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XVII. *A Balance Method of Using the Quadrant Electrometer for the Measurement of Power.* By HUBERT PARRY.

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(COMMUNICATED BY R. S. WHIPPLE, ESQ.)

ABSTRACT.

A new method of using the quadrant electrometer for the measurement of electrical power is described. It involves the use of a potential divider across the supply circuit, and a standard non-inductive resistance in series with the load. An ammeter and a voltmeter are employed to measure the supply voltage and the load current.

An example of its application to determine the power-factor of a condenser is quoted.

INTRODUCTION.

ANYONE who has used a quadrant electrometer as a deflectional wattmeter will know the difficulties in getting this instrument to obey the "Heterostatic Law" over fairly large angular deflections, and in keeping it so from day to day; it requires very great accuracy in workmanship so that the instrument shall be free from electrical control with the vane or needle in any position between the quadrants. It was to

get over these difficulties that I conceived the method described in this Paper.

Method.—The electrometer is used as a balance indicator, as shown in the figure, where A represents the needle, B and C the quadrants, R a noninductive resistance in series with the load L , D a calibrated potential divider coupled between the potential point O on the supply side of R and the far side

of the load, to which point the needle A is coupled. E is a voltmeter.

It is, of course, necessary that the instrument shall be free from electrical control: that is, that the zero shall not change at any voltage over the working range, when the voltage is applied to the needle and the quadrants shorted; this condition is easily got by slightly tilting the instrument.

Now, if a voltage be applied to the needle A , and we have a voltage on quadrant C proportional to the current, we can apply with the potential divider D a voltage in phase with the needle voltage to quadrant B , so that the average torque in the instrument is zero. As the instrument is used it will obey the "Heterostatic Law" and, should the power-factor of the circuit be unity, the voltages on B and C will be equal, hence the product of the voltages on the needle A and quadrant B will be proportional to the watts expended in R and L . If the power-factor is not unity, then the average voltage on B will be less than on C , but a voltage can be applied to B such that the average torque is zero.

Theory.—

Let v be the instantaneous voltage on the needle A ,
 „ v_1 „ „ „ „ quadrant B ,
 „ v_2 „ „ „ „ quadrant C ,
 „ v_0 „ zero potential at point O ,
 and „ R „ resistance of R : where v, v_1, v_2 are periodic functions of time.

The theoretical law of the electrometer is given as

$$\text{Torque} = K \{v - \frac{1}{2}(v_1 + v_2)\} (v_1 - v_2)$$

where K is the instrument constant. As the needle is always in the same position this law will hold good.

Hence the instantaneous torque (t)

$$= K \{v - \frac{1}{2}(v_1 + v_2)\} (v_1 - v_2),$$

$$= K [vv_1 - vv_2 + \frac{1}{2}(v_2^2 - v_1^2)].$$

Then by integrating over a complete period and taking the average we have the average torque (T)

$$= K [V V_1 - V V_2 \cos \phi + \frac{1}{2}(V_2^2 - V_1^2)] = 0,$$

where V, V_1, V_2 are square root of the mean square values and $\cos \phi$ the power-factor of the circuit.

If we divide the above expression by R and transpose terms, we have

$$\frac{VV_2}{R} \cos \varphi = VI \cos \varphi = \frac{VV_1}{R} + \frac{1}{2R} (V_2^2 - V_1^2) =$$

power expended in the resistance R and load L , where I is the R.M.S. current in the circuit.

As an example, and to show the fair agreement with results got with a standard Duddell wattmeter, a 1 mfd. condenser was tested at 90 volts, 40 cycles, for losses at air temperature.

The Duddell instrument gave :—

Watts, 0.0039 ; power-factor, 0.0012, at 92 volts, 40 cycles.

The method described gave :—

(1) Watts, 0.0040 ; power-factor, 0.0019 at 90 volts, 40 ~, 11°C.

(2) Watts, 0.0030 ; power-factor, 0.0015 at 90 volts, 40 ~, 11°C.

Below are given the detailed figures :—

V .	Potential divider ratio.	V_1	V_2	R	Freq.	Milli-amps.	Temp.
(1) 90.1	36.7×10^{-5}	0.033	2.26 ₈	100	40.25	22.6 ₈	11°C.
(2) 90.75	35.3×10^{-5}	0.032	2.28 ₂	100	40.25	22.8 ₂	11°C.

The total resistance of the potential divider is 100,000 ohms, and the division can be altered by unit steps, keeping the total resistance constant. The first decimal place is by estimation.

