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Advanced Phasor Technology

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace. The PIER Program, managed by the California Energy Commission (Energy Commission), conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End□Use Energy Efficiency
- Energy Innovations Small Grants
- Energy□Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End□Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Advanced Phasor Technology is the final report for the Advanced Phasor Technology project (contract number 500-99-013, BOA-99-206-P conducted by the Consortium for Electric Reliability Technology Solutions (CERTS). The information from this project contributes to PIER's Transmission Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier or contact the Energy Commission at 916-654-5164.

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Abstract

Key Words: Electricity grid, reliability, real-time operator tools, time synchronized phasor measurements, voltage security.

1.0 Introduction

The project funded under this work authorization represents an interim stage and the beginning of the forth phase of a multi-project ongoing RD&D activity that is coordinated by the Consortium for Electric Reliability Technology Solutions (CERTS) for the Energy Commission's Public Interest Energy Research (PIER) Transmission Research Program (TRP). Phases 1, 2, and 3 of this research were conducted through an RD&D contract directly with Lawrence Berkeley National Laboratory (LBNL), Contract # 150-99-003, Phase 1, and through several task orders from the California Institute for Energy and Environment (BOA#20, Task Order 21, Task Order 24, Work Authorization # MR-036, PIER Contract #500-02-004), all under Phase 2, and Real Time System Operations 2006 – 2007, PIER Contract # 500-02-004, MR-041, Phase 3. Additional research, through a separate subsequent contract, has been funded by the Energy Commission under two separate contracts, Contract # 500-08-054, SynchroPhasors for the Integration of Renewables with LBNL, and Contract # 500-08-048, Demonstration of Advanced Synchrophasor Technology for the Integration of Renewables on the California Grid, with Electric Power Group. This intermediate funding provided a bridge between the earlier contract, Real Time System Operations 2006 – 2007, Phase 3, and these two separate contracts, Phase 4.

1.1.1. Background and Overview

The purpose of this work authorization is to perform research into the development of new grid operating tools that rely on an emerging new class of monitoring data called phasor-measurements. These tools will ultimately enable grid operators, for the first time ever, to directly observe and, hence, enable real-time responses to the problems that led to the 1996 and 2003 blackouts. The focus of this research effort is on operator visualization and decision support tools based on using phasor measurements in real-time. There are no current precedents for such real-time applications of phasor measurements. Ultimately, the research performed will support applications that could be developed, prototyped, demonstrated, and be relied on by grid operating staff to develop and support the implementation of new operating guidelines and controls. These guidelines and controls would respond to problems, such as those that occurred in during the 1996 and 2003 blackouts, either manually or automatically.

Currently, it is not possible to observe directly the state of robustness or strength of the electric transmission grid (i.e., the grid's ability to remain stable following a disruptive event, such as a line shorting out after sagging into a tree or the unexpected loss of a big generator). Current grid monitoring technologies rely on snap-shots of local grid conditions taken several seconds apart, and snap-shots taken by different utility monitoring systems are not time-synchronized with one another. Lack of time-synchronization makes it impossible to establish a fully consistent and detailed picture across a large interconnection, such as the western U.S. grid, by trying to piece together observations from independent utility monitoring systems. Because of grid operator's inability to "see over the horizon," import limits between and among utility systems are set conservatively based on off-line studies that assume worst-case conditions. (These off-line studies, too, are subject to significant uncertainty.) The result is the transmission system is underutilized with respect to its physical capabilities and a potentially false sense of security regarding the actual reliability of the grid.

Recently a new class of grid monitoring technologies, based on phasor-measurements, has emerged that is capable of measuring frequency and voltages at very high time-resolution (typically, 30 samples per second). Of equal importance, the measurements are time-stamped using a common reference clock enabling synchronization and hence alignment of measurements from widely disparate locations. While the measurement devices, themselves, have been available for some time, only recently have communication and signal processing technologies progressed to the point where it has become feasible to gather and analyze data from a network of these devices spread across a wide geographic area, such as the western U.S., in order to support real-time operations. Previously, all applications of the data from these devices have been in support of post-disturbance analysis or model validation.

1.2. Project Objectives

The objective of this task was to research, develop, factory- and field-test prototypes for several California ISO phasor applications in close coordination with, and with oversight provided by California ISO.

The original Task objectives, taken from the contract, were to:

- Research alarming thresholds including identification of future research needs to establish additional alarm and actions research
- Research algorithms to calculate damping levels when sudden events in the system trigger sizeable oscillations deemed unsafe and to suggest corrective actions.
- Research the utilization of mode shape information available within the prototype to suggest corrective actions to suppress dangerous oscillations.
- Prepare a technical report on research findings.

1.3. Project Approach/Methods

In collaboration with researchers at University of Wisconsin–Madison, the project team conducted research on utilizing phase angle measurements gathered at several locations to measure grid stress across critical transfer paths or an area of the power system called a cutset area. The problem formulation and the derivation of relationships between phase angles, impedance changes resulting from line trips, and power flow was based on traditional circuit theory. The concepts were illustrated on the 39 bus New England test system and a 225 bus model of the WECC power system.

