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A Comparison Between the NIST PVJS-Based Power Standard and the NRC Current-Comparator-Based Power Standard

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Abstract

The results of a comparison of active/reactive power meter calibrations between the National Institute of Standards and Technology (NIST) and the National Research Council (NRC) are presented. The comparison was implemented using a transfer standard consisting of a highly stable commercial sampling-type power/energy meter. The measurements were made at 120 V, 5 A, 50 Hz and 60 Hz, at power factors of 1.0, 0.5 lead and lag, and 0.0 lead and lag. The results of the comparison indicate agreement to within the stated uncertainties of the participants.[a]

1. Introduction

The standard of alternating current power is usually obtained using a system or device which enables the time averaged product of the alternating voltage and current to be referenced back to the direct current standards of voltage and resistance. Various laboratories achieve this goal by different means, and it is useful in the interests of improving and maintaining the accuracy of such standards to make comparisons between these systems whenever suitable opportunities arise. NIST has developed a new and more accurate power standard based on a programmable Josephson voltage standard (PJVS) [1], while NRC has developed an improved current-comparator-based power standard [2].

The comparisons are implemented by means of a transfer standard which may be calibrated under more or less identical conditions, and the results may then be compared.

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Comparisons are frequently stimulated by the announcement of a more accurate and stable transfer device. Such a new transfer device has been introduced commercially and is based on a specially designed integrating analog-to-digital signal converter. The stability of this device has been enhanced by disabling the auto-ranging functions of its internal voltage and current transducers; so that only voltage signals of 120 V RMS and current signals of 5 A RMS may be measured. A device of this type has been acquired by NIST and its performance has been evaluated and appears to have both stability and repeatability of approximately 2 μW/VA over the time frame necessary to complete the comparison measurements. Under normal environmental condition of around 23.0 °C, the device is specified as having a temperature coefficient of about 3 ppm/°C. This transfer device has been used in this comparison of power standards between NIST and NRC. The rationale and format for the comparison were given in [3], with additional details and measurement results reported here.

2. NIST and NRC Power Standards

2.1 NIST Power Standard

The NIST power standard shown in Fig. 1 is based on the recent development of a system for the generation of 120 V, 5 A, sinusoidal active and reactive power over the 50 Hz to 400 Hz frequency range [1]. The system relates the amplitudes and phases of the voltage and current waveforms of the generated power to a PJVS [4] using a differential sampling technique. The system also employs a voltage amplifier that performs self-calibration and correction of gain and phase errors. The total estimated combined uncertainties of the Type A and Type B uncertainties of the reactive and active power applied to a meter under test (MUT) of the NIST system are given by U_{Qa} and U_{Pa}, respectively, where U_{Qa} is not more than 2.0 μvar/VA and U_{Pa} is not more than 2.0 μW/VA (k=1) at 120 V, 5 A, 50 Hz-60 Hz [1].

2.2 NRC Power Standard

The NRC power standard is based on an improved current comparator power bridge. In the NRC power bridge, reference currents proportional to the test voltage are compared to the test current using a current comparator. At balance, active power is derived from the ac voltage, the impedance of standards used to generate the reference currents, and the ratio of the current comparator. The known measured errors of these components can be accounted for, leaving only the measurement uncertainties of the calibration of these components. Due to the excellent stability and repeatability characteristics of the bridge components, the resulting Type A uncertainties of these components are usually about 0.1 x 10^{-6} or less. Therefore, the resulting total estimated combined uncertainties, which encompass the Type A and Type B uncertainties, are determined primarily by the Type B uncertainties of the calibration methods. For the NRC system, U_{Qa} is not more than 2.5 µvar/VA and U_{Pa} is not more than 2.5 µW/VA (k=1) at 120 V, 5 A, 50 Hz-60 Hz [2].

