Defining Good and Bad Inadvertent

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INTRODUCTION

This technical paper reviews a comprehensive list of previously suggested ways to categorize Inadvertent into "Good" and "Bad" for the purpose of setting standards to address the relationship between interconnection frequency and Inadvertent. Three previously suggested definitions are considered along with one new one. The validity of using these definitions of "Good" and "Bad" to assign penalties and rewards, whether through a market or separate from a market, is investigated. Conclusions are drawn concerning the suitability of each method for the intended purpose.

As a result of this analysis, a method for unifying the management of unscheduled energy, both Inadvertent and Energy Imbalance, under a single methodology throughout the interconnections is offered. The implementation issues associated with the offered methodology are discussed in detail. Some issues are resolved and others are left for future resolution.

AREA INTERCHANGE ERROR[1]

The oldest of the methods under consideration for the assignment of Inadvertent into "Good" and "Bad" categories is the Area Interchange Error (AIE) Survey that predates the work on Inadvertent Decomposition performed by Nathan Cohn. It attempts to use an ACE equation equivalent with average hourly values to determine responsibility for Inadvertent and categorizes Inadvertent into "Good" and "Bad." AIE is defined by equation 1.

$$\mathbf{AIE = \left(NI_A - NI_S\right) - 10B_i\overline{\Delta F}} \qquad \textbf{(1)}$$

Where:

AIE	=	**Area Interchange Error**
$\mathbf{NI_A}$	=	**Actual Net Interchange**
$\mathbf{NI_S}$	=	**Scheduled Net Interchange**
$\mathbf{B_i}$	=	**Frequency Bias for Control Area, i**
$\mathbf{\Delta F}$	=	**Hourly Average Frequency Error**

AIE is the "Bad" Inadvertent. Since the first term, the difference between actual and scheduled interchange is total Inadvertent, $\mathbf{I_i}$, the equation can be rewritten as equation 2.

$$\mathbf{I_B = AIE = I_i - 10B_i\overline{\Delta F}} \qquad \textbf{(2)}$$

Therefore, the "Good" component of Inadvertent, shown in equation 3, is $\mathbf{I_i}$ less the "Bad" component.

$$\mathbf{I_G = 10B_i\overline{\Delta F}} \qquad \textbf{(3)}$$

There are two basic problems with this approach of categorizing Inadvertent into "Good" and "Bad" components. First, improvements in system frequency performance are not directly correlated with reductions in "Bad" Inadvertent. Second, the ACE equation was developed to provide the amount of error necessary to correct the generation-load balance at 60 Hz. This seldom occurs on the interconnection, and never occurs when the periods that AIE is used to analyze are selected by significant sustained frequency deviations.

Example 1: "Bad" Inadvertent Improves Frequency

Assume an unconstrained system with more than three Control Areas; one of the control areas has a significant generation deficit resulting in low interconnection frequency; assume that a second Control Area is unable to meet its full bias obligation and that a third Control Area over supplies its bias obligation to the same extent that the second Control Area undersupplies.

In this case, interconnection frequency will be exactly where it is expected. The second Control Area will have supplied "Bad" Inadvertent to the extent that it failed to meet its full bias obligation. The third Control Area will have supplied the same amount of "Bad" Inadvertent to the extent that it oversupplied its bias obligation. If the third Control Area controls in a manner that its "Bad" Inadvertent is reduced, interconnection frequency will be worse. Combining of the second and third Control Areas will offset the "Bad" Inadvertent of one with the "Bad" Inadvertent of the other without changing frequency demonstrating that "Bad" Inadvertent is not directly related to frequency.

Additionally, the current AIE Training Document still allows a reduction in AIE, “Bad” Inadvertent, for Unilateral Inadvertent Payback. This adjustment has been ignored in this analysis because it was demonstrated in the development of CPS1, that Unilateral Inadvertent Payback should be included with the Inadvertent in the analysis of interconnection frequency control.

Comment #1:

A Control Area using Unilateral Inadvertent Payback should be held responsible for the effect that this payback has on interconnection frequency. Consideration of Unilateral Inadvertent Payback should be removed from the AIE analysis.

