DC & Low Frequency Measurements
Power-Systems Related Measurements

Watt Transfer Standard

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Abstract—**The use of a time-division multiplier power meter as a watt transfer standard between the National Institute of Standards and Technology (NIST) and an industry standards laboratory is described. Measurements of power at 120 and 240 V, 5 A, 50 and 62 Hz, and at power factors of unity and zero lagging are described. After the unit of power was transferred to the industrial laboratory, a comparison of the laboratory and NIST calibrations indicated an agreement to within 14 parts per million (ppm). Measurements at NIST to assess long-term stability (one year) indicated differences between two power meters of the type being discussed was not in excess of 11 ppm.**

I. Introduction

CONSUMERS, suppliers, and government regulators of electrical energy are paying increasing attention to cost. One of the consequences of this attention is the development and testing of more accurate meters for alternating current power and energy measurements. Another is the development of more efficient distribution equipment including transformers and reactors. Commercial revenue meters having specified uncertainties of 0.1% are now being advertised. The gradual replacement of the 1–2% induction meter by its more accurate solid-state counterpart is beginning. In order to evaluate the performance of these meters, transformers, and reactors, accurate power measurements are required. There is a growing need to establish the unit of power in industrial standards laboratories with an uncertainty suitable for measuring such performance, i.e., to better than 100 ppm.

An accurate method of measuring alternating current power uses a current-comparator power bridge which relates the power to the quantities of voltage and resistance. The standardization may be accomplished with respect to the national standards by well-known methods [1]. However, the use of such special power bridges requires skill, is time consuming, and is usually done only at national laboratories. The accurate calibration of these new alternating current wattmeters and testing of low-loss power distribution components can be greatly simplified with the use of such wattmeters. The calibration of these wattmeters, or watt converters (i.e., a device producing a dc voltage output proportional to the ac power input) can be traced easily to national standards.

The design of such a wattmeter was undertaken at the Institut Mihailo Pupin, Belgrade, Yugoslavia, and was described at the Conference on Precision Electromagnetic Measurements in 1984 [2]. This type of meter was used in 1987 for an international comparison of power standards to verify that the alternating-current power standards of Canada, the Federal Republic of Germany, the Institut Mihailo Pupin, and the United States agreed within 25 ppm [3].

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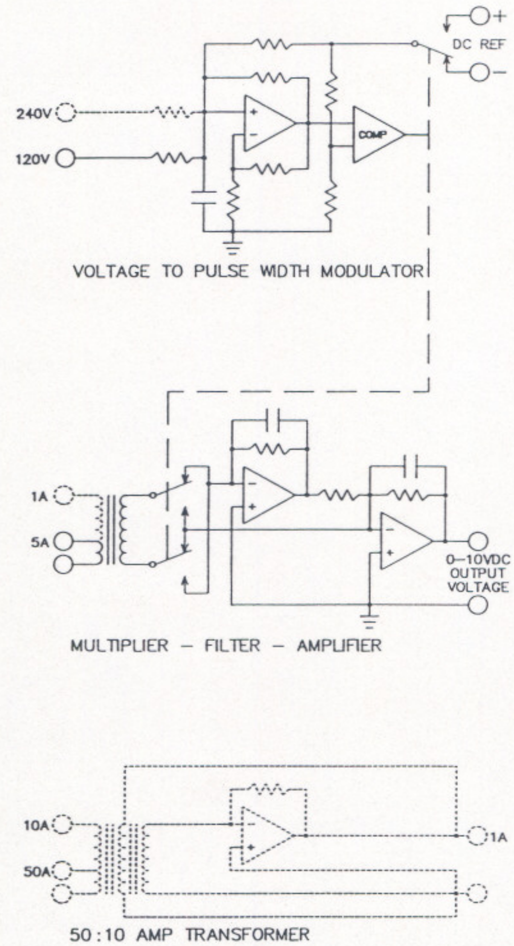

Fig. 1. Precision wattmeter.

The wattmeter described in [2] is suitable for measurements at 120 V and 5 A ac. The extension of this device for more universal purposes required provisions for other voltages and currents. These features were incorporated in the design by adding a 240-V ac input, and separate 1, 10, and 50-A ac inputs, as shown in Fig. 1. The additions are shown by the dotted portions of the figure. A scaling resistor was also added to the "voltage-to-pulsewidth modulator" input circuit. An additional 1-A winding was added to the input current transformer. Finally, a separate 50:10:1 precision current transformer was added.

Using the ac input ranges of 120 V and 5 A, the conversion constant is 10-V dc output per 600 W ac input (active) power. For the 240-V ac range and 5 A, the constant is 10 V dc output per 1200 W, and so forth. An accurate $7\frac{1}{2}$-digit voltmeter can be used to read the dc output voltage.

This paper describes experiments demonstrating that this type of wattmeter can be used to transfer the unit of power accurately

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from a national laboratory to an industrial standards laboratory without the need for specialized equipment or knowledge.

