



NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

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Frequency Response Standard Whitepaper

April 6, 2004

**Prepared by the Frequency Task Force of the NERC
Resources Subcommittee**

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PREFACE

Frequency response as used in this paper is defined as an automatic and sustained change in the power consumption or output of a device that occurs within 5-30 seconds of and is in a direction to oppose a change in the Interconnection frequency. Frequency response as so defined is declining within the Eastern and Western Interconnections when it should be increasing because of increasing load and the associated increase in generation. Frequency Response within the Texas Interconnection has been statistically constant.

The NERC Resources subcommittee posted a Frequency Response Standard for comment in 2001. The comments received against the standard centered on 1) those not understanding the metric and 2) those questioning the need for a standard.

The intent of this paper is to create an understanding of the need for a standard and the technical and economic drivers motivating its development

INTRODUCTION

The NERC Resources subcommittee drafted this paper to document the need for a frequency response standard. Provided in this paper are statistical background data showing how the frequency response of the Interconnections has declined along with an analysis of the technical and economic drivers that have contributed to the decline. Further, the paper attempts to refute through examples and simulation the arguments that this decline in the response is not a reliability issue. Instead, the paper will demonstrate that both the Western and Eastern Interconnections run a strong risk of under-frequency action if a standard is not adopted that establishes minimum levels of frequency response. The Union for the Coordination for the Transmission of Electricity (a European Standards Group) has already adopted a standard addressing the same technical issues raised within this paper. While the primary focus of the paper is the impact to each Interconnection as a whole, the need for primary frequency response also is a major consideration in islanding situations.

Background

Each Control Area's contribution to frequency support is provided by the natural response of its generators and load to frequency variations. Figure 1 depicts a typical frequency excursion caused by a loss of a large generator on an Interconnection. Frequency Response is typically comprised of two components:

“Load rejection” or the reduction in the power consumption by motors that slow down in response to a decline in frequency. This is reflected in the general slope of the line from Points A-C. Load response to a change in frequency can vary anywhere from no response from equipment like computers to 1.5 times for some motor loads. Load response occurs directly or with minimal lag as the frequency changes. In addition,

Control Areas may use “high set” interruptible loads that disconnect on a pre-determined trigger frequency.

“Generator response” or a change in the output of a generating unit due to inertia and the movement of its governor valves. Governor response from properly tuned units occurs in the 3-10 second timeframe and is responsible for the bottoming of frequency at Point C and the partial recovery of frequency to Point B.

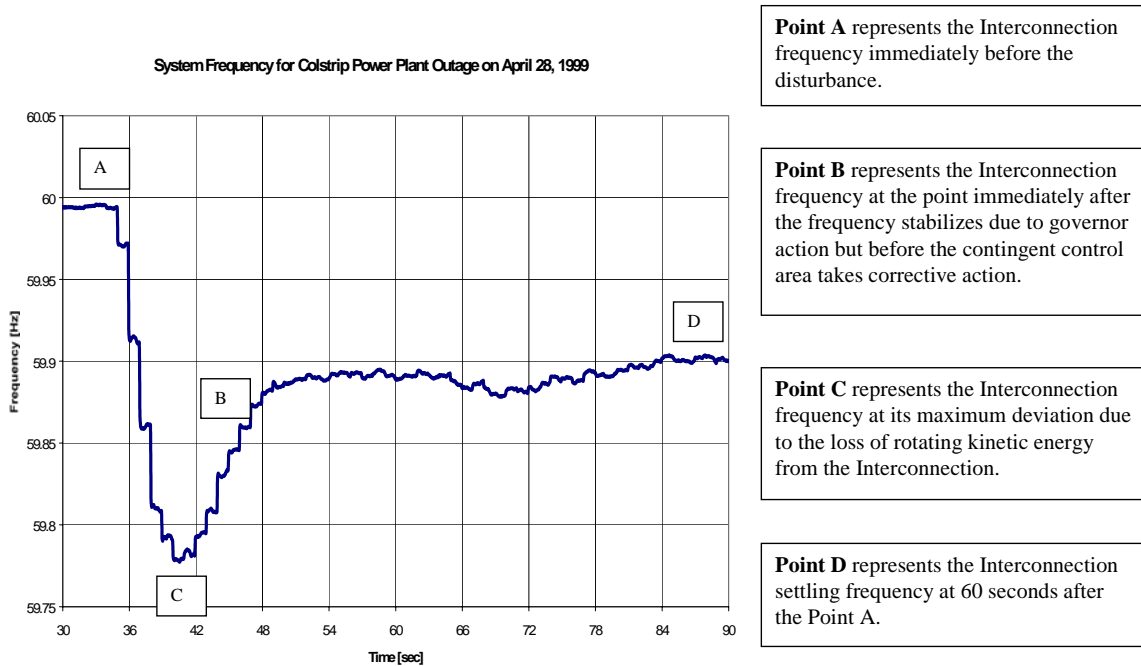


Figure 1 Typical Frequency Excursion

All else being constant, frequency will not recover to its scheduled value (typically 60 Hz) unless the Control Area that lost the resource replaces it.