3. Measurement Results

Table I. Reactive Power Calibration Results, µvar/VA

Test Frequency (Hertz)	Applied Voltage (Volts)	Applied Current (Amperes)	Phase Angle (degrees)	NIST	NIST U_{Qcal} (k=1)	NRC	NRC U_{Qcal} (k=1)	NIST-NRC	U_{Qd} (k=1)
50	120	5	-90	3.5	2.3	6.3	3.1	-2.8	3.9
50	120	5	-60	1.9	2.5	5.9	3.0	-4.0	3.9
50	120	5	+60	-17.0	2.2	-17.2	2.7	+0.2	3.5
50	120	5	+90	-19.8	2.4	-19.3	2.9	-0.5	3.8
60	120	5	-90	3.4	2.5	3.5	3.7	-0.1	4.5
60	120	5	-60	1.4	2.4	2.9	2.6	-1.5	3.5
60	120	5	+60	-16.9	2.1	-18.2	5.0	+1.3	5.5
60	120	5	+90	-18.1	2.3	-18.7	3.6	+0.6	4.3

Table II. Active Power Calibration Results, µW/VA

Test Frequency (Hertz)	Applied Voltage (Volts)	Applied Current (Amperes)	Phase Angle (degrees)	NIST	NIST U_{Pcal} (k=1)	NRC	NRC U_{Pcal} (k=1)	NIST-NRC	U_{Pd} (k=1)
50	120	5	-60	3.7	2.0	3.4	2.7	+0.3	3.4
50	120	5	0	4.1	2.4	3.7	2.9	+0.4	3.8
50	120	5	+60	-0.5	2.4	1.3	2.7	-1.8	3.6
60	120	5	-60	7.5	2.1	10.6	4.4	-3.1	4.9
60	120	5	0	3.8	2.3	4.5	3.6	-0.7	4.2
60	120	5	+60	-3.5	2.3	-5	3.4	+1.5	4.1

The results of the comparison between the NIST and NRC power standards are given in Table I, for reactive power, and Table II, for active power. Table I and Table II include values for the total estimated combined uncertainty (k=1) of the reactive power calibration results, U_{Qcal}, and active power calibration results, U_{Pcal}, for each laboratory. For each test point and for each laboratory, U_{Qcal} and U_{Pcal} are computed using

$$U_{Qcal} = \sqrt{U_{Qa}^2 + \sigma_Q^2} \text{ and } U_{Pcal} = \sqrt{U_{Pa}^2 + \sigma_P^2} \quad ,$$

where σ_Q^2 is the variance of the reactive power MUT measurements and σ_P^2 is the variance of the active power MUT measurements.

At NIST, the calibration result for each test point is the mean of at least eight MUT measurements made over a period of at least seven days. At NRC, the calibration result for each test point is the mean of six measurements over a period of 6 days. The transfer device was measured at NIST both before and after measurements at NRC. The measurements at NIST were performed during the time period of October 20 through 27, 2011 and February 25 through March 7, 2012. The measurements at NRC were performed during the time period of January 9 through 20, 2012. The environmental conditions at NIST were 23.0°C ± 0.3°C, relative humidity of 25% ± 10%, and at NRC they were 23°C ± 1°C, relative humidity of 25% ± 15%.

The observed differences between the calibration results determined at NIST and NRC are given in Tables I-II in the NIST-NRC column and lie within the stated (k=1) uncertainty bounds of the two systems.

An estimate for the combined uncertainty (k=1) of the difference between the reactive power calibration results of NIST and NRC, U_{Qd}, is given in Table I. A similar estimate for active power, U_{Pd}, is given in Table II. U_{Qd} and U_{Pd} are computed using

$$U_{Qd} = \sqrt{U_{Qcal}^2(NIST) + U_{Qcal}^2(NRC)} \text{ and } U_{Pd} = \sqrt{U_{Pcal}^2(NIST) + U_{Pcal}^2(NRC)} \quad .$$

The plots of the individual measurements over the October, 2011 to March, 2012 time period for several test points are given in Figs. 3-6. The plots were chosen to illustrate the individual measurement trends corresponding to test points with the smallest and largest U_{Qd} and U_{Pd} values from each of the reactive and active power test point spaces in order to show the best and worst case comparison results, respectively. The spread of day to day variation of the individual measurements over the period of measurements at NRC was found to be about 6 x 10^{-6}, somewhat larger as compared to that of the NIST variation of about 2 x 10^{-6} and about 4 x 10^{-6} before and after the transfer device was shipped to NRC, respectively. This day to day variation, both at NRC and NIST, was most likely due to the combined effects of temperature

