Discussion of Technical Issues Required to Implement a Frequency Response Standard

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Abstract—**NERC is investigating the implementation of a Frequency Response Standard on the North American interconnections. There are many unresolved or un-validated technical issues associated with the development of this standard. Many of these issues associated with the measurement of Primary Governing Frequency Response are discussed in this paper.**

Index Terms-- **Frequency Control, Frequency Response, Power Generation Control, Planning, Reliability.**

I. INTRODUCTION

NERC has initiated the SAR process as a first step in evaluating whether to proceed with the development and implementation of a Frequency Response Standard for the North American Interconnections. There are a number of significant questions related to the need for such a standard and for methods that could be used to implement a standard that would be acceptable to the electric industry and its stakeholders. These questions include the following:

1. Can the decline in Primary Governing Frequency Response observed be validated?
2. What are the uncertainties surrounding the observed decline in Primary Governing Frequency Response on the North American interconnections?
3. What is the significance of this decline with respect to its affect on reliability?
4. How effective are suggested methods for measuring each Balancing Authority's contribution to interconnection Primary Governing Frequency Response?
5. How could effective measures be integrated into a Frequency Response Standard?

The goal of this document is to promote discussion on the issues relevant to the above questions as an aid to move forward with appropriate processes necessary to effectively support reliability on the North American interconnections.

II. MEASURING PRIMARY GOVERNING FREQUENCY RESPONSE

Primary Governing Frequency Response (PGFR) is a complex function with characteristics shown in Figure 1 [1].
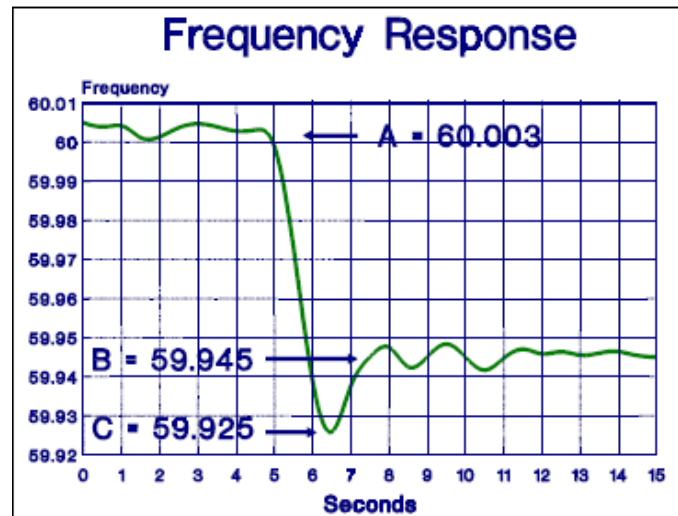
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Figure 1. Frequency Response.

The most important characteristics of PGFR appear in Figure 1.

1. A – Initial Frequency before the initiation of a disturbance.
2. B – Settling Frequency after completion of PGFR.
3. C – Minimum Frequency reached during the disturbance.
4. Decaying frequency oscillations between C and B.

Past operating practice has emphasized the measurement of the PGFR as the steady state response to the changes in frequency represented by the change between point A and point B. This is the response that is recommended for use as the Frequency Bias in the ACE equation and AGC systems using tie-line bias control. It is the response that is calculated by the NERC Frequency Response Characteristic Survey [1].

Although measuring the Settling Frequency Response has been the primary goal of past practice, the Minimum Frequency is also an important value to determine when considering the probability of triggering under-frequency load shedding relays on the North American interconnections. The selection of under-frequency load shedding coordination methods on the North American interconnections differs from some other interconnections worldwide. The North American interconnections have chosen to set under-frequency relay set points based on very short delay times in the range of a few seconds. By selecting these short delay times, Minimum Frequency becomes the most important value for reliability considerations. Some interconnections in other locations have

chosen to use delay times in the range of 1-minute. When delay times in this range are chosen the important part of the PGFR becomes the Settling Frequency instead of the Minimum Frequency. This is not a suggestion that under-frequency load shedding coordination methods should be changed. It is simply a statement that the choice of coordination methods can affect the problem that needs to be solved and the supporting measurement methods developed.