Comment #2:

The current AIE method should be reviewed to determine if it provides sufficient accuracy for its future intended use.

CONCLUSION #1

AIE is only a general measure and is not accurate. AIE fails to consistently assign responsibility for frequency deviations. This makes AIE a poor candidate for the metric to assign penalties and rewards for “Good” and “Bad” Inadvertent for frequency control.

INADVERTENT DECOMPOSITION[2,3]

Nathan Cohn uses the terms Primary and Secondary to categorize Inadvertent. Investigation of Inadvertent Decomposition (ID) reveals an analysis similar to AIE. The difference between ID and AIE is that Primary, “Bad,” Inadvertent includes corrections for off-schedule interconnection frequency and AIE does not. The correction for off-schedule frequency is required because the ACE equation indicates the MW error required to return the interconnection frequency to schedule. The similarities are obvious from the Primary and Secondary Inadvertent equations as are the adjustments for off-schedule frequency. These are shown as equations 4 and 5.

$$I_B = I_P = \left(I_i - 10B_i\overline{DF}\right) \times \left(1 - \frac{B_i}{B_S}\right) \qquad (4)$$

$$I_G = I_S = \left(10B_i\overline{DF}\right) \times \left(1 - \frac{B_i}{B_S}\right) + I_i \times \left(\frac{B_i}{B_S}\right) \qquad (5)$$

Where:

- I_P = **Primary Inadvertent**
- I_S = **Secondary Inadvertent**
- B_S = **Total Frequency Bias for Interconnection**

One additional requirement with the Cohn result is that correcting for off-schedule frequency requires knowledge of the Total Frequency Bias for the interconnection. This knowledge of the Total Frequency Bias for the interconnection is not required for the AIE calculation.

AIE was unsuitable as a measure to assign penalties and rewards for frequency control because the determination of “Bad” inadvertent is not directly correlated to frequency. Unfortunately, the same problem that occurs with AIE also occurs with Primary and Secondary Inadvertent in that improvements in system frequency performance are not directly correlated with reductions in “Bad” Inadvertent.

Comment #3:

The Cohn derived equations provide a more accurate assignment of parties responsible for causing Inadvertent, a determination of how closely each control area met their frequency bias responsibility. The difference is small when an individual Control Area represents a small portion of the interconnection frequency bias, but the difference increases when an individual Control Area represents a significant portion of the interconnection frequency bias.

CONCLUSION #2

The use of Primary and Secondary Inadvertent is a more accurate method to determine whether or not a Control Area met its frequency bias obligation and superior to the current AIE analysis used by NERC. The error in the AIE analysis increases as the number of Control Areas decreases and each becomes a larger proportion of the interconnection.

ADDITIONAL DISCUSSION ON AIE AND ID

Both AEI and ID fail to define “Good” and “Bad” relative to frequency control contributions. They define “Good” and “Bad” relative to whether or not a participant provides the exact amount of frequency bias support they had offered. If one of the participants fails to meet this obligation it is considered “Bad.” It is also considered “Bad” when another participant makes up that deficiency. “Good” and “Bad” do not relate to frequency control, they relate to whether or not a specific rule set is followed. Although this methodology may be acceptable under regulation, it is unacceptable in a market.

The unacceptability of assigning “Good” and “Bad” with the rule set used by both AIE and Inadvertent Decomposition results from the inconsistency associated with it application. In some extreme cases following the rules can result interconnection failure while in those same extreme cases breaking the rules can prevent interconnection failure. If the ultimate goal is prevent interconnection failure, then a rule set that does not support the goal of preventing interconnection failure under all conditions cannot provide the necessary basis for determining penalties and rewards associated with Inadvertent. A rule set with these characteristics will require that the judgment of what is

"Good" and "Bad" to be made after the fact. A market requires an *a priori* determination of "Good" and "Bad" Inadvertent. This is demonstrated in the following example.

Example 2: Preventing Interconnection Failure

Assume an unconstrained system with many Control Areas on a hot day when generation resources are strained. Assume that a number of these Control Areas are deficient in their generation causing interconnection frequency to decline significantly to a point just above that frequency necessary to prevent Interconnection failure. This could put an individual control area that is supplying more than it Frequency Bias obligation in the position of reducing its Inadvertent and causing interconnection failure or continuing to overproduce and causing additional "Bad" Inadvertent. In fact, we teach operators to control based on interconnection frequency when they are unsure of tie-line values due to tie-line telemetry failure.

This example highlights a common problem as we move forward with restructuring. The problem is that the industry has not been successful in defining "Good" and "Bad" behavior on an *a priori* basis. When "Good" and "Bad" behavior is not defined *a priori*, it must be determined in "real-time" or "after-the-fact." This is one of the functions of Security Coordinators.

Unfortunately, the Security Coordinator function is necessary, but it will also result in inconsistent assignment of the labels of "Good" and "Bad." This inconsistency will damage the market unless the industry defines "Good" and "Bad" behavior on a consistent and workable basis so market participants can function effectively within the limits of reliable operation. A specific definition of "Good" and "Bad" Inadvertent will reduce this problem.

CONCLUSION #3

Primary and Secondary Inadvertent analysis does not consistently assign responsibility for interconnection frequency deviations. This makes Primary and Secondary Inadvertent a poor candidate metric to assign penalties and rewards related to frequency control and resulting Inadvertent.

$CPS1_{60}$[4]

The $\mathbf{CPS1_{60}}$ measure uses a slightly different method to identify "Good" and "Bad" Inadvertent. $\mathbf{CPS1_{60}}$ views the problem solely from the contribution of Inadvertent to interconnection frequency control. It uses the same data as the two previous methods. However, it categorizes Inadvertent by the single criteria, "Does the Inadvertent improve frequency or does Inadvertent make frequency worse?" Inadvertent that improves frequency is considered "Good" and Inadvertent that degrades frequency is considered "Bad." The equation for $\mathbf{CPS1_{60}}$ is shown in equation 6.

$$\mathbf{CPS1_{60} = AVG\left[\frac{AIE_i}{-10B_{i,h}} \times \overline{\Delta F_h}\right] \le \varepsilon_h^2} \qquad (6)$$

Where:

i	=	**Specified Control Area**
h	=	**Clock-hour Average**

Substituting equation 2 into equation 6 and simplifying as shown in equation 9 provides a little better insight into how $\mathbf{CPS1_{60}}$ categorizes Inadvertent.

$$\mathbf{CPS1_{60} \Rightarrow AVG\left[\frac{I_i - 10\overline{B_{i,h}\Delta F_h}}{-10B_{i,h}} \times \overline{\Delta F_h}\right] \le \varepsilon_h^2} \qquad (7)$$

$$\mathbf{CPS1_{60} \Rightarrow AVG\left[\frac{I_i \times \overline{\Delta F_h}}{-10B_{i,h}} + \overline{\Delta F_h}^2\right] \le \varepsilon_h^2} \qquad (8)$$

$$\mathbf{CPS1_{60} \Rightarrow AVG\left[\frac{I_i \times \overline{\Delta F_h}}{-10B_{i,h}}\right] \le \varepsilon_h^2 - \overline{\Delta F_h}^2} \qquad (9)$$

Since $\mathbf{B_{i,h}}$ has a negative sign, the denominator of equation 9 is always positive. Therefore, the sign of the numerator of equation 9 indicates whether the Inadvertent is "Good" or "Bad." If the sign of the numerator is negative, indicating that the Inadvertent was in the opposite direction and reducing the frequency error, the Inadvertent is "Good." If the sign is positive, indicating that the Inadvertent was in the same direction as the frequency error contributing to it, the Inadvertent is "Bad."

CONCLUSION #4

$\mathbf{CPS1_{60}}$ Inadvertent analysis consistently assigns responsibility for interconnection frequency deviations. This makes a method derived from $\mathbf{CPS1_{60}}$ a good candidate for further investigation to consider as a metric to assign penalties and rewards related to interconnection frequency control.