The turn around in frequency from points C to B attributable to unit governor response has markedly declined and at times is non-existent in the Eastern Interconnection. The line from points C to D is shifting down and becoming horizontal. This means that on many occasions the only frequency response in the East is coming solely from load response. This critical fact is important since as will be discussed later in the paper. The changing nature of loads means that there will be markedly less load response available in the future. Therefore, reliance on load as the sole support to arrest the frequency can lead to a decline in the reliability of the grid.

One of the fundamental obligations of a Control Area as stated the Control Area Criteria of the NERC Operating Manual is the provision of frequency support. Once this support is produced it is the purpose and the intent of the frequency bias component of the ACE

equation to ensure that this response is not withdrawn after the initial transient period or through AGC action.

Ideally, an integrated set of performance-based “balancing standards” should be in place that monitors the entire spectrum of the Adequacy component of Reliability. Figure 2 shows the interrelationships of the set of “Balancing” standards, which ultimately checks that Control Areas have and deploy adequate resources to maintain reliability.

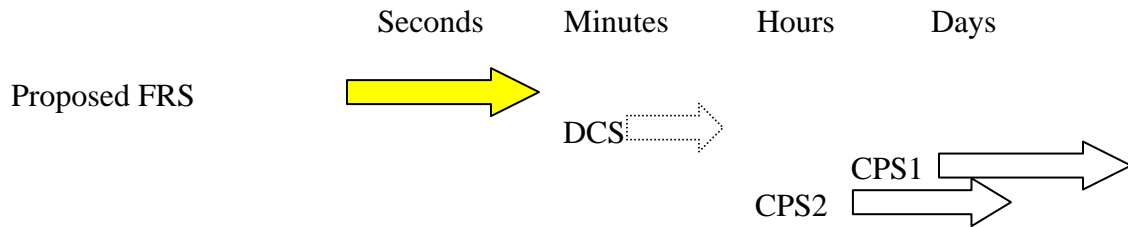
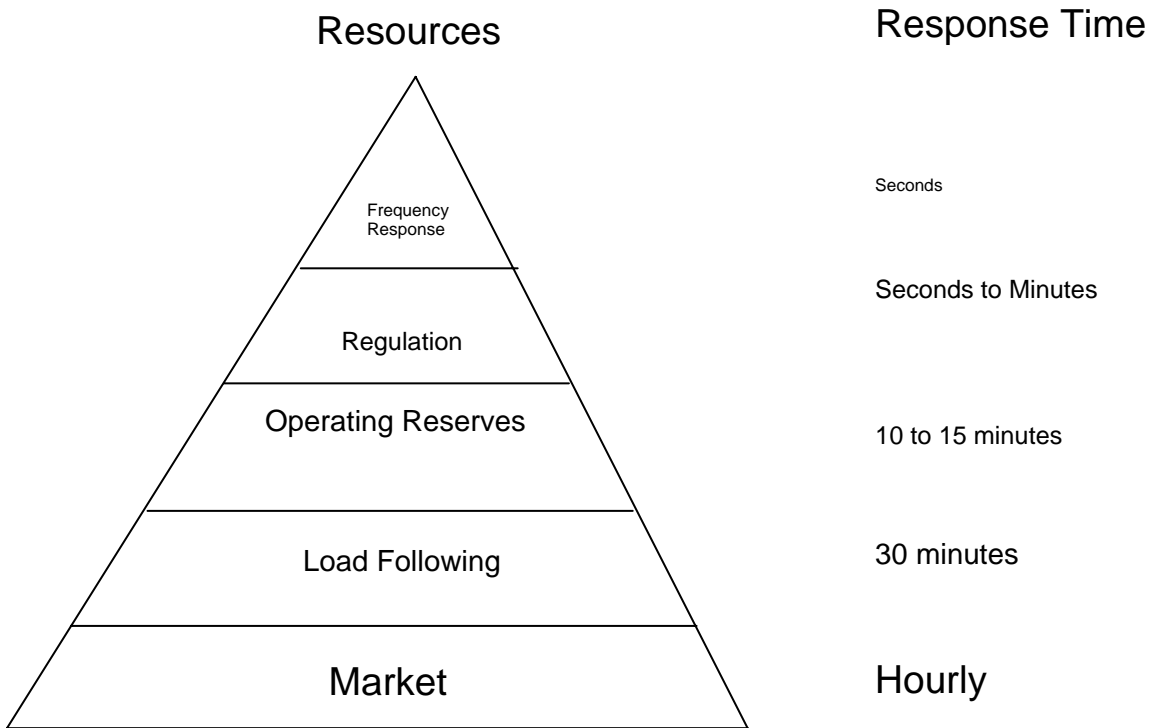


Figure 2 Interrelationships of "Balancing" Standards

The Control Performance Standards (CPS1 and CPS2) are well-defined and generally accepted by the Industry. The Disturbance Control Standard (DCS) measures deployment of reserves for specific events. This paper focuses on a proposed standard to measure sub-minute responses to changes in frequency. This sub-minute response is commonly called Governor Response (if viewed at the generator level) and Primary Frequency Control or Frequency Response (from a Control Area perspective). The resource pyramid diagram below shows the same concept in a different fashion.