A. Central Measurement for the Interconnection

The total PGFR characteristic, including the Minimum Frequency, can only be effectively measured using short time-interval resolution frequency measurement recorders. These devices are not distributed on the interconnections in sufficient numbers for them to be available for all Balancing Authorities to independently measure the interconnection PGFR. Therefore, central measurement methods should be used to determine all of the PGFR characteristics for each interconnection. The most important characteristics of the PGFR should be able to be appropriately represented by a single PGFR characteristic for each interconnection.

An important step in the measuring process for each interconnection's PGFR characteristic should be confirmation that each interconnect can be adequately represented by a single PGFR characteristic. If this can be demonstrated, then the alternatives for measuring contributions to PGFR by parts of an interconnection such as BAs and Generators are greatly expanded. This expansion of measurement alternatives will also greatly simplify the development of a workable Frequency Response Standard. It offers the possibility that currently collected data could provide the basis for measurement in a standard. If currently collected data could be used as a basis for a Frequency Response Standard, the cost and time to implement a Frequency Response Standard could be significantly reduced. This would allow more resources to be dedicated to address other reliability problems. If the validity of a single PGFR characteristic representation cannot be demonstrated, then a Frequency Response Standard would not be able to be implemented until more complex measurement methods are developed.

Some data required to perform this interconnection measurement has been collected. However there is insufficient assurance that the sampling procedures used to estimate the important parameters of the characteristics are adequate and unbiased. This is a consequence of the procedures used to select the frequency excursions to evaluate and to select methods used to estimate the MW values associated with those disturbances. This does not suggest that any of the values measured in the literature are invalid; it only suggests that methods that insure good sampling procedures will allow better conclusions from the results of the measurements.

Discussions with Sydney Niemeyer from the Texas Interconnection revealed that sampling procedures based on frequency deviations alone can result in significant sampling bias. This biases results because the frequency deviation from an event that has a large frequency response is less likely to be selected in the sample than the larger frequency deviation from a similar size event measured in MWs that has a smaller frequency response. In other words, smaller frequency responses result in larger frequency deviations and larger frequency responses result in smaller frequency deviations. Therefore, the results could indicate a frequency response with a lower value than the real response due to sampling bias.

Recent discussions with Bob Cummings from NERC suggest that the central interconnection measurements of the PGFR characteristics could be greatly improved if phasor measurements are used as a basis for measuring the interconnection PGFR characteristics. These characteristics should include the MW Disturbance Size, Initial Frequency, Settling Frequency and Minimum Frequency associated with each disturbance exceeding a threshold level on each interconnection. In addition, it may be of value to include the magnitude and duration of the oscillatory decay after the Minimum Frequency. Sample selection procedures should be determined that will insure an unbiased sample is collected on each interconnection. These can then be used as a basis for extensive statistical analysis of the results.

Although phasor data offers the opportunity to collect better data using better sampling methods, phasor data is not currently available from all of the interconnections and has not been collected for a sufficient length of time to answer the most important questions surrounding this reliability issue at this time. Therefore, until appropriate phasor data is available studies based on other data sources must suffice. Methods developed in the ERCOT study [2] suggest that frequency data with a time resolution in the order of one second could be used to provide needed answers to the questions and allow us to make reasonable decisions about how to proceed at this time.

B. Local Measurement for the Balancing Authority

In order to effectively measure the contribution of a Balancing Authority (BA), short time-interval resolution measurement would need to be available on each tie-line to that BA. Therefore, the measurement of PGFR for a BA must be performed using alternative simplified measurement methods. The Frequency Response Standard Drafting Team (FRSDT) has recommended that the PGFR be measured at the BA level using these assumptions:

1. A disturbance will effectively result in a unit step function in the value of interconnection frequency;
2. This function will provide a valid representation of the PGFR characteristic through out the interconnection;
3. The response to this change in frequency will result in a unit step function MW response to that change.

