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# **Analysis of Alternative Time Error Correction**

***Prepared for NERC RS & RCWG***

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# Executive Summary:

Energy Mark, Inc. was provided with a data set containing time-stamped Time Error and Time Error Correction data. This data was reviewed, corrected, validated and analyzed as part of an evaluation of the current Time Error Correction methods used on the Eastern Interconnection.

This information allowed an alternative Time Error Correction algorithm to be designed. The performance of this algorithm was simulated based on the data analyzed and it was demonstrated that the current Time Error Correction methods can easily be improved.

In addition, a number of conclusions and recommendations resulted from this study. They include:

## **Conclusions:**

### **Measured Actual Frequency Data Not Defined or Validated:**

The Measured Actual Frequency data supplied was not well defined and non-validated. Its use could have resulted in invalid conclusions. This demonstrates the need for a NERC Data Warehouse of defined and validated data for interconnection evaluations.

### **Time Error Data is a Better Source of Average Frequency:**

Time Error data can be effectively used to determine the average actual frequency of interconnection operation. For most purposes, Time Error data can provide more accurate Average Frequency Error data than the direct integration of sampled Frequency Error data, even for high resolution samples.

### **Time Error Data Can Validate Frequency Data:**

Time Error data can validate the average frequency data, for example, from CPS1.

### **Time Error Data Contains Cyclical Variations:**

The Time Error Data evaluated shows cyclical variations as indicated by the relationship between the hourly, daily and weekly averages. This information should influence the implementation of Time Error Corrections methods managing interconnection Time Error.

### **Better Alternatives Are Available for Time Error Correction:**

The algorithm and simulation presented here were created without expending significant effort. It demonstrates that there are alternatives available to the current Time Error Correction method that could provide better results from a reliability point of view while expending less total effort.

## **Recommendations:**

### **Validated Frequency Data Warehouse:**

NERC should have at its disposal data that has been defined, collected, and validated. This will insure that the best data is available for interconnection reliability studies. It will also insure that the data used has been validated prior to use in studies. This provides strong support for creation of the Data Warehouse that the NERC RS is defining.

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### **Include Time Error Data in the Data Warehouse:**

NERC should include Time Error Data and Time Error Correction data in the Data Warehouse. This data is a better source of Average Frequency and Average Frequency Error data than data produced by the integration of sampled Frequency or Frequency Error data.

### **Use Data Warehouse to Validate CPS1 Data:**

If the Data Warehouse includes Time Error data and Inadvertent Interchange data, then that data can be used to validate the CPS1 data. The average of the Frequency Error data used in CPS1 can be compared to the Time Error data to validate that portion of the CPS1 calculation. The Inadvertent Interchange data can be compared to the average Tie-Line Error data to validate that portion of the CPS1 calculation. This only leaves the Frequency Bias value of the CPS1 calculation not validated.

### **Continue Evaluation of the Time Error Correction Problem:**

This analysis demonstrates that the current Time Error Correction method can be improved. NERC should initiate a project with the goal of developing an improved algorithm to perform Time Error Correction while minimizing the effect on interconnection reliability.

## **Analysis of Data:**

The initial task of any good study is the evaluation and verification of the data upon which it is based.

### **Background:**

On March 13, 2003 Energy Mark, Inc. offered to perform an analysis of time error correction methods using the data on hourly time error and scheduled Time Error Corrections for the Eastern Interconnection. That data was forwarded to Energy Mark on March 14, 2003. The data is contained in the attached Excel Spreadsheet titled "TimeErrorData-Original".

### **Data Supplied:**

The data supplied by NERC for the study consisted of records spaced at time intervals of 30 minutes on the hour and half-hour and of records spaced at time intervals of 60 minutes on the hour. These records cover the period from January 1, 2001 through February 28, 2003 with the exception of the month of November 2001. Each record included the following data:

1. A Time Stamp consisting of the Date and Time that the Time Error was provided.
2. Fields to identify Time Error Corrections in progress indicating the Start, Active and End states of Time Error Corrections.
3. A field to identify whether the Time Error Correction is a FAST or SLOW correction.
4. Scheduled Frequency at the time indicated by the Time Stamp, 59.980, 60.000 & 60.020 Hz.
5. The Actual Frequency at the time indicated by the Time Stamp.

There were no headings or definitions of the data supplied leaving it up to the user to determine what the data meant and how it should be used.

### **Data Corrections:**

One of the critical parts of any study based on real world data is the review, correction and validation of the data to prepare it for use in the study. Failure to perform this review, correction and validation process adequately can easily influence the results of any study performed using that data.

The following actions were taken to prepare the data for use in a meaningful study.

1. Duplicate data records were removed from the data set. These consisted primarily of a duplicate record at the beginning of each month and duplicate records for the entire month of October 2001.
2. Blank records were inserted to create records for the month of November 2001 to insure that the graphing programs would work correctly. This will also allow the easy insertion of this data if it is eventually supplied.
3. Some Time Error values were missing from the data. When only one value was missing, the two adjacent values were interpolated providing an unbiased estimate of the missing value. In one case, four consecutive values were missing and were also supplied using interpolation.
4. There were a number of records that did not contain the Actual Frequency data. No attempt was made to estimate these missing values. These fields were left blank to insure that they did not influence the study.

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5. In one case the Scheduled Frequency during a Fast Time Error Correction for one of the many intervals of the correction was 60.02 Hz while all of the other Scheduled Frequency values for that Time Error Correction were 59.98 Hz. This value was changed from 60.02 Hz to 59.98 Hz.

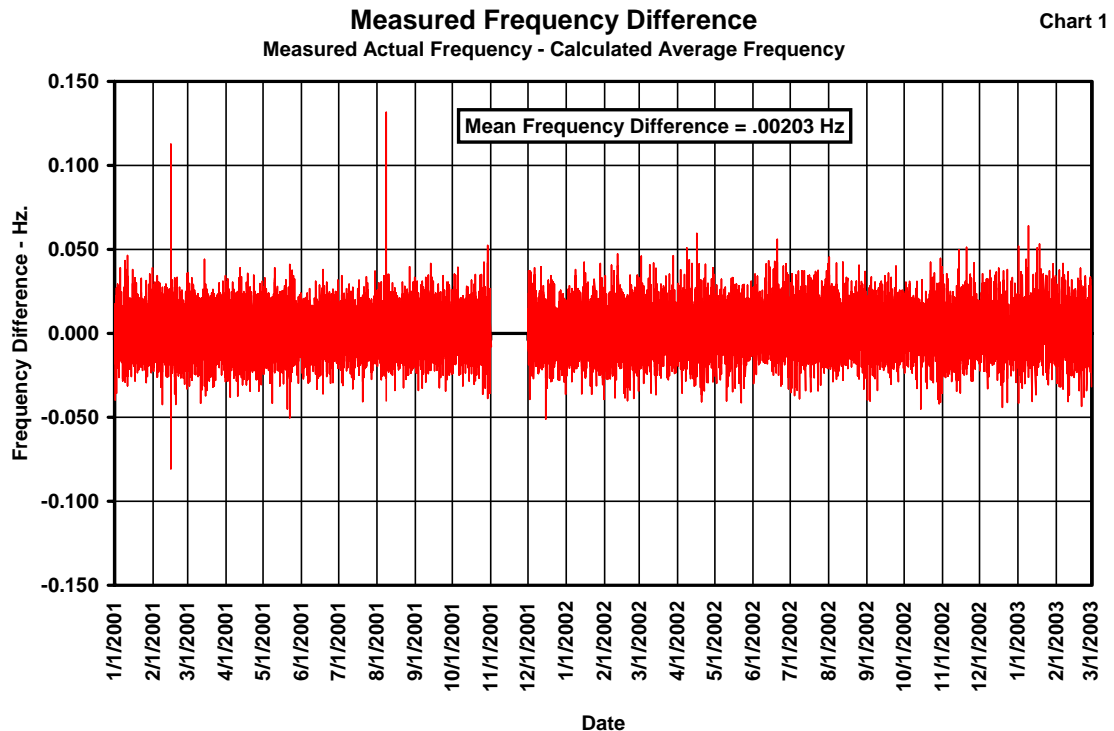
The original and corrected data is contained in the Excel Spreadsheet titled "TimeErrorData-Corrected" that has been attached with this study.

### Data Validation:

Energy Mark was uncertain whether the data supplied had been validated. Therefore, before using the corrected data it was necessary to understand the basis of the Measured Actual Frequency data. A few simple calculations and some comparisons were performed on the data to determine its source.