Note: Frequency Response is actually a negative value i.e. as frequency drops a generator's output should increase. When discussing Frequency Response, people generally talk about the raw numbers (i.e. 50MW/0.1Hz); the (-) sign is assumed. This should be kept in mind when reading this paper.

CURRENT SITUATION

Eastern Interconnection

Technical papers (Ingleson and Nagle) and analysis (Bourque) point to a continued decline in Eastern Interconnection Frequency Response. Figure 3 is a summary of this work.

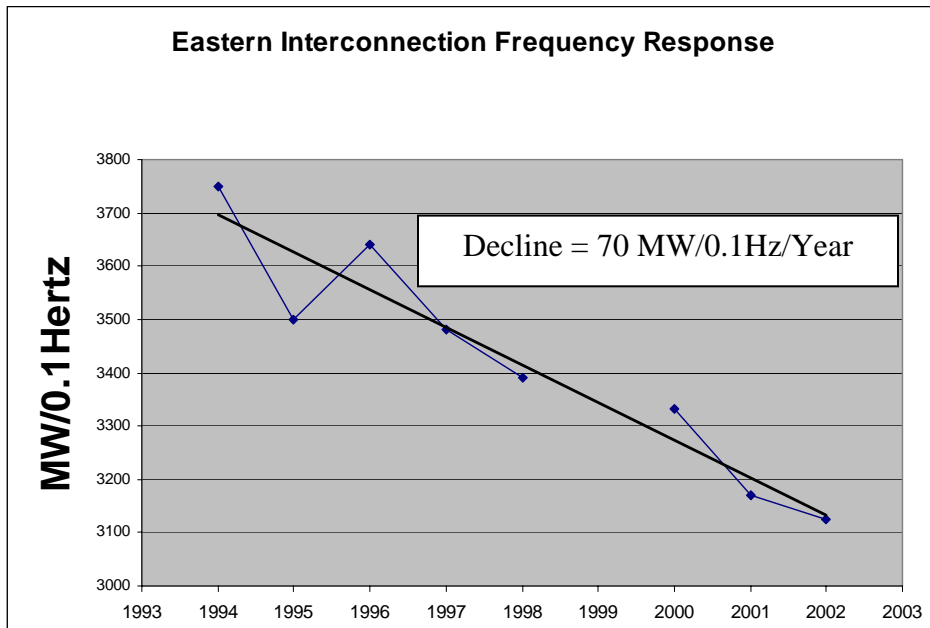


Figure 3 Trend in Eastern Interconnection Frequency Response

The plot shows an annual decline of slightly over 70 MW/0.1 Hz. This nine-year trend reflects an 18% decline in frequency response while load and generation [grew nearly 20%](#) over the same period. Frequency response should have increased proportionally with generation and load.

Western Interconnection

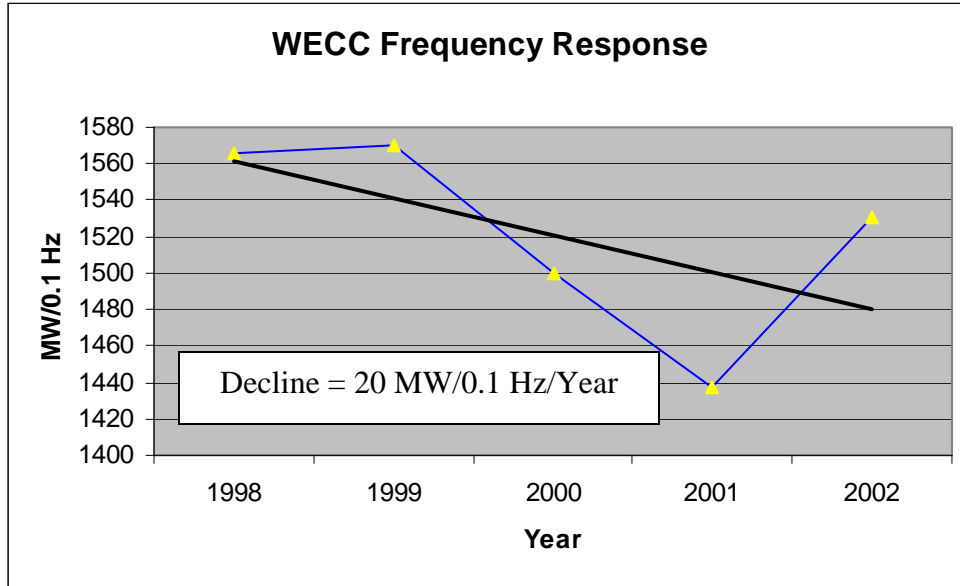


Figure 4 Trend in Western Interconnection Frequency Response

Figure 4 shows a proportionally similar decline in the Western Interconnection’s Frequency Response. The graph represents response to events 25 milliHz or larger. There were a few data points available for prior years that put the West’s response in the order of 1650MW/0.1Hz in 1994. This would be consistent with a decline of 20MW/year. Again, response should be increasing with increasing load and generation.

