Time and frequency from electrical power lines

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ABSTRACT

Due to the efforts of Henry Warren, inventor of the Telechron electric clock, electric power companies have been a source of time and frequency reference for the public for over a hundred years. However, advances in technology and changes in the electric power industry have generated a movement within the industry to end the time-reference service. Power systems in the U.S. operate at a nominal 60 Hz, but in actual operation they accumulate significant phase error. It must be deliberately backed out to keep synchronous clocks on time—a procedure known as Time Error Correction (TEC). Today, many electric clocks still depend on the power system as the reference oscillator—that is, are synchronous—while others use other time references, such as local quartz oscillators and networked time servers—a benefit of the Internet of Things. Little is known about the overall impact of TEC on timekeeping in modern times. The Blackout of 2003 spawned a new regulatory structure for the electric power industry to improve reliability, and as an unanticipated side effect, a decision process that would most likely eliminate TECs was set in motion. The specific proposal is to retire regulatory standards designated *BAL-004* and *WEQ-006*. We review the relevant structure and governing bodies of the U.S. power grids, and report on the current procedural status of these standards. In addition, we review possible scenarios for the future of the power system as an elapsed-time reference absent TEC. For this, we include analysis of the electric power at USNO, as measured over five years. The TECs appear in the data; an analysis with the industry-supplied record of the TECs indicates that without them a time deviation of about 7 ½ minutes would have occurred on the Eastern Interconnection (grid) between the daylight saving time switches of March 2016 and November 2016.

INTRODUCTION

Had this meeting on precision time been held 100 years ago, we surely would have discussed Henry Warren's latest invention. For on February 5, 1917, Mr. Warren—founder of the Warren Clock Company—filed for a U.S. patent on the first synchronous electric motor suitable for turning the gears and hands of a clock [1]. His company, and the clocks it produced, ultimately adopted the trademark name "Telechron."

As the electric power industry began to develop in the late 19th century, various types of electric clocks were introduced. Some synchronized to the Master Clock at USNO through signals sent out nationwide over Western Union telegraph. Others were from the Self Winding Clock Company of Brooklyn, New York, which used electricity as a continual source of energy. However, prior to the Telechron clock, there was no clock that used the frequency of the power system as a timing reference.

At first, the synchronous electric clock hit a snag—60 Hz electric power wasn't exactly 60 Hz after all. As Warren himself noted, "As a time-keeper the device was a failure. It was off as much as 10 or 15 minutes a day. But it was a success so far as checking the accuracy of alternations, or waves, was concerned. [2]" Seeing another opportunity, Warren developed a device to compare power line frequency to a precision pendulum clock—the Type "A" Master Clock. On October 23, 1916, Boston Edison became the first electric company to adopt a Warren Type "A" Master Clock as their frequency standard, and by 1947, Warren Master Clocks regulated over 95 % of the electric lines in the United States [3]. As an unforeseen benefit, once different electric utilities had sufficiently synchronized generation, it became possible to form the first electric power grids.

Telechron began as a master/slave clock synchronization system. A master clock at the power company would be used to ensure the accuracy of the 60 Hz frequency, while Telechron secondary clocks could be sold inexpensively in the mass market. As the electric power industry developed and grew in the early 20th century, they realized that they could also sell their service as a "correct time" service [4]. In modern parlance, timekeeping was a "killer app."

General Electric Company was quick to recognize the potential of the Telechron system, and in 1917 purchased a half-interest in the Warren Clock Company. (GE acquired full ownership in 1943, and it was merged into GE in 1951 [5].) Those of us of a certain age remember the Telechron trademark on many GE products. However, many other companies came to rely on 60 Hz power as a frequency reference as well [6].

Dependence on a 60 Hz power source was not limited to synchronous motors. Digital display clocks that became commonplace beginning in the 1970s could also rely on the 60 Hz frequency as a reference. They would count the power line cycles electronically, rather than electromechanically. (Of course, battery powered clocks and some plug-in clocks rely on quartz crystal oscillators.)

Today, there is diversity in the way consumer clocks maintain their time accuracy. Quartz crystal oscillators are ubiquitous, and modern circuits improve accuracy through automatic compensation for temperature changes. Digital televisions receive time data from broadcasters, as do smartphones from cell sites. For devices appropriately situated to receive other broadcast signals, time is available from NIST Radio Station WWVB and GPS. For computers and the increasing number of devices on "the internet of things," time is readily available from network servers. Nonetheless, many electric clocks in our homes and offices—standalone, and integrated into appliances and time-sensitive devices (e.g., event recorders, lawn sprinklers)—still use the 60 Hz reference, and we take for granted that these clocks will maintain their time setting, at least to within a few seconds. However, after 100 years, the era of your power company providing a correct-time service may be coming to an end.

TIME ERROR CORRECTION

The Warren master clocks were not only frequency references, they also compared the integrated number of periods of both the pendulum clock and the power line. Their primary function, after all, was to steer the many secondary clocks to the time of the master one. However, in recent decades, electric power companies have had better frequency references. Precise synchronization of frequency across many generators is a key to forming power grids. And while 60.000 Hz is the normative goal, as a practical matter the frequency will vary with shifting loads and changing amounts of generation. A rising demand for electricity is felt by the turbine generators as an increased countertorque, which slows their rotation slightly until a feedback system applies more input power—and vice versa. Indeed, mismatched frequencies within a grid are indicative of unbalanced generation and load.

Even though the system is controlled to maintain constant frequency, phase noise is inevitable. Over time, there can be a significant accumulation of phase error, which is reflected as time error on synchronous clocks. In modern practice, the electric power industry monitors this time error, and once it reaches a threshold—10 seconds in the Eastern U.S., 5 seconds in the West, and at operator discretion in most of Texas—a procedure called manual Time Error Correction (TEC) is initiated to back it out. While the details vary a bit between the three major "Interconnections" (power grids) in the U.S.—Eastern, Western, and ERCOT (Texas)—in essence a central authority in each Interconnection monitors the Time Error and can issue an order for all producers in that Interconnection to target a different frequency: 59.980 Hz to retard synchronous clocks, or 60.020 Hz to advance them. For each hour of operation at these frequencies (a 20 mHz offset), synchronous clocks will nominally gain or lose 1.2 seconds (subject to variation due to the vagaries of generation and load).

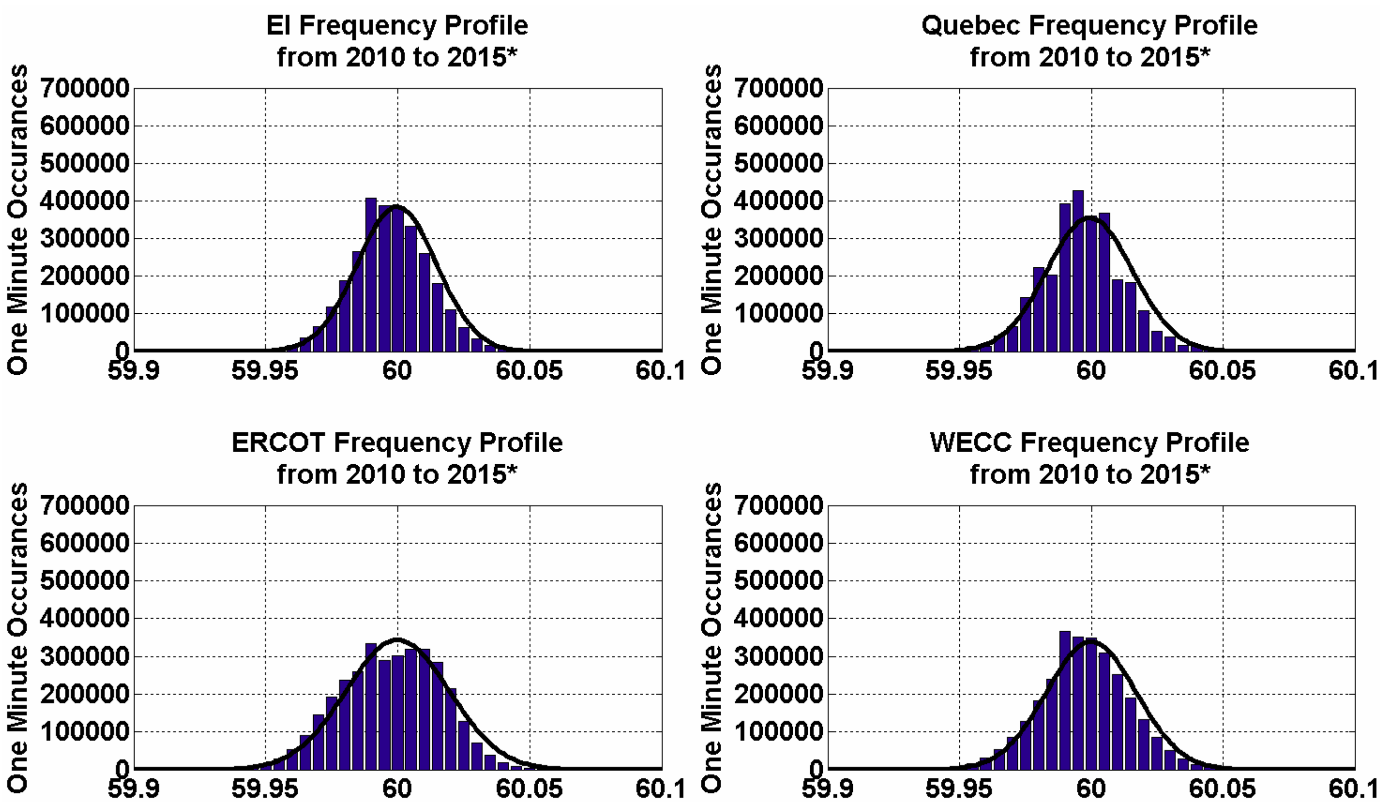

Figure 1. Histograms of one-minute average frequencies, in hertz, from the beginning of 2010 through June 2015, for the four major North American Interconnections. Source: North American Electric Reliability Corporation, Ref. [25].

This is why synchronous electric clocks are so amazingly consistent over long periods of time. It isn't that the power system is itself a more stable oscillator than, say, a quartz one; it's because there is an invisible hand that intervenes to keep these clocks on time.

STANDARDS IN THE BULK POWER INDUSTRY

A defining event for the electric power industry was the Blackout of 2003, which affected an estimated 50 million people in Ontario and seven U.S. Northeast and Midwest states [7]. Congress, determined that such a thing should never happen again, established a new regulatory regime for Reliability Standards in Sec. 1211 of the Energy Policy Act of 2005. The Federal Energy Regulatory Commission (FERC) was given new oversight authority. FERC was required to select a non-governmental "Electric Reliability Organization" to develop and enforce such standards, which FERC would then consider for adoption as binding Federal regulation. In 2006, the North American Electric Reliability Corporation (NERC) was chosen to fulfill this role.

Put another way, NERC acts as a voluntary consensus standards organization, in many ways similar to ANSI and ASTM. Standards intended to ensure the reliability of the bulk power system are developed through open participation and transparent process, study and voting. Once NERC has voted to adopt a new standard or to revise an old one, the document is submitted to FERC, which conducts a notice-and-comment rulemaking. This may result in a standard being legally enforceable, with stiff penalties for violations. Conversely, FERC may retire a standard if NERC so requests.

In addition to NERC, a second non-governmental organization, the North American Energy Standards Board (NAESB), develops voluntary consensus standards for the industry. While NERC standards are reliability-oriented, NAESB standards are business-oriented. "[NAESB] serves as an industry forum for the development and promotion of standards which will lead to a seamless marketplace for wholesale and retail natural gas and electricity, as recognized by its customers, business community, participants, and regulatory entities [8]."

Both NAESB and NERC have adopted industry standards for Time Error Correction. NAESB standard *WEQ-006* [9] requires, among other things, that all three Interconnections conduct TECs, what their respective trigger thresholds should be, and that balancing authorities within the Interconnections should participate [10]. NERC standard *BAL-004* requires, among other things, that "The Interconnection Time Monitor shall monitor Time Error and shall initiate or terminate corrective action orders in accordance with the NAESB Time Error Correction Procedure [11-12]."

FERC has adopted both of these standards into regulations. *BAL-004* was made enforceable in 2007 [13]. *WEQ-006* was re-adopted most recently in 2014 (Version 3) [14], and a pending rulemaking would update the regulation to Version 3.1 [15]. However, in 2007 an unanticipated side effect arose. While the Interconnection Time Monitor had previously been an innocuous volunteer position, now non-compliance with the letter of *BAL-004* could lead to a penalty of up to $325,000. Perhaps not surprisingly, "[t]he entities [that] have been serving as 'volunteers' don't want to continue to serve in this role if they are subject to sanctions for non-compliance [16]."

FIRST ATTEMPT TO RETIRE TIME ERROR CORRECTION

To address this situation, NERC developed a revision to *BAL-004* (*BAL-004-1*), and in 2009, they petitioned FERC to adopt it [17]. One of the proposed changes was to remove the requirement to initiate TECs in accordance with NAESB's procedure (*WEQ-006*). NERC argued that time error was not a reliability issue, and therefore there should not be a requirement in a reliability standard to conduct TECs. In taking this action, the industry had taken its first step back from its tradition of reliably providing correct time as well as power.

As the proceeding further developed, NERC raised a new argument that TEC was actually deleterious to reliability. "While it is expected that actual frequency will deviate to a certain extent from scheduled frequency (and indeed the Bulk Power System has been designed to allow for such variability), intentionally moving away from a scheduled frequency target of 60 Hertz serves no reliability purpose and effectively 'wastes' the safety margins designed into the system by the engineers who planned it [18]." Furthermore, TEC was characterized as an unnecessary relic from a bygone era. "[I]s Time Error Correction still a needed and valuable service, particularly in light of the data showing that Time Error Corrections appear to be placing the reliability of the Bulk Power System at greater risk? NERC's Balancing Authority Controls Standard Drafting Team, which is responsible for the redrafting of *BAL-004*, believes it is not. While proceeding cautiously, that team is tentatively recommending that the practice of Time Error Corrections be halted [19]." NERC filed a Motion to Defer Action on the proposed revision to regulation, given that "…research and analysis regarding Time Error Correction is ongoing, that NERC and its stakeholders are exploring the possibility of implementing a Field Test to evaluate elimination of Time Error Corrections, and that the results of such a field test may lead to the withdrawal of NERC's request for the approval of BAL-004-1 and the retirement of BAL-004-0 [20]."

Ultimately, in 2012, the NERC Board of Trustees rescinded approval of *BAL-004-1*. "While it was clear that eliminating Time Error Corrections would likely have no negative impact on reliability that was insurmountable, it also became clear that the potential for other problems was largely undefined and not well understood. Following exhaustive discussion and debate over several months, it was ultimately determined by the OC [Operating Committee] at their March 6-7, 2012 meeting that NERC should discontinue its pursuit of the elimination of Manual Time Error Corrections [21]." Further, NERC petitioned FERC to withdraw its proposal for any regulatory changes to *BAL-004* [22]. In their petition, NERC reported that they had determined the proposed changes to be "unnecessary."

CURRENT ATTEMPT TO RETIRE TIME ERROR CORRECTION

The issue was revived in February 2015, when a Periodic [Standards] Review Team within NERC recommended that BAL-004-0 be retired and that manual Time Error Correction be eliminated as a continent-wide NERC standard [23]. Strictly, this was not a call to end the practice of TECs, as had been the case before, but merely a recommendation to retire the formally documented operating procedure under which TECs had been conducted.

This recommendation worked its way through the NERC standards development process, which included three rounds of comments and two rounds of balloting [24]. A white paper prepared in advance of the last round of comments [25] made several arguments in favor of the proposal. The principal one was a carefully worded variant of previous themes: "The practice of using manual TEC to place the Interconnection closer to the settings for automatic underfrequency load shedding does not support or enhance reliability. Therefore, BAL-004-0 should be retired." That is, the 20 mHz frequency offset of TEC did not support reliability because it put the operating point closer to the threshold of Underfrequency Load Shedding

(UFLS), also known as the Frequency Relay Limit (FRL). In the Eastern Interconnection, the FRL is 59.7 Hz [26], thus the margin is reduced from 300 mHz to 280 mHz. (The FRL is not to be confused with the Frequency Trigger Limits (FTL) at 59.95 Hz and 60.05 Hz, which if exceeded for five minutes, merely causes notification messages to be generated.)

The white paper continued with other arguments, which included: TEC is a strictly commercial service that does require a mandatory and enforceable Reliability Standard. There is no documentation that TEC has been important since 1976. Quartz oscillators provided a more reliable and less expensive method to keep accurate time. GPS is even better. Grid frequency is not the appropriate source for alignment to official time. Manual TEC is occurring less frequently. Newer versions of other reliability standards, *BAL-003-1* and *BAL-001-2*, will maintain the grid closer to an average of 60 Hz, so TEC will be redundant. (The authors do not necessarily concur with these arguments. For example, while *BAL-003-1* and *BAL-001-2*, may result in smaller frequency deviations from 60 Hz, it is not clear how they could control the *average* frequency, which would be the key to substituting for TECs.)

On November 2, 2016, the NERC Board of Trustees voted to file requests for the retirement of Reliability Standard *BAL-004* with applicable regulatory authorities (FERC in the U.S and the National Energy Board in Canada) [27]. The petition to FERC was filed a week later [28]. On January 18, 2017, FERC approved the petition [29].

Approval for retirement of *BAL-004* is contingent on the retirement of *WEQ-006*. On February 2, 2016, NERC filed a formal request with NAESB asking them to retire *WEQ-006* [30]. This request was received favorably [31] and has been circulated for comment [32]. If approved within NAESB, it is likely that this will also result in a petition to FERC. A limited period for public comment would follow.

USNO DATA MONITORING

For situational awareness, the USNO began monitoring the time offset of the electrical power supplied by its local utility in 2011, by using a counter to measure the time intervals between the on-second marks of UTC(USNO) and the next upward-moving zero volt crossing of the incoming alternating electrical current. Since 2011, we have accumulated over 63 million observations at 2 second intervals. An independent system was also in operation from January 9, 2013 to October 20, 2014, with 5.5 million observations at 1 second intervals.

In this measurement scheme, y is a measured time interval ($0\ \text{s} \le y \le t_{cycle}$, where $t_{cycle} = 1/(60\ \text{Hz}) \cong 0.0167$ s). Figure 2 shows an example of these data. The phase wraps stem from the fact that the power line frequency, f_{PL}, is not exactly 60 Hz, and therefore in a period of length ΔUTC seconds between two measurements there can be one zero-crossing more or less than $60\ \text{s}^{-1}$ ΔUTC zero-crossings. (ΔUTC = 2 s for the results reported here.)

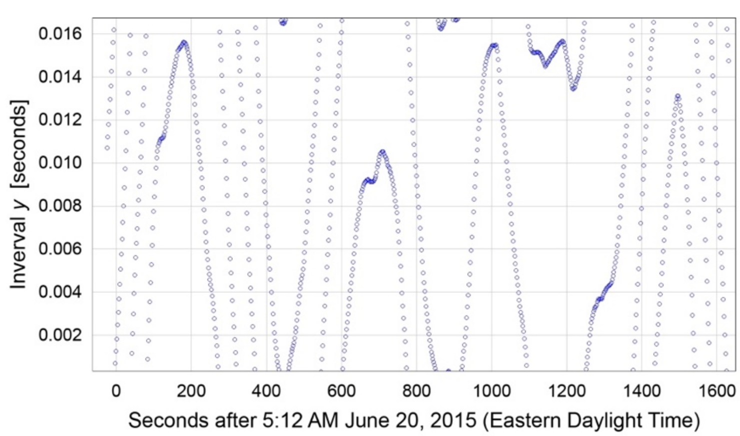

Figure 2. Typical USNO monitor data.