1. The Time Error Change between adjacent records was calculated for each pair of adjacent records. This indicated the Time Error Change for either half-hour or one-hour intervals.
2. The Time Error Change values were then used to calculate the Average Frequency Deviation from 60 Hz for each interval. For half-hour intervals, the Time Error Change divided by the 30 minutes in the interval, yields the Average Frequency Deviation from 60 Hz. For one-hour intervals, the Time Error Change divided by the 60 minutes in the interval, yields the Average Frequency Deviation from 60 Hz.
3. The Average Frequency Deviation was added to 60 Hz to get the Calculated Average Frequency for the interval.
4. The Measured Frequency Difference was calculated by subtracting the Calculated Average Frequency from the Measured Actual Frequency.

The Measured Frequency Difference was charted for the two year plus range of the data records.



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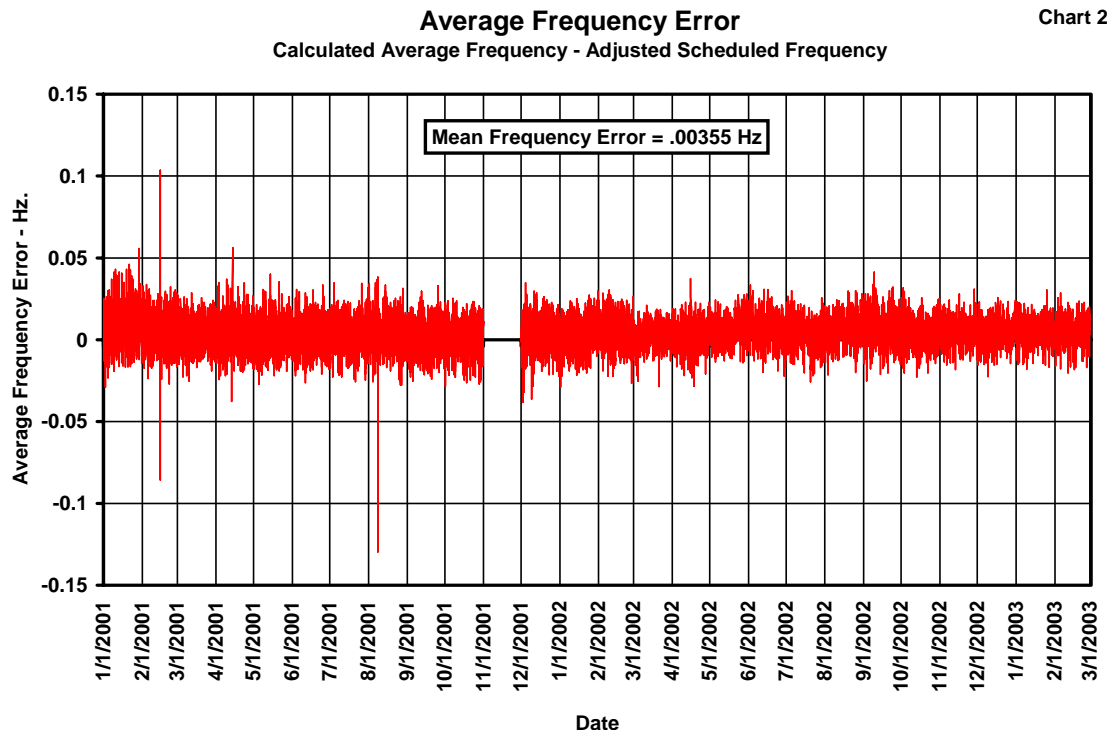
Chart 1 shows that Measured Actual Frequency data is not Measured Average Frequency over the preceding interval. This data is consistent with instantaneous frequency at the time of the time stamp. It is not useful for use in this study and was therefore deleted from the data used for further analysis.

## Data Development for Simulation:

Improving the methods of performing Time Error Correction requires development of a data set that can be used for simulation. This can be done with simple data comparisons.

### Calculation of Average Frequency Error:

The Date-Time Stamps indicated that the data for each record was collected from the first sample following the start of the hour or half-hour. This method of sampling requires some adjustments in the data to align it correctly for analysis. The Scheduled Frequency values supplied in the data records were adjusted by one measurement interval (moved to one interval later) to match the Calculated Average Frequency values that represent the average frequency during the 30 or 60 minute period ending with the time stamp. This adjustment is necessary because the Scheduled Frequency captured in each record represents the Scheduled Frequency for the 30 or 60 minute interval immediately following the Date-Time Stamp. The Adjusted Scheduled Frequency values were subtracted from the Calculated Average Frequency values from the previous analysis (Data Validation) for each half-hour or hour based on the Time Error data to yield the Average Frequency Error associated with each half-hour or one-hour record. This data is in **Chart 2**.



This Average Frequency Error data was subjected to additional analysis to determine whether it can be used as a basis to determine what would happen to Time Error without Time Error Corrections. This is a necessary step before the effect of implementation of new Time Error Correction methods can be simulated.

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### Average Frequency Error Analysis:

These Average Frequency Error values were divided into three groups, 1) Average Frequency Error during Fast Time Error Corrections, 2) Average Frequency Error when Scheduled Frequency is 60 Hz. and 3) Average Frequency Error during Slow Time Error Corrections. The data associated with this analysis is shown in **Table 1. – Average Frequency Error Statistics** below.

**Table 1. – Average Frequency Error Statistics**

AVERAGE FREQUENCY ERROR ANALYSIS	ALL INTERVALS	FAST INTERVALS	NO T.C. INTERVALS	SLOW INTERVALS
AVERAGE ERROR	0.00355	0.00767	0.00264	0.00308
STANDARD DEVIATION	0.00857	0.00860	0.00829	0.00915
MINIMUM VALUE	-0.12967	-0.12967	-0.03833	-0.01100
MAXIMUM VALUE	0.10367	0.05567	0.10367	0.03700

These statistics show that the Average Frequency Error may decrease as the Scheduled Frequency increases. However, this trend is not consistent. Although this effect is not insignificant, there is insufficient information contained in the data to model the effect. More importantly, these statistics show that there are no significant differences between the variations (standard deviations) of the Average Frequency Error resulting from Time Error Corrections. This data shows that it is reasonable to estimate that the Frequency Error can be assumed to be independent of the Time Error Corrections. Therefore, it is reasonable to assume that Frequency Error can be used to estimate the Time Error without Time Error Corrections. In addition, the result of Time Error Corrections can be estimated by adding the Frequency Error to the Scheduled Frequency. Therefore, the remainder of this study will be based on the following assumptions.

#### **Assumption 1:**

**The operation of the Eastern Interconnection without Time Error Corrections can be estimated by adding the Average Frequency Error to a Scheduled Frequency of 60 Hz.**

#### **Assumption 2:**

**The effect of Time Error Correction methods can be simulated by adding the Average Frequency Error to the Scheduled Frequency, 60 Hz. as adjusted by the Time Error Correction Frequency Offset.**

Once Measured Actual Frequency data was evaluated, the remainder of the data was modified to provide equal intervals throughout the study period. By eliminating all of the half-hour data, a data set containing only consistent hourly data was created. Use of this data insures that different intervals do not affect the evaluations or the statistics resulting from those evaluations. This data is contained in an attached Excel Spreadsheet titled "TimeErrorData-Analysis".

## Identification of Data Characteristics:

Once the data was corrected and its ability to represent the problem effectively verified, important characteristics of the data were identified. The significance of these characteristics are discussed below and shown graphically.

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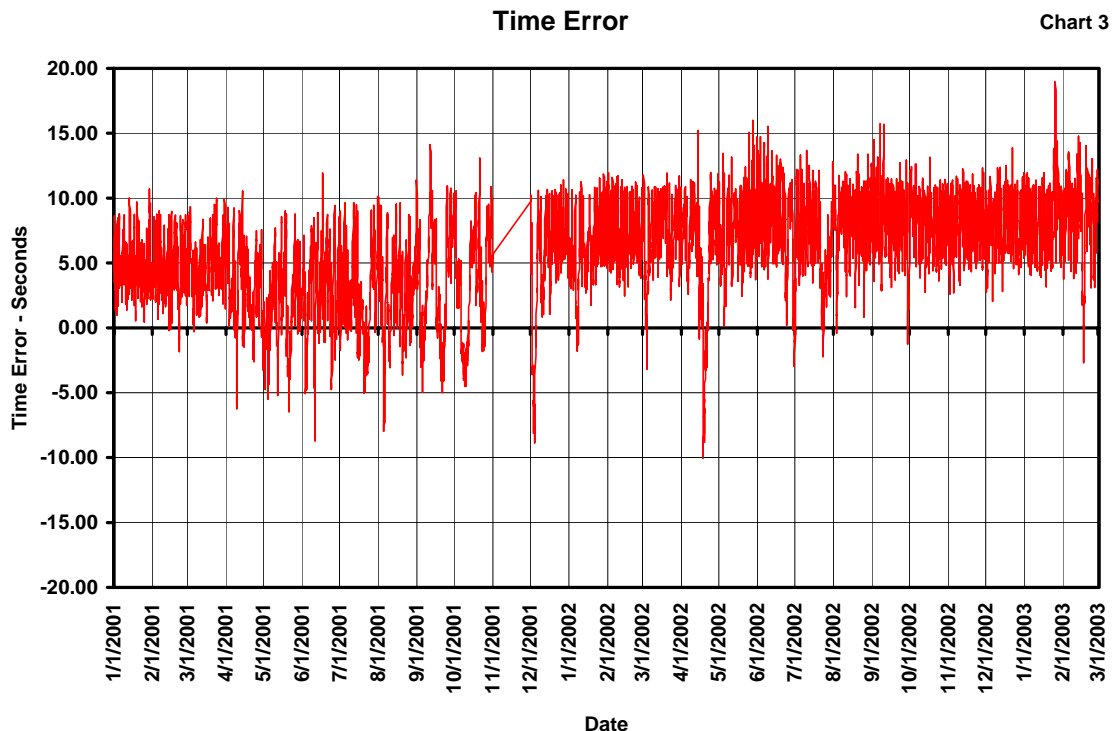
### Time Error Correction:

Before attempting to evaluate the future possibilities for Time Error Correction, an understanding of the basic data characteristics for the current method of Time Error Correction should be benchmarked and evaluated. There are a number of characteristics of the Time Error Correction data that require evaluation, 1) Average Time Error, 2) Time Error RMS from zero, 3) Average Actual Frequency, 4) Actual Frequency RMS from 60 Hz., 5) Average Scheduled Frequency, 6) Scheduled Frequency RMS from 60 Hz. These basic values should provide us with a starting point for understanding the current Time Error Correction method. Some basic statistics associated with these values is presented in **Table 2 – Time Error Statistics**.

**Table 2. – Time Error Statistics**

TIME ERROR ANALYSIS	TIME ERROR	SCHEDULED FREQUENCY	ACTUAL FREQUENCY
RMS ERROR	9.43584	0.00795	0.00976
AVERAGE	5.73031	59.996	60.000
MINIMUM VALUE	-10.04	59.980	59.925
MAXIMUM VALUE	18.97	60.020	60.057

The data is also presented graphically in Charts 3, 4 and 5. These charts and statistics will be used as the basis for judging the quality of Time Error Correction methods considered.

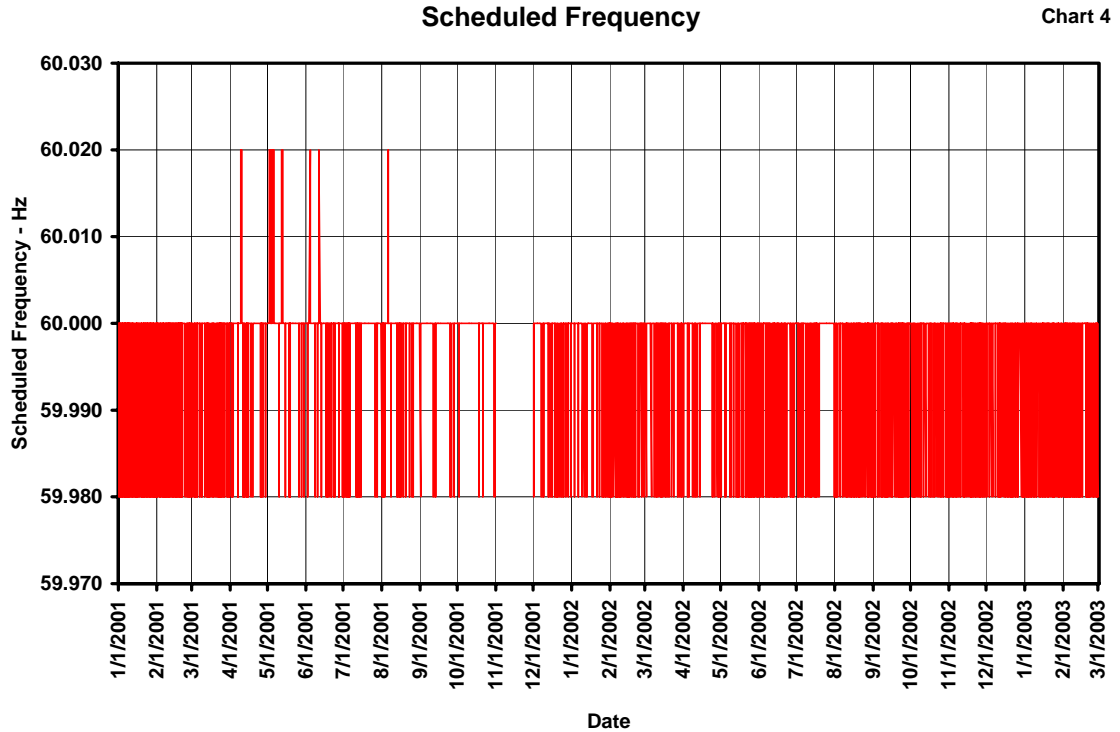


**Chart 3** shows that the Time Error is highly variable over short intervals as shown by the wide solid area in the chart. This prompts the question, “Is power quality better if the Time Error changes more slowly even if the variation in Time Error is not reduced?” I do not know the answer to that question, but if I assume that clocks are adjusted periodically, then a slower change in Time Error

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will result in less absolute error between clocks set at different times. Therefore, power quality may be better when the Time Error changes more slowly.

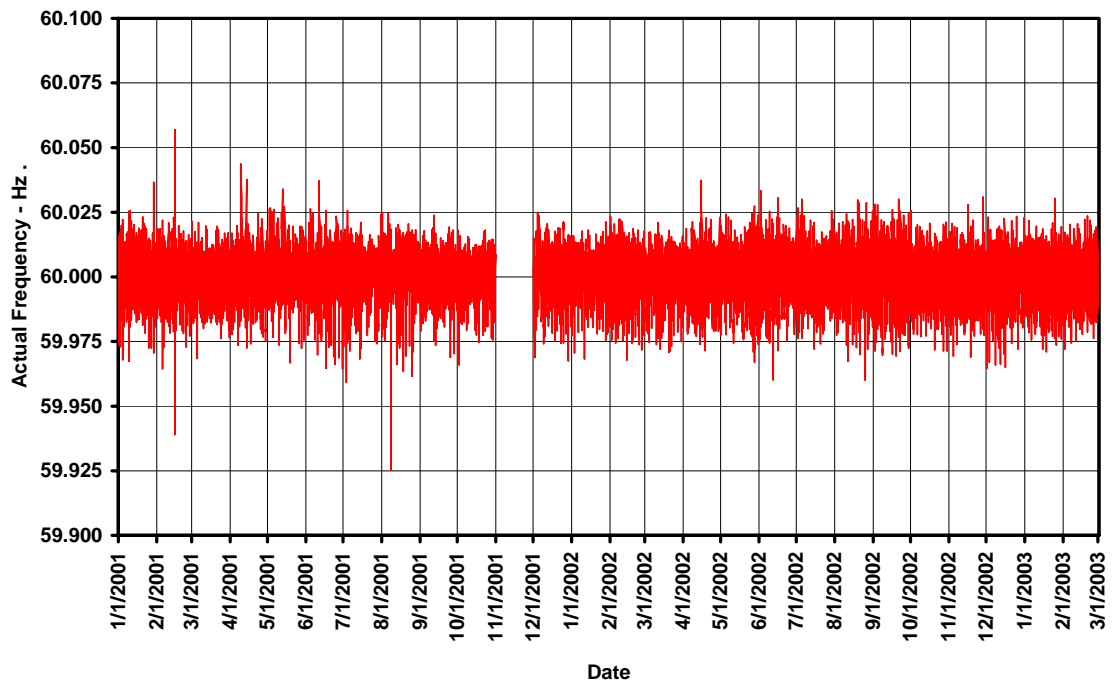


**Chart 4** shows the Scheduled Frequency over the period for which data was supplied. As with **Chart 3**, **Chart 4** shows the great variability of the Scheduled Frequency required for the current Time Error Correction method. This method can be likened to the result that is observed when following a very young, a very old, or a drunk driver who tends to over-steer the car. The car will weave back and forth within the traffic lane. This is why new drivers are taught to “aim high when steering” and to make small corrections to the steering wheel. The current Time Correction method is like a drunk driver weaving back and forth across Time Error.

**Chart 5** shows the frequency variation that results from the frequency error and the scheduled frequency adjustments made to correct the Time Error. It is difficult to draw any conclusions from this chart, but it is an important piece of information that will be used later to make comparisons with simulated results from other Time Error Corrections methods.

**Actual Frequency**

**Chart 5**



### **Time Error Analysis:**

Before attempting to evaluate either the existing method or new methods to provide Time Error Correction, the characteristics of the Average Frequency Error and associated Time Error data were evaluated. This was done by creating a data set to represent the Average Frequency Error and Time Error under the assumption that Time Error remains uncorrected. This data was created by calculating the Time Error Change and Time Error using the Average Frequency Error data. This Average Frequency Error for each record was multiplied by 60-minutes to get the Time Error Change. This Time Error Change was added to the Time Error from the previous interval to get the Time Error associated with the current interval.