Texas Interconnection

The trend in the Texas Interconnection frequency response has been statistically flat. Figure 5 is a different representation of response over an 8-year period (1995-2002). The plot is a “box and whisker” graph. The rectangle or bar for each year represents the range of the “middle 50%” of observed events. The average value is the horizontal line within the year’s rectangle. The “whiskers” attached to each box represent the upper and lower “quartiles”. The asterisk in 1999 is an “outlier” or rare events. The plots represent 65 “medium sized” events over this period.

Comparing the Texas Interconnection Frequency Response to the other Interconnections is a challenge. This is because ERCOT has two groups of “high set” interruptible load. The first group trips at 59.8 Hz, the second at 59.7 Hz. Customers in the Texas Interconnection choose to participate in this and ERCOT uses it as a supplement to governor response. Once disconnected, the load provides no other assistance to frequency control such as inertial response. Additionally, this interruptible load provides no response to high frequency events.

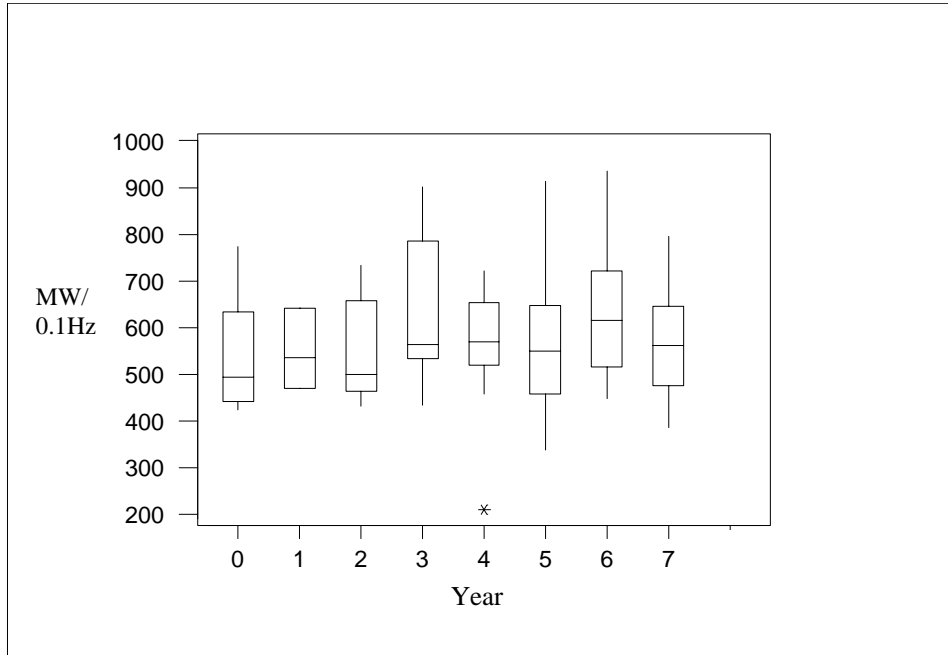


Figure 5 ERCOT Frequency Response 1995-2002

IS THERE A PROBLEM?

Those arguing against the need for a standard contend that the decline in the frequency response illustrated above is not a significant reliability problem. The argument put forward against a standard is that even if frequency response is declining there is so much margin in the system that reliability i.e. loss of load from under- frequency is not impacted. The calculation to demonstrate this argument is straightforward. The first significant amount of under-frequency load shedding in the Eastern Interconnection is set at 59.70Hz¹. The current level of frequency response of the Eastern Interconnection is taken as 3100MW/0.1Hz. Therefore an under-frequency decline to 59.7Hz would require a generation loss of 9300MW. This is well beyond any generation loss that has ever occurred except in an islanded situation. Furthermore, at the current rate of decline of 70MW/yr, as shown in figure 3 it will be thirty-four years before the response level declines to a level where a loss of even 2400MW becomes a problem with respect to potential under-frequency load shedding.

As a starting point, this paper will show that the above logic is based on at least three incorrect assumptions.

The first assumption is that the Interconnection frequency starts at 60Hz. An examination of Eastern Interconnection frequency statistics shows significant periods when the

¹ The highest under-frequency setting in the Eastern Interconnection is 59.82 Hz. This is limited to a single Control Area. The 59.7Hz setting is widely used as a first step.

Interconnection frequency is operating at or below 59.98Hz. If 59.98 Hz is used to determine how long before the loss of 2400MW causes an under-frequency the result reduces to 25 years. This is still beyond the range of concern.

The second and most critical assumption is that the frequency response will be 3100MW/0.1 Hz. This is representative of the average frequency response within the Eastern Interconnection. However, the standard (or average) deviation of responses is $\pm 1870\text{MW}/0.1\text{ Hz}$; giving a range of responses from 4970 to 1230 MW/0.1 Hz. If the lower response of 1230MW/0.1Hz is used in the calculation then, even today, a loss of 2400Mw has significant potential to cause under-frequency load shedding to occur. The fact that an under-frequency event has not happened yet is only coincidence. The multiple unit trips that have approached 2400MW have, fortunately, occurred when there was good response available.

