysis. For monitoring purposes the instantaneous phasor measurement are stored for one second in normal conditions and for 15 seconds in fault conditions for later analysis such as validating operations of the protection system and electromagnetic transient models. On line TSA and VSA tools are also under development.

**Japan**
Japan's longitudinal power system structure produces various types of system oscillations. These abnormal operating conditions make the use of phasor monitoring technologies suitable for real time wide-area monitoring. Research is being done to develop an on-line global monitoring system of Japan's power system dynamics using synchronized phasor measurements. The system being developed is characterized by utilizing lower cost phasor units installed at the domestic 100V level.

**Brazil**
During the first part of 2004 Brazil established the MedFassee project. Its main objective is the development of a phasor measurement system (PMS) simulator prototype with applications for monitoring and control of power systems operation. The prototype will consist of three phasor measurement units and a data concentrator and will include several wide area monitoring and control applications.

**Other Countries**
It has been reported that the following countries have installed and integrated phasor measurement units for research or to develop working prototypes for wide area monitoring and control: Switzerland, 4 units; Croatia, 2 units; Greece, 2 units; Mexico, more than 4 units and South Africa, 2 units.

## 2.2 Primary Synchronized Phasor Technology Hardware Elements

- ***Phasor Measurement Unit (PMU)*** – Calculates phasor voltages and currents in rectangular components from 16-bit point-on-wave sampling of 60 Hz waveforms, as well as frequency measurements. Provides output data at rates up to 60 Hz for transmission to remote locations. PMUs have a modest capability for storing locally triggered events.

- ***Phasor Data Concentrator (PDC)*** – Receives and correlates time-tagged phasor data from PMUs and other PDCs to create a system-wide phasor data set. It then streams this data to other applications. It internally records the entire data set if a disturbance is detected in any PMU. Normally operated at a data rate of 30 Hz.
- ***Wide Area Network (WAN)*** – Equivalent to an internet WAN but with additional security and redundant capabilities
- ***Real Time Database and Data Archiver*** – Data collector and archive for both monitoring and archiving data for Reliability Coordinators' use and for post analysis and assessment applications.

These devices are all designed for networked operation, in combination with a variety of other devices and toolsets for real time monitoring, alarm generation, displays, and data analysis [9], [10], and [11].

## 2.3 Generic Requirements for Real Time Wide-Area Monitoring, Control and Protection

- ***Event Triggering -*** Continuous recording should be provided. In cases where this is not done, recorders should be equipped to trigger on system disturbances such as over/under frequency events, major facility tripping, severe voltage disturbances, and sudden changes in power flow on critical facilities. Manual triggering capability should also be provided. A typical instability event can be anywhere from 1 to 60 seconds in duration or longer. A minimum recording duration of 30 seconds should be used for recorders configured with single event recording capability. Recorders with recording capability of 5 minutes for triggered events are preferred.
- ***Pre-disturbance Recording -*** Disturbance recorders should be equipped to record a minimum of 10 seconds of pre-disturbance information, however 60 seconds of pre-disturbance information is preferred.
- ***Networking -*** Most instability events, involve a widespread area, and involve oscillations and control interactions between neighboring utilities and geographic operational regions. This dictates the need for utilizing multiple recording devices at key locations.
- ***Time Synchronization -*** To provide meaningful data, all recorders in the area or region of interest should be time correlated. The use of GPS synchronized clocks is mandatory.
- ***Data Retrieval -*** Following a regional disturbance, data from all recorders must be systematically retrieved and correlated. A central archiver system for data retrieval is preferable.

# 3. REAL TIME WIDE-AREA MONITORING, CONTROL AND PROTECTION SYSTEMS AND ITS HARDWARE-SOFTWARE ARCHITECTURE

## 3.1 Wide Area Monitoring, Control and Protection Systems for a New Operational Level

New emerging technologies for real time wide-area monitoring, control and protection have been directed mainly into the following three directions: [12]

- Monitor, control and protect the transmission system against spreading of disturbances and their negative consequences, i.e. blackouts. The majority of control areas operate their power network according to N-1 criteria. However, facing new operational market-based environments with minimal possibility to influence the generation dispatch and resulting operation of the system under conditions for which it has not been designed is now forcing control areas to use, analyze and monitor risk based N-0 criteria to accept the higher risk and reinforce their wide area monitoring, protection and control systems.
- Increase transmission capacity in particular transmission corridors, mainly between two different electricity markets or reducing congestion within different electricity markets.
- Improve transmission assets utilization by refining the planning, operation, control, protection processes and models.

The research, development and application of phasor technology for power system operations during the last twenty years in different parts of the world have demonstrated that systems built using this technology can be very effective to meet the above three objectives and can respond to the new wide area operational challenges in three major areas:

- Real Time Wide-Area Monitoring and Analysis
- Real Time Wide-Area Control
- Real Time Wide-Area Adaptive Protection

The same research has demonstrated that this emerging Wide Area System should be implemented with a minimum set of requirements such as appropriate hardware-software and data communications architectures, specific signal processing functions, and specific applications for real time operations such as: Wide Area monitoring for regional Reliability Coordinators and Transmission Dispatchers, analysis and diagnosis tools for Operation Engineers, phasor data continuous and event archiving for post mortem analysis and assessment, and Wide Area coordinated and adaptive real time control and protection schemes based on synchronized phasor measurements.

Figure 1 shows where the new emerging Real Time Wide-Area Monitoring, Control and Protection System (WA-MCP) fits within the current power system hierarchical monitoring, control and operational structures. It should be noted that the emerging operational layer 4 is not a replacement for current SCADA and EMS systems but is the complement required by the new Wide Area operational environments originated by competitive markets. Levels 1, 2 and 3 from Figure 1 show the three types of monitoring and control systems, which work independently most of the time. Level 1 shows the local control and protection at substations and power plants. The protection at this level-1 acts locally to protect individual equipment but without any online coordination with other protection equipment. Levels 1 and 2, SCADA and EMS, are the network control and management systems using a static view of the power system. Even if they control and manage with certain level of coordination, they are not able to take any type of dynamics control actions. At level 4 Figure 1 shows some of the major applications found feasible for each of the three major utilization areas:

- ***Monitoring and Analysis*** – Real time wide-area load generation balance , ACE-Frequency, Wide Area Real Time Grid Dynamics Monitoring (RTDMS)
- ***Real Time Control*** – Wide area remedial action, emergency frequency control, oscillation damping

- ***Adaptive Protection*** – Coordinated adaptive protection, dynamic settings for local protection using phasor measurements

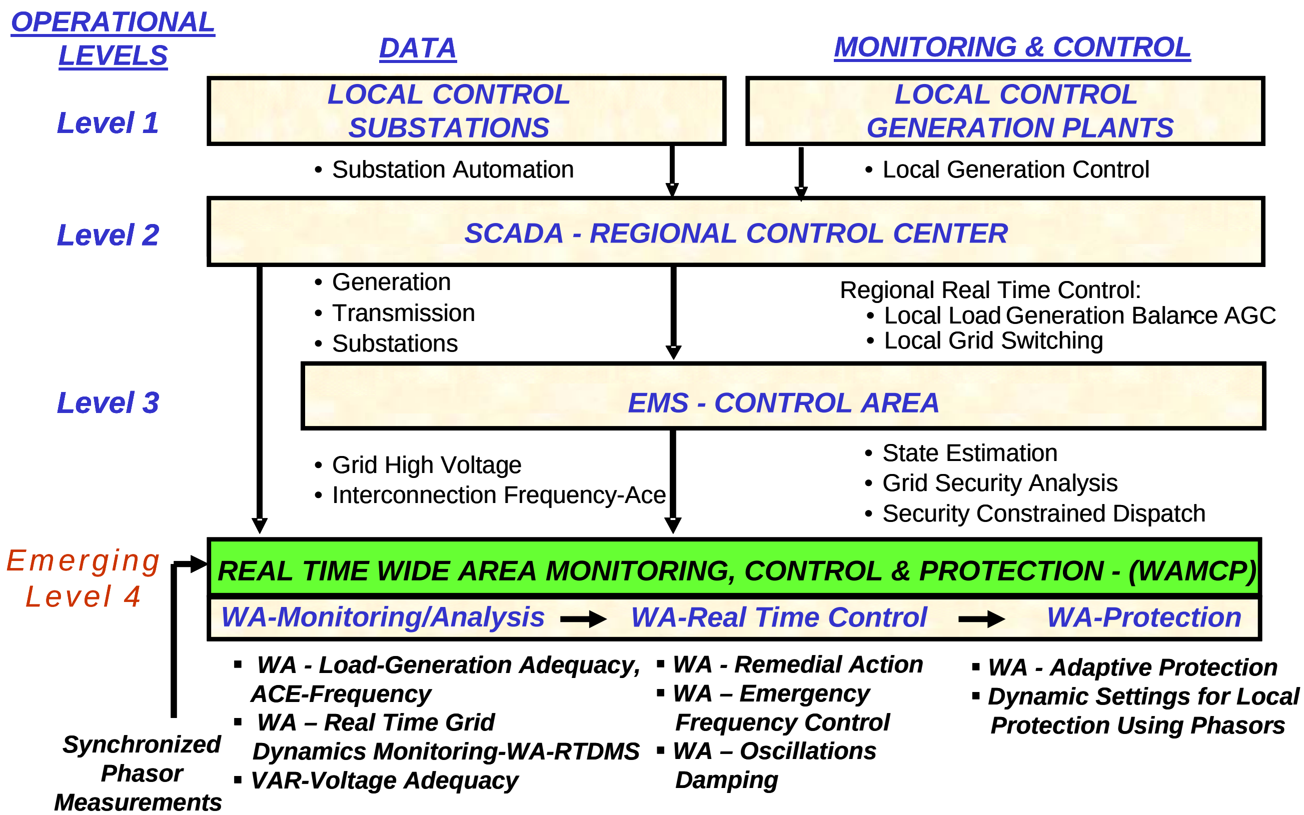


**Figure 1 – Integrated Real Time Wide-Area Monitoring, Control and Protection System**

## 3.2 Real Time Wide-Area Monitoring, Control and Protection System - Generic Hardware-Software Architecture

Figure 2 shows the generic architecture for a WA-MCP system. Four layer architectures as the one shown in Figure 2 are emerging as the most suitable approaches for wide area monitoring, control and protection.

- ***Layer 1, Phasor Data Acquisition*** – PMUs and Digital Fault Recorders (DFRs) are located in substations to measure voltage, current and frequency.  The basic phasor measurement process derives positive-sequence, fundamental frequency phasors from voltage and current waveforms. PMUs can be programmed to store data triggered by events such as under/over voltage and frequency.
- ***Layer 2, Phasor Data Management*** – The PDC collects data from PMUs and other PDCs and correlates it into a single data set. It streams the data set to applications via the applications data buffer.
- ***Layer 3, Data Services*** – This Layer includes the set of services required for supplying data for the different applications. The major services are: capability to supply the data in the proper format required for applications and fast execution to leave sufficient time for running the applications within the sampling period. It also provides system management by monitoring all the input data for loss, errors and synchronization.
- ***Layer 4, Applications*** – Three major areas have been identified for applications: Real Time Wide-Area Monitoring and Analysis, Real Time Wide-Area Control and Real Time Wide-Area Adaptive Protection.