The difference between the y of consecutive measurements, Δy, is expected to be near 0 s or t_{cycle}, since the irregularities of the zero-crossing times makes them wander ahead of or behind the integer-second times of UTC(USNO). Approximately 0.02 % of the observations were discarded because $0.25\ t_{cycle} < |\Delta y| < 0.75\ t_{cycle}$. These appeared to be artifacts of the measurement system, which was not designed for this purpose.

The instantaneous frequency of the power line can be computed from the measurements as:

$$f_{\mathrm{PL}} = \frac{\left(60\ \mathrm{s}^{-1}\right)\Delta\mathrm{UTC} + N}{\Delta\mathrm{UTC} + \Delta y} \ , \tag{1}$$

where N, the number of cycle slips, is 0, –1, or +1. N is chosen so as to bring the inferred f_{PL} closest to 60 Hz, which is equivalent to making $\Delta y + N\, \mathrm{t}_{\mathrm{cycle}}$ closest to 0 s.

The wrap-corrected frequencies (Fig. 3) were used to infer the time t_{PL} by integrating up from the first datum (Fig. 4); a user's clock would integrate from the device's last reset against UTC(NIST) or UTC(USNO).

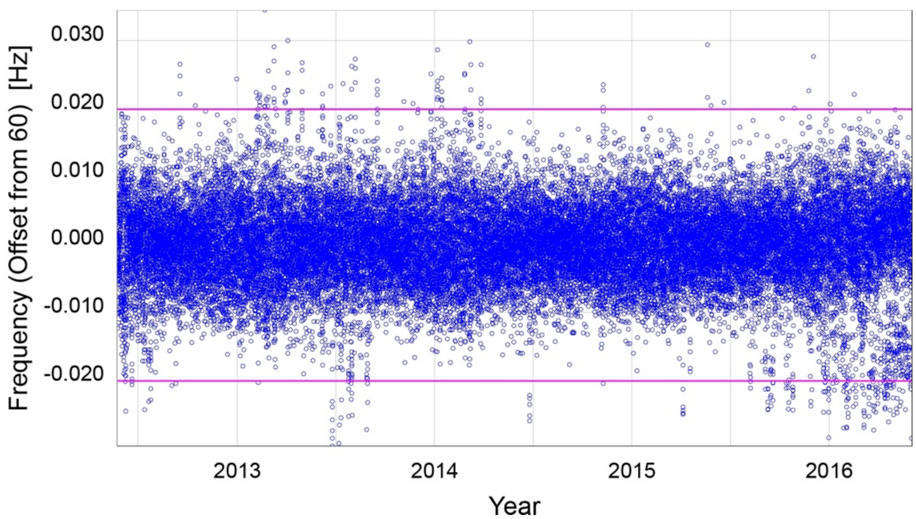

Figure 3. The frequency of the electric power provided to the USNO minus its nominal 60 Hz value. Frequencies outside the region enclosed by the horizontal bars likely indicate times of TECs.

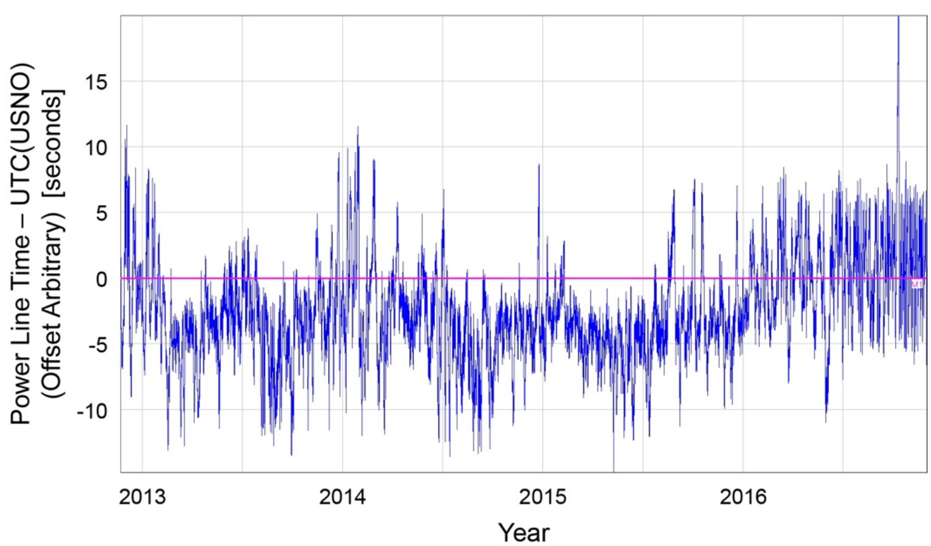

Figure 4. Power Line Time – UTC(USNO), as observed at the USNO, 1-minute averages. This is the time error that an ideal clock would display if it had been started on-time at the beginning of the dataset. In practice, clocks that do not provide a single-touch one-hour advancement or retardation feature are reset by the user at the beginning and end of Daylight Saving Time.

On the U.S. Eastern Interconnection, TECs are implemented in the form of intentional 0.02 Hz adjustments of the frequency, over periods of up to 14 hours. They are initiated when the offset from UTC reaches approximately 10 seconds and halted when the offset has been reduced to about 6 seconds. These can be seen as outliers in the frequency data, although they are not distinct in a histogram of the hourly frequency deviations from 60 Hz (Fig. 5). The inference that these frequency outliers were intentional TEC insertions was largely confirmed by data kindly supplied by the NERC Resources Subcommittee, although one frequency outlier (Fig. 6) was apparently due to other causes.

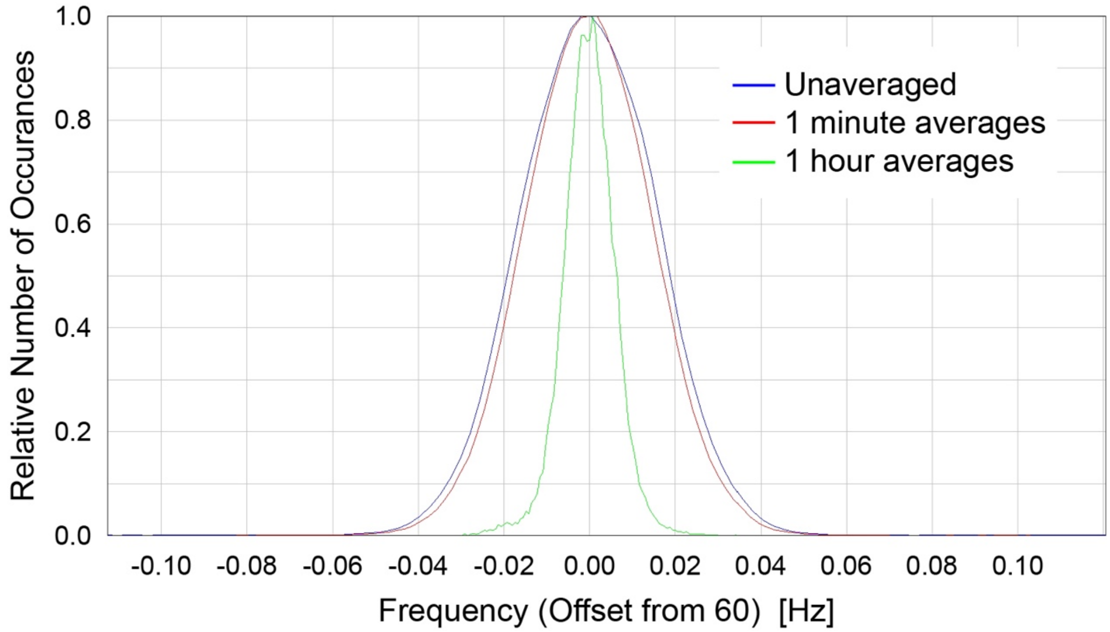

Figure 5. Histogram of Power Line Frequencies as observed at the USNO, averaged over different periods.

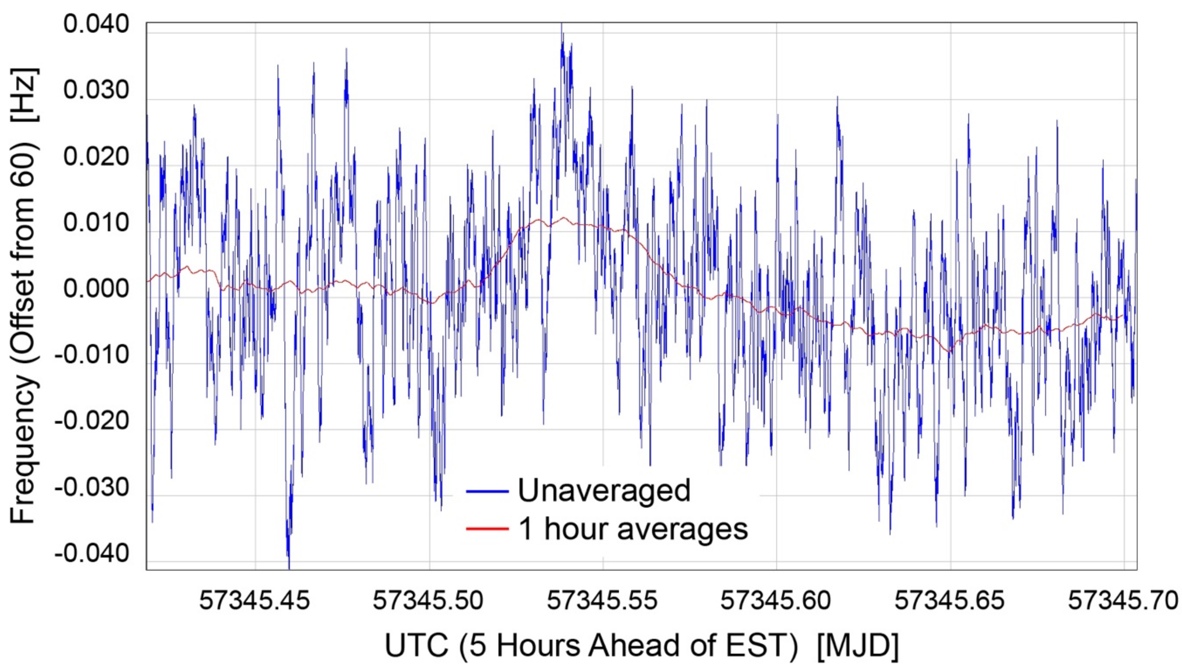

Figure 6. A frequency variation not associated with a recorded TEC. The time advanced > 4 seconds over this period.

In order to ensure the accuracy of our remaining analysis, we confine ourselves to the data since January 1, 2014. Figure 7 shows the cumulated time corrections of the TECs whose intentional insertion was confirmed. It shows that a clock reset for Daylight Saving Time (DST) in March 2016 would have been over 7 minutes off when Standard Time was re-implemented in November, unless it had been reset in the period. In many but not all sections of the U.S., such resets can also be forced a few times a year by power interruptions.

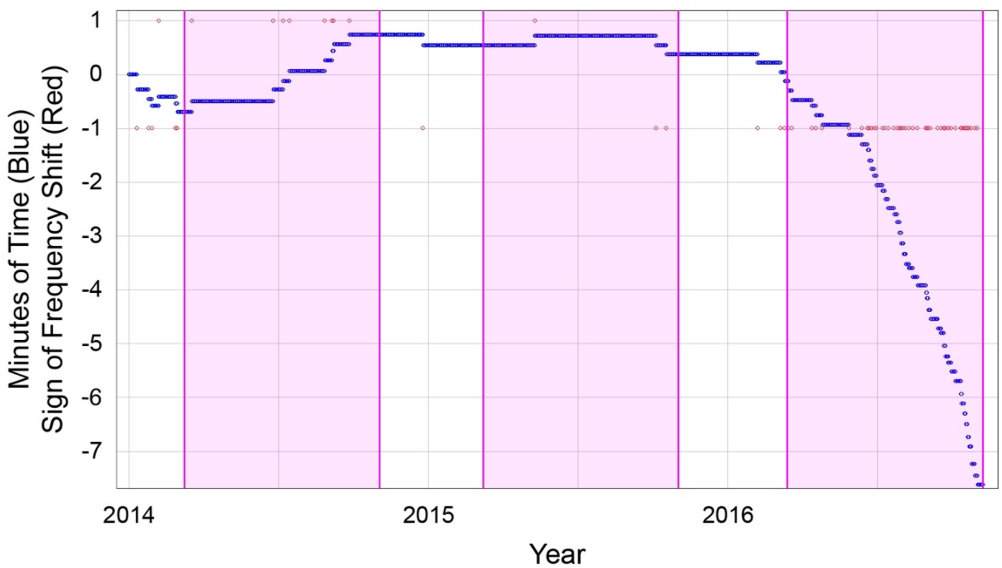

Figure 7. Cumulative effect of TECs. The large number and consistent sign of the corrections in the summer of 2016 imply that the power line frequency would have been slightly higher than 60 Hz most of the time. The shaded areas indicate periods of DST; presumably clocks dependent on the power line for time would be reset at the beginning and end of DST.

Figure 8 shows the effect of removing the TECs from real data, and Fig. 9 is the Allan Deviation of the uncorrected and TEC-removed data over the period of Fig. 8. As would be expected, the great improvement in long-term stabilities brought about by TECs also brings about a slight degradation of frequency stability on hourly to daily timescales.