Work previously performed on the Texas Interconnection indicates this simplification can be effectively implemented by using a two-step process to measure the PGFR [2]. This two-step process would assume the response is a unit step function for the purposes of performing wide scale measurement across the interconnection. This method of measuring the traditional

PGFR for determining Frequency Bias settings and BA contributions to total interconnection response would be supplemented by separate measurements of the minimum frequency as a proportion of the traditional frequency response measurement. This supplemental measure would be performed using short time-interval resolution measurements centrally. The two measurements could then be combined to enable the desired result for evaluating reliability effects associated with PGFR.

III. REPRESENTING PGFR AS A UNIT STEP FUNCTION

The FRSDT has suggested that 1-minute average data from CPS1 can be used as the data source for measuring the PGFR if that response is evaluated as a unit step function. They have suggested that all 1-minute averages be evaluated for changes in frequency. Two adjacent 1-minute averages associated with changes in 1-minute average frequency greater than 30 mHz would be used for estimating the PGFR for the BA. This would greatly simplify the implementation of a Frequency Response Standard because the data to support the standard is already being collected.

Some of those participating in this effort have performed sample calculations using this method. The results of those sample calculations apparently indicate that this method provides reasonable estimates of the PGFR. This is not unexpected, but there are problems with the suggested method that are easily be modified while at the same time providing a degree of self-checking within the measurement method itself.

The weakness with the suggested method is that it is inconsistent with respect to its selection of a sample of events to evaluate the PGFR. The inconsistency occurs because the initiation of the unit step function associated with a disturbance occurs randomly during the 1-minute averaging intervals. The random nature of these events coupled with the suggested method will select an event for analysis if it occurs near the 1-minute boundary. It will reject that same event if it occurs near the center of the 1-minute averaging interval. In most sampling, inconsistency in the sample selection method will result in sampling bias. The size and quality of the sample can be improved by changing the sample selection method. Improving the size and quality of the sample will also improve the conclusions that can be drawn from analysis of the sample. It is recommended that the implementation of a modified sampling method be investigated.

This investigation should not only include consideration of this selection inconsistency, but should also include consideration of the bias problem resulting from frequency threshold methods in general.

Detailed Example Problem

If a disturbance is represented as a unit step function that occurs randomly over time, the selection criteria for including a two minute interval in the sample of intervals to evaluate, can be described by the following inequality:

$$Y - \left[\frac{(60-x)Z + xY}{60} \right] \geq C \tag{1}$$

where: Y = Initial Frequency, Minute 1 average
Z = Settling Frequency, Minute 3 average
x = Disturbance time in seconds after start of 1-minute averaging interval
C = Change in frequency required for selection

The first term of the above equation is the average frequency of Minute 1. The second term of the equation is the average frequency of Minute 2. Solving the above inequality for Z yields (2).

$$Z \leq \left[\frac{(60-x)Y - 60C}{60-x} \right] \tag{2}$$

If the disturbance occurs at the start of the 1-minute averaging interval, then the difference between Y and Z needs to only be greater than or equal to C. On the other hand, if the disturbance starts 30 seconds into the 1-minute averaging interval, the difference between Y and Z must be equal to or greater than two times the value of C.

This sampling procedure also requires that we look at the difference between Minute 2 and Minute 3. This is necessary because the greatest difference in average frequency occurs between Minute 2 and Minute 3, when the disturbance occurs later than 30 seconds into Minute 2. The equations for Minute 2 compared to Minute 3 follow as (3) and (4).

$$\left[\frac{(60-x)Z + xY}{60} \right] - Z \geq C \tag{3}$$

The first term of the above equation is the average frequency of Minute 2. The second term of the equation is the average frequency of Minute 3. Solving the above inequality for Z yields (4).

$$Z \leq \left[\frac{xY - 60C}{x} \right] \tag{4}$$

The simple solution to the above sample selection problem is to use the difference between the average frequency of Minute 1 and the average frequency of Minute 3 to select the appropriate samples for analysis. This method also provides an additional advantage. It provides as many as twice the number of valid samples for analysis when compared to the FRSDT suggested method. Therefore, it is recommended that the research include evaluation of a sample selection criteria based on an interval of three consecutive 1-minute frequency averages instead of a sample selection criteria based on an interval of two consecutive 1-minute frequency averages. This analysis indicates that are criteria based on a three minute

interval rather than a two minute interval will provide better results.