### **Time Error Data:**

This Time Error data was analyzed by calculating the change in Time Error for intervals of 1-hour, 1-day, and 1-week. The results were charted to provide reasonable limits on how closely Time Error can be controlled without expending unreasonable effort. Many processes contain natural cyclical variations. It is significantly easier to control these processes to limits that lie outside these natural cyclical variations than it is to attempt to control the same processes to limits that lie within these natural cyclical variations. When control is attempted within the limits of the natural variation, the control process must continually fight the natural variation to achieve the desired control. When control is attempted within limits that lie outside the natural variation of the process, the control can be tuned to adjust only the mean of the variation without fighting the natural variation itself. For example, if the natural variation of Time Error during a day is approximately +/-10 seconds, then it will be significantly easier to control Time Error within limits that are greater than +/-10 seconds than to control Time Error within limits that are less than +/-10 seconds. The change in Time Error for 1-hour, 1-day and 1-week were charted to provide a visual indication of data variation. These charts follow.

Time Error Change

Chart 6

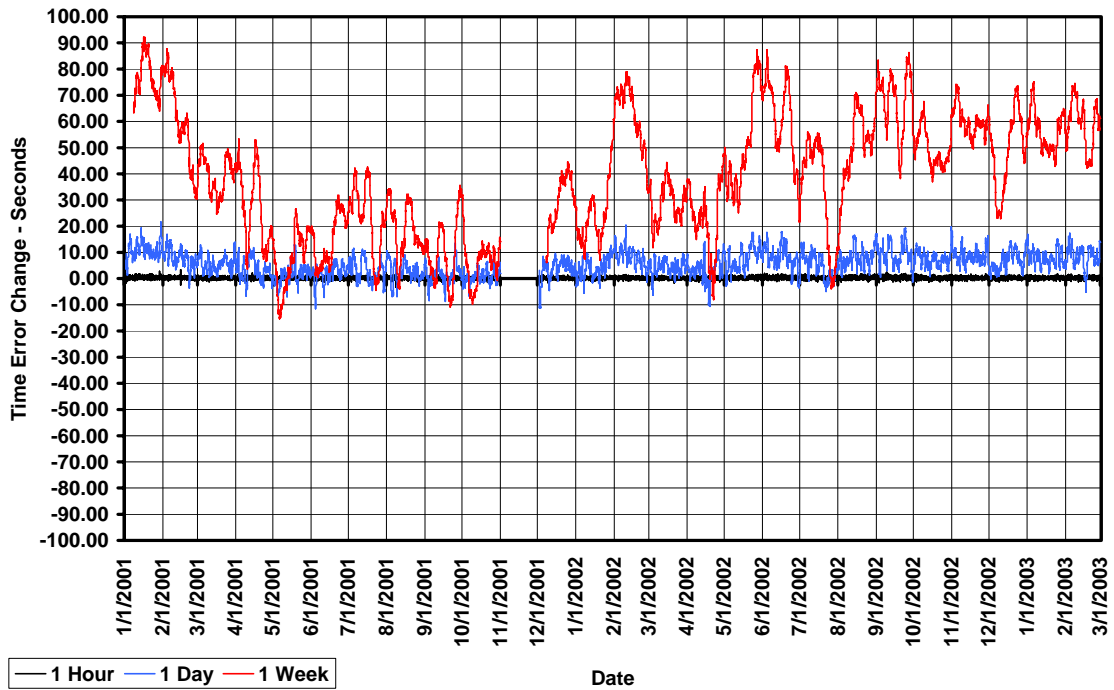
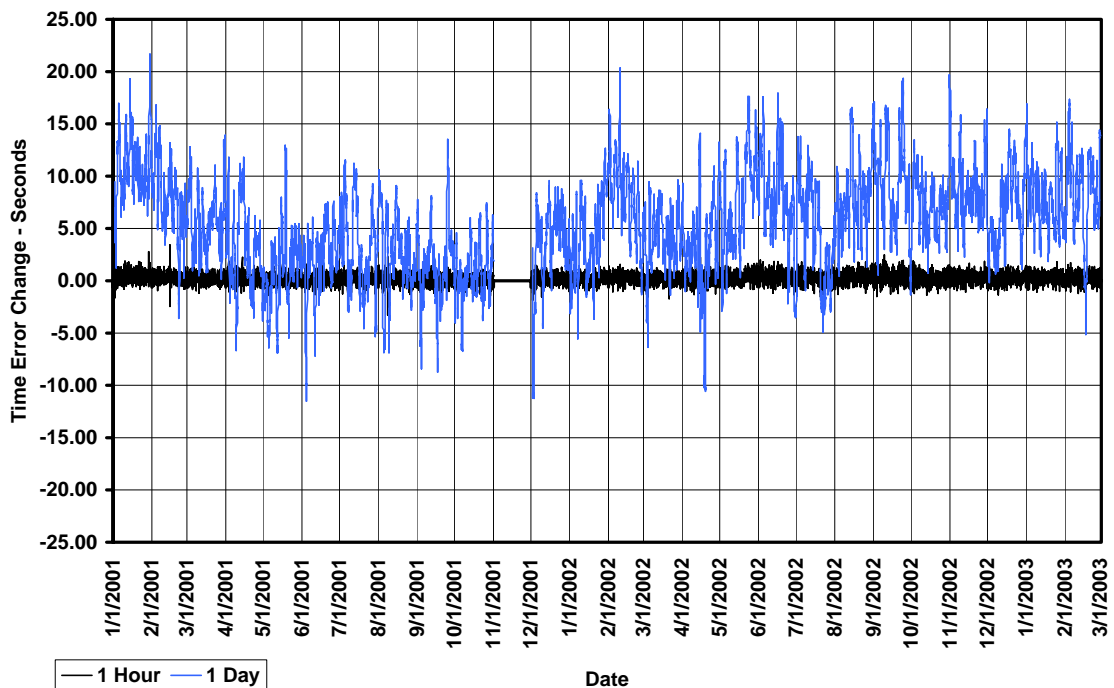


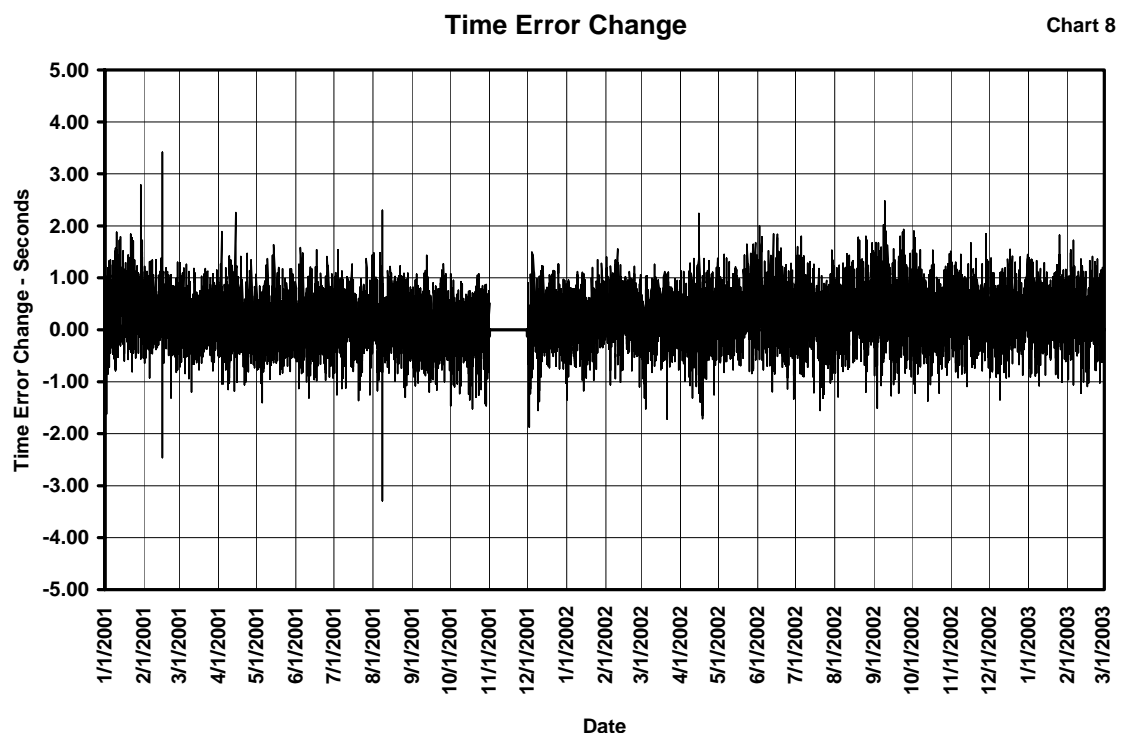
Chart 6 indicates patterns in the variation, but does not reveal all of the information desired. To better see daily and hourly data, the weekly data was removed and the chart was rescaled.

Time Error Change

Chart 7



The most important information these charts reveal is the change in Time Error during a single day. **Chart 7** shows that the Daily Time Error Change frequently exceeds plus 15 seconds and minus 5 seconds but seldom exceeds plus 20 seconds and minus 10 seconds. This provides reasonable limits to the daily Time Error variation that can be easily controlled. Time Error probably can be controlled to within +20 and -10 seconds or +/-20 seconds for balanced limits. Attempts to control to tighter limits might take considerably greater control actions at much greater cost. These additional control actions could be significant enough to tighten normal frequency control and should not be performed without additional analysis demonstrating justification. In order to better see the hourly data, the daily data was removed and the chart was rescaled.



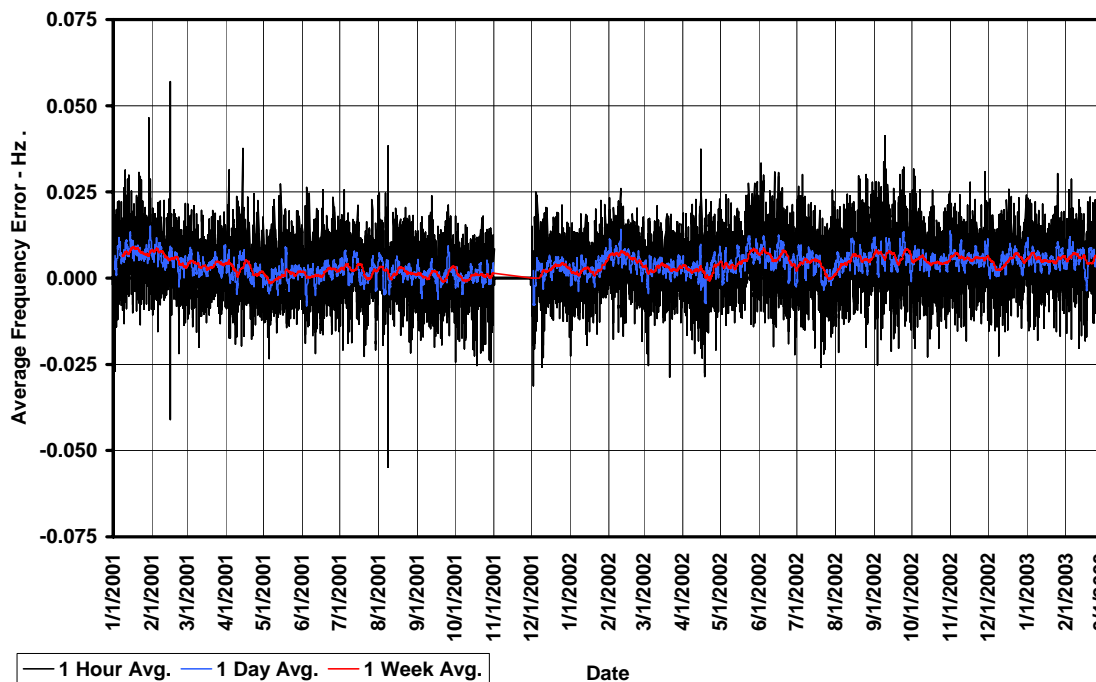
This charted hourly data, **Chart 8**, provides little additional information other than there is a great deal of variability in the hourly Time Error Change. Although these charts reveal some information they do not provide all of the information that we need. In an attempt to extract more useful data the Time Error Change data presented in these charts was converted to Average Frequency Error data and charted in a similar manner.

### **Average Frequency Error Data:**

The Time Error Change data was converted to Average Frequency Error data for the same change periods used for the Time Error Data, 1-hour, 1-day and 1-week by dividing the data by 60, 1440, and 10,080 respectively to get Average Frequency Error data. This data was then charted. The results are shown on **Chart 9**, **Chart 10** and **Chart 11**.

Average Frequency Error

Chart 9



**Chart 9** shows that the 1-hour Average Frequency Error is significantly greater than would be reasonable to fully offset with a Time Error Correction. These Average Frequency Errors frequently exceed 25 mHz, and sometimes exceed 50 mHz. Scheduled Frequency Adjustments necessary to offset errors of this magnitude would create a reliability problem in themselves. These short-term deviations must be corrected over longer correction periods to keep Scheduled Frequency Adjustments small enough to have a minimal reliability effect.

**Chart 9** also clearly shows the nested nature of the Average Frequency Error as the averaging period is increased from 1-hour to 1-day to 1-week. Evaluation of these nested values should provide the additional information desired from the analysis.

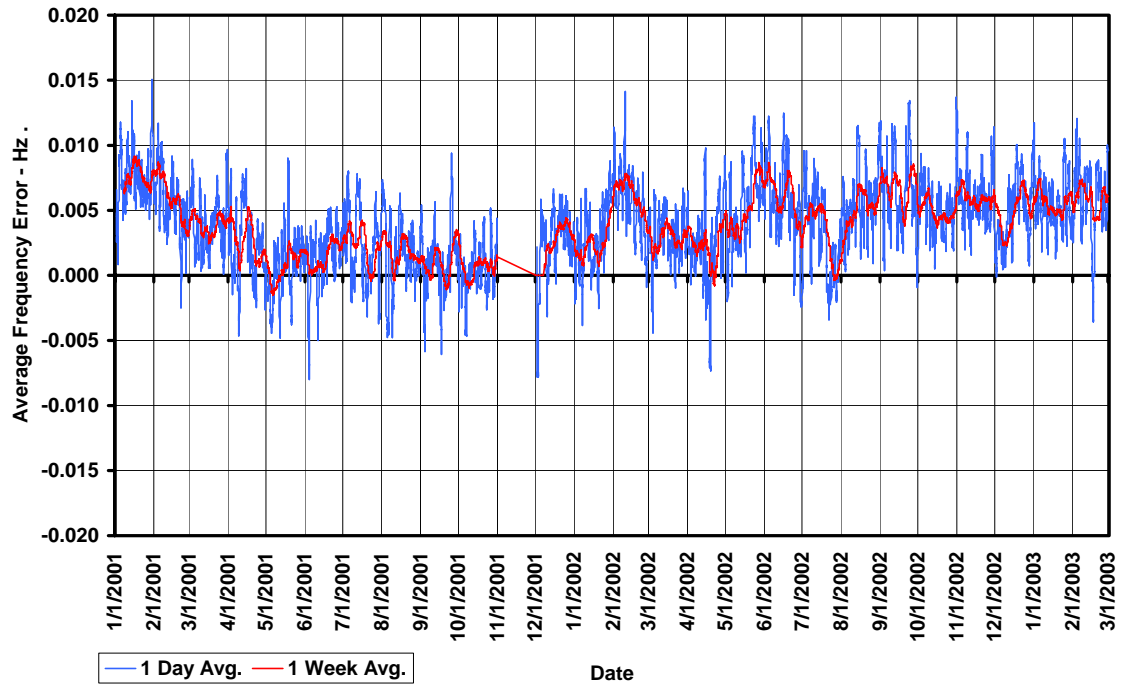
The 1-hour Average Frequency Errors were removed from **Chart 9** and the chart was rescaled and presented as **Chart 10**. **Chart 10** clearly shows that the Average Frequency Error for 1-day barely exceeds 15 mHz indicating that Time Error Correction should be able to be effectively implemented using Scheduled Frequency Offsets of +/-15 mHz or less. This would provide effective time error correction within the daily limits of +/-20 seconds while influencing reliability less than the current Scheduled Frequency Offsets of +/-20 mHz.

**Chart 10** and **Chart 11** also show that there is little value in using a longer averaging period such as 1-week because there is only a small reduction in the Average Frequency Error between 1-day and 1-week. The reduction in Average Frequency Error required is only a few mHz. This would be a bad trade-off because going to a weekly Average Frequency Error would increase the reasonable limits to values significantly greater than the +/-20 seconds that can be achieved using a daily basis for Time Error Correction.

The Average Frequency Error charts provide the information that we desire to use as a basis for the design of a logical Time Error Correction method.

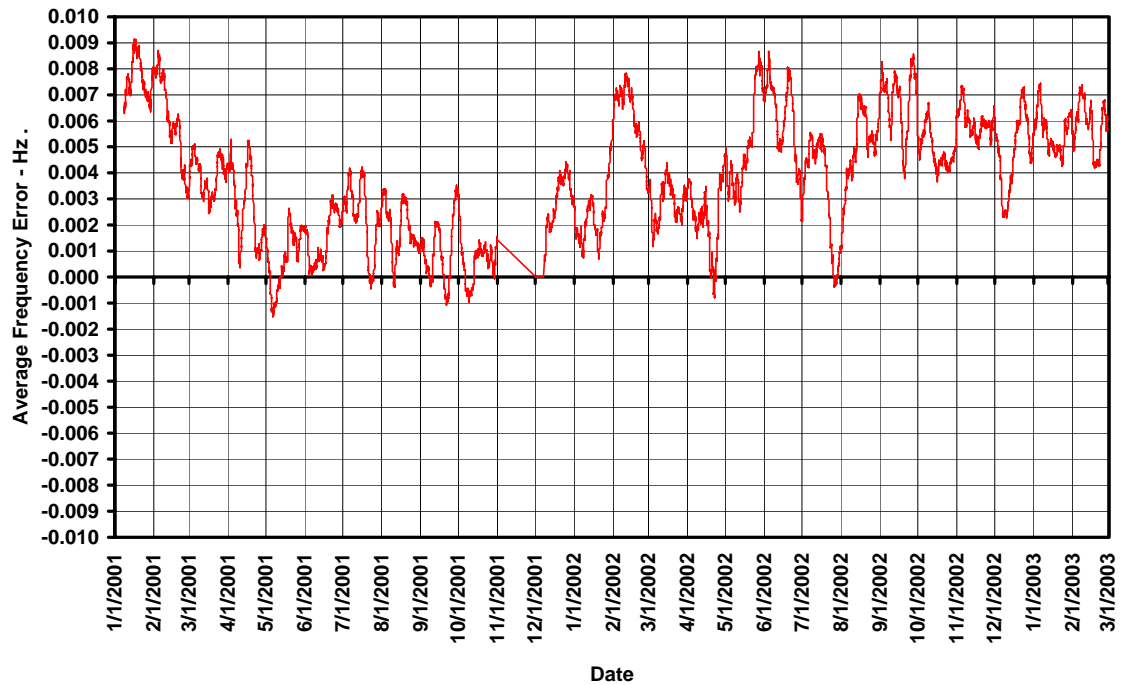
Average Frequency Error

Chart 10



Average Frequency Error

Chart 11



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### Time Error & Average Frequency Error Summary Information:

The information that can be extracted from the data and charts indicates that the following could be a reasonable basis for a Time Error Correction method.

1. The Time Error Correction method could be based on a Scheduled Frequency Offset from 60 Hz.<sup>1</sup>
2. The Frequency Offset would be scheduled at steps of 0.001 Hz. instead of a single step of 0.020 Hz. These smaller adjustments would reduce the “drunk driving” effect that the larger single step 0.020 Hz. offset is causing.
3. The Frequency Offset would be adjusted hourly. The more often the Frequency Offset is adjusted, the smaller those adjustments would need to be.
4. The Frequency Offset would be based on information from the hour ending one-hour before the beginning of the scheduled offset-hour. This would provide the necessary time between calculating the required Frequency Offset and its implementation by all of the Balancing Authorities to allow for effective communication of the value and implementation in the control systems.
5. The Frequency Offset would be sized to offset the average daily and weekly frequency errors. If only the experienced frequency error is offset, there is little risk of causing overcorrection or the instabilities that can result.
6. The Frequency Offset would be biased to center the daily variation around 60 Hz. Since the intent is to allow the short-term variation to continue, this bias would slowly move the remaining variation until it is centered around zero Time Error.
7. The Time Error would be corrected to within +/- 20 seconds, a range consistent with the daily Time Error variation. These limits would be confirmed in a simulation.

There is an additional assumption that has a significant effect on the choices made in the development of the algorithm offered.

### Assumption 3:

**The development of power markets will continue. This continued development will be incompatible with the management of cumulative Inadvertent Interchange payback-in-kind accounting methods. This will result in the implementation of financial Inadvertent Interchange settlement. Therefore, Time Error Correction methods based on Inadvertent Interchange payback-in-kind accounting will be unsupportable.**

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<sup>1</sup> CPS1 requires that the Scheduled Interchange sum to zero over the interconnection. This allows only methods of Time Error Correction that use a Frequency Offset to be included within the CPS1 calculation. When the Time Error Correction is included within the CPS1 measure, the enforcement of CPS1 would also provide incentives to participate in Time Error Corrections.

## **Time Error Correction and Reliability:**

In the previous section, statements were made with respect to the relationship between Time Error Correction and reliability. Before going further in the development of a Time Error Correction algorithm this relationship should be defined in greater detail. This section provides that explanation of that relationship and how it is affected by the Time Error Correction Method chosen.

### **Frequency Reliability Limits:**

Frequency Reliability for an interconnection requires that operations be performed in a manner that keeps Frequency within limits that prevent a cascading failure of the interconnection. The outside limits of operations are derived from the acceptable operating range of the generators on the interconnection. The other limits are related to limits derived from these generator limits.

#### **Generator Frequency Limits:**

Generators are designed to operate within specific rotational limits. If the generator operates outside these design limits for more than short periods the generator will be subject to damage and catastrophic failure. The lower limit is usually in the range of 58.5 Hz. and if a generator operates below this limit very long it is subject to damage from resonance vibrations. The upper limit is usually in the range of 63 Hz. and the generator will fail from large rotational forces if this limit is exceeded. Since all generators have similar limits, operation even near these limits is prohibited because that range of operation can cause the failure of multiple generators and failure of the entire interconnection. In order to prevent these kinds of failures, under and over frequency relays are set to cause other actions to disconnect either load or generation rebalancing the interconnection before these limits can be approached.

#### **Under-frequency & Over-frequency Relay Limits:**

Under-frequency and Over-frequency relays are coordinated to cause the disconnection of predetermined amounts of load before the lower frequency limit can be reached and to disconnect predetermined amounts of generation before the upper limit can be reached. The relay settings are designed to implement these rebalancing actions without putting the total interconnection at risk of failure. Since these relays act without consideration of market economics and without compensation of the parties disconnected to achieve the rebalancing, these relay limits become the upper and lower effective reliability limits for the interconnection.

#### **Scheduled Frequency:**

The interconnection is normally operated at a frequency of 60 Hz. The operating range between this scheduled frequency of 60 Hz. and the upper and lower effective limits as determined by the relay settings is the reliable range of operation available. This available range can be consumed by the factors that cause variation in the balance between load and generation. These factors cause this frequency margin to be consumed.

### **Frequency Margin Consumption:**

The range of reliable operations is defined by the Frequency Reliability Limits described above. This range or margin of reliable operations is allowed to be consumed by operating uncertainties. If these uncertainties jointly consume less than the total range or margin, the interconnection will remain

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reliable. If these uncertainties jointly consume more than the total range or margin, the interconnection may become unreliable. There are three basic variations that consume the frequency margin.

### **Frequency Excursions from Extraordinary Events:**

One uncertainty factor that consumes this margin is the change in frequency resulting from extraordinary events normally referred to as disturbances or contingencies. The amount of frequency margin that is consumed by an event is directly proportional to the size of the disturbance or contingency and inversely proportional to the amount of Frequency Response available at the time of the event. Therefore, there are factors that affect how much margin must be retained for these events. These are size of the event and the event probabilities, and the frequency response available to respond to the event. Adjustments to any of these characteristics can affect the amount of margin consumed by these events.

### **Frequency Control Error from Normal Variations:**

In addition to extraordinary events there is the normal variation in load and generation that cause imbalances between the two. The frequency variations can be reduced by either the amount of secondary control applied to reduce these variations or the amount of frequency response available to reduce the effect of a given amount of imbalance. Adjustments to the variation in load or generation, adjustments to the amount of secondary control available to offset this variation or adjustments to the amount of frequency response can affect the amount of margin consumed by these variations.

### **Time Error Correction Scheduled Frequency Offset:**

Finally, the Scheduled Frequency Offset can reduce the amount of margin available for consumption by the previous two factors. A reduction in the RMS value of the Scheduled Frequency Offset will increase the amount of margin available to the other factors to meet reliability needs of the interconnection. This is how Time Error Correction affects reliability.

## Time Error Correction Method:

The data characteristics identified in the previous sections were used to create a simple feedback control algorithm to achieve Time Error Correction. This algorithm was then simulated on the data developed from the Time Error information supplied by NERC. The following sections describe the algorithm developed and provide a comparison to the current method of performing Time Error Corrections on the Eastern Interconnection.

### Continuous Time Error Correction:

Continuous Time Error Correction could be performed by applying much less effort in terms of Scheduled Frequency Offset with a significantly reduced reliability effect as compared to the current Time Error Correction method.

The algorithm would consist of two terms. The first term would correct the weighted average daily and weekly Time Error using a weighted daily and weekly Scheduled Frequency Offset average. The second term would simply provide a small bias to nudge the Time Error variations toward an average Time Error of zero. These two components should provide a simple but effective Time Error Correction algorithm.

