DC - 1 MHz Wattmeter Based on RMS Voltage Measurements

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Abstract - A wideband wattmeter for measuring active power over a frequency range of dc to 1 MHz is described. The wattmeter is based on the three voltmeter method in which three rms voltage measurements are used to calculate power.

I. INTRODUCTION.

The three voltmeter method for measuring power was described by Ayrton nearly 100 years ago. More recently, various implementations of the technique have been described [1,2]. The applied power is derived from a set of three rms voltage measurements using the law of cosines.

II. WATTMETER DESIGN

A wideband wattmeter has been developed based on this principle that consists of a commercial digital voltmeter (DVM), a four-terminal resistor, two inductive voltage dividers, an isolation transformer, and associated control circuitry. This wattmeter was designed to be used with a source of synthetic power to test wattmeters over a wide range of power, power factor, and frequency. A simplified circuit diagram of the test system is shown in Fig. 1.

A test voltage \( V \) is applied to the voltage terminals of the wattmeter under test (MUT) and to inductive voltage divider \( T_1 \), which is used in conjunction with the buffer amplifier \( A_1 \) to scale \( V \) to \( V_1 \) (approximately 5 V rms). The test current \( I \) is applied to the four-terminal resistor \( R \) in series with the current terminals of the test wattmeter. The voltage developed across \( R \) is converted to a ground-referenced voltage \( V_2 \) (also approximately 5 V rms) using the two-stage transformer \( T_2 \) and buffer amplifier \( A_2 \). Amplifiers \( A_1 \) and \( A_2 \) are special composite, non-inverting amplifiers needed to minimize the loading errors of \( T_1 \) and \( T_2 \). They introduce errors of less than 5 parts in \( 10^6 \) in the 50 Hz to 1 kHz range [3]. Difference voltage \( V_D = V_1 - V_2 \) is converted to a ground-referenced voltage \( V_3 \) using a center-tapped inductive voltage divider \( T_3 \), thereby avoiding the need for any active circuitry to perform the difference function. A high precision, wideband DVM is used to measure the three ground-referenced voltages \( V_1, V_2, \) and \( V_3 \). These voltages are related to the phase angle \( \theta \) between \( V_1 \) and \( V_2 \) by the Law of Cosines:

\[
V_D^2 = V_1^2 + V_2^2 + V_1 V_2 \cos \theta
\]

which may be expressed as:

\[
V_1 V_2 \cos \theta = V_D^2 - V_1^2 - V_2^2.
\]

The magnitude of the difference voltage \( V_D \) can be described in terms of the three measured voltages and the ratio of \( T_3 (0.5) \) by the following equation:

\[
V_D = [2( V_1^2 - V_2^2 - 2V_1 V_2 \cos \theta)]^{1/2}.
\]

The power applied to the test wattmeter is given by:

\[
P = V_1 \cos \theta = (r_1 r_2 V_1 V_2 \cos \theta)/R
\]

where \( r_1 \) is the step-down ratio of \( T_1 \) and \( r_2 \) is the step-up ratio of \( T_2 \).
III. CONCLUSION

The final paper will describe the implementation of this wattmeter in a system to calibrate test wattmeters that operate at 120 V and 5 A, at any power factor, over a wide frequency range with a low audio-frequency active power uncertainty of $30 \times 10^6 (1-\sigma)$.

Standards to support precision power measurements presently are limited to the audio frequency range [4]. The wattmeter described here was developed to support the calibration of commercial power analyzers capable of measuring power components out to 1 MHz. Complete performance results as well as results of comparisons with other power measurement standards will be given in the final paper.

REFERENCES:


