NIST Program for Traceable Power and Energy Measurements Under Non-Sinusoidal Waveform Conditions

G. N. Stenbakken, T. L. Nelson, B. C. Waltrip, and D. I. Bergman, *IEEE Members*

Abstract-- **In response to industry requests to have calibration services for distorted power instrumentation, NIST is developing a new sampling system to provide this service. This development effort is aimed at providing calibration of instruments that will make measurements in accordance with the IEEE Trial Use Standard 1459-2000 on power measurements in distorted and unbalanced conditions. The system will make use of several NIST developed instruments and sensors.**

Index Terms-- **Calibration systems, distorted power, international comparison, harmonic analysis, sampling system**

I. Introduction

The National Institute of Standards and Technology (NIST) has received several requests in recent years from instrument manufacturers wanting traceability of distorted power instrumentation. These requests are for traceability of both measuring equipment for and signal sources of distorted power. Most of these requests have been for calibrations at the traditional rms power signal levels of 120 V and 5 A. Several factors in the electrical utility field are driving these requests. First, much research has shown that some measurement equipment give significant errors when measuring distorted signals [1]. A second factor is the interest in including harmonic power in electric energy billing to account for the cost of delivering energy to nonlinear loads [2]. To add this factor to the billing algorithm requires an accurate measure of the amount of distorted power introduced into the power network. Also, the increase in distributed power generators requires the monitoring of the quality of the power being supplied to the network. All these factors point to the need for instrumentation that can accurately measure generally accepted quantities for distorted power, specifically, quantities such as those defined in the IEEE Trial Use Standard 1459-2000 Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions [3,4].

II. Distorted Power Calibration System

In response to these requests NIST has begun a program to develop calibration services for distorted power and energy. The following compares characteristics of the present calibrations services with what will be added for the new distorted power calibration services.

These new services will make power and energy calibrations over a broader frequency range than those services presently offered. NIST now offers calibrations at power frequencies of 50 Hz or 60 Hz and calibrations at 400 Hz. Although calibrations can be supplied at other frequencies, these tests are not part of the NIST routine calibration services. The new services will cover all frequencies from 50 Hz to 3000 Hz. The present services only provide calibrations using a single sinusoidal frequency at a time for both the voltage and current signals. The new service will work with signals that have many harmonics in both the voltage and current waveforms. The new calibration reports will provide information for voltage and current signals at many harmonics. The present services only calibrate power and energy measurement instrumentation. The new services will include calibration of power sources. More details on the calibration services to be offered are given below.

III. Description of Proposed Calibration System

A new system is being assembled to perform these calibrations. It makes use of several NIST-developed measurement instruments and signal sources. The measurement system will use the sampling comparator system and the NIST Wideband Sampling Voltmeter [5]. The sampling comparator probes are low noise sampling probes that have a 3 dB bandwidth of 20 MHz [6]. The frequency response of these probes is calibrated in the time domain by using the comparator to measure a well-characterized step-like signal. These probes will be used in both the voltage and current channels. The voltage channel will use a voltage divider to attenuate the 120 V rms signal to approximately 2 V rms. The current of about 5 A rms will be converted to a voltage with a 0.1 ohm shunt recently developed at NIST. This shunt will be temperature corrected by monitoring its temperature during the calibration. The design of the shunt allows for calculation of its phase shift.

The power source signals will make use of two commercial 16-bit arbitrary waveform generators. These generators will produce signals for the voltage and current waveforms. A high voltage amplifier will be used to boost the voltage channel signal to 120 V rms. A NIST designed transconductance

The authors are with the Electricity Division, EEEL, National Institute of Standards and Technology, Technology Administration, U.S. Department of Commerce, Gaithersburg, MD 20899. (email: gerard.stenbakken@nist.gov)

0-7803-7990-X/03/$17.00C2003 IEEE

amplifier will be used to convert the current channel signal to a 5 A rms current [7,8].

The traceability of the calibration will be maintained through the measurement instruments. The current shunt, voltage attenuator, and sampling comparator probes will receive periodic calibrations to basic standards. When calibrating measurement instruments, the output of the power sources will be monitored with the measurement instrumentation. The development of this system is part of a program to develop a high accuracy sampling measurement system for power and energy.

The new calibration services will include calibrations for both power sources and measurement equipment. The sources will be calibrated for distorted voltage and current signals from the fundamental power frequency (50 Hz to 60 Hz) to the 50th harmonic. Standard distorted waveforms will be used to calibrate the measurement equipment. The NIST measurement capability will be limited initially to a total rms voltage and current of 120 V and 5 A.