### Daily and Weekly Weighted Average Time Error:

The first term of the algorithm would capture the average Time Error for each additional hour and include it in an average Cumulative Time Error that would weight the most recent hour the greatest and adjust that weight on a constantly decaying basis until the effect of that hour would disappear after about 1-week. The decay rate of the averaging method was chosen to create a total weighting over the weekly weighting and averaging period such that the sum of the adjustments resulting from the Time Error offset for all hours would exactly equal the Time Error effect of the single hour Time Error. Finally this Cumulative Time Error would be used to calculate a Scheduled Frequency Offset that would adjust the scheduled frequency to perform the Time Error Correction.

The specific values used weight the most recent hour by a factor of 0.0326 and weight the sum of the previous hour's errors by a factor of 0.9674. This term in equation form would be as follows:

#### Daily & Weekly Average Time Error Offset Weighting Equations:

$$CE_{t-1} = ( TE_{t-2} \times 0.0326 ) + ( CE_{t-2} \times 0.9674 ) \quad (1)$$

$$FO_t = - \text{Round} ( CE_{t-1} / 60 ) \text{ to the nearest } 0.001 \text{ Hz.} \quad (2)$$

Where:  $CE_t$  = Cumulative Weighted Time Error for hour t.

$TE_t$  = Time Error for hour t.

$FO_t$  = Frequency Offset for hour t.

The following example shows how this method of creating a decaying weighting would work.

1. Assume that a Time Error of +1.00 second occurs in hour 1.
2. Since the information about the magnitude of the hour 1 ( t ) Time Error would not be available until sometime in hour 2, ( t + 1 ), the frequency offset for this error could not be applied until the beginning of hour 3, ( t + 2 ).

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3. The weighted Time Error for this +1.00 second error will be  $+1.00 \times 0.0326$  for hour 3.
4. The weighted Time Error for this +1.00 second error will be  $+1.00 \times 0.0326 \times 0.9674$  for hour 4,  $+1.00 \times 0.0326 \times 0.9674^2$  for hour 5,  $+1.00 \times 0.0326 \times 0.9674^3$  for hour 6, etc.
5. This weighting was chosen because the sum of the weighted values for all of the hours' weighted errors will sum to the Hour 1 Time Error value at the end of one week and effectively remain at that value thereafter. This insures that the sum of the weighted Cumulative Time Errors will exactly equal the hourly Time Error creating the that sum.
6. The weighting is similar for every hourly Time Error independent of the hour in which it occurs. For example, a Time Error in the hour 2 would have a weighting of 0.0326 in hour 4, a weighting of  $0.0326 \times 0.9674$  in hour 5, etc.
7. This weighting algorithm requires only one value to be passed from hour to hour, the previous hour's weighted Cumulative Time Error. As each new hour's Time Error is included it is simply multiplied by 0.0326 and added to the previous hour's Cumulative Time Error multiplied by 0.9674, which now includes the previous hour's Time Error in the sum.
8. The weighted Cumulative Time Error would then be converted to a frequency offset by dividing it by -60 and rounding that value to the nearest 0.001 Hz. to get the first term of the frequency offset.

The specific calculation is shown in Column H of the attached Excel Spreadsheet titled "TimeErrorData-Simulation".

### Time Error Centering Bias:

The second term is simply an additional offset value of +0.001, 0.000, or -0.001 Hz. that is added to the Daily and Weekly Average Offset. The value is set to zero for hour 3 when the Time Error for hour 1 lies between +/- 10 seconds. If the Time Error for hour 1 is greater than +10 seconds, then the value for hour 3 is set to -0.001 Hz. If the Time Error for hour 1 is less than -10 seconds, then the value for hour 3 is set to +0.001 Hz. This small bias gently nudges the Time Error toward a value of zero without causing over control or eliminating the natural variations that occur in Time Error. The specific calculation for this Time Error Centering Bias is shown in Column J of the attached Excel Spreadsheet titled "TimeErrorData-Simulation".

The Total Frequency Offset is calculated by simply adding the Daily and Weekly Average Frequency Error Offset to the Time Error Centering Bias Offset. The Total Frequency Offset is then used to adjust the scheduled frequency.

### Time Error Simulation:

The algorithm described above was simulated on the data provided to get an indication of how well it would solve the Time Error Correction problem. The total data series was simulated using the algorithm. The results of that simulation are shown below in tabular form, Table 3. – Simulated Time Error Statistics. They have also been charted so the effect can be seen visually. Table 2. – Time Error Statistics has been repeated so that the results of the simulation can be more easily compared to the present Time Error Correction method.

**Table 2. – Time Error Statistics**

TIME ERROR ANALYSIS	TIME ERROR	SCHEDULED FREQUENCY	ACTUAL FREQUENCY
RMS ERROR	9.43584	0.00795	0.00976
AVERAGE	5.73031	59.996	60.000
MINIMUM VALUE	-10.04	59.980	59.925
MAXIMUM VALUE	18.97	60.020	60.057

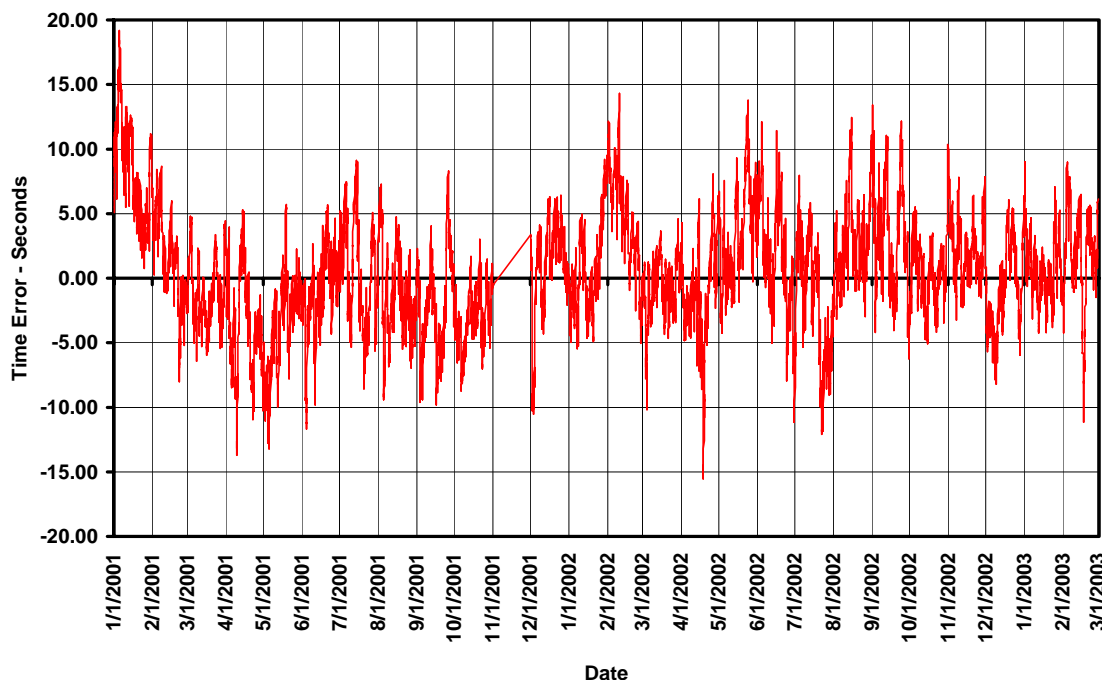
**Table 3. – Simulated Time Error Statistics**

SIMULATED TIME ERROR ANALYSIS	SIMULATED TIME ERROR	SIMULATED SCHEDULED FREQUENCY	SIMULATED ACTUAL FREQUENCY
RMS ERROR	4.74781	0.00281	0.00758
AVERAGE	0.35014	59.996	60.000
MINIMUM VALUE	-15.53	59.987	59.941
MAXIMUM VALUE	19.19	60.006	60.052

The Simulated Time Error Correction algorithm improved all of the Time Error Statistics related to reliability without significantly affecting the total range of Time Error experienced. The RMS value of the Time Error fell from about 9.5 seconds to less than 4.75 seconds, a 50% reduction. The average Time Error fell from about 5.75 seconds to about 1/3 of a second. The RMS value of the deviation from 60 Hz. for the Simulated Scheduled Frequency and the Simulated Actual Frequency is probably the best indicator of the effect on interconnection reliability. These values fell from 0.00795 Hz. and 0.00976 Hz. to 0.00281 Hz. and 0.00758 Hz. respectively. Both of these indicate significant improvements in reliability. These improvements were achieved without significantly increasing the limits of the Time Error that would be experienced as indicated by the Minimum and Maximum Values.