(3 ppm/°C) and stability/repeatability characteristics (± 2 μW/VA) of the transfer standard. At NRC the room temperature variation was ± 1 °C, while that at NIST was ± 0.3 °C. Depending on the temperature controller, the worst case temperature variation at NRC and NIST could be 2 °C and 0.6 °C, respectively. This could possibly be the reason why the day to day variations of the measurement results at NRC were about 3 times higher than those at NIST. The increase of the variations at NIST of about 2×10^{-6} to about 4×10^{-6} from before and after the transfer device was shipped to NRC, respectively, could well be due to an additional transportation effect. A longer term study of the transfer device is planned, with additional comparisons between the NIST and NRC systems.

4. Conclusion

The results of a comparison between the NIST PJVS-referenced power standard and the NRC improved current-comparator-based power standard at 120 V, 5 A, 50 Hz and 60 Hz indicate that the NRC and NIST measurement systems are in agreement within the stated (k=1) uncertainty bounds of the two systems.

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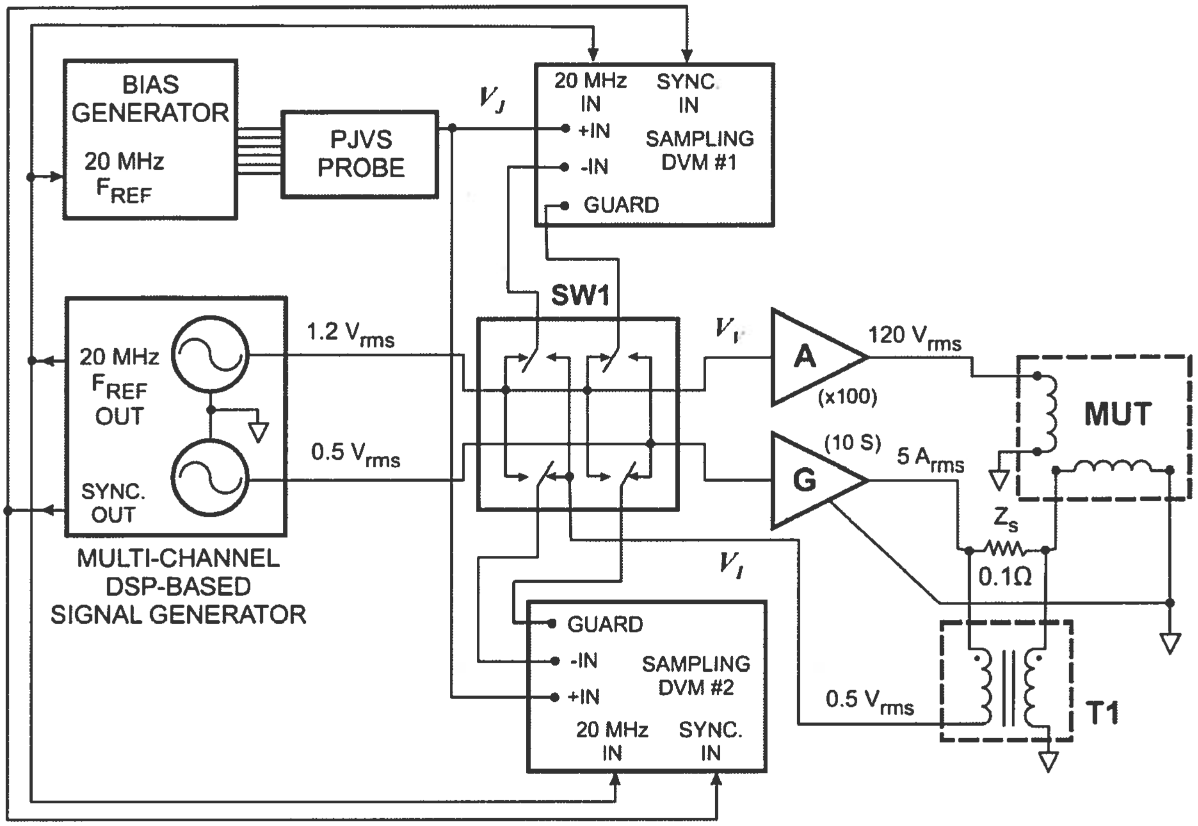

Fig. 1. Simplified diagram of the NIST power standard.

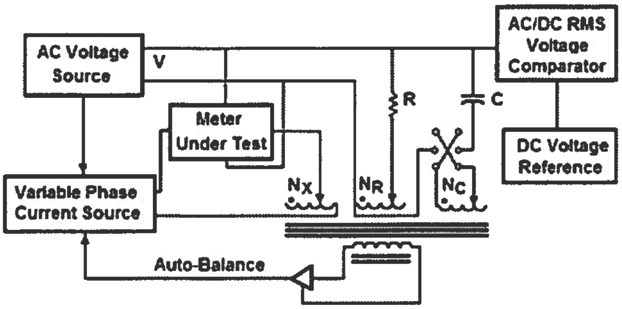

Fig. 2. Simplified diagram of the NRC power standard.

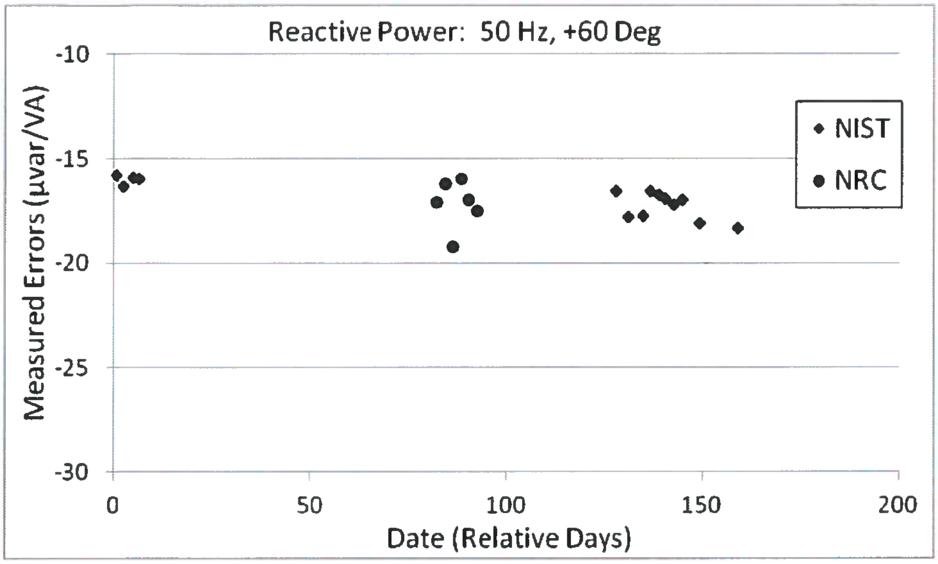

Fig. 3. Best case reactive power comparison results: 50 Hz, +60 degrees.

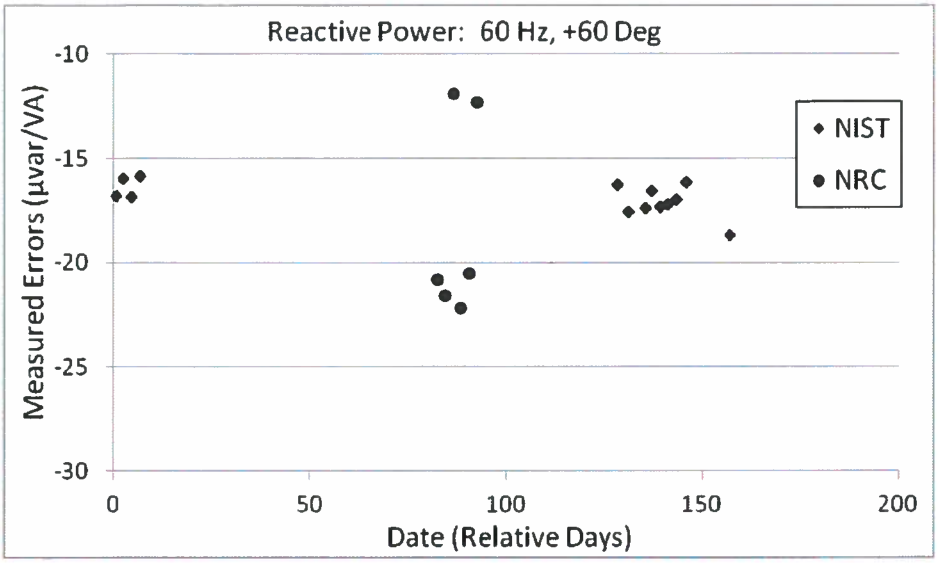

Fig. 4. Worst case reactive power comparison results: 60 Hz, +60 degrees.