II. Procedure

In the experiment two wattmeters were used. The objects of the experiment were to show that the meter is stable and also that the calibration can be transferred from one meter to another meter with ease. The first meter was sent to NIST for testing in September 1988. NIST reported corrections to the conversion constant at 120 V, 5 A; 240 V, 5 A; 50 and 62 Hz, and at unity and zero power factors lagging. This meter was used in January 1989 with its corrections in an industrial standards laboratory to determine corrections to the conversion constant of the second wattmeter. The second wattmeter was then sent to NIST for determination of the corrections to its conversion constant with respect to the national standards. The difference between the conversion constant as determined at the industrial standards laboratory and at NIST is a measure of the stability of the wattmeter and of its ability to be used as a transportable standard. The elapsed time from the initial test of the first meter to the last test of the second meter was 9 months.

The procedures for transferring the calibration from a reference wattmeter to a second uncalibrated wattmeter are simple. A stable source of ac voltage and current with adjustable power factor is applied simultaneously to the voltage and current inputs of the 2-W converters. A digital voltmeter is used to measure the two wattmeter dc voltage outputs. The arrangement is shown in Fig. 2. The difference between the two dc output voltages is corrected for the calibration of the standardized meter and the result is the correction to the conversion factor of the second meter.

Using the source referred to above, the dc voltage outputs of the wattmeters have a short-term stability of a few parts per million over a 20 min interval. The digital voltmeter averaging feature was used so that each measurement was the average of 10 readings at 3.2-s intervals. Further, the measurements were repeated on four successive days and the average of the four measurements was used to calculate the correction for the wattmeter. The temperature of the standards laboratory was maintained within $\pm 0.5°C$ during the tests. Since the measured temperature coefficient of the power meters is less than 2 ppm of apparent input power per degree Celsius, temperature variation in the laboratory had only a minor influence on the measurements.

A measure of the short-term stability of the entire system shown in Fig. 2 was obtained by observing the readings of a DVM connected to one of the watt converters for a 20-min interval. The tabulation of the DVM readings is given in Table I for settings of 5 A, 120 V, 50 Hz, and at power factors of unity and zero lagging. At unity power factor, the readings varied from a high value of 10.00057 V (representing 600×1.000057 W) to a low value of 10.00054 volts, a total change of only 3 ppm. Except for the last reading, no reading differed from the preceding reading by more than 1 ppm. At zero power factor lagging, the total change over the 20-min interval was 1 ppm (of 600 W).

In measurements made at NIST in February and May 1990, differences between two watt converters were determined. Both of the converters had also been tested in May 1989. Comparison of the measurement results of two converters indicated that changes of the differences between the two converters was 11 ppm or less, depending on the testing conditions of frequency or power factor. The results of these tests, as well as other measurements and calibrations of these watt converters over the past several years, indicate stabilities that support reliable calibration with uncertainties within 50 ppm of the apparent power (applied volt-amperes) input.

For the procedures used by NIST to calibrate watt converters, the reader is referred to [3], which has a description of the equipment used for wattmeter testing by the standards laboratories of Canada, the Federal Republic of Germany, the Institut Mihailo Pupin, and the United States.

In the second experiment, the calibration from NIST for one of the standard wattmeters at 120 V, 5 A, 50 and 62 Hz, and at power factors of unity and zero lagging, was transferred to another wattmeter at the same voltages, frequencies, and power factors, but at a current of 50 A. For this experiment, the first wattmeter was tested by NIST in May 1989. It was then used in March 1990 to determine the corrections to the second wattmeter at 50 A. Both wattmeters will be tested at NIST.

The procedures used for the transfer of the calibration from 5 A to 50 A at the industrial laboratory are based on the technique given by Miljanic [4]. The arrangement of the equipment is shown in Fig. 3. A stable source provides 120 V and 5 A at the desired frequency and phase applied simultaneously to the reference wattmeter and to a gain-of-10 current amplifier to

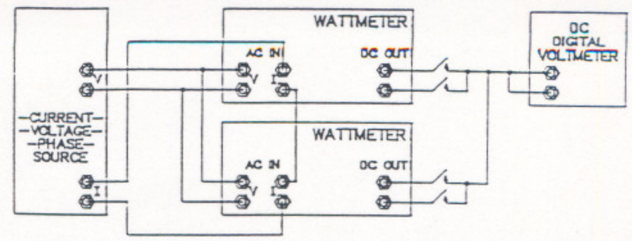

Fig. 2. Arrangement for comparing the calibrations of two alternating current wattmeters.

TABLE I
MEASURED OUTPUT READINGS OF A WATT CONVERTER AS MEASURED BY A DVM IN A 20-MIN TIME INTERVAL

Time Interval* (min)	Average DVM Reading** Unity Power Factor (volts)	Average DVM Reading Zero Power Factor (volts)
1	10.000 57	−0.000 24
2	10.000 57	−0.000 24
3	10.000 56	−0.000 23
4	10.000 57	−0.000 24
5	10.000 56	−0.000 24
6	10.000 56	−0.000 23
7	10.000 56	−0.000 23
8	10.000 55	−0.000 24
9	10.000 56	−0.000 24
10	10.000 56	−0.000 23
11	10.000 55	−0.000 23
12	10.000 55	−0.000 23
13	10.000 55	−0.000 24
14	10.000 54	−0.000 24
15	10.000 54	−0.000 24
16	10.000 54	−0.000 24
17	10.000 55	−0.000 23
18	10.000 55	−0.000 24
19	10.000 54	−0.000 23
20	10.000 57	−0.000 23

*Setup as shown in Fig. 2.
**Test settings were 120 V, 5 A, and 50 Hz.