**Simulated Time Error**

**Chart 12**



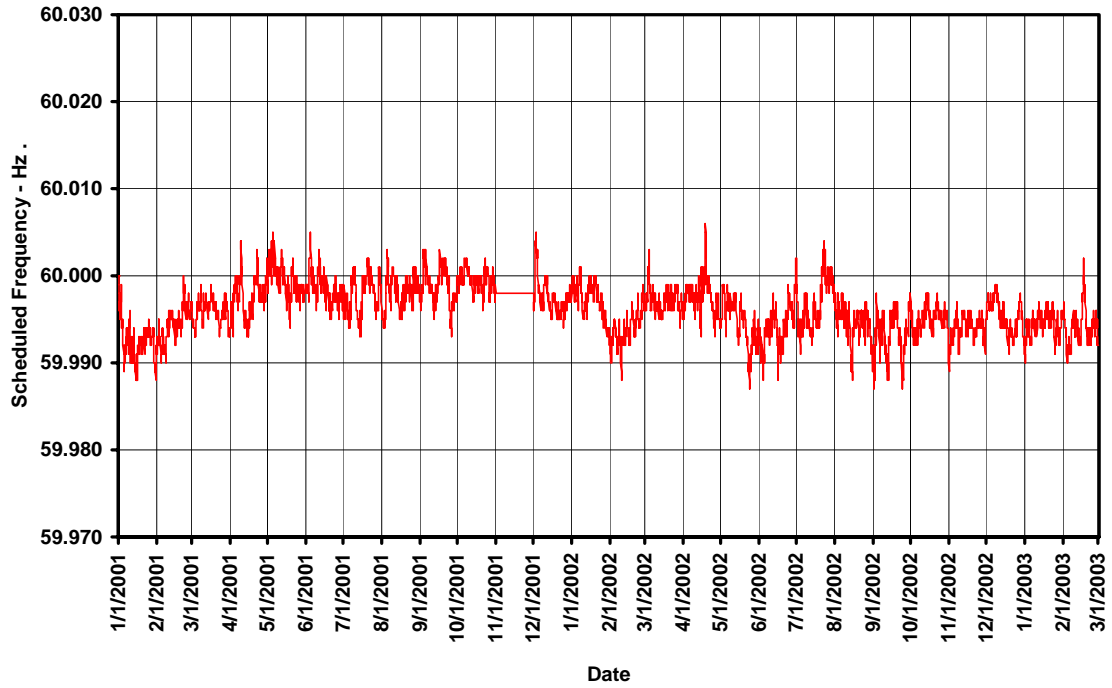
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Chart 12 shows the Time Error from the simulation and can be directly compared to Chart 3. It shows a significant reduction in average Time Error and Time Error variation.

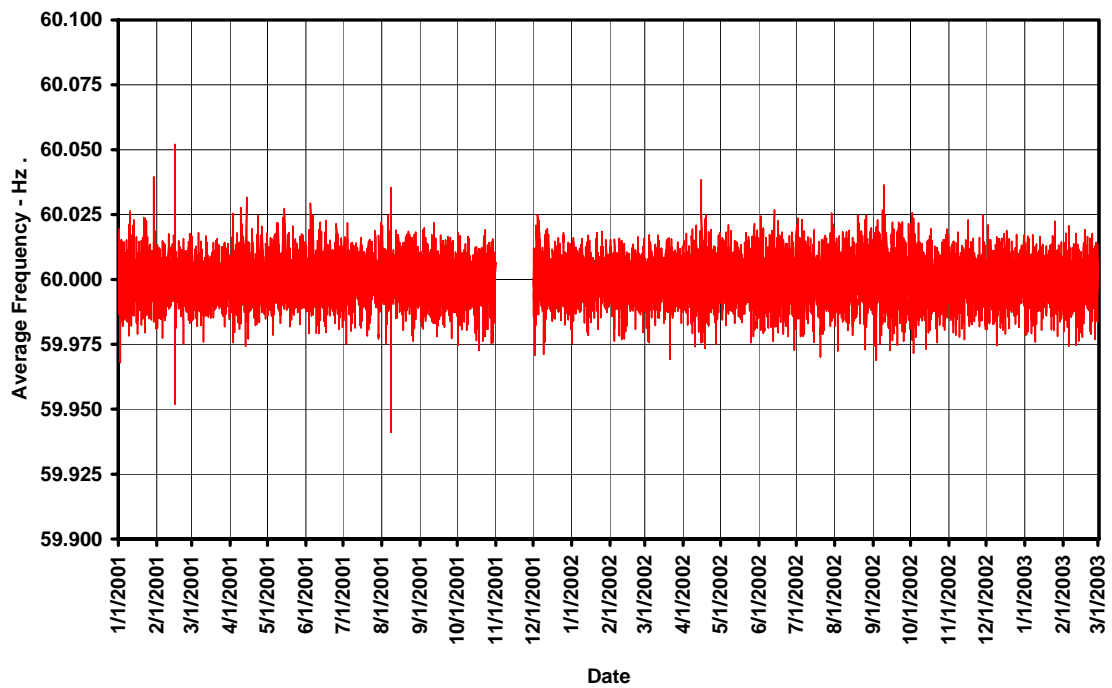
### Scheduled Frequency

Chart 13



### Average Frequency

Chart 14



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**Chart 13** shows the Simulated Scheduled Frequency. **Chart 13** can be directly compared to **Chart 4**. This comparison is the most dramatic of the comparisons of the data from the current Time Error Correction method and the Simulated Time Error Correction Algorithm. It shows that much of the variability is being created by the current Time Error Correction method itself. The current method is equivalent to using a sledge hammer when a tack hammer would suffice.

**Chart 14** shows the Average Frequency resulting from the simulation. It can be directly compared to **Chart 5**. Although the comparison is not as dramatic as the previous one, the reduction in Average Frequency can be seen.

The Time Error Correction algorithm suggested above should be carefully evaluated and considered for implementation. Its implementation would not only improve Time Error Correction, but would also reduce the detrimental effects that Time Error Correction have on reliability. Since the value of this component of power quality is unknown, it is prudent to minimize the effect of Time Error Corrections on reliability while continuing to evaluate the value.

Energy Mark, Inc. is willing to discuss and re-evaluate any of the data or methods presented in this document for modification to meet other perceived needs that may not have been included in this evaluation.

## **Conclusions:**

The following specific and general conclusions can be drawn from the analysis of the data supplied and the alternative algorithm simulation.

### **Measured Actual Frequency Data:**

The Measured Actual Frequency data supplied is not the average frequency over the time interval between records. Because of the variation and magnitude of the difference, it is likely that this data is the instantaneous frequency sampled at the time of the time stamp. If the data validation had not been performed on this data, it could have easily been assumed to be average frequency data over the time interval between records. The use of this data in the time error study would then lead to invalid conclusions about the nature of the problem and the solutions that might be used to resolve it.

### **Time Error Data:**

Time Error data can be effectively used to determine the average actual frequency of interconnection operation. For most purposes, Time Error data can provide more accurate Average Frequency Error data than the direct integration of sampled Frequency Error data, even for high resolution samples.

### **Time Error Data Can Validate Frequency Data:**

Time Error data can be used to validate the average frequency data from for example CPS1 measurement.

### **Time Error Data Contains Cyclical Variations:**

The Time Error Data evaluated shows cyclical variations as indicated by the relationship between the hourly, daily and weekly averages. This information should influence the implementation of the Time Error Corrections methods used to manage interconnection Time Error.

### **Better Alternatives Are Available for Time Error Correction:**

The algorithm and simulation presented here was created without expending considerable effort. It demonstrates that there are alternatives available to the current Time Error Correction method that could provide much better results from a reliability point of view while expending less total effort.

## **Recommendations:**

The following specific and general recommendations are derived from the data correction, validation, analysis, and simulation performed as part of this study.

### **Validated Frequency Data Warehouse:**

NERC should have at its disposal data that has been defined, collected, and validated. This will insure that the best data is available for interconnection reliability studies. It will also insure that the data used has been validated prior to use in studies. This provides strong support for creation of the Data Warehouse that the NERC RS is defining.

### **Include Time Error Data in the Data Warehouse:**

NERC should include Time Error Data and Time Error Correction data in the Data Warehouse. This data is a better source of Average Frequency and Average Frequency Error data than data produced by the integration of sampled Frequency or Frequency Error data.

### **Use Data Warehouse to Validate CPS1 Data:**

If the Data Warehouse includes Time Error data and Inadvertent Interchange data, then that data can be used to validate the CPS1 data. The average of the Frequency Error data used in CPS1 can be compared to the Time Error data to validate that portion of the CPS1 calculation. The Inadvertent Interchange data can be compared to the average Tie-Line Error data to validate that portion of the CPS1 calculation. This only leaves the Frequency Bias value of the CPS1 calculation un-validated.

### **Continue Evaluation of the Time Error Correction Problem:**

This analysis demonstrates that the current Time Error Correction method can be improved. NERC should initiate a project with the goal of developing an improved algorithm to perform Time Error Correction while having a minimal effect on interconnection reliability.