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A HIGH FREQUENCY POWER MEASUREMENT SYSTEM USING A COMMERCIALLY AVAILABLE THERMAL RMS-DC CONVERTER

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Abstract − A high bandwidth power transducer, based on an inexpensive, commercially available, standard IC package covering frequency ranges from DC to 100 kHz is described. The power transducer can be used for accurate power measurements with distorted waveforms and at high frequency.

Keywords: power transducer, inexpensive, standard IC package

1. INTRODUCTION

For electric power measurements, the multiplication of the two ac signals can be performed either electronically or thermally. A power measurement technique based on comparing the ac power with a known dc power using thermal techniques is still very accurate [1]. Unfortunately, the cost of the thermal converters in power comparison systems using the thermal technique is high. Recently, requirements for the precise measurement of electrical power, not only at power frequency but also at frequencies up to hundreds of kilohertz, have arisen. Because of the widespread use of electronic ballasts for fluorescent lamps, step-down converters and non-linear loads in industry, there are special requirements for precise power measurement when both voltage and current signals are distorted. The wideband rms-dc converter integrated circuit (IC) package does not rely on conventional single-junction or multi-junction thermal converters to achieve high accuracy ac measurements. It is based on a commercially available dual-heater converter mounted in a standard IC package [2]. The device is a thermally based rms-dc converter building block. The input ac voltage warms the heater, resulting in increased output from the temperature sensor. The heating is proportional to the rms value of the input ac voltage. The dc output of the temperature sensor is the measure of this heating. In this application, the value of an ac voltage, or a current, is determined by comparing it with an internal dc reference. The standard IC package is used as a voltage comparison device [3].

In order to satisfy their requirements, the authors developed a wideband power transducer using a commercially available standard IC package. The advantages of the watt-converter are its high frequency range, low cost, simplicity and high accuracy. The main component of the developed watt-converter consists of a sum amplifier, a differential amplifier, a buffer and an inexpensive, commercially available, dual-heater converter, mounted in a standard IC package.

2. PRINCIPLE OF OPERATION

Operation of the power transducer is based on comparing the ac power with a known dc power. The structure of the transducer is shown in Fig.1. The voltage divider (VD) with a nominal input voltage of 240 V, and the shunt (S) for 5 A current, were constructed using metal film resistors. The nominal output voltage for both VD and S is 1 V. The power transducer uses the well-known method of the mean squared values of the sum and the difference of two voltages.

$$UvUi = \frac{1}{4}[(Uv + Ui)^2 - (Uv - Ui)^2] \tag{1}$$

Amplifiers A1 and A2 are differential amplifiers with high input impedance. The control signal S2 is used to reverse simultaneously the polarity of the signals applied to the switch inputs Uv and Ui at 8 Hz. Amplifiers A3 and A4 form sums and differences of the modulated input signals. Amplifiers A5 and A6 provide currents through one of the two heaters (250 Ω) of the wideband rms-dc converter proportional to the sum and difference of input signals. By reversing the input signals, the effects of the dc drifts of all amplifiers and the dc reversal of the rms-dc converter are practically eliminated.

A low reversal frequency helps to minimize the effect produced by the rise and fall times of the amplifiers and by the charge injected into the measurement circuit by the control signals. In power measurement of the rms-dc converter, the modulated sum input signal of A5 is applied to the heater H1 and the modulated difference input signal of A6 is applied to the heater H3. A7 is an instrumentation amplifier with high gain and fast slew rate. The voltages of the temperature sensing diodes D1 and D2 are a measure of

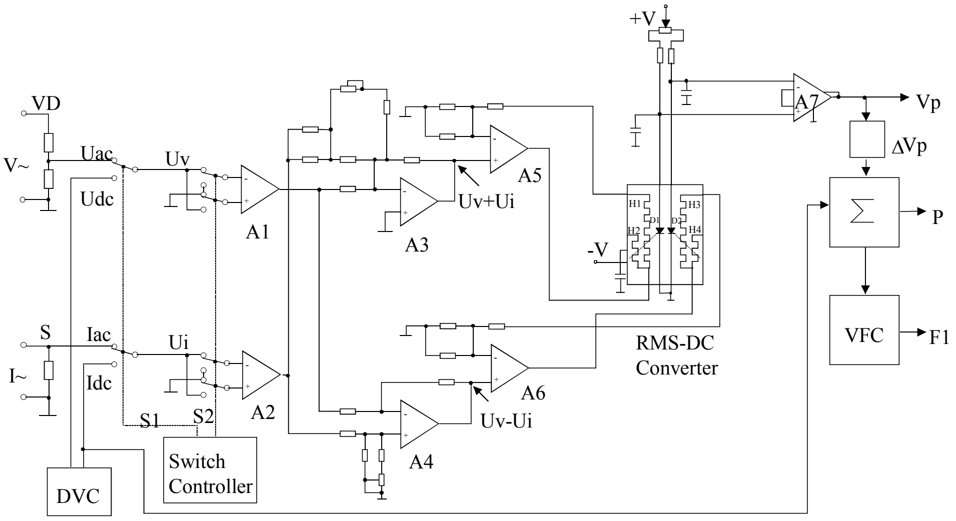

Fig.1. Schematic diagram of the thermal-type power transducer

the difference between the $(Uv+Ui)^2$ and $(Uv-Ui)^2$ signals. The control signal S1 is used to change the ac/dc input signals. In the dc mode, dc input signals are applied the inputs of the rms-dc converter, and the output voltage Vp of the converter in the dc mode Vp_{dc} is given by

$$Vp_{dc} = kUv_{dc}Ui_{dc}, \tag{2}$$

where k is the calibration coefficient of the power transducer.

The output voltage of the transducer Vp_{dc} can be obtained from the dc-input voltage Uv of the A1 amplifier in dc mode Uv_{dc} and the ac-input current Ui of the A2 amplifier in the dc mode Ui_{dc}.

The output voltage Vp of the transducer in the ac mode Vp_{ac} can be obtained from the ac-input voltage Uv of the A1 amplifier in the ac mode Uv_{ac} and the ac-input current Ui of the A2 amplifier in the ac mode Ui_{ac}.

$$Vp_{ac} = kUv_{ac}Ui_{ac} \tag{3}$$

If Ui_{dc} is adjusted until $Vp = 0$, then Vp_{ac} is expressed by

$$Vp_{ac} = Vp_{dc} = kUv_{dc}Ui_{dc}. \tag{4}$$

Therefore, if the condition given by (4) is fulfilled, ac power Vp_{ac} can be obtained from a known dc power Vp_{dc}. However, practically, the outputs of the power transducer Vp_{ac} have a dc power Vp_{dc} and an ac/dc difference power ΔVp because asymmetries between the heaters and the temperature sensors of the thermal rms-dc converters are not cancelled by interchanging the ac and dc quantities. In this case, Vp_{ac} is

$$Vp_{ac} = k(Uv_{dc}Ui_{dc} + \Delta Vp). \tag{5}$$

The output voltage P is formed by a summing amplifier in accordance with (5) and is converted to frequency $F1$ by a voltage-to-frequency converter.

3. EXPERIMENTAL RESULTS

The frequency characteristic of the thermal power transducer designed as shown in Fig.2 was evaluated directly by comparison to a dc reference source. The experiments were performed in the frequency range of 5 Hz to 100 kHz at power factors of unity, 0.5 lagging, and 0.5 leading. Ac voltage sources were from a phase standard oscillator (Clarke-Hess, model 5000) with two channels.

Ac input signals were applied to the inputs of the power transducer simultaneously with the reference dc signals Udc and Idc, produced by an external direct voltage calibrator (DVC). As a dc reference, a dc calibration instrument (Fluke 5520A) was used. To monitor precisely ac input signals level, two multi-junction thermal converters (TC1, TC2) and high-precision digital voltmeters (Wavetek 1281, Fluke 8506A: DVM1, DVM2) were used. The values displayed by the DVM determine the ac-input level of the power transducer by an ac/dc voltage comparison up to high frequency.

Four measurement stages were introduced to minimize the ac/dc difference power effects caused by the amplifier gain and mismatch of the parameters of the thermal rms-dc converter. The difference between ac and dc power with frequency have been measured and found to be less than 0.4 % up to 10 kHz, less than 0.5 % up to 50 kHz and less than 0.8 % up to 100 kHz at power factors of 1, 0.5 (lead and lag).

The ac/dc power differences were measured in the transducer shown in Fig. 3. At unity power factor, the power transducer, with its ac voltage and current inputs joined together, was compared with a traceable ac voltage and phase standard. The comparison was carried out at a single voltage level for frequencies up to 100 kHz. Vac and Iac in Fig.3 and Fig.4 denote the ac input signals.