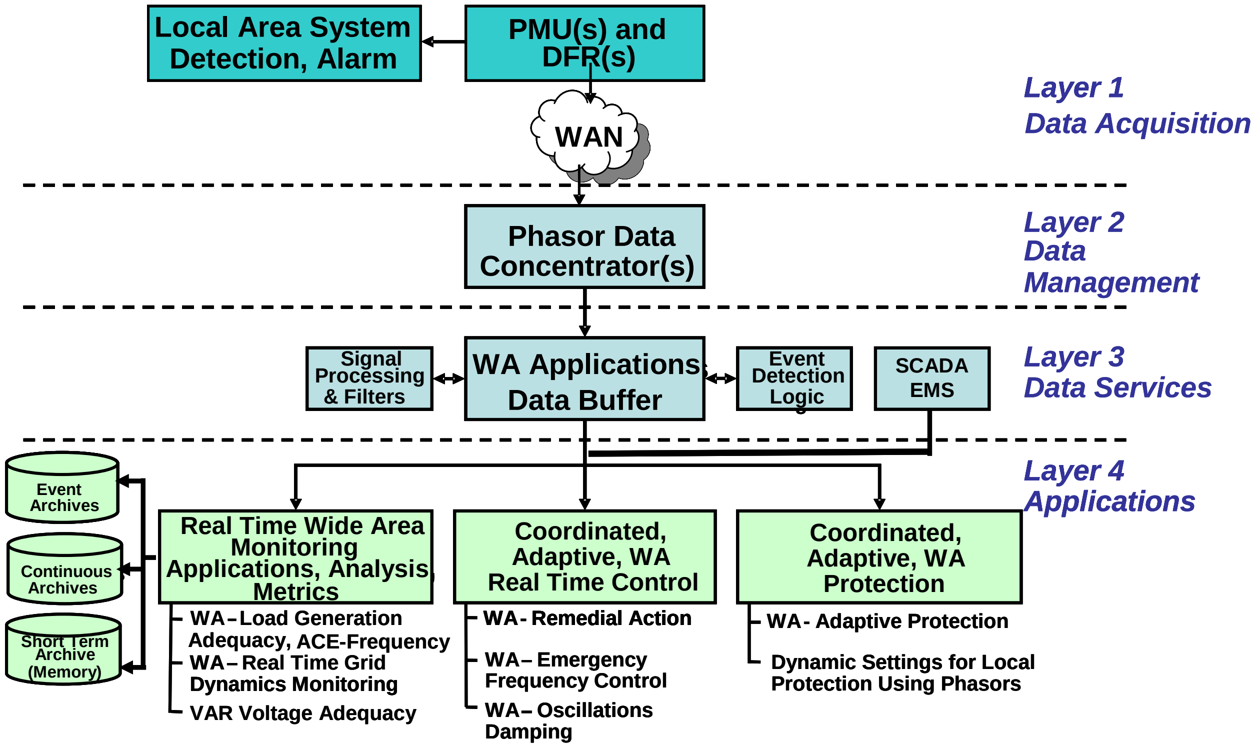


**Figure 2 – Real Time Wide-Area Monitoring, Control and Protection System Architecture**

# 4. REAL TIME WIDE-AREA MONITORING, CONTROL AND PROTECTION SYSTEM – APPLICATIONS FUNCTIONAL REQUIREMENTS

The following four subsections will describe the major Real Time Wide-Area applications using phasor technologies that have been identified for:

- Wide Area Monitoring and Analysis
- Wide Area Real Time Control
- Wide Area Adaptive Protection
- Wide Area State Estimator Improvements

## 4.1 Wide Area Monitoring and Analysis Functional Requirements

Two sets of monitoring and analysis applications will be described. The first set is the frequency data collection and the analysis applications defined and specified by NERC for the North American interconnections. The second set is the 19 monitoring applications identified and discussed during the Real Time Team breakout session at the EIPP meeting in Portland on December 2004. Table-1 in section 5 of this paper summarizes these applications and its phasor data requirements.

**Wide Area Frequency Data Collection and Analysis, NERC Requirements**

Following are the functional requirements for a system that will allow monitoring of wide area interconnection frequencies as well as analysis and assessment of frequency behavior to validate the effectiveness of reliability performance metrics and evaluation of modification or definition of new performance metrics

- Automatically transmit frequency data from a minimum of three different locations in an interconnection.
- 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).
- Archived frequency data shall be stored at a minimum rate of one sample per second and the resolution shall be no less than the specified accuracy of the associated frequency transducer.
- Maintain on-line archived frequency data for a minimum of five (5) years.
- Include report production and database query capabilities that offer standard periodic reports and event driven reports based on the archived data.
- Provide database query and report writing tools to generate both graphic and tabular format reports.
- Allow only authorized users to view and query the frequency database contents.

**Wide Area Frequency Response Monitoring, Rate of Change and Performance** [13]

The objective here is to monitor and track the local and interconnection frequencies, as well as changes in frequency that can be mapped to precise generation-load imbalances within the interconnection. Variations in and across local frequency measurements can further be used to assess system coherency and dynamic stress under normal operating conditions.

**Voltage Angle Monitoring**

The objective is to provide system-wide snapshots of the voltage angle dynamics and the ability to monitor them with respect to alarming thresholds. Furthermore, phase angle differences across different points are a measure static stress across the grid and its proximity to instability, and therefore can be monitored with respect to predetermined stability threshold limits.

**Voltage Magnitude/VAR Monitoring**
Phasor measurements also offer the ability to monitor system wide voltage magnitude profiles across the grid to identify the low and high voltage regions. In addition, the voltage and the current phasors measured by PMUs can be used to computer the MVAR flows at the monitored generators and transmission lines.

**Flow Gates and Interface Monitoring**
The objective here is to use the voltage and current phasors to compute the real power flow across identified flow gates and to alarm operators when established thresholds levels are exceeded.

**Phasor Assisted State Estimation**
State estimation plays a key part in the real time monitoring and control of power systems. It provides estimated data to network analysis security and optimization applications as well as to power system dispatchers. The measurement set normally includes voltage magnitude, branch real and reactive flow, real and reactive injection, and ampere magnitude measurements.

There are inherent challenges with the state estimation process. The process depends on a network model and is vulnerable to network changes and inaccuracies. Secondly, state estimators are more suited for steady-state monitoring but are too slow for disturbance monitoring. The ability of phasor technology to directly measure these quantities and display them at high rates resolves both of these issues.

Phasor measurements offer a means to corroborate state estimator results. Additionally, the use of phasor measurements directly in the state estimation process, including the analysis of their impact and benefit on solution algorithms, observability analysis and the bad data identification, have been and are continually being investigated. Currently, phasor metering has achieved a level of precision that makes phasor telemetry a valuable source of measurement data [3]. There already are operational State Estimators that use phasor measurements. See Spain in the Background section of this paper.

**State Measurement – Open Phase Detection**
Open phase detection logic within phasor-based protection relays monitor the current in breakers to detect the open phase conditions and breaker failure detection.

**Disturbance Monitoring (Waveform & Phasor Data)**
The accurately time tagged phasor measurements at very high rates can precisely trace system disturbances thru their evolution process. This accurate timing information is also crucial for detecting trends or parameter estimation (model fitting) from a window of observations.

**Pattern Recognition**
The precise timing information of this data makes it useful outside the confines of one local set of electrical buses where the measurement is taken. Measurements from PMUs in different geographic locations can be compared and correlated, as well as trending analysis can be performed with time of day, season, peak load, major line outages, etc on the set of archived phasor data. Such analysis will define monitoring guidelines and alarming thresholds for the entire grid.

**Oscillation Monitoring (System & Machine Oscillations) – System (12 samples/sec) Machine (120 samples/sec)**
Low frequency electrical modes exist in the system that are of interest because they characterize the stability of the power system and limit the power flow across regions. While there is a danger that such modes can lead to instability in the power system following a sizable contingency in the system, there is also the risk of these modes becoming unstable (i.e., negatively damped) due to gradual changes in the system. The ability to continuously track the damping associated with these low frequency modes in real time and under normal conditions would therefore be a valuable tool for dispatchers and power system engineers. Operators would be alarmed if the damping of these modes falls below predetermined thresholds (e.g. 3% or 5%). The low

frequency oscillations are best observed from data corresponding to power flows thru long transmission lines that represent the weak links between densely interconnected regions in the power network [21] [22] [23] [24].

**Voltage Stability Monitoring**
Perhaps the most explored and suitable field, since the phenomenon of voltage instability can be solved locally only to a limited extend. Phasor technology offers the ability to accurately measure voltages at various points across the power network at a very high rate. Furthermore, phasor measurements at a load bus contain enough information to accurately detect the voltage stability margin thru a corridor and define a Voltage Stability Index (VSI) for it. It is a well-known fact that for a simplistic two-bus system with a constant power load (i.e., a constant source behind an impedance and a load), the maximum loadability condition occurs when the voltage drop across the source impedance is equal to the voltage across the load. Hence, the idea is to use the phasor measurements at the bus to dynamically track in real time the two-bus equivalent of the system (a.k.a. Thevinin equivalent). As these Thevenin parameters are being tracked dynamically, they reflect any changes that may occur in the power system operating conditions and consequently provide the most accurate assessment of loadability estimates [18] [19] [20].

**Spectral Analysis – Frequency, MW, MVAR, Voltage**
The high resolution phasor data from various types signals (e.g., MW flows on transmission lines or frequency measurements at monitored generator buses) can be analyzed for its spectral content to monitor and track the low frequency modes and quantify the size of these fluctuations.

**Distributed Analysis (Fast Simulation & Modeling)**
The high resolution data can be used to provide faster-than-real-time simulation and modeling of electricity grid dynamics at different levels of topological detail over a range of different time domains. The capability to model and simulate system behavior fast enough to anticipate changing system conditions is essential to support automated control capabilities and the self-healing electricity grid of the future is the purpose of the Fast Simulation & Modeling.

**System Probing and Model Validation**
Planning models are essential for interpreting observed system behavior, and for predicting future behavior under assumed conditions. Continual refinement of models and practices is essential to a robust planning process and, ultimately, to overall power system reliability. Benchmark data for model validation can be obtained for ambient behavior, chance disturbances, or staged tests [25].

In the WECC power system, planned tests are coordinated by the Performance Validation Task Force (PVTF) of the WECC Modeling and Validation Work Group to compare and calibrate the planning models. Some of the input signals for the test involve:

- Ambient noise within the system reflecting small fluctuations due to random load switching and other low level stimuli
- Staged generator trips, with automatic generation control (AGC) and other controls suspended.
- Insertions of BPA’s 1400 MW Chief Joseph dynamic brake.
- Mid-level probing (± 125 MW) of individual oscillation modes by HVDC modulation
- Low-level broadband probing (± 20 MW) by HVDC modulation

**System Performance Monitoring (QoS)**
Phasor measurements can be used to monitor and improve required levels of reliability and quality of service (QoS) [26].

**On-line Thermal Rating of Transmission Lines**

Thermal limits on transmission lines are usually very conservative as they assume high ambient temperatures and no wind conditions. The ability to monitor the actual line temperature is therefore of great value in determining the true transfer limits.

Different solutions have been proposed. Some of them use only measured electrical quantities while others utilize weather data in conjunction with current measurement. With phasor measurements from both ends of a line, this is possible. In particular, the voltage and current phasors from the two ends of the line taken over a specified time window can be used to obtain the equivalent parameters for the transmission line reflecting the most current conditions. The estimated resistance of the conductor and the net losses, along with the physical characteristics of the line, can then be used to deduce the line temperature.

## 4.2 Real time Wide-Area Control Functional Requirements

**Short Term Stability Monitoring, Detection and Control (Transient Instability)**

Transient stability assessment is traditionally performed off-line thru step-by-step time simulations using detailed generator modeling. The computational burden of performing such studies continually and on-line with detailed models is prohibited at present. In addition, they don't provide a continuous quantitative stability measure for a particular case.

