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Using Synchrophasors for Frequency Response Analysis in the Western Interconnection

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SUMMARY

Frequency response has received a lot of attention in recent years at the national level, which culminated in the development and approval of NERC BAL-003-1 Frequency Response and Frequency Bias Setting Reliability Standard. WECC JSIS, NASPI, BPA, CERTS and PNNL collaborate on the common goals to deliver to the industry applications for frequency response analysis at interconnection, Balancing Authority and individual power plant levels. This paper describes a Frequency Response Analysis Tool that has been used for establishing a frequency response baseline for the Western Interconnection. It describes how synchrophasor data are used in determining generator response characteristics – "frequency responsive," "under load control," or "baseloaded." This paper also discusses and provides an example of how the distribution of frequency response across a region can impact power pick-up on major transmission paths.

KEYWORDS

Frequency response, Frequency Response Analysis Tool, Synchrophasor data application, NERC BAL-003-1

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I. Background

Federal Energy Regulatory Commission (FERC) states in [1]: "Frequency response is a measure of an Interconnection's ability to stabilize frequency immediately following the sudden loss of generation or load, and is a critical component of the reliable operation of the power system, particularly during disturbances and recoveries." Frequency response has received much attention in recent years at the national level, culminating in the development and approval of the NERC BAL-003-1 Frequency Response and Frequency Bias Setting Reliability Standard [2]. The Standard determines the amount of frequency response required in each interconnection and the allocation of Frequency Response Obligation among Balancing Authorities. The Standard is largely based on technical work done in the NERC Frequency Response Initiative [3] and LBNL-led work on frequency response metrics [4].

The reliability implications of frequency response are much broader than the scope of NERC BAL-003-1 Reliability Standard, whose main goal is to prevent under-frequency load shedding for credible resource loss contingencies in an interconnection. Frequency response distribution can have significant implications on power pick-up on major transmission paths [5,6]. Excessive governor pick-up on certain transmission paths can lead to overloads and voltage instability, and thereby impact transmission reliability margins. Impacts of frequency governing on damping of inter-area oscillations should be taken into account, as experienced in the Western Interconnection, when aggressive tuning of hydro-governor tuning and deficient response from thermal governing can result in poorly dampened oscillations [7]. Finally, certain governing characteristics are required for stable islanded operation and black-start capabilities.

The Western Electricity Coordinating Council (WECC) has a long history of frequency response monitoring. WECC made several attempts to develop its own regional Frequency Responsive Reserve (FRR) standard or criteria [5], well before the NERC Standard. WECC's objectives were to: (a) ensure that an adequate amount and quality of frequency responsive reserves are carried in the interconnection, and (b) achieve even distribution of frequency response across the interconnection to mitigate the frequency response impacts on transmission paths. WECC has used synchrophasor data to monitor frequency response in the Western Interconnection.

Accurate models are required for reliable and economic power system operations. WECC has been conducting model validation studies at power plant and system-wide for well over a decade [8, 9, 10]. In the early 2000's, the validation studies indicated significant differences between the simulated and actual frequency responses, which led to the development of thermal governor modelling recommendations and a process where Generator Operators classify their units as "frequency responsive," "under load control," or "baseloaded." Bonneville Power Administration (BPA) implemented the practice of using synchrophasor data for governor response validation [10]. These efforts greatly improved the accuracy of frequency response representation in power system studies, as evident from a number of system-wide validation studies.

II. Goals of Frequency Response Analysis

The Consortium for Electric Reliability Technology Solutions (CERTS) was formed in 1999 to research, develop, and disseminate new methods, tools and technologies to enhance the reliability of U.S. electric power system and efficiency of competitive electricity markets. The North American SynchroPhasor Initiative (NASPI) is a collaborative effort between the U.S. Department of Energy, North American utilities and grid operators, vendors, national labs and researchers to improve power system reliability through wide-area synchronized measurement and control and the use of synchrophasor technology. The WECC Joint Synchronized Information Subcommittee (JSIS) was formed in 2009 as the successor to the WECC Disturbance Monitoring and the WECC Wide Area Measurement groups, to provide technical guidance for management of synchronized wide-area data in the Western Interconnection, as well as development and deployment of applications that use synchronized wide-area measurements.