This three minute procedure should then be developed as the first step in a multi-step procedure modified to eliminate the bias introduced by using a frequency threshold.

IV. MULTIPLE SAMPLE ADVANTAGES

There are a number of advantages associated with selecting a sampling method that yields multiple samples to represent single events. The first advantage is that more information on the quality of the measurement is reveled by multiple samples. If there are inconsistencies in the data, multiple samples can be used to evaluate the effect that these inconsistencies would have on the results of analysis. In order to highlight the value of this sampling method some of the problems associated with the data sampled are listed below.

1. Differences between centrally-measure frequency and locally-measured frequency.
2. Differences between centrally-measured disturbance size (MW) and locally-measure disturbance size.
3. Differences in central-clock time and local-clock-time. (Time Skew)
4. Differences in timing between the frequency data used and the disturbance size data used. (Time Skew)
5. Differences in timing between central frequency data and local frequency data. (Time Skew)
6. Differences in timing between central disturbance size data and local disturbance size data. (Time Skew)
7. Differences in timing between local frequencies measured at one BA as compared to another. (Time Skew)
8. Differences in timing between local disturbance sizes measured in one BA as compared to another. (Time Skew)
9. Timing differences due to EMS sampling intervals. (maximum EMS cycle interval of 6 seconds)

Multiple samples can be used to investigate the affect these sampling differences could have on the final results of the standard measurements and the resulting quality of any standard developed based on these sampling techniques and data analysis.

V. COMPARE CENTRAL TO LOCAL MEASUREMENT

The measurement methods discussed above should provide the necessary data to look at the PGFR from the perspective of both the interconnection and the BA. They should also eventually provide the opportunity to compile data from both sources that could be compared for consistency. A comparison between central measurement and the sum of the local measures should give an additional indication of the quality of the measured PGFR from both sources.

An important part of this comparison is the realization that the sum of the Frequency Responses from all of the BAs on an interconnection must total a response of zero. This condition occurs as a consequence of the metering methods used on the interconnections.

1. Each tie line between BAs is metered in common with one BA assigning the flow a positive value and the other BA assigning the flow a negative value, the sum of the tie line flows must sum to zero.
2. The frequency on an interconnection is effectively the same throughout the interconnection when measured over intervals useful for determining the PGFR.
3. The PGFR is measured as the ratio of the change in tie line flow over the change in interconnection frequency.
4. Since the sum of the tie line flows must sum to zero, the change in the sum of the tie line flows must also sum to zero.
5. Since the frequency is effectively the same throughout the interconnection, the change in frequency must also be the same.
6. Therefore, the sum of the PGFRs for all of the BAs on an interconnection must sum to zero for each event.

This means that the information about the PGFR for each BA and the information about the disturbance events causing these responses must be parsed into two categories from the same data source. These two data categories then become the sources of determining the causes and responses for each event and the probability distributions for all events. The parsing method chosen to perform this parsing is critical to the quality of the resulting probability distributions.

VI. USING ACE AND FREQUENCY BIAS

The measurement method suggested by the FRSDT deviates from the methods suggested in the Frequency Response Survey Training Document in that it uses ACE instead of Tie Line flow to determine the Settling Frequency Response. This change in methodology should work well for all BAs using a fixed linear frequency bias, but requires an investigation of all of the methods used for determining frequency bias when a variable frequency bias has been approved for use.

This investigation is expected to result in acceptance of the suggested method for all variable frequency bias users that are using a variable linear bias that does not change during an event. Non-linear variable bias and variable bias that can change during a disturbance measurement period will require further evaluation to determine the acceptability of the suggested method.