There are different online proposed approaches. Phasor measurement data allows to accurately tracing the progression of a transient in real time, once a contingency or disturbance has launched it. The internal generator phase angle can be easily calculated from the voltage and current phasor measurements at the generator buses using the generator's transient impedance. After the start of a transient swing has been detected, most proposed algorithms track the initial swing(s) during the first second of the transient using a sliding window to classify the swing as stable or unstable depending on the resulting outcome. As a control action, these schemes propose disconnection of the affected generator from the power grid.

Bonneville Power Administration is developing a Wide Area stability and voltage Control System (WACS) that relies on synchronized positive sequence phasor measurements to implement a fast control for interarea transient stability that operates in hundreds of millisecond time frame based on voltage measurements from several stations [17]

WACS provides single discontinuous stabilizing action such as generator tripping or capacitor bank switching, or true feedback control. It supplements the basic continuous controls by relieving stress for very large disturbances, providing a region of attraction and a secure post-disturbance operating (equilibrium) point.

For first swing transient stability, control action must be taken prior to the peak of the forward interarea angle swing (i.e., 1.0 – 1.5 seconds). Phasor measurement based control action can be taken within 0.3 seconds. The delay time associated with the phasor measurement, fiber optic communications, phasor data concentrator throughput, transfer trip, and circuit breaker tripping/closing is approximately 3, 2, 2, 1, and 2/5 60 Hz cycles respectively, or around 10 cycles for tripping and 13 cycles for closing (167 and 217 ms) [17].

**Frequency Instability – Island Detection and Reconfiguration**

Algorithms have been proposed to monitor the status of power plants when they are connected or disconnected as a consequence of a contingency and, in case of a contingency, quickly predict the final frequency after the transients settle down after a given disturbance. This is done using the simplified load models which depend on voltage and frequency changes and are completely disregarded in case of local protection action (under-frequency relays). If the predicted frequency deviates too much from the desired one, appropriate actions are taken to restore the frequency. These actions shall consider present network situation, and are coordinated (i.e. only the necessary amount of load is shed and at the most suitable locations). These actions should be executed as soon as the dangerous situation is identified and the needed input data are processed.

**Voltage Instability**
Perhaps the most explored and suitable field, since the phenomenon of voltage instability can be solved locally only to a limited extent. As a part of WACS project, Bonneville Power Administration has developed a slow subsystem for voltage stability that operates in a few or tens of seconds time frame and is based on many voltage and generator plant reactive power measurements from multiple locations that are combined using fuzzy logic [17]

**Power oscillations, also referred as power swings**
On-line monitoring of the power oscillation modes could be used for on-line tuning of Power System Stabilizers to achieve the best performance reacting to the actual conditions in the network. Although the qualitative benefit is obvious, its quantification is very difficult to achieve. It has been shown, however, that the installation of a damping controller in the HVDC line connecting Sweden and Finland in the south has helped to increase the transfer capacity between these two countries through the northern AC connection by 400 MW.

**Transmission Capacity Upgrades**
Different phasor technology application approaches have been proposed for this category. Based on the identified potential it is proposed to apply the technology platform package divided into three steps:

**Step 1** comprises using PMUs together with the corresponding communication and monitoring software. No direct control interaction is applied to the grid. The additional transfer capability results directly from the exact reserve margin estimation. This is referred to as an open loop application.

In **Step 2** the monitored quantities can directly be fed into network controllers like step down or step up transformers, already existing compensation equipment, etc. This is defined as a closed loop application.

**Step 3** comprises incorporating all properties of step 1 and step 2. In addition, new network controllers are installed or the operational philosophy is changed to a risk based operation which is secured by the applications. Therefore this is referred to as the control and protection step.

## 4.3 Coordinated Adaptive Protection Functional Requirements

NERC Disturbance statistics show that 67% of the number of disturbances in a 17-year period was protection related. Use of coordinated wide area adaptive protection could have a significant impact in disturbances reduction. Research on this area suggests that wide area adaptive protection should progress in two forms: anticipative and responsive. In the anticipative form the protection system characteristics are altered in time of system stress. In the responsive form the protection system reacts to an emergency by taking additional switching actions to restrict the impact of a protection miss operation [14].

## 4.4 State Estimator Process Improvements

State estimation plays a key part in the real time monitoring and control of power systems. It provides estimated data to network analysis security and optimization applications as well as to power system dispatchers. The measurement set normally includes voltage magnitude, branch real and reactive flow, real and reactive injection, and ampere magnitude measurements. Currently phasor metering already achieved a level of precision that made phasor telemetry a valuable source of measurement data [3].

The use of phasor measurements in state estimation, including the analysis of their impact and benefit on solution algorithms, observability analysis and the bad data identification, have been and are continually being investigated. There already are operational State Estimators that use phasor measurements. See Spain in the background section of this paper.

# 5. REAL TIME WIDE-AREA MONITORING, CONTROL AND PROTECTION APPLICATIONS – PHASOR DATA REQUIREMENTS

The following three subsections describe specific phasor data requirements for each of the three wide area application categories: monitoring and analysis, real time control and real time adaptive protection.

Table-1 contains a summary of the 19 monitoring and analysis applications identified by EIPP Real Time Team including its specific phasor data requirements.

## 5.1 Real Time Wide-Area Monitoring and Analysis – Phasor Data Requirements

For monitoring and analysis applications the phasor data requirements will be described by the data requirements defined by NERC for frequency data collection and analysis purposes, and using Table-1 for the 19 monitoring and analysis applications identified by EIPP.