The project team also conducted statistical analysis of actual phasor measurement data gathered over an entire year that was provided by Bonneville Power Administration (BPA) to identify normal voltage phase angle difference ranges of operation and associated alarming limits. Several clustering techniques were used to identify pairs of buses for which phasor measurements are available and across which the phase angle difference should be monitored. This work leverages similar efforts currently underway under the phase angle baselining project in support the North American Synchrophasor Iniatiative (NASPI).

Additionally, a new version of the Real Time Dynamics Monitoring application (RTDMS v6) was developed for NASPI. It incorporates improvements to its alarming capabilities based on end-user feedback and was adapted for the California Independent System Operators (CA ISO) phasor data. The enhancements pertaining to the alarming threshold research include a framework that allows RTDMS users & IT support to subscribe and receive automated email notifications on threshold violations, poor data quality/availability, and RTDMS system failures; ability to generate long-term statistics charts (e.g. hourly/daily average box-and-whisker plots or XmR plots) to suggest alarming limits; and flashing visual alarming messages within the RTDMS client applications.

Finally, the project team has also been collaborating with BPA and Washington State University (WSU) to research and implement a real time oscillation detection capability in RTDMS for automatic rapid identification of the damping levels during and immediately following system disturbances and to issue alarms for system operators and recommended action alerts when pre-established damping level thresholds are violated. This capability incorporates three signal-processing algorithms, namely, Prony, Martrix Pencil and Fast Fourier Transform in conjunction with a set of rules to carry out the damping estimation reliably and automatically without manual supervision. This work also compliments the research currently underway at University of Wisconsin–Madison and Pacific Northwest National Lab (PNNL) to utilize mode shape information to suggest corrective actions to suppress dangerous oscillations. These research findings will also be prototyped and tested on RTDMS under a follow-on CEC contract.

1.4. Project Outcomes

The major project outcomes have included:

- The definition of a novel phase angle based metric that provides grid stress information between specific regions and across critical power transfer interfaces that is proportional to the power flow across the interface and the net transfer capacity of the interface. This new metric is a generalization of the phase angle difference concept and it was illustrated on the 39 bus New England test system and a 225 bus model of the WECC power system and the results have been published in the following conference proceedings:

  I. Dobson, M. Parashar, C. Carter, "Combining phasor measurements to monitor cutset angles", 43rd Hawaii International Conference on System Sciences, Kauai HI, Jan. 2010.

  I. Dobson, M. Parashar, "A cutset area concept for phasor monitoring", submitted to 2010 Power and Energy Society General Meeting in Minneapolis, MN (submitted).

- A preliminary list of suggested key phase angle difference pairs and associated alarming limits across the Western Interconnection for monitoring grid stress across the Western Interconnection.
- Release of a new version of the RTDMS system (RTDMS v6) with improvements to existing alarming capabilities presently undergoing field-testing at the CA ISO.
- Implementation and factory testing of oscillation detection capabilities to quickly detect and characterize the damping levels following system events.
- This final technical report, *Advanced Phasor Technology*, on research findings satisfies the contract deliverable.

1.5. Conclusions and Recommendations

1.5.1. Conclusions

The focus of this work has been to conduct research, and prototype a class of phasor based operator tools that leverage the intrinsic properties of these new kinds of measurements, namely, time synchronization, higher time-resolution to assess grid dynamics, and direct "state measurement" (as opposed to "state estimation"). The statistical analysis of historical phasor data that was conducted provide meaningful alarming limits on phase angle differences to monitor grid stress and reasonably distinguish between normal and abnormal grid conditions in real time. The additional phase angle metric that has been proposed is a generalization of the phase angle difference concept and preliminary findings indicate that this new metric is very responsive to the grid stress across the specific interface it is monitoring and insensitive to changes in other regions, and may therefore be a more useful metric than the traditional phase angle difference concept. Furthermore, the algorithms and associated rules to accurately detect dangerous oscillations following an event and quickly characterize the dynamic stability of the grid in terms of its damping levels exploit the high-resolution property of these measurements and would be a useful application within a control room environment. The initial test results of these algorithms are very promising.

1.5.2. Recommendations

The interest in phasor technology has been steadily growing in recent years. Given the projected deployment of phasor measurement units within WECC and North America in general over the next several years, there is an increasing need to develop phasor based tools and deploy them within a control room environment. The research work that has been performed under this contract is directed towards this overall goal. The research findings suggest that phasor based information can be successfully used to monitor grid stress on a wide-area basis as well as accurately classify dynamic stability of oscillations that are introduced during system events. These concepts, however, need to be further tested and demonstrated in a field environment before they can be depended on in real time operations.

1.5.3. Benefits to California

The benefits to California include real-time wide-area situational awareness beyond local control areas, improved grid reliability, and better congestion management across critical interfaces such as the California Oregon Intertie.

2.0 Glossary

Acronym	*Definition*
BPA	Bonneville Power Administration
California ISO	California Independent System Operator
CERTS	Consortium for Electric Reliability Technology Solutions
LBNL	Lawrence Berkeley National Laboratory
MRTU	Market Redesign and Technology Update
PIER	Public Interest Energy Research
RD&D	Research Development & Demonstration
RTDMS	Real Time Dynamics Monitoring System
RTSO	Real Time System Operations
TRP	PIER Transmission Research Program
WECC	Western Electricity Coordinating Council