UNCERTAINTY IN THE MEASUREMENT OF THE ELECTRICAL NETWORK FREQUENCY

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This paper describes a qualification technique suitable for determining the uncertainty of Electrical Network Frequency (ENF) measurements obtained from a frequency counter performing the so-called "zero crossing" technique. The frequency counter was initially qualified using a 60-Hz sinusoid synthesized by a function generator. The internal clocks of the frequency counter and the function generator can be synchronized to an external rubidium-based master clock.

INTRODUCTION

There have been a number of investigations regarding fluctuations of frequency in the electrical power grid (also called the electrical network frequency, abbreviated ENF). This paper focuses on the technical procedures used to qualify measured ENF information. It also discusses the importance of a formal uncertainty analysis when archiving ENF data.

The operator of an electrical grid needs to maintain the network frequency within a specified tolerance; however, there will always be some degree of random fluctuation in the ENF. These fluctuations have been proposed as a "thumbprint" for use in forensic science investigations of digital audio recordings. The underlying premise is that the temporal pattern of deviations from the nominal grid frequency is unique over some historical time period. If a residual artifact from the network frequency were unintentionally recorded on a forensic specimen, the authenticity of the specimen could be verified by matching its unique ENF frequency-versus-time signature to an historical archive of ENF fluctuations.

Several investigators have employed a variety of techniques to measure and then report the archival ENF fluctuations. Grigoras described several methods including a short time fast Fourier transform (STFT) as well as measuring the time between zero crossings of the fundamental ENF. Cooper used a bridge rectifier to generate high frequency harmonics of the ENF. In this way, Cooper multiplied the ENF fundamental by 100 prior to analysis, thereby attaining improved FFT frequency resolution for the STFT. Sidhu employed a combination of a digital signal processor with a lookup table to rapidly compute the coefficients of a digital filter whose center frequency tracked that of the ENF fundamental every 1.4 milliseconds. For the most part, these investigators computed the ENF using analog to digital hardware whose internal clock is not traceable to a national frequency standard.

This paper describes a qualification technique suitable for determining the uncertainty of measurements obtained from a frequency counter performing the so-called "zero crossing" technique. The frequency counter was initially qualified using a 60-Hz sinusoid synthesized by a function generator. The internal clocks of the frequency counter and the function generator can be synchronized to an external rubidium-based master clock.

Each trial measurement comprised 256 seconds of a continuous 60-Hz sinusoidal test signal. The frequency counter measured 2560 samples of the test signal (i.e., a rate of 10 samples per second). At this sampling rate, the frequency counter measured one out of every 6.666 periods of the ENF. The arrays of measured test data typically had a "worst case" frequency deviation of ±50 parts per million (60.003 to 59.997 Hz). The typical computed standard deviation for each 2560-sample array was <1 part per million (0.00006 Hz).

DISCUSSION

A pair of charts is shown below. The left chart is a time plot of a 60-Hz sinusoidal signal as synthesized by a function generator using its
independent temperature-compensated time base. The sampled data are overlaid with a trend line to illustrate the capability of the qualified ENF instrumentation when measuring a low-drift, low-jitter sinusoidal signal. The data indicate that the mean frequency of the function generator signal is minus one ppm relative to the master rubidium clock that controls the frequency counter. In contrast, the chart on the right is a measurement of an ENF signal using the same pre-qualified instrumentation. The drift and jitter are an order of magnitude greater than the residual frequency deviations from the function generator.

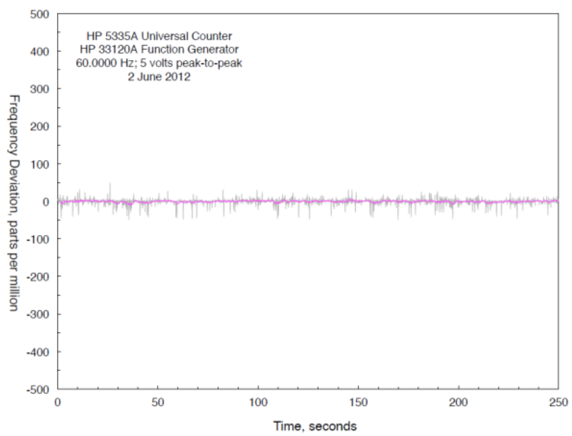

Figure 1. [Insert title]

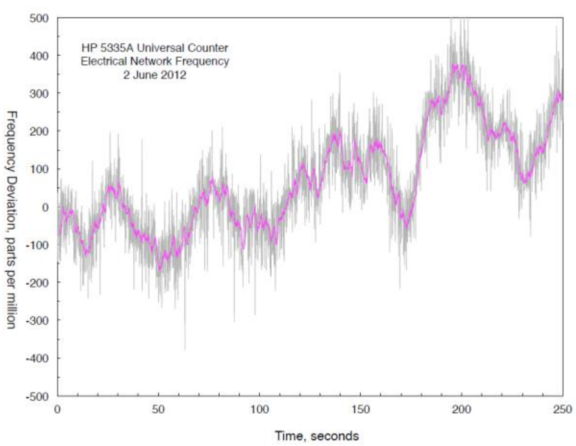

Figure 2. [Insert title]

The pre-qualified instrumentation was used to measure the ENF every five minutes during several sessions, each of which lasted 30 minutes. The pair of charts below illustrates the corresponding frequency deviations in the time domain. The sessions were measured 10 minutes apart. There appears to be some rapid frequency deviations occurring during these two sessions.