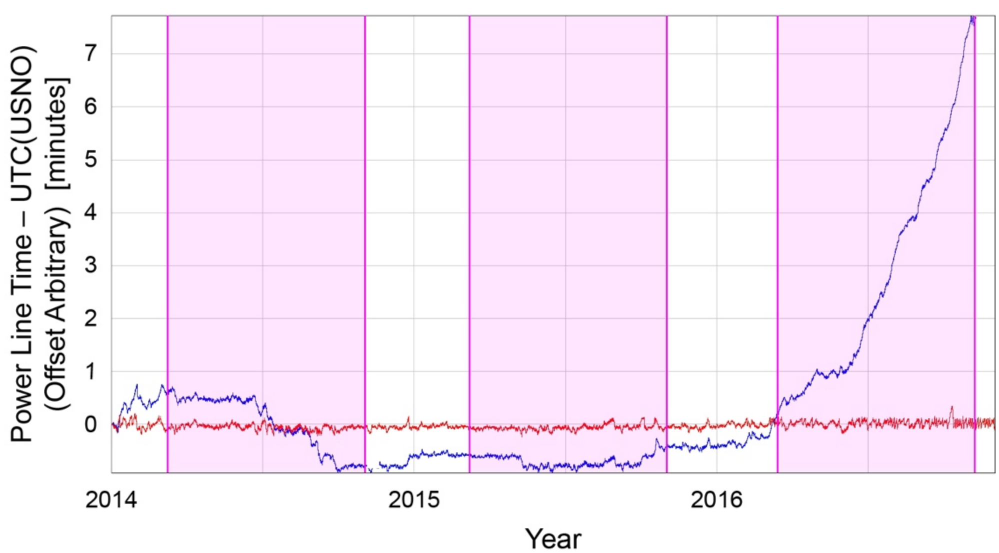

Figure 8. Power Line Time as observed (red) and on a *pro forma* basis without TECs (blue) by subtracting the actual TECs. The shaded areas indicate periods of Daylight Saving Time.

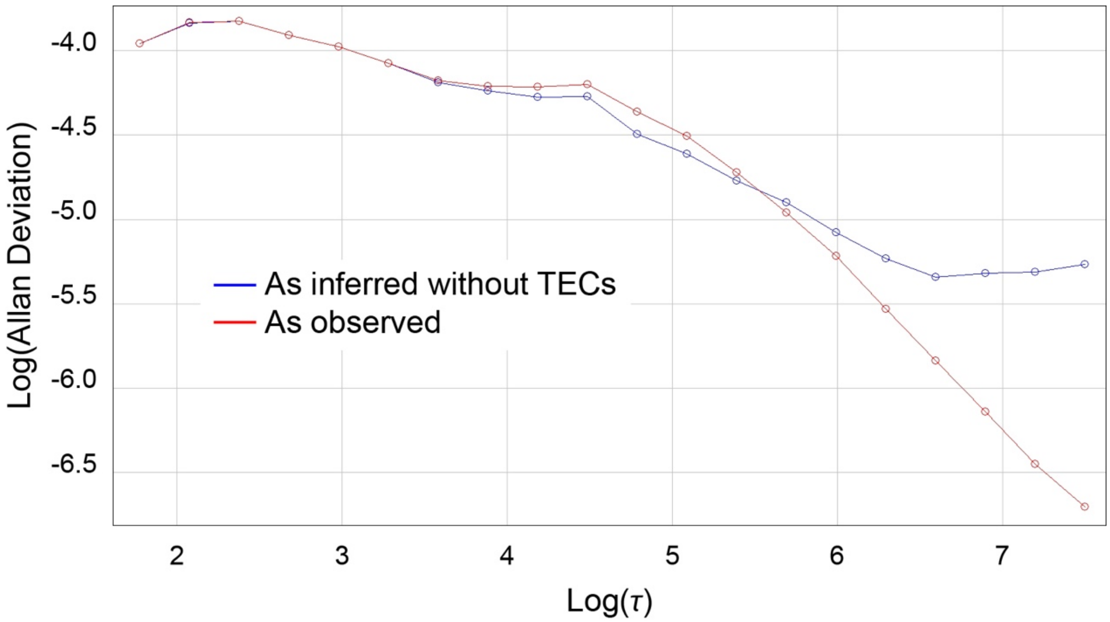

Figure 9. The Allan Deviation of Power Line time as observed, and as inferred without TECs.

EXTREMELY HYPOTHETICAL STEERING STRATEGIES

While it is unlikely that the power authorities would adopt any form of steering to replace the TECs, we have considered two families of steering strategies, without consideration of the practical implications for implementation. One family of strategies involves proportional steering, in which the frequency is routinely adjusted by the sum of a frequency gain times the frequency offset and a phase gain times the phase offset [33]. Another family of steering strategies, which we shall term "triggered" steering, is a generalization of the current practice on the Eastern Interconnection to act only when the time exceeds a certain trigger value. The frequency is then adjusted by a fixed amount (0.02 Hz) until the phase is brought back to a specified fraction of the trigger value.

In both cases, a model is needed in order to extract the phase and frequency from the raw data; this is a function of the jitter in the data. Using the TEC-removed dataset, it was found that a model which computes the frequency from the difference between each datum and one two minutes earlier was a good choice; therefore this section uses frequencies as determined by subtracting adjacent two-minute averages.

Figure 10 is the result of simulations to show the effect of increasing or decreasing the magnitude of the TEC by a power of 10 on a triggered steering strategy. TECs reduced to 0.002 Hz would result in only a 2.8 second time shift per day, which is not enough to keep up with the frequency variations observed last summer. However, the plots show little difference between TEC frequency offsets of 0.02 Hz and 0.2 Hz, and those two curves are similar to the actual data observed at the USNO (Fig. 4). Since the red curve (for TEC of 0.02 Hz) is an attempt to mimic the actual procedure that was followed, the difference between it and the observed data may be ascribed to the different measurement locations as well as the difference between a not-fully automated control system and the theoretically exact one of the model.