**Wide Area Frequency Data Collection and Analysis – Phasor Data Requirements**

The interconnection frequency collection and analysis requirements defined by NERC can be satisfied very effectively using phasor measurements due to its improved accuracy, data synchronization and wide area locations. The following two sections will describe in detail the data monitoring and the data archiving requirements defined by NERC for this type of application

- There shall be at least three (3) geographically and electrically separated frequency transducers within each of the Interconnections.
  - 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 North America Eastern Interconnection one transducer shall be located within the NPCC or MACC region, one transducer either within the FRCC or SERC region, and one transducer within the SPP or MAPP region. Within the Western Interconnection one transducer shall be located within or near BPA's service are 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.
- Frequency data shall be collected at a minimum scan rate of 0.1 second (100 milliseconds intervals). Transmittal or communication from the frequency transducer to the data warehousing facility may take place on an asynchronous basis (i.e., need not be in real time). Sites with asynchronous transmission must have a minimum of 5 hours of local data storage to accommodate for data transmission failure.
- Each frequency data sample shall be appropriately identified as to Interconnection, source, and time of collection to the nearest 0.01 second. The time stamp shall be in Greenwich Mean Time (GMT or UTC).
- Synchronization of the frequency sampling intervals, time stamp information and any other time information required should be obtained from sources directly traceable to the NIST time source.
- Frequency data shall be collected to a resolution of at least +/- 0.001 Hertz (three decimal places)
- Frequency transducers shall be calibrated or certified at least annually to ensure an accuracy of as least +/- one milliHertz utilizing instrumentation with calibration directly traceable to NIST time standards.
- Anti-Aliasing Filters shall be utilized per best utility industry practices to prevent high frequency components of the frequency signal from introducing error into the sampled frequency data.

- At each of the frequency transducer sites, a time error device shall be installed and time error shall be measured and transmitted. The time error shall be stored and uploaded to the central warehouse at the same rate as the frequency data. The requirement for triggering to collect at a higher rate shall not apply to the time error collection.
- 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.
- 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 achieved in a manner similar to standard frequency data for future access.
- Sufficient resources should be allocated to locally store fifty (50) triggered events per site.
- 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.
- 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 the Interconnection Frequency Monitor via direct electronic communications (ICCP or other direct, real time communications).

**Wide Area Frequency Data Collection and Analysis - Archiving and Reporting Requirements**

- Frequency data for each of the sites shall be archived as per the following specifications:
  - Frequency data shall be archived at a minimum accessible resolution of at least once per second.
  - 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.
  - The database software used to archive, retrieve and process the data shall be a commercially available, industry standard product (such as Oracle, Access, etc.) that has been in production for at least five (5) years and is well supported in the industry. Customization shall be minimized and any programming code, scripts or SQL queries developed to store, access, or prepare reports from the data shall belong to and be the property of NERC or its successor organization.
  - All data shall belong to NERC or its successor organization. Should the contract for data collection and storage be terminated all data shall be immediately turned over to the designated successor.
- Scheduled frequency set point data for each of the Interconnections 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.
- Secure access to archived frequency data for each of the Interconnections and Hydro Quebec shall be provided as per the following specifications:
  - Data shall be made available to approved personnel via a web based, on line system.
    - Initially User Name and Password will secure the FDCAS system. At a time that NERC implements the e-MARK standards, the FDCAS system will then be secured by digital certificates.
  - 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.

- 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 transducers, 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
  - Periodic and on-demand reports on data quality and database integrity shall include at a minimum:
    - Error reporting, including transducer errors, transducer 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.
- The system shall 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 i.e. which Interconnection or Hydro Quebec, which location within the Interconnection or Hydro Quebec if applicable, and the date and time.
  - Graphic output of archived data shall be available in hourly, daily, weekly and monthly standard formats
  - Event driven report shall be available on a per-site basis in both graphic and tabular format for at least the following events:
  - 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.
- Alarm and notification capability shall be provided such that if designated values such as median frequency deviation exceeds a enterable value the data in the reporting table will be flagged in red, and a notice will be sent to a pre-established email list indicating the limit that was exceeded, the limit setting, the actual value of the parameter, in which Interconnection or HQ the limit occurred, and the date and time of violation. All limit checking is to be performed on error checked data.

**Wide Area Frequency Data Collection and Requirements - User Interface Requirements**

- The Frequency Response 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.

- 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.
- Report generation and user interface system needs to be able to accommodate both 23 and 24 hours days that occur during seasonal time zone conversions.
- Predefined queries that would generate tabular reports and graphics 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.
- 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. The user will have a display option that allows them to select viewing the data in tabular format, graphical format, or both tabular and graphical format.
- Database query and report writing tools shall be provided to generate both graphic and 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

## Summary of Phasor Data Requirements for the Monitoring and Analysis Applications Identified by the EIPP Real Time Team

Table 1 summarizes the phasor data requirements for each of the 19 monitoring and analysis applications identified by EIPP Real Time Team, and categorized by the following data requirement types:

- Data Resolution
- Data Archive
- Duration of Archiving
- Data Retrieval Format
- Alarming Required
- Use of Application - Action, Forecasting , Maintenance, Protection
- Action Level
- Applications Intended Use - Local or Regional Problem
- Integration with Other Data Required