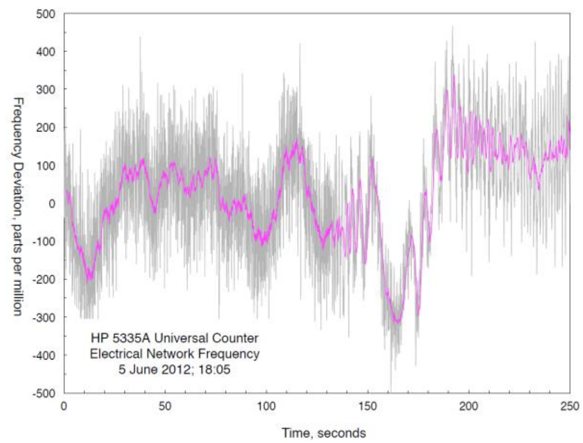

Figure 3. [Insert title]

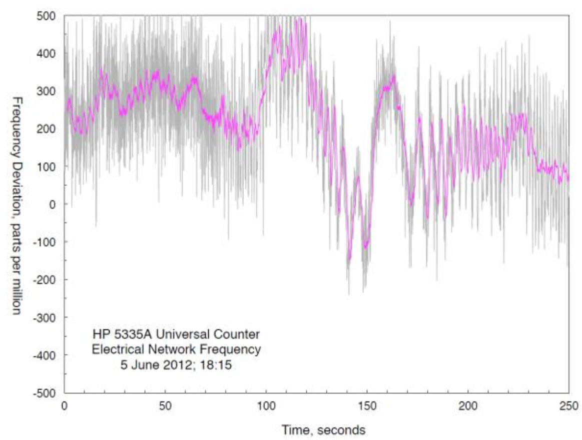

Figure 4. [Insert title]

These individual five-minute ENF sessions were collected as separate files. Each file was later processed by an FFT analyzer to obtain a power spectrum of its frequency deviations. This analysis technique is intended to reveal patterns in the drift and jitter of the ENF.

The two charts below illustrate spectra from these same two sessions. The deviation spectrum spans from zero to 12.5 hertz. On these charts, zero hertz represents the mean deviation of the ENF relative to

60 hertz. In this presentation, however, the sense of the mean ENF deviation is indeterminate since the spectrum displays both positive-going and negative-going deviations as positive frequency values. Above zero hertz, the spectrum consists of drift and jitter (low and high frequency deviations, respectively).

The peaks in the spectrum indicate that deviations from the ENF exhibit some periodicity. This periodicity characteristic is less obvious in most of the other ENF measurement sessions (not shown here).

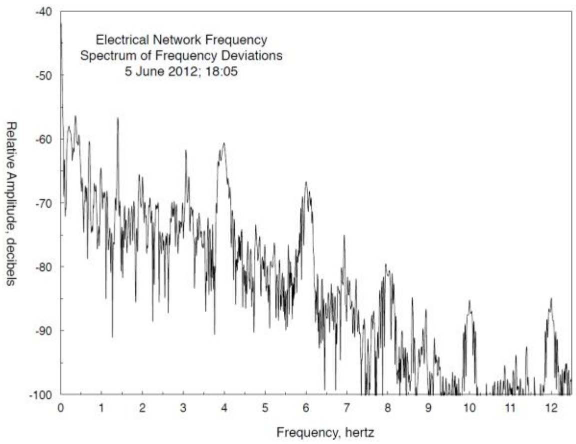

Figure 5. [Insert title]

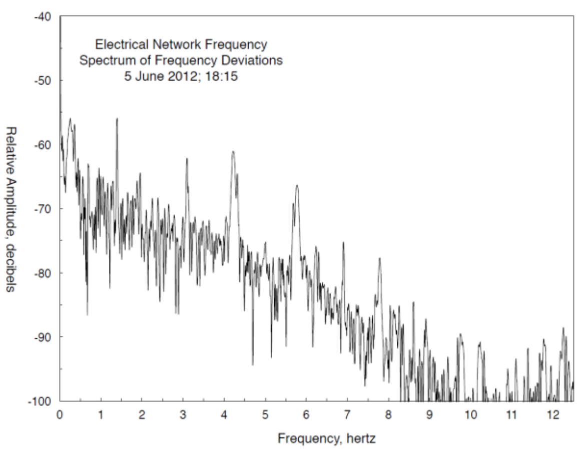

Figure 6. [Insert title]

CONCLUSIONS

In the field of metrology, it is important to qualify a measurement system with respect to traceable national standards. Measuring the ENF with non-qualified equipment might be sufficiently precise, however, the uncertainty of the resulting data are unverifiable. The uncertainty of the frequency-counting system described here has a "worst case" frequency deviation of ±50 parts per million. This qualified performance is significantly less than typical for the ENF.

As a guideline, the frequency stability of the ENF measurement system (i.e., both drift and jitter) should be at least an order of magnitude better than that of the ENF itself.