A third assumption that is believed to be unfounded but is harder to disprove explicitly is, namely that the decline in frequency response will continue at a rate of only 70MW/0.1Hz. Many drivers are contributing to the response decline. Among these are:

- Steam turbine generators operating on “sliding pressure” or “boiler-follower” control and/or with “valves wide-open” (VWO) operation.
- Blocked governors on nuclear units for licensing reasons.
- Less heavy manufacturing in North America (proportionally fewer large motor loads and a reduction in “load rejection”).
- Variable-speed drives on motors that do not provide the traditional “load rejection”.
- A larger proportion of combine cycle units being installed on the system. Combined-cycle units when operating at full output operate in temperature control mode. When the frequency declines, there is a drop in combustion air volume that results from the slowing of compressor speed. This drop in combustion air volume can cause a reduction in the unit output. Figure 6 is a graph of the output of a combine cycle unit responding to a frequency decline.

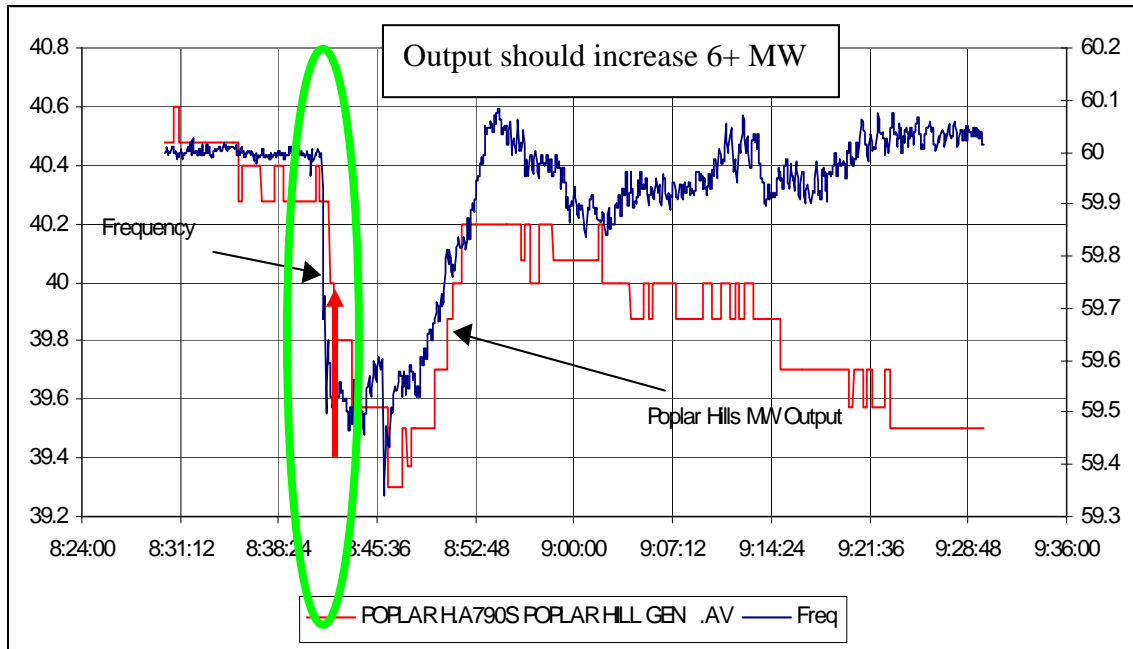


Figure 6 Combustion Turbine Response to Frequency Change

The blue line in Figure 6 is frequency and the red is MW output of the generators. The oval envelops the Frequency Response time window. For a change in frequency of -0.83% , the station lost 2.5% of machine output. If the plant provided 5% droop, its output should have increased 6.6 MW with the frequency event. The drop in output implies a POSITIVE Frequency Response characteristic.

While this is one specific model of combined-cycle unit, the graph is illustrative of this class of unit. As more of this class of unit comes on line, not only may there be no response but the response may actually decline as the frequency declines. This is of particular concern during Interconnection valley periods when these units may potentially make up a large proportion of the on-line generation. It is noteworthy that this phenomenon in the form of deloading or outright tripping after no more than one or two seconds of good response was a contributing factor in the Malaysia blackout in 1996 (Mansour 2003). Combined-cycle units can be tuned to provide correct frequency response; however, the operators need to be educated to the problem or have contractual or financial obligations and incentives to ensure that their units meet the requirements.

- Deregulation has resulted in a large increase in reserve-sharing groups. In the past, many Control Areas carried full reserves for their individual largest contingency and some for multiple contingencies. De-regulation and competitive

pressures have ended both of these practices. The majority of Control Areas have formed into Reserve Sharing Groups and each now carries its proportional share of the largest contingency.

While some of the above trends have slowed, the rate of decline has not been linear. In four out of the eight years examined, the frequency response decline has been over 100MW/0.1Hz.

Analysis of a Load Only Response

Currently, the wide variation of frequency response tends to be a self-correcting problem. During high load periods when units are operating at full output, the frequency response is available from the load. In light load periods when there is less load response, the on-line units are at less than full output and produce governor response. Without a standard in place, however, there is no guarantee that unit response will continue. What happens if it does not? A simple calculation provides the answer.