VII. WHAT IS THE SIGNIFICANCE OF PGFR

The final and most important step in the process of measuring and analyzing PGFR is to develop a method that will reveal the relationship between the interconnection PGFR and the significance of that PGFR to reliability. This relationship can be determined by evaluating the joint probability of total frequency error in relationship to the four main variables that provide the individual probabilities contributing to that total frequency error. The four sources of imbalance and resulting frequency error are:

1. Normal imbalances are caused by all of the small imbalance errors resulting from unexpected changes in load and generation. This error has been shown to

approximate a normal distribution.

2. Abnormal imbalances are caused by sudden disturbances resulting from unexpected generation, line and load trips. This error has previously been effectively estimated using an exponential probability distribution.

3. Declining imbalances are experienced during the recovery from the abnormal imbalance resulting from disturbances. These imbalances should be able to be assumed to be mutually exclusive of the normal imbalances and estimated as a function of the disturbance probability distributions and recovery requirements specified by the Disturbance Control Standard.

4. Frequency offsets result from time error correction procedures. This error can be estimated based on the average time error experienced and the time error correction procedures.

The above four probability distributions should enable the estimation of the total joint frequency distribution on an interconnection. The resulting distribution will provide the probability of an interconnection exceeding an appropriate specified limit such as the under-frequency relay setting.

Since each of these contributors is affected by different operating variables, it should also be possible to estimate the sensitivity of the total reliability risk to limits for these variables. For example:

- The normal distribution is primarily controlled by ε_1.
- The exponential distribution is primarily controlled by the generation inventory on the interconnection.
- The declining imbalances are distributed as determined by the magnitudes and recovery times specified by the Disturbance Control Standard.
- The frequency offsets are primarily controlled by the time error correction rules.

It should be possible to use the above relationships to estimate the total frequency error probability distribution for an interconnection, and also determine the sensitivity of that total distribution to each of the controlling parameters.

VIII. SUMMARY AND CONCLUSIONS

There are a number of important issues that need to be investigated on the way to developing a Frequency Response Standard that will be acceptable to the industry.

- The trends in PGFR on each interconnection need to be confirmed.
- The significance of these trends with respect to the reliability of each interconnection need to be determined.
- If the trends in PGFR are expected to have an effect on the reliability of any interconnection, then additional investigations must be performed.
- Measurement methods must be demonstrated that will indicate the contribution of each BA or generator to the interconnection PGFR.
- Methods must be developed to assign responsibility for

providing PGFR to the BA or generator participants.

- All of the results of the above analysis must be integrated into a Frequency Response Standard acceptable to the industry and its stakeholders.

Discussion of the above issues should provide a reasonable plan to continue the examination of a Frequency Response Standard.

IX. REFERENCES

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XI. BIOGRAPHY

Howard F. Illian graduated from Carnegie Institute of Technology (Carnegie-Mellon University) in 1970 with a B.S. in Electrical Engineering.
From 1970 until 1976 he worked for ComEd in the field of Operations Research, and was Supervisor, Economic Research and Load Forecasting from 1976 until he was reassigned to Bulk Power Operations in 1982 where he was Technical Services Director when he retired in 1998. He is now President of Energy Mark, Inc., an energy market consulting firm specializing in the commercial relationships required by restructuring.
He has authored numerous papers in the field of Engineering Economics, and has testified as an expert witness in this field before the Illinois EPA, the Federal EPA, and the Illinois Commerce Commission. He has developed and applied several new mathematical techniques for use in simulation and decision making. He has served on the NERC Performance Subcommittee, the Interconnected Operations Services Implementation Task Force, the Joint Inadvertent Interchange Task Force, and the NAESB Inadvertent Interchange Payback Task Force. Recent work includes significant contributions to the development of new NERC Control Performance Standards including the Balancing Authority Ace Limit and a suggested mathematical foundation for control based on classical statistics. His current research concentrates on the development of technical definitions for Ancillary or Reliability Services and their market implementation.