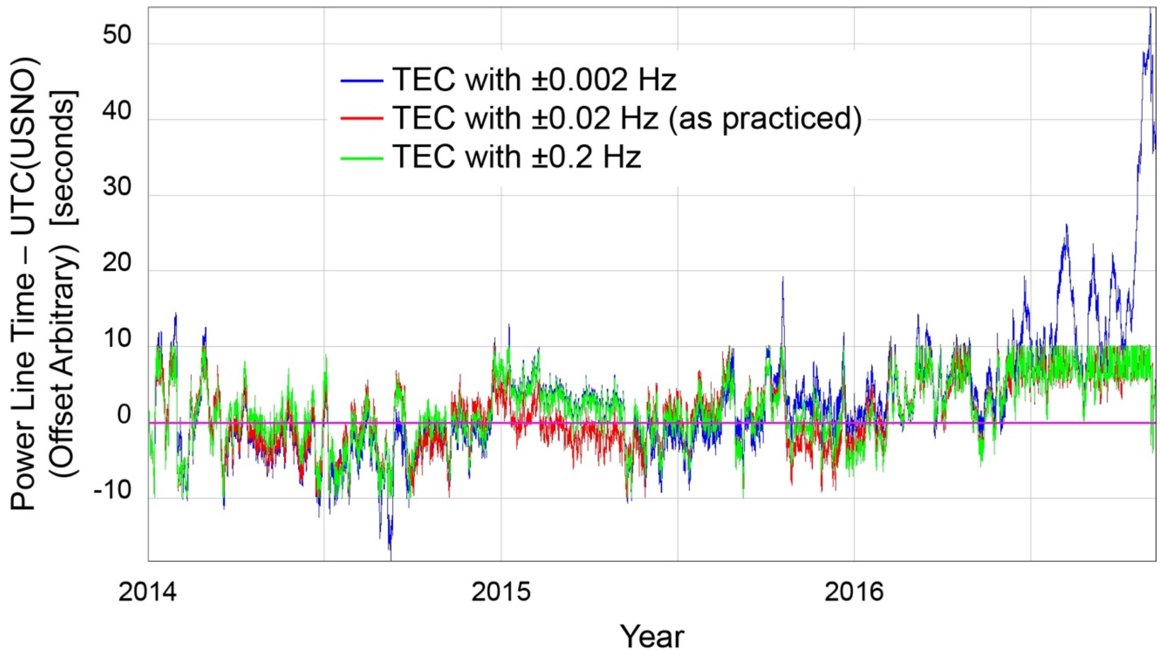

Figure 10. Simulations of Power Line Time with TECs practiced as currently (with 0.02 Hz offsets), with smaller frequency offsets (0.002 Hz), and with larger frequency offsets (0.2 Hz). The large variation in the blue curve in the last half of 2016 implies that the average frequency over that period (before TECs were applied) differed from 60 Hz by more than 0.002 Hz.

Figure 11 shows the effect of changing the threshold value for triggering a TEC, and Table 1 summarizes the associated TECs. Most of these TECs, of course, would have been in the summer of 2016.

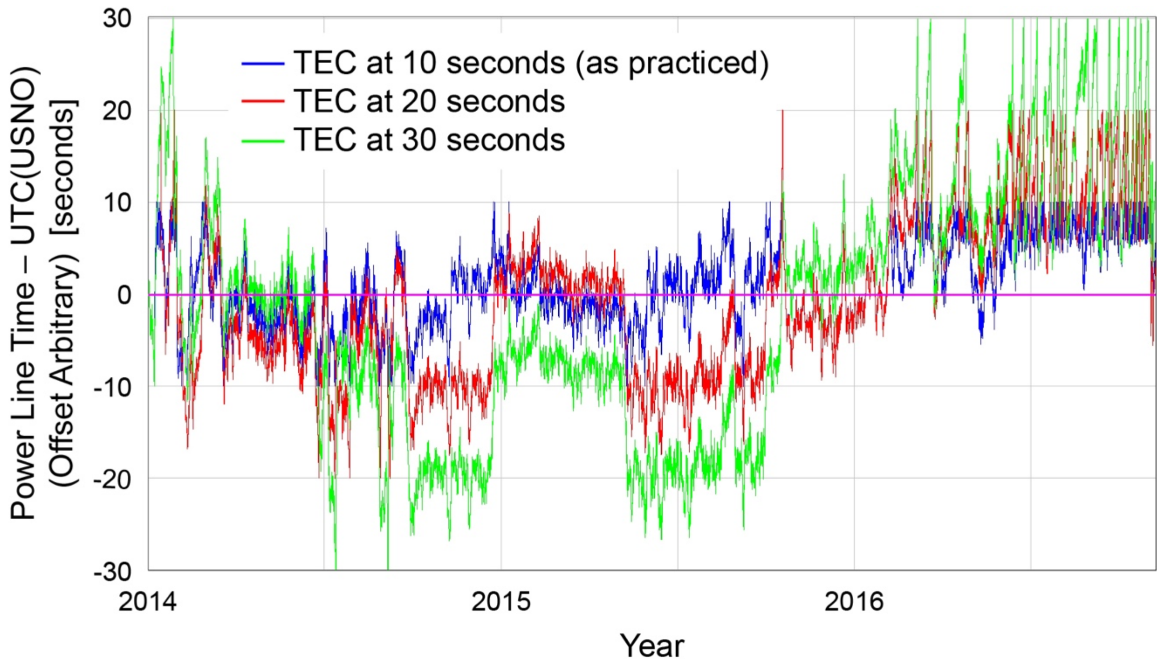

Figure 11. Simulation of Power Line Time if TECs were initiated when the time offset exceeded 10, 20, or 30 seconds.

Strength	Trigger	Termination	Duration	TEC-Hours
Hz	Seconds	Seconds	Hours	Hours × Hz
0.002	10	6	515.7	1.0
0.02	10	6	579.5	11.6
0.2	10	6	57.1	11.4
0.02	20	6	499.2	10.0
0.02	30	6	467.8	9.4
0.02	30	10	465.9	9.3

Table 1. Total duration of steering in simulations varying the strength of the TEC, or the offsets required to initiate or terminate a TEC event.

A proportional steering method can be characterized by a phase gain g_x and a frequency gain g_y. The frequency steer is given by:

$$\Delta f = g_x x + g_y y \quad , \tag{2}$$

where x is the offset in Power Line Time from UTC and y is its dimensionless frequency. By way of illustration, in the computer code used for this section, time deviation x was expressed in seconds and the frequency deviation y was expressed in units of seconds/day, as the deviation of the frequency from 60 Hz (divided by 60 Hz).

While the gains can be given any values, oscillatory behavior is minimized in a critically damped situation [33], which in our simple model reduces the number of free parameters to just one: the desired recovery time after a fluctuation or disturbance. As noted in the reference, the critically damped gains are given by:

$$g_x = \frac{1}{\Delta t}\left(1 - \mathrm{e}^{-\frac{\Delta t}{\mathrm{T_c}}}\right) \tag{3}$$

$$g_y = 2\sqrt{\Delta t g_x} - \Delta t g_x \quad , \tag{4}$$

where Δt is the time interval between data points, and $\mathrm{T_c}$ is the recovery time.

In Fig. 12 we compare the observed value of Power Line Time with a simulation in which 2 minute averages were steered in a critically damped situation with a time constant of one day. The subsequent figure is a histogram of the frequency steers called for by proportional steering with our approximate model for how the power grid actually behaved.