The Eastern Interconnection peaks at 600,000 MW and remains at loads of 200,000MW and below for roughly 20% of the time. At best, motor and other similar types of loads respond on a linear basis as the frequency declines. In other words a 1% change in frequency, equivalent to 0.6Hz, produces a 1% change in load. A drop in the Interconnection frequency that reaches the first step of under-frequency load shedding, 59.7 Hz, represents a 0.5% change in frequency and therefore would produce only a 0.5% change in load or 1000MW. There are roughly 16-22 single generators of this size or larger within the Eastern Interconnection. Without unit or other equivalent frequency support, a single unit trip could potentially cause the Eastern Interconnection to drop firm load.

The following simulation results show the response of the Eastern Interconnection under two scenarios. The load level analyzed is 280,000MW or about the load on 4/23/03 when there was a loss of 2500MW on the system. Figure 7 shows the response of the system assuming there had only been load response available. The model assumes a linear decline of load with frequency as stated above. At 59.5Hz, the simulation drops 7% of the load by under-frequency load shedding.

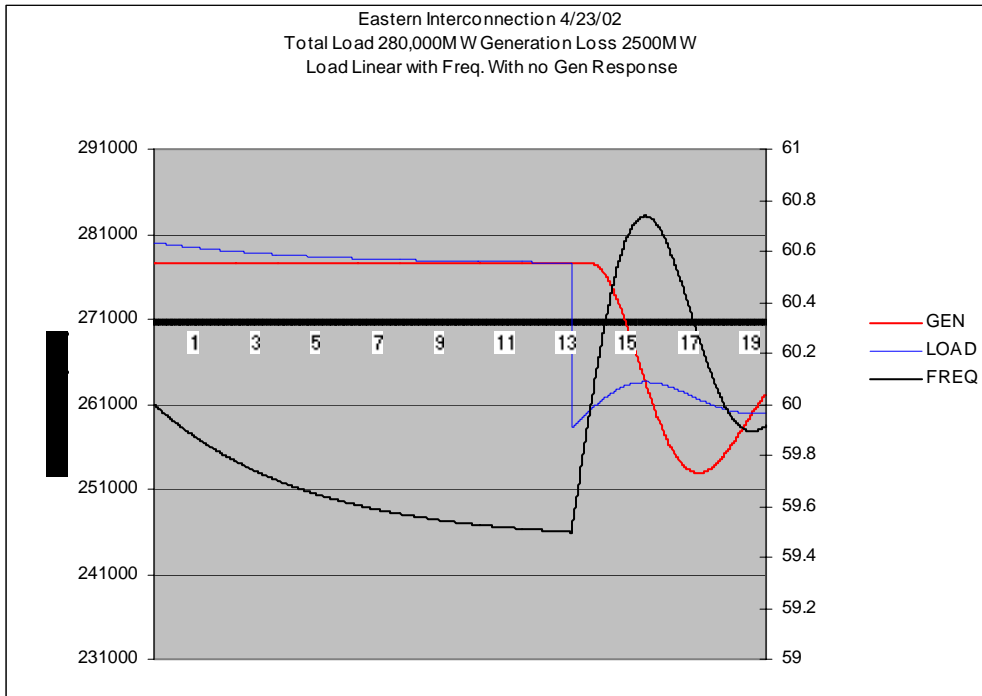


Figure 7 Simulation Assuming no Governor Response

Figure 8 shows the same system conditions and assumptions except that there is 1000MW of generator governor reserves.