$CPS1_{60}$ VALUES

The $\mathbf{CPS1_{60}}$ measure in addition to categorizing Inadvertent as "Good" and "Bad" also assigns values relative to how "Good" or "Bad" the specific Inadvertent is with respect to its contribution to average interconnection frequency error. "Bad" Inadvertent that occurs when average frequency is far off-schedule is penalized more in the measure than the same amount of "Bad" Inadvertent that occurs when average frequency is only slightly off-schedule. "Good" Inadvertent that occurs when average frequency is far off-schedule is rewarded more in the measure than the same amount of "Good" Inadvertent that occurs when average frequency is only slightly off-schedule. This differentiation of the relative value of Inadvertent is appropriate.

The uninvestigated issue is whether Clock-hour averages provide a consistent and accurate representation of each participant's contribution to frequency control.

CLOCK-HOUR AVERAGING ACCURACY

Demonstrating **$CPS1_{60}$** with Clock-hour average data helps.

Example 2 – Using Clock-hour Average Data:

Assume Control Area A over-generates by 100 MW during the first half hour and under-generates by 90 MW during the second half hour. Assume Control Area B under-generates by 70 MW during the first half hour and over-generates by 80 MW during the second half hour. Assume Control Area C under-generates by 30 MW during the first half hour and over-generates by 10 MW during the second half hour. Finally, assume the interconnection experiences over-frequency during the first half hour, and during the second half hour the interconnection experiences under-frequency. The inadvertent for the hour is the same for both Control Areas A & B. They each have Inadvertent of +5 MWh. Control Area C has Inadvertent of -10 MWh.

Consider the contribution of each to the frequency control. Control Area A contributed to the frequency deviation from 60 Hz in both the first and the second half hour. Control Area A should then accumulate "Bad" frequency control. Control Area B prevented the frequency from deviating further than it otherwise would have during both half hours. Control Area B should then accumulate "Good" frequency control. Control Area C helped frequency during both half hours but less than Control Area B.

In this example, Control Area A demonstrates "Bad" control and "Bad" unscheduled energy during both half hours. Control Area B demonstrates "Good" control and "Good" unscheduled energy during both half hours. Control Area C demonstrates "Good" control and "Good" unscheduled energy during both half hours. The Clock-hour averages indicate a much different result.

High Frequency Result:

If clock-hour frequency averages 60.005 Hz, **$CPS1_{60}$** values plus Inadvertent as "Bad" and minus as "Good."

Scheduled Frequency Result:

If clock-hour frequency averages 60.000 Hz, **$CPS1_{60}$** values Inadvertent as neither "Good" nor "Bad."

Low Frequency Result:

If clock-hour frequency averages 59.995 Hz, **$CPS1_{60}$** values plus Inadvertent as "Good" and minus as "Bad."

These results are inconsistent with our previous determinations of "Good" and "Bad" Inadvertent.

LIMITING CONDITIONS

The example highlights the problem of applying clock-hour averages to transmission customers that have significant variations in balancing error at periods less than two hours. Clock-hour averaging is appropriate for most loads, but it is not accurate when applied to highly varying loads, arc furnaces and steel mills, and controllable loads, water pumping. Since generators are controllable and can be highly variable, clock-hour averaging may be inaccurate for generators except slowly-varying generators such as run-of-river hydro. Most loads are not highly variable. Clock-hour analysis can be applied without fear of significant error in assigning responsibility for contribution to frequency control requirements within these classes of loads.

CONCLUSION #5

"Good" and "Bad" clock-hour average Inadvertent alone is inadequate to accurately price all frequency control. Clock-hour average Inadvertent is inaccurate for determining Penalties or Rewards for hourly average Inadvertent except within classes that exclude highly varying loads and generators.

Comment #4:

Can **$CPS1_{60}$** lead to a partial solution to the problem? Could another compatible measure applied along with **$CPS1_{60}$** compensate for **$CPS1_{60}$**'s inability to accurately measure the contribution of variations with periods under two hours?

