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Area of Interest 1: Interregional Electricity Reliability Issue and Assessment Analysis:



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# Area of Interest 1: Interregional Electricity Reliability Issue and Assessment Analysis

## Final Report

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## Disclaimer

# Abstract

In 2010, the U.S. Department of Energy (DOE) tasked Lawrence Berkeley National Laboratory (LBNL) and the Pacific Northwest National Laboratory (PNNL), in separate contracts, to provide coordinated technical support to the electricity industry for two national electricity reliability initiatives. The first initiative focused on improving the frequency response of each of the three North American interconnections. The second initiative focused on improving industry understanding of the causes and consequences of fault-induced delayed voltage recovery, which has been observed in all three interconnections. Both initiatives were conducted in close coordination with the North American Electric Reliability Corporation (NERC) and the Western Electric Coordination Council (WECC) and involved the participation of leading utilities from across the United States. This is the final report on LBNL's activities. It consists of summaries of each activity, including references to published documents that were prepared through the course of the project. (Activities under taken by PNNL are reported on in a separate report.)

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# 1. Introduction and Overview

In 2010, the U.S. Department of Energy (DOE) tasked Lawrence Berkeley National Laboratory (LBNL) and the Pacific Northwest National Laboratory (PNNL), in separate contracts, to provide coordinated technical support to the electricity industry for two national electricity reliability initiatives. The first initiative focused on improving the frequency response of each of the three North American interconnections. The second initiative focused on improving industry understanding of the causes and consequences of fault-induced delayed voltage recovery, which has been observed in all three interconnections.

Frequency response refers to the collective ability of generators (primarily, but loads can also participate) to arrest and reverse sharp declines in interconnection frequency immediately following the unplanned loss of generation. Inadequate frequency response means that widespread cascading blackouts may ensue from the unplanned loss of generation. Recent studies have found declining trends in interconnection frequency response. The Frequency Response Initiative (FRI) sought to confirm and better understand the reasons for these declines and then support actions to reverse them.

Fault-induced delayed voltage recovery (FIDVR) refers to unexpected delay in the recovery of voltage to its nominal value following the normal clearing of a fault. Initial observations of these delays by utilities in the western interconnection led to concerns that they might precipitate widespread cascading blackouts. The FIDVR initiative sought to identify the physical mechanisms that caused the delay, assess the risks the delay and recovery posed to the reliability of the U.S. power system, and, if appropriate, identify appropriate measures to manage these risks.

Both initiatives were conducted in close coordination with the North American Electric Reliability Corporation (NERC) and the Western Electric Coordination Council (WECC) and involved the participation of leading utilities from across the United States.

This is the final report on LBNL's activities. It consists of summaries of the activities undertaken in support of both initiatives, including references to published documents that were prepared through the course of the project. Activities under taken by PNNL, in conjunction with LBNL, are referenced, when appropriate, but are reported on in greater detail in a separate PNNL technical report.

See: Chassin, D.P., et al. (2015). *ARRA Interconnection Planning Report*. Pacific Northwest National Laboratory, June 2015.

## 2. The Frequency Response Initiative

Frequency response refers to the collective ability of generators (primarily, but loads can also participate) to arrest and reverse sharp declines in interconnection frequency immediately following the unplanned loss of generation. Inadequate frequency response means that widespread cascading blackouts may ensue from the unplanned loss of generation. Recent studies have found declining trends in interconnection frequency response. The Frequency Response Initiative (FRI) sought to confirm and better understand the reasons for these declines and then support actions to reverse them.

The initiative confirmed the importance of generator governors in ensuring reliability during frequency response events. The initiative conducted the technical analysis required to support the adoption of revisions to NERC's reliability standards to ensure that interconnections and balancing authorities take appropriate actions to ensure adequate frequency response. The initiative also developed monitoring and compliance tools that support the standard.

LBNL was involved in four activities in support of the FRI: (1) Technical support for preparation of NERC Frequency Response Initiative report; (2) Frequency event monitoring for all three interconnections; (3) Technical support for revisions to NERC Standard BAL-003; (4) Development of a tool for measuring frequency response.

### 2.1. Technical support for preparation of NERC Frequency Response Initiative report

In 2012, NERC published the *Frequency Response Initiative Report* (see citation below). LBNL staff and contractors (John Undrill, Energy Mark, and Advanced System Research) provided technical support for the development of the report, including: (a) an analysis of the balancing authority frequency response survey; (b) an analysis of the generator governor survey; and (c) an analysis of historic interconnection frequency response.