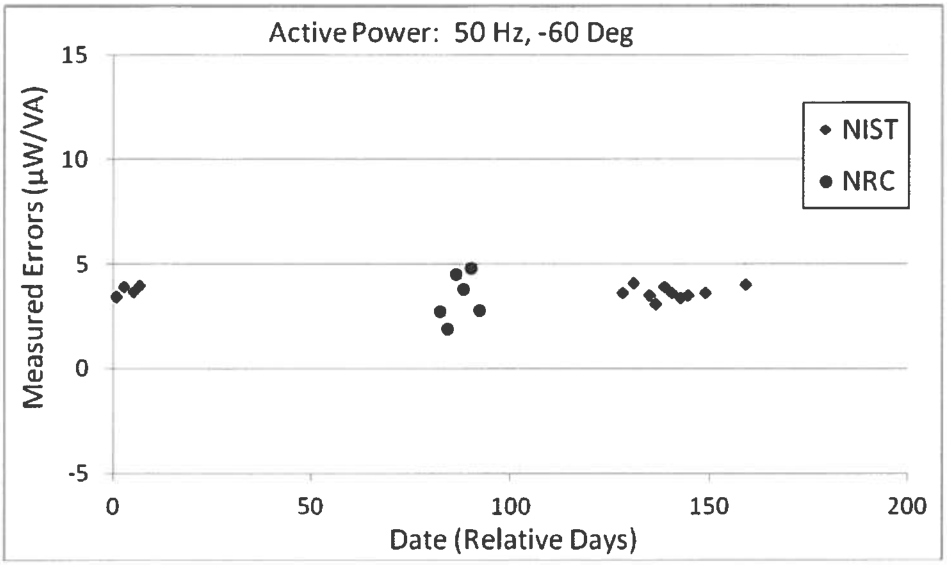

Fig. 5. Best case active power comparison results: 50 Hz, -60 degrees.

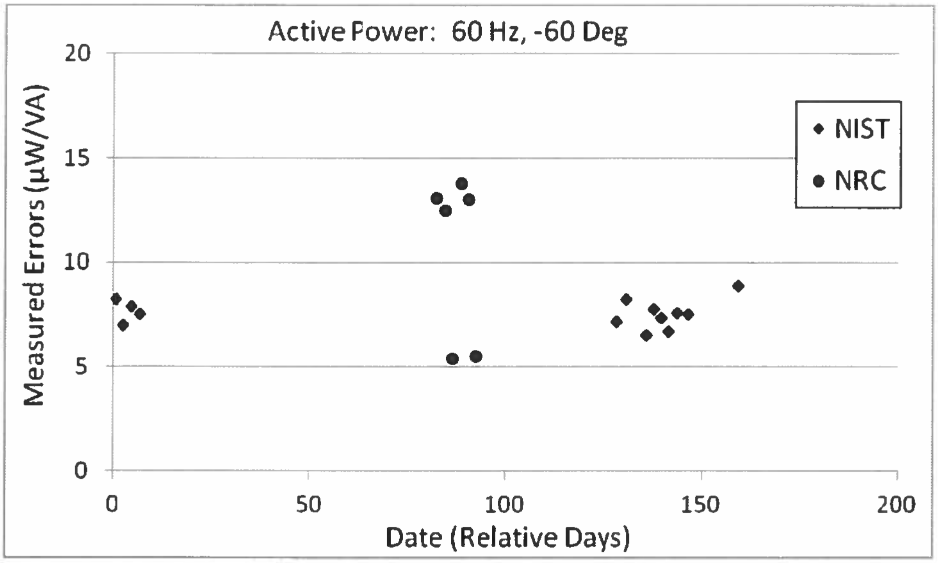

Fig. 6. Worst case active power comparison results: 60 Hz, -60 degrees.