WECC JSIS, NASPI, BPA, CERTS and the Pacific Northwest National Lab (PNNL) collaborate in the common goal to deliver applications to the industry for frequency response analysis at the interconnection, Balancing Authority and individual power plant levels. Their efforts include:

- Develop and deploy applications for interconnection-wide frequency response analysis,
- Develop and deploy applications that enable Balancing Authorities to calculate Frequency Response Measure per NERC BAL-003-1from synchrophasor and SCADA data,
- Baseline historic frequency response performance for an interconnection, Balancing Authorities, and power plants,
- Develop and deploy applications for monitoring and validation of frequency response of power plants to help a Balancing Authority to determine its inventory of frequency-responsive resources,
- Baseline power pick-up on major transmission paths due to frequency response, and
- Research new methods in frequency response analysis beyond NERC BAL-003-1.

III. Frequency Response Analysis Tool

Figure 1 shows a typical frequency recording following a resource loss in the Western Interconnection. Point A is frequency prior to a resource loss, calculated as an average frequency over 16 seconds prior to an event. Point B is the settling frequency, calculated as an average frequency from 20 to 52 seconds following a resource loss. Point C is the minimum (nadir) frequency. NERC Frequency Response Measure (FRM) is calculated at point B. Reference [4] considered nadir-based frequency response measurement at point C.

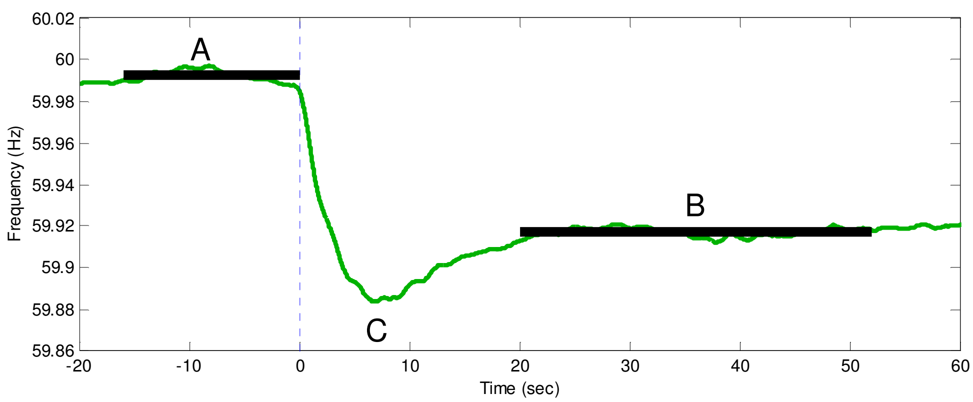

Figure 1: system frequency following resource loss

Nadir-based frequency response is a better measure of the primary frequency response. WECC uses PMU measurements to calculate both, the nadir and Point B frequency responses. However, the nadir response measurement at BA level requires synchronized high resolution PMU measurements of BA frequency and interchange power flows. Most BAs in NERC footprint use 4-second non-synchronized data, making the nadir frequency response nadir measurement not feasible. Therefore, frequency response at Point B is used as a practical alternative in NERC BAL-003-1 Reliability Standard.

WECC JSIS worked with CERTS and PNNL to develop a Frequency Response Analysis Tool (FRAT) to manage the database of under-frequency events and calculate the frequency response baseline. The application can use both PMU data, where available, and SCADA data. Frequency response calculations are consistent with Frequency Response Measure (FRM) in NERC BAL-003-1 for an interconnection and Balancing Authority. In addition to NERC FRM, the application calculates the nadir frequency response. The frequency response metrics are saved in an extensive database, with information going back to 2008, thereby providing a unique baseline of Western Interconnection system frequency response. Figure 2 shows an interactive display of the Frequency Response

Analysis Tool. The primary users of the Frequency Response Application Tool are Balancing Authorities and Reliability Coordinators.

Frequency response is calculated for an interconnection, as well as for a Balancing Authority. BA calculation requires interchange measurements. Unfortunately very few interchange points have PMUs today, so the BA frequency response calculations use SCADA data. SCADA measurements are not time-synchronized and the result of such skew is seen in the area interchange (see the second plot in top right corner of the display in Figure 2). SCADA data also lags PMU measurements by several seconds. Thus, at present those BAs that are using SCADA data for frequency response monitoring are likely to be reporting response values that are not precisely synchronized with interconnection-wide frequency response values measured using PMUs. It will be highly desirable to have PMUs or relay-enabled PMUs at all tie-lines for measurement synchronization, to obtain better quality frequency measurements.

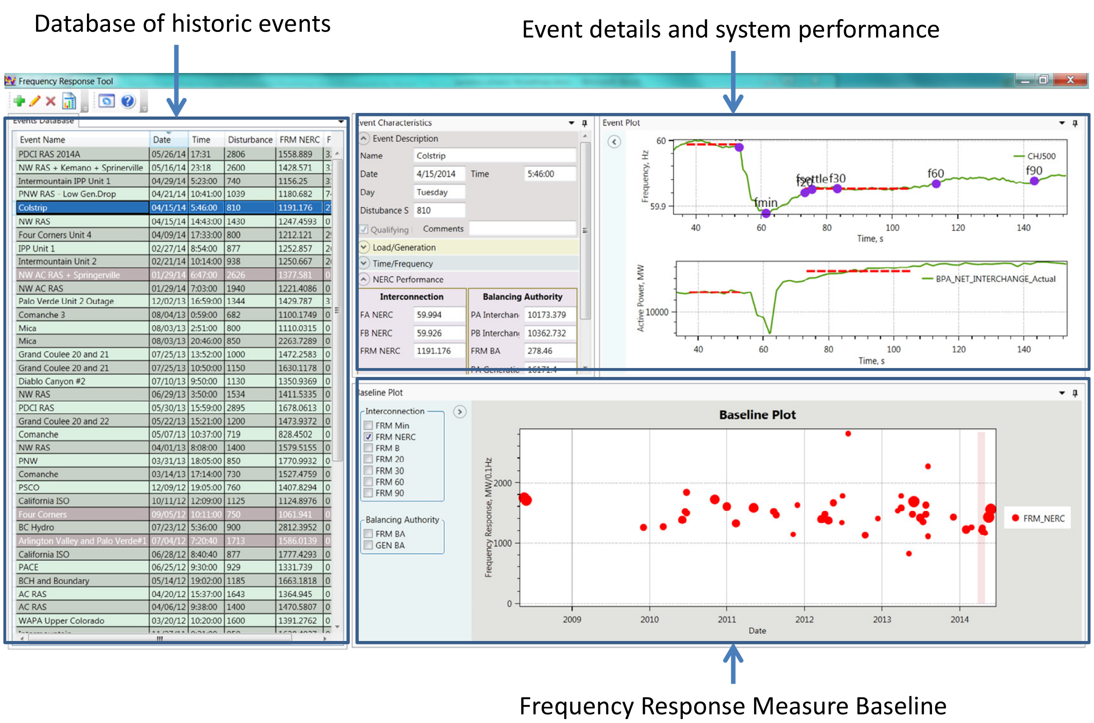

Figure 2: Frequency Response Analysis Tool

With the database of frequency events developed, a variety of plots can be made for frequency response analysis. Figure 3 shows a baseline of frequency response in the Western Interconnection. Red dots represent frequency response measure calculated using the NERC FRM methodology. Blue diamonds represent frequency response measure at nadir frequency. The size of the dots is proportional to amount of generation lost during an event. Similar baseline plots are also available for individual Balancing Authorities. Let us make a few observations on WECC frequency response baseline:

- the interconnection response is very consistent over the years, particularly for large events,
- Western Interconnection performance averages about 1,400 to 1,600 MW per 0.1 Hz, which is well above NERC Western interconnection frequency response obligation of about 950 MW per 0.1 Hz
- nadir response, as discussed earlier, is more consistent measure of the frequency response

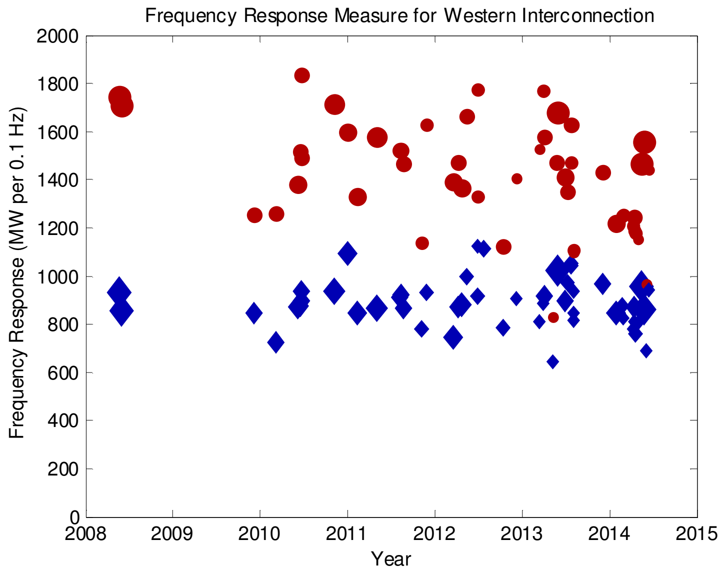

Figure 3: Frequency response baseline for Western Interconnection
(The size of a dot is proportional to amount of generation lost; red dots are measured at settling frequency per NERC FRM; blue diamonds are measured at the frequency nadir)

Figure 4 shows a relationship between the frequency response metrics and size of the disturbance event. Red dots represent NERC FRM calculations at the settling frequency, and blue diamonds represent the response at the frequency nadir. NERC FRM is consistent for larger events, while there is wide variability in measured frequency response for smaller events. Frequency response at the nadir appears to be more consistent over a wide range of events.

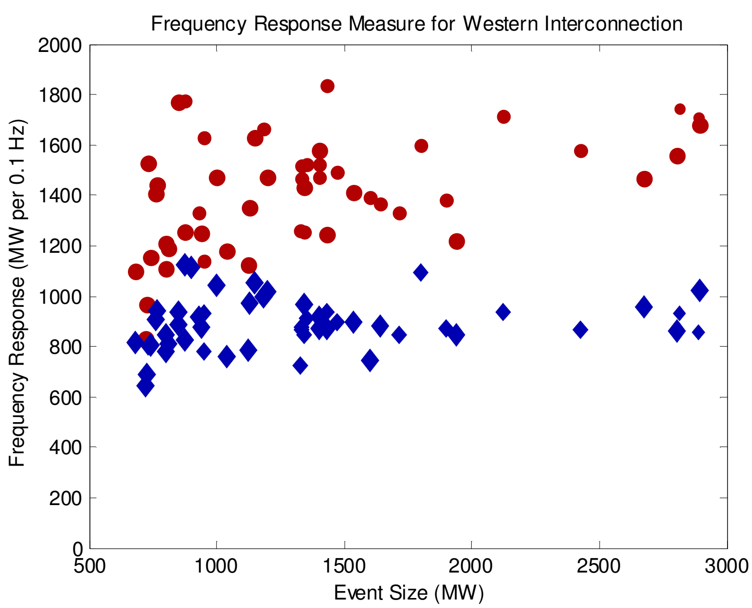

Figure 4: Relationship between event size and historic Frequency Response Measure
(The size of a dot is proportional to date of event, so large dots = more recent events)

Figure 5 shows a relationship between frequency deviations at nadir (C) and settling (B) points. The ratio appears to increase with larger events, as expected from the system physics.

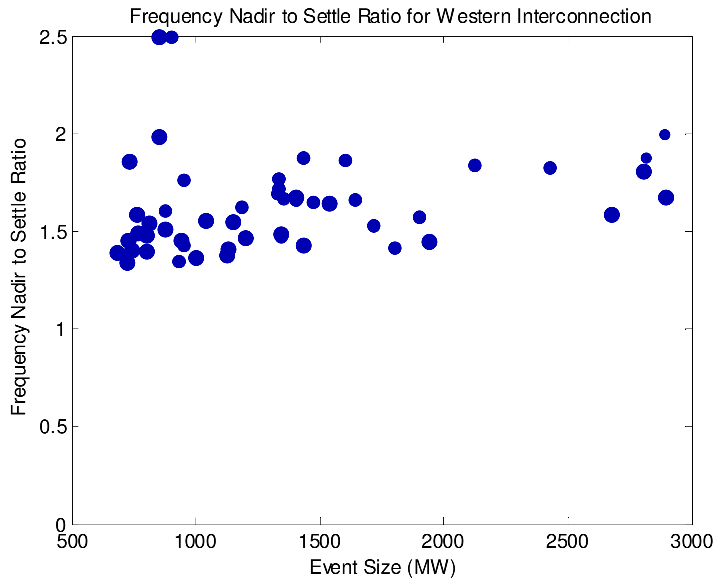

Figure 5: Ratio between frequency deviations at nadir (C) and settling (B) points

WECC-performed studies suggest that interconnecting a large amount of electronically coupled generation in the West will affect the system frequency response. The developed Frequency Response Analysis Tool has provisions to correlate the frequency response metrics with interconnection and BA generation mix – hydro, thermal, wind and solar generation.

IV. Power Plant Frequency Response Monitoring

To meet its Frequency Response Obligation, a Balancing Authority needs to acquire frequency response from generators and other providers. The Balancing Authority needs to have monitoring applications in place to verify that the procured amount of frequency response is delivered.

BPA has been using PMUs to monitor frequency response since 2000 [10]. Today, BPA can perform assessment of generator performance within minutes following a system event. In 2002, WECC conducted a comprehensive analysis of governor responses of power plants, classifying them as "frequency-responsive", "under load control" or "baseloaded" [9]. Synchrophasor data are very effective for identifying frequency response types, as illustrated in Figure 6. A frequency response-type flag is entered as a part of generator data in WECC base cases, which are later used in dynamic simulations and governor powerflow studies.

Synchrophasor data are preferred for power plant frequency analysis because of its high time granularity. SCADA, AGC or plant controller data, measured at two-second speeds, may be used for general assessment of the response shape. However, it is often difficult to make a definitive conclusion from SCADA data because of the data resolution and time skew. While two-second SCADA data may be marginally useful, four to six-second SCADA data can be very misleading for power plant response analysis. As more PMUs are deployed at power plant points of interconnection, frequency response monitoring and validation will improve.

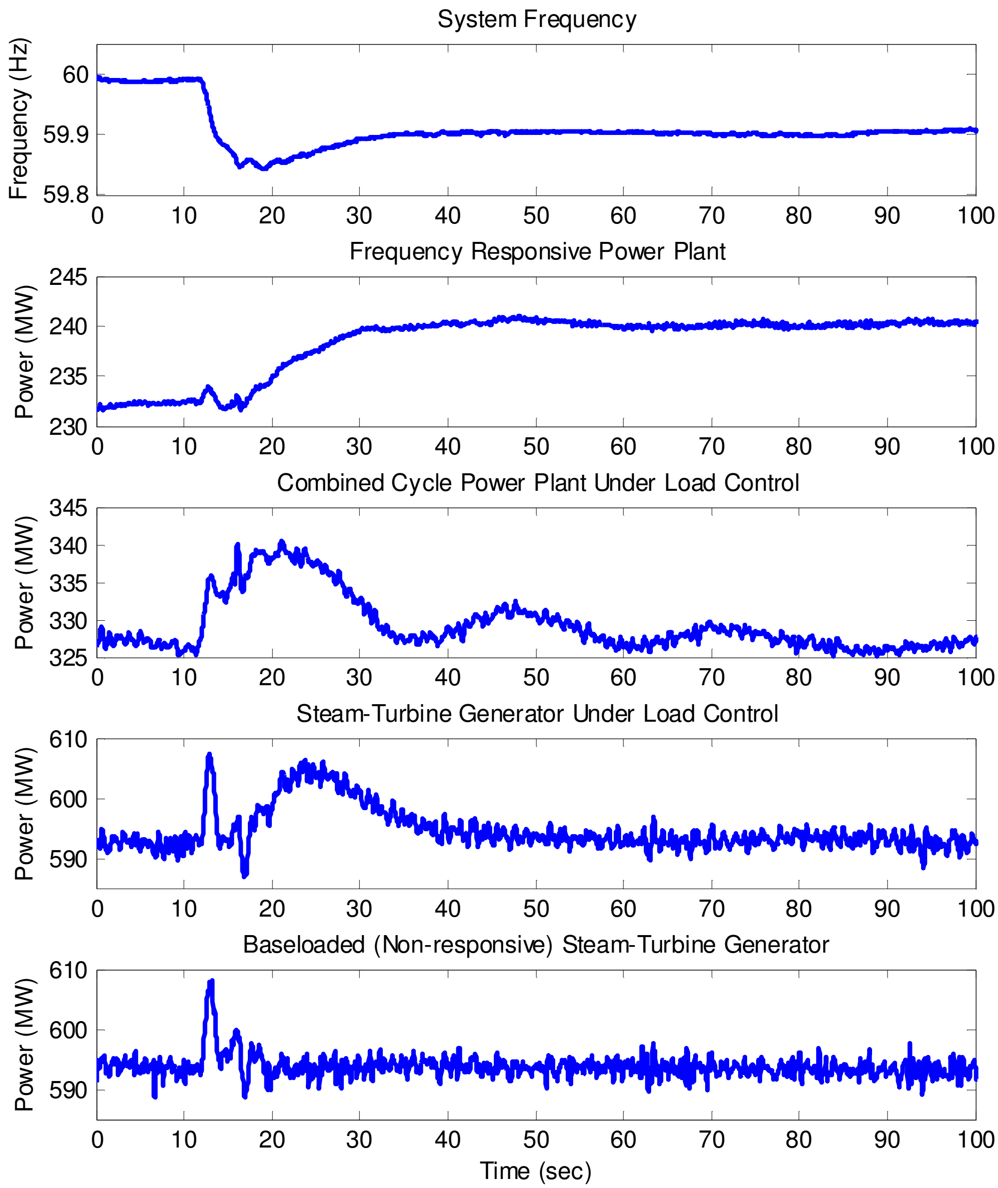

Figure 6: Types of frequency responses

V. Analysis of path power pick-up

As discussed in the FERC AD-13-8 Docket, frequency response distribution can impact the System Operating Limits (SOLs) on major transmission paths. The SOL of the California-Oregon Intertie (COI), a 4,800 MW path in the Western Interconnection, is voltage-stability limited in post-transient time frame because of excessive power pick-up to resource losses in Pacific Southwest. Most of the frequency-responsive hydro generation is located in the Pacific Northwest, while most of the baseloaded thermal generators are in the South, thereby creating a frequency response imbalance within the interconnection. When a generator trip occurs in South, majority of governor response comes from Pacific Northwest and British Columbia, which increases COI loading.

Figure 7 shows a typical COI pick-up for a 1,350 MW generation outage in southern part of WECC. COI voltages declined with the power pick-up on COI due to governor response until dispatchers took corrective actions.