CONTINUED DISCUSSION OF $CPS1_{60}$

$CPS1_{60}$ was developed as a compliance measure for control areas that have a frequency response obligation as defined by their frequency bias, the denominator of the left side of equation 9 As a compliance measure, it not only must accurately measure the control area's contribution to frequency control, the numerator of the left side of equation 9, relative to that obligation but must also determine whether that contribution met minimum requirements, ε_h^2. This creates numerous difficulties. First, it can only be applied to control areas that have a frequency response obligation. Second, it includes a minimum acceptable performance level for those control areas. Finally, if applied, "How will the minimum acceptable performance level as determined by **$CPS1_{60}$** interact with the minimum acceptable performance level as determined by **CPS_1**?" This raises another question, "Can the measurement component contained in **$CPS1_{60}$** be stripped out and applied to the problem of valuing Inadvertent without the including the frequency response obligation or the minimum limit?" This question is answered in later sections of this paper.

UNIFYING UNSCHEDULED ENERGY

What characteristics would a measure unifying Inadvertent and Energy Imbalance have? The primary complaint against Inadvertent is that Control Areas performing commercial functions have a commercial advantage because Inadvertent can be paid back in-kind while non-control areas performing commercial functions are required to pay for Energy Imbalance monetarily.

Any solution offered for the management of Inadvertent also must adequately resolve this issue by removing any commercial advantage that Control Areas may derive from their handling of Inadvertent. It should be acceptable for Inadvertent to be unified with Energy Imbalance by making Inadvertent look similar to Energy Imbalance, by making Energy Imbalance look similar to Inadvertent, or by developing a new unified definition for unscheduled energy that applies to both Inadvertent and Energy Imbalance.

Taking a step back and looking at what we have accomplished so far in the management of transmission constraints may provide some insight into the problem of managing unscheduled energy in a market.

TRANSMISSION CONSTRAINT MANAGEMENT

Initial attempts to manage transmission constraints were based on traditional regulated utility rule sets. Although these attempts worked, they were not without problems and they were found to be economically inefficient.

The most recent efforts to manage transmission constraints have been structured around market solutions, principally locational and flow-gate pricing mechanisms. These methods have been designed to assign prices on the transmission network so that the difference between any two locations on the network will equal the marginal redispatch cost associated with managing the loading on the interposing constraint. In addition, these methods have also captured the basic price of the energy in the process of managing the transmission. Finally, the methods reduce to the correct market pricing eliminating separate rewards and penalties for constraints, and eliminating all rewards and penalties when the system is unconstrained.

The apparent success of these methods provides guidance with respect to the properties necessary to implement a unified unscheduled energy management solution. First and most importantly, any method of valuing and pricing unscheduled energy must be market based because it will be required to provide correct price signals in conjunction with a market based transmission constraint management pricing system. A system of fixed penalties and rewards will not be able to automatically adjust for market conditions to provide the correct price signals along side a transmission constraint management system that automatically adjusts to market conditions.

It must also capture the necessary price components of the unscheduled energy. These components include the energy value, the transmission constraint value and the frequency control value. In fact it is the unequal management of the energy value that raised the issue. If methods can be developed to manage each of these price components that are compatible with each other when applied concurrently, we might have a way to unify the management of all unscheduled energy and resolve the problem created by Inadvertent and Energy Imbalance. The inadequacy of clock-hour averages to capture high frequency components of unscheduled energy will be deferred for later consideration. What then would the individual price components for managing unscheduled energy look like?

ENERGY

Whether the unscheduled energy is Inadvertent or Energy Imbalance, the methods used to price the energy on an unconstrained transmission system are appropriate to develop the energy price for unscheduled energy. These energy pricing systems would include both market based systems and prices developed by Energy Management Systems where markets are not yet functioning. These energy pricing systems are based on the assumption that load and generation schedules are balanced so they do not address the problem of frequency control or transmission constraints. Since the system is always balanced by the natural frequency response, these methods are valid for both systems operating at scheduled frequency and systems operating at other than scheduled frequency.

TRANSMISSION CONTRAINTS

Locational energy pricing and flow-gate transmission pricing are equivalent with respect to the mathematical methods used to develop a solution to the transmission constraint problem. The difference between the two is presented in the form of the solution to represent the transmission constraint pricing. In the locational pricing method, the energy price in integrated into the pricing solution so that there is a single price and the value of the flow across a transmission constraint is represented by the price difference between locations at each side of the constraint. Flow-gate pricing methods attempt to separate the base energy price from the transmission congestion price, handling the transmission congestion price as an adder to the energy price. In either case, both the energy price and the transmission congestion price are included in the result. This requires that the method for developing a frequency control price supply only an adder to the energy price as opposed to a combined energy and frequency control price.