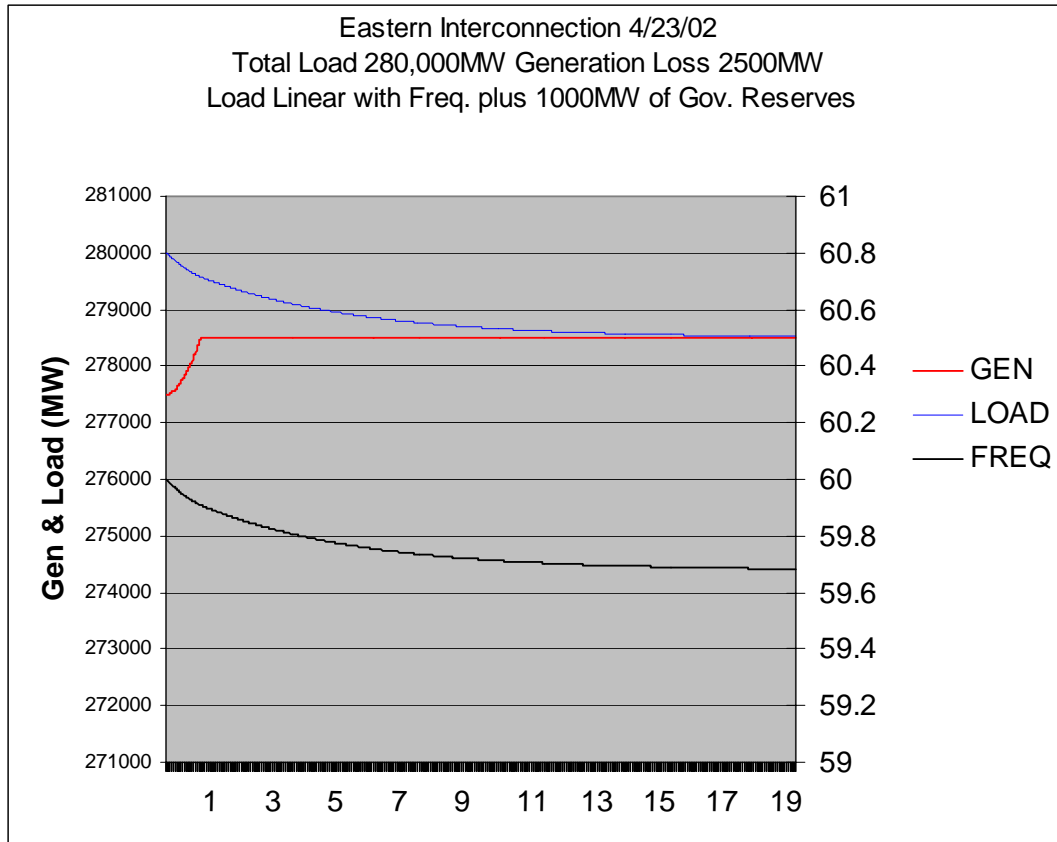


Figure 8 Simulation with 1000 MW of Governor Reserves

The impact of the governor response even though only half of the unit loss is sufficient to maintain the frequency above the under frequency tripping point.

Without a frequency response standard there is no assurance that unit response will be available in any of the Interconnections. Current economics will continue to drive most units to operate at maximum output. Presently, system operating conditions are counterbalancing and the problem is self-correcting. As pointed out above, combined-cycle units are an increasing proportion of the generation. What incentive is there for other, newer technologies to incorporate frequency response if no requirement (i.e. a standard) exists to define adequacy?

Secondary Impacts

There are many secondary effects from having an unknown and uncontrolled frequency response. Among these are:

- System oscillations may not be damped and may actually be aggravated. Recent testing of governor response in the Western Interconnection (Pereira) shows that existing models using an expected 5% governor droop are overly optimistic. Calculations indicate only 40% of expected response was obtained. As a result,

oscillations persist for roughly twice as long as models predict, and they are substantially stronger.

- Some areas may be incapable of “self restoration” during islanding and black-start conditions.
- Without a measure or requirement, market forces will likely continue to drive a decline in performance.
- Stability transfer limits will be incorrect if assumptions about frequency response are wrong.
- There is no way to tell whether the decline in response is spread among all Control Areas or whether there are regions with little or no response (and therefore not able to provide support to the Interconnection during disturbances or “self start” during restoration).

CURRENT REQUIREMENTS

This section highlights the current requirements and good practices regarding Frequency Response.

The NERC *Control Area Criteria* document outlines the fundamental obligations of the operation of the grid. In particular, it states:

The CONTROL AREA shall operate generation or have the necessary contracts to operate generation to... Provide its frequency bias obligations.

Policy 1 has several guides (suggested good practices) regarding governors:

- Generating units with nameplate ratings of 10 MW or greater should be equipped with governors operational for Frequency Response unless restricted by regulatory mandates.
- Turbine governors and HVDC controls, where applicable, should respond to system frequency deviation, unless there is a temporary operating problem.
- All turbine generators equipped with governors should be capable of providing immediate and sustained response to abnormal frequency excursions. Governors should provide a 5% droop characteristic. Governors should, as a minimum, be fully responsive to frequency deviations exceeding ± 0.036 Hz.
- Turbine control systems that provide adjustable limits to governor valve movement (valve position limit or equivalent) should not restrict travel more than necessary to coordinate boiler and turbine response characteristics.

ISN'T EXISTING POLICY SUFFICIENT?

Current NERC policy, as seen above, has no “requirements” for primary frequency response. Policy 1C deals primarily with Bias, which relates more to determining regulation and Secondary Frequency Control, rather than Frequency Response. The

portions of Policy 1C regarding governors are “guides” and carry no force. This may partially explain why Frequency Response is declining. Mandatory requirements for governors, even if adopted, do not guarantee that the unit would not be operated at wide-open valves and, therefore, have no response for an under-frequency condition. In other words, both responsiveness and depth of response must be assured.

COMMENTS TO THE FIRST PROPOSED FREQUENCY RESPONSE STANDARD

A Frequency Response Standard was proposed in mid 2001 in conjunction with approval of the current version of Policy 1. Table 1 summarizes the comments received.

Summary Comment	Respondents
“Wordsmithing” or clarification or minor modification comments	62
Governor requirement needs more definition (what is a “governor” on a combined cycle unit) and should be consistent with Planning Standards.	1
In favor of a standard	3
Measure should be tested before implementation	2
Add a requirement for common set points for under-frequency load shedding so that one CONTROL AREA won’t drag another one down,	1
“Loss of load” risk should not be the basis for establishing the standard.	1
There does not appear to be sufficient evidence on hand at this time to warrant rigorous Standards and possible non-compliance penalties.	1
Not sure using one-minute data will measure what’s needed.	1

Table 1 Summary of Comments to Policy 1C

The Balancing SAR task force posed questions to the Industry on the need for a Frequency Response Measure (FRM) that would likely mirror the FRS suggested by the Resources Subcommittee. The NERC Director of Standards returned the proposal because of concerns raised by the Industry. A closer look at the responses reveals that the Industry was not so much opposed to the standard as they were looking for information and clarification of the requirements. Table 2 summarizes the responses.