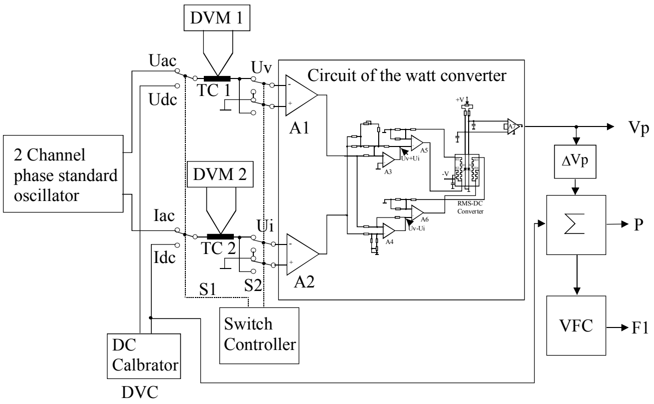

Fig.2. Test method of a power transducer

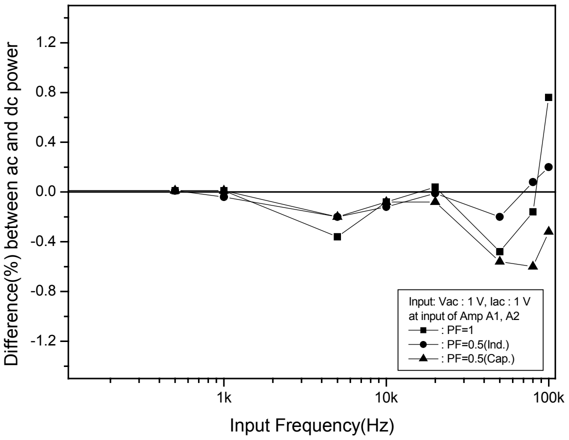

Fig.3. AC/DC power difference versus frequencies

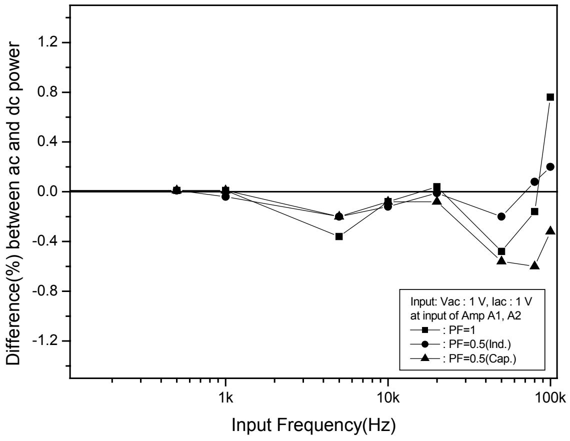

Fig.4. Non-linearity error vs. frequencies variation

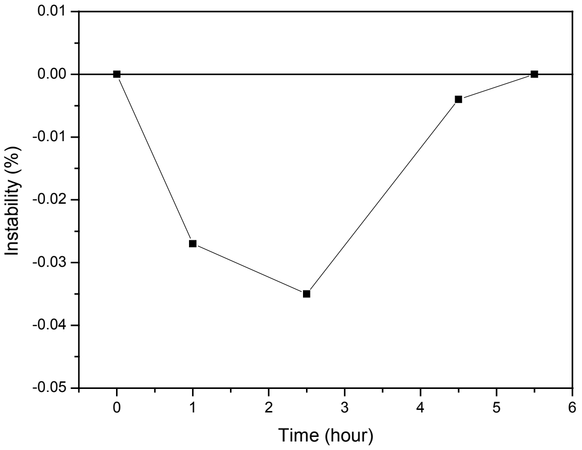

Fig.5. Instability characteristics

The non-linearity error is shown in Fig.4. The measured errors are less than 0.1 % up to approximately 1 kHz, and less than 0.4 % up to 10 kHz. At 100 kHz, the non-linearity error did not exceed 0.8 % at unity power factor or at the other power factors.

The results of instability during a 5.5 hour test are shown in Fig.5. Preliminary results indicate that instability is in the order of 0.04 %. No significant long-term drift has been detected to date.

4. CONCLUSIONS

A wideband power transducer using a commercially available standard IC package was studied. It was found that an rms-dc converter could be used as a high frequency thermal power comparator and for distorted-waveform power measurement. The advantages of the transducer are its simplicity, low cost and fast response time.

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