FREQUENCY CONTROL

It is advantageous to price the frequency control contribution separate from the energy contribution leaving the energy price to address transmission constraints in addition to the basic value of the energy itself. It is desirable for any method chosen to have a property similar to transmission constraint pricing in that the locational price disappears when there is no transmission constraint. Therefore, the method should provide for a frequency control adjustment that disappears when the participant's minimum frequency control responsibilities have been met or when interconnection frequency is on schedule and only provide a penalty when these minimum responsibilities are not met or are in danger of not being met. In addition, the method could provide a reward for over-compliance proportional to the value of that over-compliance.

Close investigation of the $\mathbf{CPS1_{60}}$ equations reveals components that may be useful in our search for a frequency control measure that can be applied along with the transmission constraint methodologies that may or may not use the energy value as an integral part of their method. Thus the goal is to find a way to measure and value the Frequency Control Contribution (FCC).

FREQUENCY CONTROL CONTRIBUTION (FCC)

Using clock-hour measurements, the best measure we have for each participant's contribution to frequency control starts with the numerator of the $\mathbf{CPS1_{60}}$ equation as transformed in equation 9. As it turns out when the mathematics of the calculation of the numerator are investigated, the long term average of the numerator is proportional to a measure of the clock-hour average frequency response contained in the imbalance error for that participant. Dividing the numerator by the square of the clock-hour average frequency errors adjusts it to represent the actual amount of frequency control provided in the error. This is a significant result, since the actual frequency response, $\boldsymbol{\beta}$, of a transmission participant on the interconnection is a pure measure of that participant's contribution to interconnection frequency control. It doesn't matter whether the participant is a control area or a transmission customer. Therefore, the energy component of the unscheduled energy is represented by $\mathbf{U_i}$ as shown in equation 10, and the clock-hour Frequency Control Contribution of unscheduled energy is accurately represented as $\mathbf{-10\beta_{i,h}}$ shown in equation 11.

$$\text{Unscheduled} \Rightarrow \text{Energy} = U_i \tag{10}$$

$$FCC_h \Rightarrow -10\overline{\beta_{i,h}} = \frac{\frac{1}{n}\sum\left(U_i \times \overline{\Delta F_h}\right)}{\frac{1}{n}\sum\left(\overline{\Delta F_h}\right)^2} \tag{11}$$

An appropriate market price is already available for the energy component. If a market price could be developed for the frequency control component, then the problem of unifying unscheduled energy could be resolved by simply requiring the settlement of both the energy component and the frequency control component on a periodic basis. This would solve the problem associated with the unequal handling of Inadvertent and Energy Imbalance and would also solve the Inadvertent payback problem since there would no longer be Inadvertent balances to manage.

We are already metering and collecting all of the data required for implementation of this product in a market. The only unsolved problem is the setting of the market price for the FCC. Even if there is no market in frequency control at this time, a price could be set by NERC to approximate that market price. This approximated price could be used until markets in primary and secondary frequency control are implemented, and once implemented the market price would be substituted in the settlement system for the approximated price initially set by NERC.

CONCLUSION #6

A Unified Unscheduled Energy protocol, including both Inadvertent and Energy Imbalance, could be implemented based on the settlement of energy and frequency control using the FCC equations derived from $\mathbf{CPS1_{60}}$. It could be initiated with a fixed estimate of the frequency control price that would be replaced by a market price once a market has been created.

THEORY OF FCC

Although it may not be obvious, the FCC calculation is actually a linear regression that measures the best fit when frequency error is regressed against, MWh error. The general linear regression equation is given by equation (12).

$$Y = aX + b \tag{12}$$

The least square fit for this equation can be derived by writing the general form of the error term for **Y** and taking the first derivative of that error term to find the minimum values for the error squared. There is also a specific form of a linear equation that assumes the y-intercept crosses both axes at the origin. This form sets the constant **b** equal to zero and is shown in equation (13).

$$Y = aX \tag{13}$$

The right side of equation (13) is an estimate for **Y**. The least squares objective minimizes the difference between the value of **Y** and the estimate for **Y**, **aX**. The objective is to select a value for **a** such that:

$$\sum\left(y_i - ax_i\right)^2 \quad \text{is minimized.} \tag{14}$$

Rearranging terms gives:

$$\sum y_i^2 - 2a\sum x_i y_i + a^2\sum x_i^2 \tag{15}$$

Taking the first derivative with respect to **a** gives:

$$\frac{dY}{da} = 2\sum x_i y_i + 2a\sum x_i^2 \tag{16}$$

Setting the derivative equal to zero and solving for **a** gives:

$$a = \frac{\sum x_i y_i}{\sum x_i^2} = \frac{\frac{1}{n}\sum x_i y_i}{\frac{1}{n}\sum x_i^2} \tag{17}$$

Substituting this result into equation (13) gives the general solution to the regression through the origin.

$$Y = aX = \frac{\frac{1}{n}\sum x_i y_i}{\frac{1}{n}\sum x_i^2} X \tag{18}$$

If **Y** is the Unscheduled Energy, $\mathbf{U_i}$, and **X** is the frequency error, $\mathbf{\Delta F}$, the equation becomes equation (19).

$$U_i = -10B_i \times \overline{\Delta F_h} = \frac{\frac{1}{n}\sum \overline{\Delta F_h} \times U_i}{\frac{1}{n}\sum \overline{\Delta F_h}^2} \times \overline{\Delta F_h} \tag{19}$$

This is the same result as shown in equation (11). Therefore, it can be seen that the unscheduled energy is being correlated with the frequency error to determine the amount of clock-hour frequency response contained in the unscheduled energy or the energy delivery error.

FCC IMPLEMENTATION

Implementation of FCC is possible on an interconnection that has not restructured from vertically integrated, on an interconnection that has completed restructuring and is market driven, or an interconnection that is in transition and mixed between restructured and unrestructured participants.

Required Data:

FCC implementation requires only a subset of the AIE data and is not only reasonable but necessary for reliable operations. It is the minimal data that can be justified under the most lenient definition of "good-business-practice." The FCC implementation data includes only hourly agreed to scheduled and actual interchange data between control areas on the interconnection, and a single hourly average frequency error for the interconnection. The hourly scheduled and actual interchange will include all adjustments for meter error and schedule error. These are the $\mathbf{NI_A}$, $\mathbf{NI_S}$ and $\mathbf{\Delta F}$ components of the **AIE** equation.

Data Not Required:

The FCC implementation does not require Frequency Bias, **B**, data to be reported or captured, but the capture and reporting of Frequency Bias data may be a desirable for the audit of CPS data reported for control areas. FFC implementation without Frequency Bias data removes one source of fear that the Frequency Bias data can be unfairly manipulated to the detriment of some participants.

Energy Settlement:

The energy component of FCC, the unscheduled energy would be settled using the methods available for the participants involved in the transfer of unscheduled energy. If those methods include other important price signals such as transmission constraint pricing, those prices can remain as the prices used for settlement of the unscheduled energy component. If those prices contain other appropriate financial characteristics they will also remain unaffected. The unscheduled energy price signal is unaffected by FCC. The energy price determines the amount of the settlement using equation 20.

$$E\$_{i,j} = -U_{i,j} \times PE_{i,j} \tag{20}$$

Where:

i	=	**First Designated Participant**
j	=	**Second Designated Participant**
$\mathbf{U_{i,j}}$	=	**Unscheduled Energy from i to j**
$\mathbf{PE_{i,j}}$	=	**Unscheduled Energy Price from i to j**
$\mathbf{E\$_{i,j}}$	=	**Energy Dollar Settlement from i to j**

The settlement amounts for unscheduled energy would be captured and priced hourly and settled on an agreed periodic basis, probably monthly since the Energy Imbalance markets currently settle monthly in most cases, thus retaining the integrity of those settlements.

FCC Settlement:

The Frequency Control Component of unscheduled energy could be settled using equation 21.

$$FCC\$_{i,j} = -10\overline{\beta_{i,h}} \times PC \times H \tag{21}$$

Where:

$\mathbf{\beta_{i,h}}$	=	**Clock-Hour Avg. Frequency Response**
PC	=	**Frequency Control Component Price**
H	=	**Hours in Settlement Period**
FCC$	=	**FCC Dollar Settlement**

The characteristics associated with the root data used to calculate the settlements causes some interesting results. First, if schedules are required to be balanced and schedule errors are resolved, the sum of inadvertent energy on an interconnection is zero. In addition, if the internal control area schedules are included, the schedules within a control area are balanced, and schedule errors are resolved, then the sum of the Energy Imbalances within a control area is zero.

The above will be true, if all participants, including generators, within a control area are included in the Energy Imbalance calculation. Further, any unmanaged Energy Imbalances within a control area will result in an equivalent amount of Inadvertent for that control area. Therefore, Energy Imbalance is a subset of Inadvertent and the two are equivalent from an unscheduled energy viewpoint. Since both have the characteristic that they sum to zero, any market that includes all unscheduled energy, Energy Imbalance and Inadvertent, will also sum to zero across the interconnection.

Settlement Risk:

Many of the settlement methods suggested to price energy or energy components in a market do not result in a settlement that sums to zero for all participants. Since the sum of the unbalanced energy for the interconnection is zero for each hour and the average frequency error for each hour is the same throughout the interconnection, the sum of the $\mathbf{FCC_h}$ over the interconnection will also sum to zero. Since the $\mathbf{FCC_h}$ over the interconnection sums to zero for each hour and the price for each hour is also the same for each participant, the sum of the settlement dollars for the interconnection also sums to zero. This is represented by equations (22), (23) and (24).

$$\sum U_i = 0 \tag{22}$$

$$\sum FCC_h = \sum -10\beta_{i,h} = 0 \tag{23}$$

$$\sum FCC\$_{i,j} = 0 \tag{24}$$

Therefore, the settlement risk associated with managing the settlement for the FCC is minimal, because the settlement amounts for each hour sum to zero. This eliminates the need to solve the problem of what to do with surplus or deficit dollars associated with the settlement.

CONCLUSION #7

There is minimal settlement risk associated with managing the settlement of FCC since the sum of the settlement payments is zero for the interconnection.

Determining a Tolerance or Dead-band:

Since the FCC methodology results in small penalties and rewards for small Frequency Control Components and large penalties and rewards to large Frequency Control Components, there is no need for a non-settlement tolerance or dead-band to be applied to the settlement methodology. On the contrary, the creation of a non-settlement tolerance or dead-band destroys the zero sum property of the settlement methodology.

CONCLUSION #8

Defining a non-settlement tolerance or dead-band will increase the risk associated with managing the settlement process.

UNRESOLVED ISSUES

There are a number of unresolved issues associated with the analysis and proposal stated above. They include the following issues at a minimum.

- Any proposal that unifies Inadvertent and Energy Imbalance would require FERC approval and the changing of tariffs.
- The higher frequency components of unscheduled energy have not been addressed.
- Market design for frequency control is not addressed.
- The relationships between the unscheduled energy markets and the ancillary services markets are not addressed.

As this proposal is considered, discussed, evaluated, and modified, the above list is sure to expand.

CONCLUDING COMMENTS

I am confident that the above proposal can be implemented without having a detrimental effect on interconnection frequency control. This is the case because the settlement of Inadvertent includes at least partial incentives to continue to provide shared interconnection frequency control. I am also confident that a workable frequency control market that includes the necessary primary frequency control product can also be implemented.

References:

[1] "Area Interchange Error Training Document," NERC Operating Manual, January 1, 1992.

[2] Cohn, Nathan, "Decomposition of the Time Deviation and Inadvertent Interchange on Interconnected Systems, Part I: Identification, Separation and Measurement of Components," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-101, No. 5, May 1982.

[3] Cohn, Nathan, "Decomposition of the Time Deviation and Inadvertent Interchange on Interconnected Systems, Part II: Utilization of Components for Performance Evaluation and Corrective Control," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-101, No. 5, May 1982.

[4] "Control Performance Standards and Procedures for Interconnected Operations," EPRI RP3555-10, Final Report, August 1996.