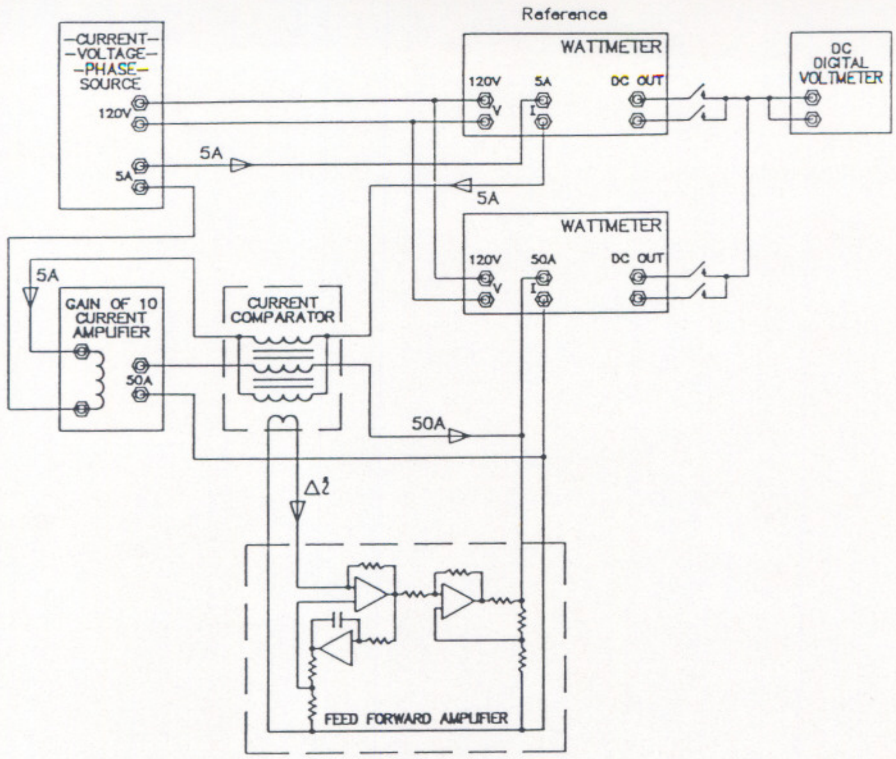

Fig. 3. System for comparing the calibration of two wattmeters, one at 120 V, 5 A, and the other at 120 V, 50 A.

TABLE II
COMPARISON BETWEEN THE CALIBRATION CORRECTION IN PARTS PER MILLION OF WATT CONVERTER CONVERSION CONSTANT AS AT AN INDUSTRIAL STANDARDS LABORATORY AND AT NIST

Test Conditions	Industrial Standards Laboratory Calibration Corrections (ppm)	NIST Calibration Corrections (ppm)	Difference in Calibration Corrections (ppm)
50 Hz 120 V 5 A 1 PF	−14	−8	−6
62 Hz 120 V 5 A 1 PF	−24	−10	−14
62 Hz 120 V 5 A 0 PF Lag	−1	−10	+9
62 Hz 240 V 5 A 1 PF	−42	−42	0
62 Hz 240 V 5 A 0 PF Lag	−6	−7	+1

generate 50 A. The 50 A and the same 120 V are applied to the second wattmeter.

To compensate for the imperfections of the gain-of-10 current amplifier, the 5-A current and 50-A current are compared in a current comparator, and the error between exactly 10 × 5 A and the 50 A current is detected. The current error, δi, is fed forward and applied as a correction to the 50 A at the current input terminals of the watt converter to be calibrated, thus transferring, within the limitations of the current comparator and amplifier, the calibration of the reference wattmeter at 120 V, 5 A to a second wattmeter at 120 V, 50 A.

III. RESULTS

Table II compares the corrections in parts per million to the conversion constant at 5 different test points as determined in the industrial standards laboratory in January 1989 and as determined at NIST in June 1989. The maximum difference of 14 ppm to the corrections to the conversion constant for this six-month period occurred for an input of 120 V, 5 A, unity power factor, and at 62 Hz.

These results are measures of the stability of the two meters used over the period of the tests as well as the random errors of the measurements at NIST and the industrial laboratory. In a transfer standard, one looks for good long-term stability. Recent test results suggest that long-term stabilities (one-year period) in the order of 10 ppm might be realistically expected. When NIST systematic uncertainties are considered, calibration of this type of watt converters can be accomplished to within 50 ppm or better.

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