This is quite good when one considers the low power-factor, and that the instrumental losses are of the same order as those to be measured. In the above test the voltage V was measured by a reflecting electrostatic voltmeter where the sensitivity is such that 8 cm. of scale represent 1 volt. V_1 is calculated from potential divider data and V ; V_2 from the current and resistance R , or measured with an A.C. potentiometer.

CONCLUSION.

It will be seen that the voltmeter is the only instrument needing a scale; these instruments can be made with strong control and will keep their accuracy from day to day. The potential divider and series resistance need no special comment, except to say that the potential division must be true as regards phase as well as magnitude. The advantages are

that no wattmeter scale is needed, and therefore no calibration, and the electrometer does not need to be so accurately made as for the deflectional method. The voltmeter and potential divider would still be needed for calibration if the electrometer was used as a deflectional instrument.

The disadvantages are, slowness of working, and the need to have a very steady supply for accurate work.

I have used the method for over a year with quite good results, and as far as I am aware it is new. I have published it in the hope that it may be of interest and use to others.

DISCUSSION.

Mr. C. C. PATERSON said he had worked for 10 to 15 years with electrometers for power measurements. He would like to see the method tried out more fully under varying conditions. With small power-factors one always had the result as the difference of two large terms when using the electrometer.

Another point was that the two voltages V_1 and V_2 were not in phase. Of course, V_2 was small but it would surprise him to find that it was legitimate to add them as the author had done.

Dr. E. H. RAYNER said they had not yet tried the method at the National Physical Laboratory, but were certainly going to. He wondered if the difficulty mentioned in connection with small power-factors could not be overcome by connecting the needle to the mid-point of a large dividing resistance. There was always a danger, however, with small power-factors that the dividing resistance was not true as regards phase on account of the distribution of capacity.

Dr. A. RUSSELL congratulated the author. The method was novel to him. The old method was quite good for high voltages, but for low voltages he thought the author's method would be superior.

Dr. D. OWEN said: The author's Paper, of modest dimensions, contains an idea which promises to add decidedly to the value of the quadrant electrometer as used for the measurement of electrical power. The method, being a null one, possesses several advantages. In the first place, it makes it possible to utilise to the full the possession of an electrometer of the highest sensibility attainable in virtue of mechanical design. Further, as the constant of the electrometer disappears from the expression for the power, the usual calibration experiment with non-inductive load becomes unnecessary.

In the form proposed, however, the method has one decided disadvantage, namely, that at low power-factors the power required was obtained as the difference of two separately determined quantities, each of which might be of much greater magnitude. This is so, indeed, in the very test chosen by the author for illustration, and the effect is evident in the considerable discrepancy between two successive tests on the same condenser.

Dr. Rayner has expressed the possibility of this source of error being overcome by connecting the needle to the mid-point of the non-inductive resistance across the mains. This had occurred to me, and on trying it I found it to be the case. The adoption of this modification would not only eliminate the source of error occurring at low power-factors, but would simplify the expression for the power in the general case. Denoting by V/n the voltage drawn from the potential-divider (denoted by V_1 by the author) the expression for the power supplied to the load becomes

$$W = \frac{V^2}{R} \cdot \frac{n-1}{n^2}$$

All that is required in a test now is to adjust the tapping-point on the potential-divider until the electrometer needle is at zero, and at that instant to read off V on the voltmeter. n may be observed at leisure, and the only remaining factor in the calculation of the power is the standard non-inductive resistance R .

Mr. PARRY communicated the following reply :—

The theory of the method is based on the conception of the electrometer acting as two instruments in opposition—the one having elements A and B working at unity power factor with potentials V , V_1 and V_0 ; the other with elements A and C working at the power-factor of the load and potentials V , V_2 and V_0 . If Mr. Patterson will look at it from this viewpoint I think he will find the latter part of his remarks answered.

As pointed out by Dr. Owen and Dr. Rayner, the difficulties at low power factor are eliminated by making the needle potential $\frac{V}{2}$; it had not occurred to me to do this, though I knew of this property in the deflectional methods.

Dr. Owen's formula can be expressed in a slightly more convenient form by taking $V_1 = KV$; then

$$W = \frac{V^2}{R} (K - K^2).$$

K can generally be read directly on a potential divider.

The method has checked out very well with results got by dynamometer wattmeters working over a power factor range of 1 to 0.3. I shall be very pleased to hear the N.P.L. opinion after they have tried the method.

In conclusion, I should like to thank Dr. Owen for the large trouble he has taken over my small Paper.