See: North American Electric Reliability Corporation (2012). *Frequency Response Initiative Report.* Available from: http://www.nerc.com/docs/pc/FRI_Report_10-30-12_Master_w-appendices.pdf

### 2.2. Frequency event monitoring for all three interconnections

LBNL coordinated activities of Oak Ridge National Laboratory (ORNL), which was funded via a subcontract from PNNL, to implement a system that records and sends in real time automated notifications to NERC on frequency events occurring in all three U.S. interconnections. The frequency event monitoring system, called FNet, is based on low-cost frequency monitoring devices that are connected via wall plugs from a broad network of locations spread across each of the three interconnections. Recorded events from FNet are also used as the basis technical studies conducted in support of revisions to NERC Standard BAL-003.

### 2.3. Technical support for revisions to NERC Standard BAL-003

LBNL contractors John Undrill, Energy Mark, and Advanced System Research, participated in a variety of technical support activities leading to the revisions to NERC Standard BAL-003. As a result of these efforts the NERC Standard BAL-003 contains for the first time requirements for interconnection frequency response and creates obligations for balancing authorities to maintain minimum levels of frequency response.

See: Martinez, Carlos A. (2013). *NERC Frequency Response Standard, Current Status, Issues, and 2010 to 2013 Field Trial Results In NERC Frequency Response Standard (BAL-003-1)*. Available from: http://eetd.lbl.gov/publications/nerc-frequency-response-standard-curr

Martinez, Carlos A., and Rafael Campo. (2012). *NERC Interconnections 2009-2012 Frequency Response Statistics, Typical Frequency Events Profiles, and Observations on NERC-FRI Report Statistics In NERC Interconnections Frequency Response Performance*. Available from: http://eetd.lbl.gov/publications/nerc-interconnections-2009-2012-fre-1

Martinez, Carlos A., Howard F. Illian, and L. Patterson. (2010). *Research Results and Recommendations for Automatic Processes for Identifying Interconnections Frequency Events and Estimate Frequency Response In Frequency Events Identification and Frequency Response*. Available from: http://eetd.lbl.gov/publications/research-results-and-recommendations-

### 2.4. Development of a tool for measuring frequency response

LBNL coordinated activities of PNNL to develop a software tool that uses synchrophasor measurements to measure interconnection and balancing authority frequency response. Subsequent to this, work to further enhance the tool and extend it to measure generator frequency response performances is being undertaken with additional DOE support coordinated through the Consortium for Electric Reliability Technology Solutions (CERTS).

See: Etingov, Pavel, Dmitry Kosterev, and T. Dai. (2014) *Frequency Response Analysis Tool*. Available from: https://certs.lbl.gov/project/frequency-response-analysis-tool. The Frequency Response Tool is available from https://svn.pnl.gov/FRTool.

## 3. The FIDVR Initiative

Fault-induced delayed voltage recovery (FIDVR) refers to unexpected delay in the recovery of voltage to its nominal value following the normal clearing of a fault. Initial observations of these delays by utilities in the western interconnection led to concerns that they might precipitate widespread cascading blackouts. The FIDVR initiative sought to identify the physical mechanisms that caused the delay, assess the risks the delay and recovery posed to the reliability of the US power system, and, if appropriate, identify appropriate measures to manage these risks.

The initiative confirmed that stalled residential air conditioning (AC) units (powered by single-phase induction motors) were the cause of FIDVR. The initiative also confirmed that FIDVR events were common to utility distribution systems, but generally speaking did not pose a significant threat to the reliability of the bulk transmission system. The initiative is recognized as having contributed materially to renewed efforts by the power industry to better understand trends affecting the characteristics of loads, especially those involving power electronics, and their interactions with the power system.

LBNL led organization and coordination for four closely related activities in the FIDVR initiative: (1) End-use equipment testing; (2) Field monitoring of utility distribution circuits; (3) AC modeling studies; and (4) Promulgation of the Composite Load Model.

## 3.1. End-use equipment testing

LBNL contracted with Southern California Edison (SCE) to conduct a series of tests of air conditioning equipment at their laboratory testing facilities in Westminster, California. The tests verified aspects of equipment stalling and equipment protection for both single-phase residential and three-phase small commercial units. These tests were coordinated with companion test conducted by Bonneville Power Administration (BPA) at their laboratory testing facilities in Vancouver, Washington.

See: End-use device testing reports prepared by SCE, which are available from the FIDVR website: https://fidvr.lbl.gov/research/end-use-device-testing

## 3.2. Field monitoring of utility distribution circuits

LBNL procured 40 power-quality monitoring devices from Power Standards Laboratory (PSL). The PSL units were set-up to record of both RMS and waveform information from FIDVR events. The units were lent to Southern California Edison (SCE), Centerpoint Energy, and Dominion Energy, who installed them within distribution circuits in their service territories that they believed were prone to FIDVR events. The units recorded multiple FIDVR events over the course of the summers during which they were deployed. These recordings were used to validate simulation modeling of FIDVR events.