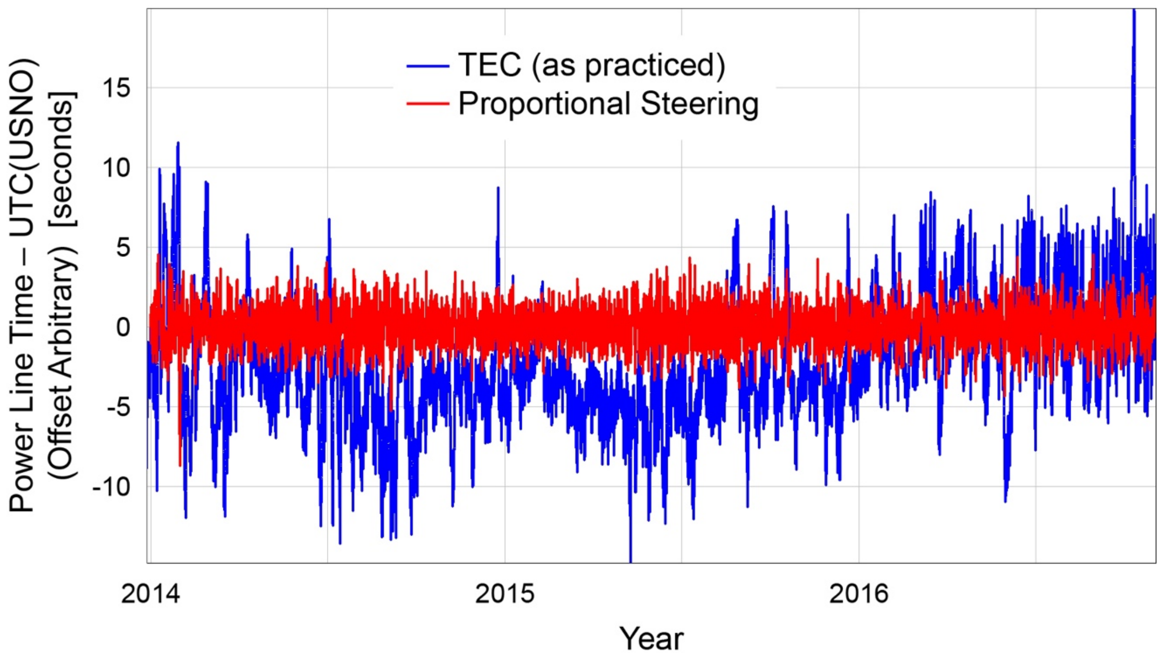

Figure 12. Comparison of a simulated proportional steering strategy (red) with a triggered strategy (blue)

As is evident in Fig. 13, the much larger number of proportional steers enables them to be much smaller in magnitude than the TECs, which appear only at +0.02 Hz and –0.02 Hz.

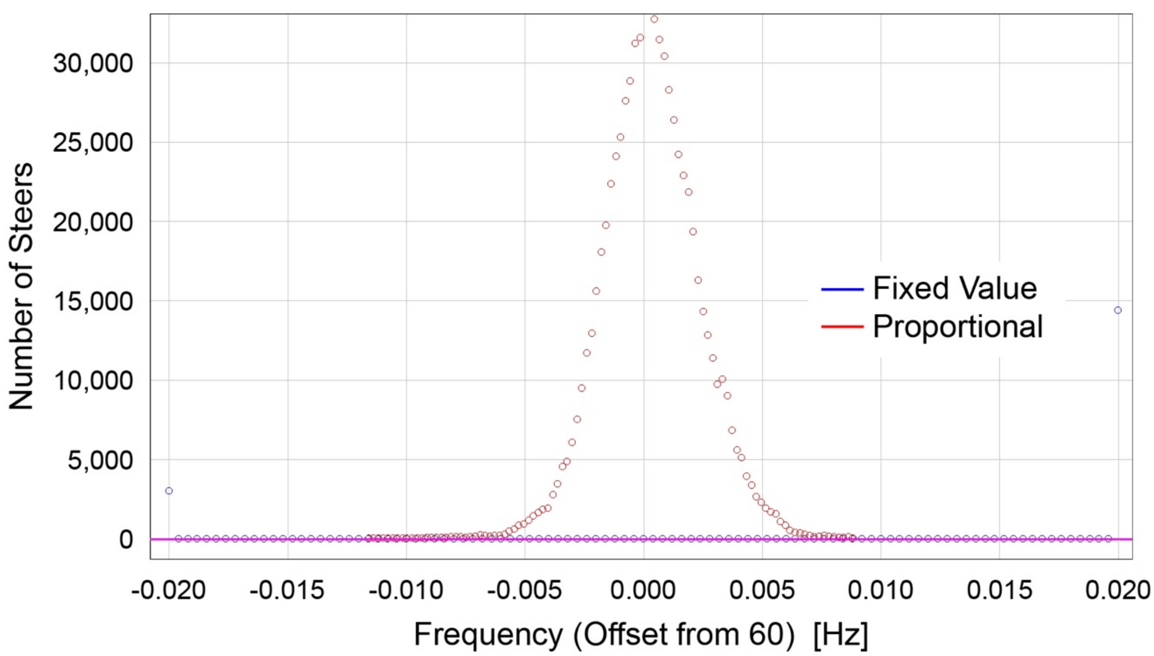

Figure 13. Histogram of steers of the proportional steering strategy (red) with a model of the current triggered system (blue).

ACKNOWLEDGMENTS

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DISCLAIMERS

The purpose of this paper is to inform about contemporaneous issues affecting time keeping and time dissemination. Any opinions, recommendations, findings, and conclusions do not necessarily reflect the views or policies of NIST, USNO, or the United States Government. Neither the National Institute of Standards and Technology (U.S. Department of Commerce) nor the U.S. Naval Observatory (U.S. Department of Defense) take any positions with respect to the merits of these issues before other Federal agencies and other decision-making bodies. Certain commercial equipment, products, and services are identified in this paper in order to describe the context adequately. Such identification is not intended to imply recommendation, endorsement, or criticism by NIST or USNO, nor is it intended to imply that the equipment, products, or service identified are or were necessarily the best available for the purpose.

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[10] A "Balancing Authority" is a subdivision of an Interconnection that is responsible for resource planning to ensure a real-time balance between generation and load within its area of responsibility. For a map showing the Interconnections and balancing authorities within the U.S., please see: http://www.eia.gov/todayinenergy/detail.php?id=27152

[11] NERC Standard *BAL-004-0 — Time Error Correction*; online at http://www.nerc.com/files/BAL-004-0.pdf

[12] The Western Interconnection also utilizes an automatic TEC system to reduce the number of manual TECs. It is governed by a separate standard, "WECC Standard *BAL-004-WECC-02 — Automatic Time Error Correction*; online at https://www.wecc.biz/Reliability/BAL-004-WECC-2%20From%20NERC%20site%209-26-2016.pdf

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