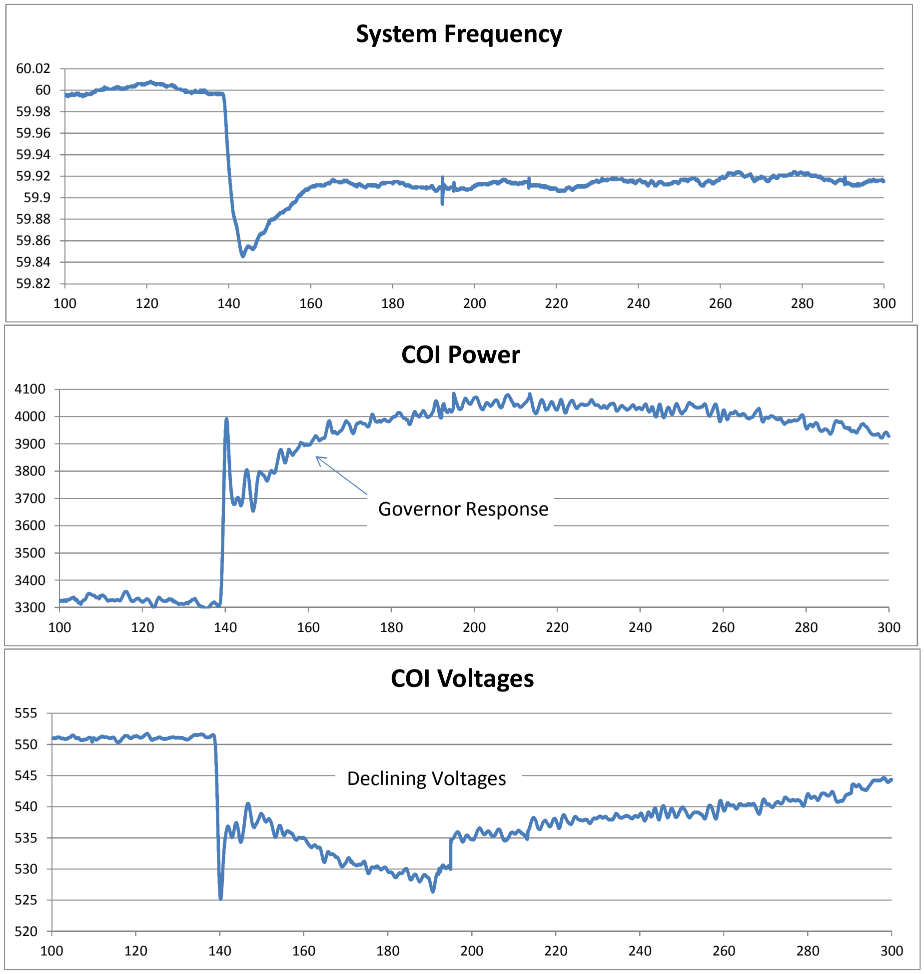

Figure 7 : Frequency response impact on power pick-up and voltages on COI

BPA and CAISO baseline COI power pick-up for generation outages in South, and then use the baseline to benchmark the planning and operational models used for setting System Operating Limits.

VI. Future Work in Frequency Response

Simplicity is a key advantage of NERC BAL-003-1 Reliability Standard. At the same time, simplicity is also its major limitation. The applicability of the BAL-003-1 methods for complex events that include sequential loss of generation is not obvious. The requirement for "linearity" of the frequency response, i.e. providing the same response rate for large and small events, is also questionable. As seen in Figures 4 and 5, NERC FRM is highly variable for small events and does not extrapolate well to large events. While calculating frequency response at nadir is better at the interconnection level, as it produces more consistent and relevant results, allocating such response to Balancing Authorities may be problematic because of the quality of interchange SCADA measurements. In addition, we believe that the "linear" response requirement disadvantages non-conventional frequency response providers, such as loads, which could be used as frequency responsive reserves for large frequency deviations. It will be desirable to acquire some frequency response from loads for large and infrequent off-nominal frequency events. While NERC BAL-003-1 is here to stay for the foreseeable future, additional research into alternative practical methods of measuring and delivering reliability-enhancing frequency response is needed.

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