See: Distribution System Monitoring reports prepared by SCE, which are available on the FIDVR website: https://fidvr.lbl.gov/research/dsm.

## 3.3. AC modeling studies

LBNL contracted with John Undrill to develop a detailed electromechanical model of single-phase induction AC units. This basic model was used and enhanced in three follow-on studies of FIDVR. First, LBNL contracted with Schweitzer Engineering Labs (SEL) to develop a simulation model for a complete distribution circuit populated with single phase induction AC units at various locations within the circuit. SEL ran the model using a real-time digital simulator and conducted hundreds of sensitivity studies of FIDVR. SEL's analysis confirmed the role of point-on-wave and unit loading in determining whether AC units would stall.

Second, LBNL contracted with John Undrill to work with Arizona State University (ASU) to implement the single-phase induction AC unit model in a commercially available software tool known as PSCAD. Implementation in PSCAD enables other researchers to conduct FIDVR studies of distribution circuits.

Third, LBNL contracted with University of Wisconsin (UW) to conduct additional simulations of the basic single phase AC induction unit. The UW studies identified a mechanism that helps explain why voltage recovery is generally localized and hence rarely poses a threat to the reliability of the bulk transmission system.

See: Ravikumar, Krishnanjan Gubba. (2012). *RTDS Testing Final Report*. SEL Engineering Services. Available from: https://fidvr.lbl.gov/publications/rtds-testing-final-report

Liu, Yuan, Vijay Vittal, John Undrill, and Joseph H. Eto. (2013). "Transient Model of Air-Conditioner Compressor Single Phase Induction Motor." IEEE Transactions on Power Systems 28, no. 4 (2013): 4528-4536. Available from: https://fidvr.lbl.gov/publications/transient-model-air

Lesieutre, Bernard. (2015). *Point-on-Wave Simulations of Single Phase Induction Motor with Compressor Load*.

## 3.4. Promulgation of the Composite Load Model

The composite load model was developed by utilities in the Western Interconnection to improve the accuracy of the transmission planning studies they use to set reliability-based limits that guide the operation of the western bulk transmission system. The model contains an explicit, but highly aggregated, representation of the factors that affect FIDVR, as well as other aspects of the electrical behavior of end-use loads. As a result of recent changes to NERC's reliability standards, utilities will need to rely on tools, such as the composite load model, in order to conduct the planning studies required by the standards.

LBNL led or coordinated several activities that facilitate the use of the composite load model both within the west as well as in other parts of the United States. First, PNNL developed a software tool that facilitates preparation of the data files that are required as inputs to the composite load model. These tools are described in separate standalone reports prepared by PNNL.

See: Load Model Data Tool (LMDT), available from https://svn.pnl.gov/LoadTool

Second, LBNL contracted with John Kueck to work with PNNL staff to develop guidance on motor protection settings to use in the composite load model. The guidance was based on detailed review of the major types of motors found in applications within the residential, commercial, and industrial sectors.

See: Chapter 8 ("Motor Response and Protection in Commercial Buildings Narrative") of: Chassin, D.P., et al. (2015). *ARRA Interconnection Planning Report*. Pacific Northwest National Laboratory.

Third, LBNL contracted with DNV-GL to work with ISO-New England and its transmission companies to develop a full set of inputs for the composite load model specific to the seven regions of the northeastern portion of the United States. DNV-GL's work was based on review and analysis of end-use survey information developed by the U.S. Energy Information Administration and end-use information developed by New England transmission companies.

See: Gifford, William, et al. (2014). *End-Use Data Development for Power System Load Model in New England - Methodology and Results*. DNV GL Energy, April 2014. Available from: https://certs.lbl.gov/publications/end-use-data-development-power-system

Fourth, LBNL contracted with Mitsubishi Engineering to conduct the initial phase for a sensitivity study of the composite load model. The study was coordinated with the WECC Load Modeling Task Force and involved analysis of the transmission planning models used by Pacific Gas and Electric, PacifiCorp, Salt River Project, and Southern California Edison. Subsequent phases of this study are being funded by DOE through the CERTS program.

See: Tenza, Nick, and Scott Ghiocel. (2015). *WECC Load Model Sensitivity Study: An Analysis of the Sensitivity of WECC Grid Planning Models to Assumptions Regarding the Composition of Loads*. Available from: http://eetd.lbl.gov/publications/wecc-load-model-sensitivity-study-an-

Etingov, Pavel, Dmitry Kosterev, and T. Dai. (2014) *Frequency Response Analysis Tool*. Available from: https://certs.lbl.gov/project/frequency-response-analysis-tool

Chassin, D.P., et al. (2015). *ARRA Interconnection Planning Report*. Pacific Northwest National Laboratory.