**Table 1: Real time Wide-Area Monitoring and Analysis Applications and Data Requirements Summary**

| Type of Real time Application | Data Resolution | Data Archive | Duration of Archiving | Format of Data Retrieval | Alarming Required | Use of Application - Action, Forecasting , Maintenance, Protection | Action Level | Applications Intended Use - Local or Regional Problem | Integration with Other Data Required |
|---|---|---|---|---|---|---|---|---|---|
| 1. Frequency monitoring and rate of change | 30 Samples per Second<br>1 Sample per Second | Short Term<br>Long Term | 24 hours<br>2 years | OPC<br>PDCStream | Yes | Action | STF | Wide Area Monitoring | |
| 2. Phasor Assisted State Estimation (1 sample/sec) | 1 Sample per Second | Short Term or Long Term | 1 hour | OPC<br>PDCStream | No | Monitoring/ Forecasting | OI | | SCADA |
| 3. State Measurement – Open phase detection | 30 Samples per Second | Memory Buffer | Seconds | OPC<br>PDCStream | Yes | Protection | SA/A | Local Monitoring | |
| 4. Disturbance monitoring (Waveform & Phasor Data) | 30 Samples per Second | Event Archive | 5 minutes of pre and post disturbance data | PhasorFile<br>COMTRADE | No | Post-Disturbance Analysis | OI | Local/Wide Area Monitoring | |
| 5. Pattern Recognition | 30 Samples per Second<br>1 Samples per Second | Short and Long Term | 24 hours<br>1 year | OPC<br>PDCStream | No | Forecasting | OI | Wide Area Monitoring | SCADA |
| 6. Short Term Stability monitoring, detection and control | 30 Samples per Second | Memory Buffer | 1 hour | OPC<br>PDCStream | Yes | Action | SA/A | Local Monitoring | |
| 7. Long Term Stability monitoring, detection and control (Voltage and Modal-damping) | 30 Samples per Second | Memory Buffer and Short Term | 24 hours | OPC<br>PDCStream | Yes | Action | STF | Wide Area Monitoring | SCADA |
| 8. Stress Detection – Alarming, forecasting, GIS location | 30 Samples per Second | Memory Buffer and Short Term | 24 hours | OPC<br>PDCStream | Yes | Action | STF | Wide Area Monitoring | SCADA |
| 9. Oscillation monitoring (System & Machine Oscillations) | 30 Samples per Second | Memory Buffer and Short Term | 1 hour | OPC<br>PDCStream | Yes | Action | SA | Local/Wide Area Monitoring | |
| 10. Islanding and reconfiguration | 30 Samples per Second | Memory Buffer and Short Term | 1 hour | OPC<br>PDCStream | Yes | Action | SA/A | Wide Area Monitoring | |
| 11. Flow gates and interface monitoring | 30 Samples per Second | Memory Buffer and Short Term | 24 hours | OPC<br>PDCStream | Yes | Action | OI | Wide Area Monitoring | SCADA |
| 12. Voltage/VAR monitoring | 30 Samples per Second | Memory Buffer and Short Term | 24 hours | OPC<br>PDCStream | Yes | Action | STF | Wide Area Monitoring | SCADA |
| 13. Spectral analysis on frequency, MW, MVAR, Voltage Signals | 30 Samples per Second | Memory Buffer and Short Term | 1 hour | OPC<br>PDCStream | No | Monitoring/ Forecasting | OI | Local/Wide Area Monitoring | |
| 14. Dynamic thermal rating | 30 Samples per Second | Short Term | 24 hours | OPC<br>PDCStream | Yes | Action | STF | Local Monitoring | SCADA |
| 15. Distributed analysis (Fast Simulation Modeling) | 30 Samples per Second | Memory Buffer and Short Term | 1 hour | OPC<br>PDCStream | No | Monitoring/ Forecasting | | Local/Wide Area Monitoring | SCADA |
| 16. System Probing | 30 Samples per Second | Memory Buffer and Short Term | 1 hour | OPC<br>PDCStream | No | Maintenance | OI | Wide Area Monitoring | |
| 17. Power system equipment failure detection (Machine condition monitoring) | 30 Samples per Second | Memory Buffer and Short Term | 1 hour | OPC<br>PDCStream | Yes | Monitoring/ Maintenance | STF | Local Monitoring | SCADA |
| 18. Machine, line and load characterization (Model building and validation) | 30 Samples per Second | Memory Buffer and Short Term | 1 hour | OPC<br>PDCStream | No | Maintenance | | Local/ Wide Area Monitoring | |
| 19. Measurement System Performance monitoring (QoS) | 30 Samples per Second | Memory Buffer and Short Term | 24 hours | OPC<br>PDCStream | No | Monitoring | OI | Wide Area Monitoring | |

*Action Level – Operator information only (OI), Operator action in specific time frame (STF), Semi-automatic (SA) or Automatic (A)

## General Real Time Monitoring Archiving Capabilities

The sampling period required for each monitored quantity is at least 100 ms and the frequency range of interest for the power system transients is from 0 to 2.5 Hz. (Simulation studies carried out by utilities using eigenvalue programs have indicated that electromechanical modes of interest do not exceed 2.5 Hz).

Three levels of archiving have been suggested for RT-WAMCP systems for online disturbance analysis and for monitoring and replay purposes:

1) Short term continuous data retention of 33 ms data (30 Samples/Second) for 30 days
2) Long term continuous archiving of 1s data for 1-2 years (Frequency data ONLY for 5 years to fulfill NERC requirements).
3) Event archiving of 3-5 minutes of pre and post disturbance 33 ms data during events for 1-5 years.

In addition, the system should also have circular data buffers of 33 ms data for 1-2 hours in its volatile memory, at any time. This would include frequency deviations and fundamental Fourier components at 60 Hz. of positive, negative and zero sequence voltages and current phasors.

The acquisition of data for the sampled data buffer, as well as updating of all the other rotating buffers is performed on-line on a continuous basis.

## General Recorded Event Requirements

Each disturbance should trigger the accumulation of a disturbance buffer. The system should store the following data during each disturbance as a minimum:

- The instantaneous sampled data of the waveforms at specific Hz criteria
- The fundamental component of the AC values and the frequency deviation from 60Hz.

The amount of these data before and during a disturbance should be programmable. The triggered system must record for at least 10 seconds prior to the triggering and have a record length of more than 30 seconds (preferred length is 3-5 minutes). Successive disturbances may be collected completely using the same record length. The Archiver should hold approximately 1000 disturbance buffers. The oldest disturbance data should be overwritten, even if they are not retrieved already by the central computer [15].

## General Statistical Monitoring Buffers Requirements

When there are no disturbances, in addition to the raw data, the Archiver should compute and store derived statistical process data quality parameters on a continuous basis such as the mean and covariance of the voltage phasor, current phasor and frequency deviation over several minutes. Monitoring applications should be able to retrieve these statistics for its own functionality.