IV. International Comparison

The international community must have confidence in these calibrations. Thus, a pilot project to work on developing a key comparison of distorted power has been approved by the Consultative Committee for Electricity and Magnetism (CCEM) of the Bureau international des poids et measures (BIPM). This pilot project is making use of a portable distorted power source developed by the National Research Council (NRC) of Canada [9]. This source provides standard distorted waveform voltage and current signals. The international participants will measure the signal pairs and report the amplitudes of the voltage and current harmonics from the fundamental through to the 50th. The phase of each harmonic will be determined relative to the voltage fundamental. The results of this project will help each participant in the development of its calibration systems. Currently, four countries are taking part in this project being lead by NRC.

V. Conclusion

NIST is developing new calibration services to provide traceability of distorted power and energy measurement and generation instrumentation to basic standards. This system will be compared to similar systems in other countries in an international comparison. Development of the system is underway and will make use of instruments developed previously at NIST for calibrations of ac voltage and current meters and sources.

VI. References

[1] R. Arseneau, "Calibration system for power quality instrumentation," in *Proc. 2002 IEEE Power Engineering Society Winter Meeting*, vol. 2, pp. 1437-1440.

[2] A. McEachern, W. M. Grady, W. A. Moncrief, G. T. Heydt, and M. McGranaghan, "Revenue and harmonics: an evaluation of some proposed rate structures," *IEEE Trans. Power Delivery*, vol. 10, pp. 474-482, Jan. 1995.

[3] IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions, IEEE Trial-Use Std 1459-2000.

[4] E. W. Gunther, and M. F. McGranaghan, "Power measurements in distorted and unbalanced conditions - an overview of IEEE Trial-Use Standard 1459-2000," in *Proc. 2002 IEEE Power Engineering Society Winter Meeting*,, vol. 2, , pp. 930-934.

[5] J. P. Deyst, O. B. Laug, T.M. Souders, and B. C. Waltrip, "A wideband sampling voltmeter," *IEEE Trans. Instrumentation and Measurement*, vol. 46, pp. 947-953, Aug. 1997.

[6] D. I. Bergman, and B. C. Waltrip, "A low noise latching comparator probe for waveform sampling applications," *Proc. 19th IEEE Instrumentation and Measurement Technology Conference, IMTC/2002*, vol. 1, pp. 309-314.

[7] O. B. Laug, "A 100 A, 100 kHz transconductance amplifier," *IEEE Trans. Instrumentation and Measurement*, vol. 45, pp. 440–444, Apr. 1996.

[8] O. B. Laug, "A high-current very wide-band transconductance amplifier," *IEEE Trans. Instrumentation and Measurement*, vol. 39, pp. 42-47, Apr. 1989.

[9] R. Arseneau, M. E. Sutherland, S. Svensson, and J. J. Zelle, "Comparison of nonsinusoidal calibration systems at NRC Canada and SP Sweden," *IEEE Trans. Instrumentation and Measurement*, vol. 50, pp. 275-277, Apr. 2001.

VII. Biographies

Gerard N. Stenbakken (M '71) was born in Minnesota, U.S.A. on March 17, 1941. He received a B. of Physics from the University of Minnesota, Minneapolis, MN, a M.S. in Physics, and a M.S. in EE from the University of Maryland, College Park, MD.

He started working at Vitro Laboratories in 1963 and moved to the National Bureau of Standards (now the National Institute of Standards and Technology) in 1969. His areas of interest include semiconductor resistivity measurements, sampling metrology, testing strategies, and magnetic field modeling.

Thomas L. Nelson (M'88), is an Electrical Engineer in the Electricity Division at the National Institute of Standards and Technology, Gaithersburg, MD, where he performs measurements and develops standards for electric power and energy. He is active in three international comparisons of electric power. He serves on several IEEE committees, and is Chairman of C-12, the American National Standard Code for Electricity Metering.

Bryan C. Waltrip (M'87) received the B.S. degree in Electrical Engineering and Computer Science from the University of Colorado, Boulder, CO and M.S. degree in Electrical Engineering from The Johns Hopkins University, Baltimore, MD.

Since 1984, he has been employed as an Electronics Engineer at the National Institute of Standards and Technology (NIST) Electricity Division, Gaithersburg, MD, where he is currently working in the area of precision measurements for ac voltage, ratio, phase, power, and impedance.

David I. Bergman (M '99) received the BSEE degree from the University of Maryland, College Park and the M.S. degree in electrical engineering from the Johns Hopkins University, Baltimore, MD in 1988 and 1994 respectively. From 1988 to 1999 he worked at the National Aeronautics and Space Administration (NASA).

Since 1999, he has been an Electronics Engineer with the Electricity Division, National Institute of Standards and Technology, Gaithersburg, MD where he is currently working to develop precision sampling instrumentation and improved methods for testing complex electronic devices.