Summary Comment	Respondents
Difficulty measuring	6
Didn’t understand measure	1
Only if Generation governors required in “interconnection standard”	1
More work needed in definition	1
In favor	6
Should hold sub-entities (generators, LSEs) accountable	6

Current guides requiring generators to respond are adequate	2
Eliminate the Frequency Response Measure	1

Table 2 Summary of Comments Received on a Frequency Response Measure

FREQUENCY RESPONSE STANDARD CONSIDERATIONS

Introduction

A frequency response standard must explain clearly what is to be measured and why. This will help with the design of the process and provide direction on how it should evolve. Logical goals and considerations for a FRS include:

- Benchmark and track performance (both Control Area and Interconnection).
- Maintain historic levels of reliability (or some other level justified by an in-depth analysis).
- Be performance-based rather than commodity-based.
 - This is similar to CPS where impact on interconnection frequency is measured rather than requiring a target set-aside of regulating resources.
 - Specifically measuring Frequency Response allows more flexibility in meeting the needs of the Interconnection and Region (a target spinning reserve amount does not ensure Frequency Response)
 - Rather than telling entities how to meet the standard, let the Industry and markets find innovative solutions.
- Be “tunable”, thereby providing a means to adjust the standards as information allows.
- Be empirically valid (results statistically provable).
- Be objectively calculated.
- Be consistent and verifiable in application by all parties.
- Enable simple compliance monitoring.
- Be consistent with direction of the Industry (i.e. FERC RTO rule, IOSITF, etc.).

Issues

A Frequency Response Standard should address the following issues:

- There must be a minimum response for each event (rate, amount, and duration) such that the problems described above do not occur. Reliance on average response could result in all areas being short at the same time (similar to the short-term excursions seen with CPS1). The amount (depth of response) should not be under-emphasized. One shortcoming of the recommendations in policy today is that there is no guidance regarding how much governor response (in MW) is required at the 5% droop rate. This has led to confusion among plant operators and turbine-generator manufacturers alike, and has resulted in an objectionable lack of response from some units when the

boiler controls are suppressed out of legitimate fear of tripping the unit on a frequency change.

- The measurement selected must be accurate and, to the extent practical, easy to implement.
- The requirements must integrate with and be consistent with the assumptions used in setting the BAAL limits within the Load and Balancing Standard (if and as ultimately adopted)
- A method of allocation must be developed
- The standard should not preclude market solutions (e.g. allow purchasing of response as long as deliverability and restoration criteria can be met). There must be a means for sale/purchase of frequency response as for any other quantity.

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ACRONYMS, TERMS AND DEFINITIONS

ACE - AREA CONTROL ERROR: ACE is the algebraic sum of the net scheduled and net actual interchange and a bias term based on the difference between scheduled and actual system frequency. This parameter is used to determine a Control Area's control performance with respects to its impact on system frequency.

CPS – CONTROL PERFORMANCE STANDARD: CPS defines a standard of minimum control performance. Each Control Area is to have the best operation above this minimum that can be achieved within the bounds of reasonable economic and physical limitations. Each Control Area shall monitor its performance on a continuous basis against two standards: CPS1 and CPS2.

CPS1 – CONTROL PERFORMANCE STANDARD 1: Over a (running) year, the average of the clock-minute averages of a Control Area's ACE times the clock minute average frequency error shall be less than a specific limit. This limit is a constant derived from a target frequency bound reviewed and set as necessary by the NERC Resources Subcommittee.

CPS2 – CONTROL PERFORMANCE STANDARD 2: The average ACE for each of six ten-minute periods during the hour (i.e., 10, 20, 30, 40, 50 and 60 minutes after the hour) must be within L_{10} at least 90 % of the time during each calendar month.

DCS – DISTURBANCE CONTROL STANDARD: The standard used to monitor a Control Area's ability to recover from a disturbance.

ERCOT – ELECTRIC RELIABILITY COUNCIL OF TEXAS: One of the ten NERC regional coordinating councils.

FRC – FREQUENCY RESPONSE CHARACTERISTIC: For any change in generation/load balance in an interconnection, a frequency change occurs. FRC defines how any system (Control Area) responds to this change during any imbalance resulting from a sudden loss of load or generation. System frequency does not usually return to its pre-disturbance level until the Control Area experiencing the imbalance corrects its imbalance.

FRS – Frequency Response Standard.

IOS – INTERCONNECTED OPERATING SERVICES: IOS are the elemental 'reliability building blocks' from generation (and sometimes load) necessary to maintain bulk electric system reliability, (sometimes referred to as ancillary services, such as regulation, load following, contingency reserves, Frequency Response, reactive power supply, and black-start capability).

LSE- Load Serving Entity.

NAESB – North American Energy Standards Board.

SAR - Standards Authorization Request.