## General Local Data Retention Requirements

Mass storage devices effectively allow significant data retention times before being overwritten on monitor devices set up for continuous recording. Dynamic Monitors should be set up for a minimum of ten calendar day's retention of continuous records and a minimum of two months retention of triggered events. Events recorded during staged system tests shall be retained for up to one year. This data should also be retained for a minimum of two months.

## 5.2 Real Time Wide-area Control – Phasor Data Requirements

### Trigger Criteria Requirements

There are four basic factors involved in detecting the onset of a dynamic event. They are:

- Magnitude
- Persistence
- Frequency content
- Context

A simple disturbance trigger might examine just magnitude and persistence; it is useful to think of the context factor as adjusting such thresholds to system condition, such as network stress or the operational status of key system resources.

A partial list of thresholds through which events can be detected, and perhaps recognized, includes the following:

- Steps or swings in tieline power flow.
- Large change or rate of change, in bus voltage or frequency.
- Sustained or poorly damped oscillations, perhaps in conjunction with some other event.
- Large increase in system noise level.
- Increase of system activity in some critical frequency band.
- Unusual correlation or phasing between fluctuations in two given signals.
- Pre-specified instant of time.
- Magnitudes crossing a threshold/previous value, up/down, increase/decrease/change.
- Parameters sensitivities

A similar set of criteria for the end of the conservation of data should be programmed independently.

Triggering of data collection involves detecting critical power system disturbances. An initial trigger could be by sensing system frequency greater than 60.05 Hz or less than 59.95 Hz. Triggering when the frequency rate of change is greater than 0.05 Hz/s could also be used. Other trigger events include major intertie losses, and industrial load trips. Also a manual trigger should be implemented.

Other characteristics and requirements for triggering are:

- The trigger must initiate recording when phenomena of interest are detected. The phenomena of interest are persistent oscillations in the range of 0.25 to 1.0 Hz and of such magnitude to cause significant deviations of power flow on the transmission system.
- The pre-trigger and post-trigger recording time must be sufficient to capture the beginning and the end of the oscillation. If the trigger condition is detected again while recording is in progress, recording should continue until the magnitude of the oscillation drops to a level that no longer meets the trigger conditions.
- The oscillation records should be available for the monitoring applications. The user should be able to modify the settings of oscillation trigger via configuration files.

**Accuracy of Synchronized Measurements for Control**

Wide Area Adaptive Monitoring and Control – For predicting stability or for control of oscillations, accuracies of plus or minus one tenth of a degree and in some cases accuracies of plus or minus one degree should be adequate [15].

## 5.3 Coordinated Real Time Adaptive Control – Phasor Data Requirements

**Communication Timing**
Wide area adaptive protection depends on the speed with which the RT-WAMCP system can identify and analyze the emergency as well as the speed with which remedial control action can be effected. It has been researched that the total adaptive process involves the following six activities with the corresponding communication time estimates shown for each: [14]

- Sensor Processing Time – 5 ms
- Transmission Time of Information – 10 ms
- Processing Incoming Message Queue – 10 ms
- Computing Time for Decision – 100 ms
- Transmission of Control Signal – 10 ms
- Operating Time of Local Device – 50 ms

TOTAL Time – 185 ms

These estimates of communication times are based on the assumption that utilities will have a complete fiber optic network available with dedicated channels provided as necessary for high priority communication and control signals.

Three layer architecture has been proposed for the hierarchical hardware for wide area adaptive protection. The lowest level of local protection occurs at the relay level. The middle layer at the substation level contains many Intelligent Electronic Devices (IED) that realize protection for small regional systems. At the highest third level, each substation is interconnected with neighboring substations for wide area protection and control.

**Accuracy of Synchronized Measurements for Adaptive Protection**
Most adaptive relaying tasks would be served by a synchronization accuracy of about plus or minus 0.1 degree [16].

# 6. CONCLUSIONS AND RECOMENDATIONS

Competitive markets, restructuring, aging transmission lines, lack of transmission expansion and environmental constraints in the electricity industry are impacting operations and increasing the need for the implementation of wide area real time monitoring tools and visualization solutions. These monitoring tools and visualization solutions will rapidly detect and help correct abnormal conditions encountered in interconnections that could threat the reliable operation of the electrical grid.

A new set of real time wide-area monitoring tools using phasor technologies are being targeted for use in the new emergent Real Time Wide-Area Monitoring, Control and Protection levels of operation that fit well within the current power system hierarchical monitoring, control and operational structures. These tools will significantly help Reliability Coordinators to carry out their wide area monitoring responsibilities.

It has been demonstrated that the two new key components of a successful portfolio of real time wide-area monitoring tools are: phasor technologies and multi-view geographic visualization solutions. Research and prototyping of phasor technologies have identified the most suitable hardware-software architectures and the most appropriate set of real time, wide-area applications for Dispatchers and Reliability Coordinators. The experience gained by CERTS with the deployment of wide area monitoring tools has demonstrated that these new tools can prove very effective to help Reliability Coordinators to maintain reliable interconnections by closely monitoring their wide area jurisdictions.

To accelerate the dissemination of wide area tools using phasors, the following areas will require additional work:

A) Streamline the preparation of data confidentiality agreements between involved parties. It should not take months and some time even years to put these agreements in place.

B) Evaluate the current vintage of phasor measurement hardware. Provide research to prototype the next generation of phasor measurement hardware as well as data communication technologies.

C) Improve and disseminate the maintenance processes needed to support phasor technologies hardware and software.

D) Define and agree on the utilization of the most appropriate data communication protocols.

E) Establish training programs for dispatchers and Reliability Coordinators in the use of phasor-based tools in real time operations.

F) Continue research and prototype for real time control and adaptive protection applications for a future automatic switchable grid.

G) Continue research and prototype to identify the most appropriate data and functional interfaces between SCADA, EMS systems and phasor-based wide area applications.

H) Coordinate research and development between different stakeholders to avoid duplication.

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