TESTING POTENTIAL TRANSFORMERS

By H. B. Brooks

The ratio and phase angle of an instrument transformer may be accurately determined by laboratory methods. The commercial importance of such transformers has stimulated the development of accurate methods in recent years.[1] In many cases, however, it is not practicable to dismount transformers and send them to a laboratory, and a method is wanted which, while giving all needed accuracy, can be carried out at the point of installation, using commercial instruments and the ordinary supply voltage. Such a method of testing potential[2] transformers will now be described. No claim for originality of principle is made, as the only novel feature is the use of facilities which are available in any properly equipped a. c. power plant, in addition to a potential transformer whose ratio and phase angle are known.

Briefly, the idea of the method is as follows: From the practical point of view, an error in ratio or phase angle which produces a visible error in the reading of an indicating wattmeter is an error which needs to be known, while errors smaller than this are negligible. We may therefore use an indicating wattmeter in such a way that differences in ratio or phase angle of an unknown transformer and a standard transformer have the best possible opportunity to produce a deflection. By properly choosing conditions, this deflection may be readily made to give the numerical values of the quantities desired.

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[1] Rosa and Lloyd, This bulletin, **6**, p. 1; 1909; Reprint No. 116. Agnew and Fitch, Elec. World, **54**, p. 1042; 1909; Reprint No. 130. E. Orlich, Elektrotechnische Zs., **30**, pp. 435, 466; 1909. L. T. Robinson, Trans. Am. Inst. Elec. Eng., **28**, p. 1005; 1909. F. A. Laws, Elec. World, **55**, p. 223; 1910. Sharp and Crawford, Trans. Am. Inst. Elec. Eng., **29**, p. 1517; 1910. Agnew and Silsbee, Proc. Am. Inst. Elec. Eng., **31**, p. 1267; June 1912.

[2] There is some discussion as to whether the term "voltage transformer" should not be used to the exclusion of the term "potential transformer." At the present time, both expressions are in use.

The primary windings of the standard transformer and the transformer to be tested are connected to the same supply, as shown in Fig. 1. The secondary windings are connected in series so that their voltages are opposed. The secondary voltages will be nearly equal and will rise and fall in unison as the line voltage varies. The thing to be measured is the difference between the two secondary voltages, which difference in general would be only a few volts. As the lower end of the scale of an alternating-current voltmeter is practically useless, this small

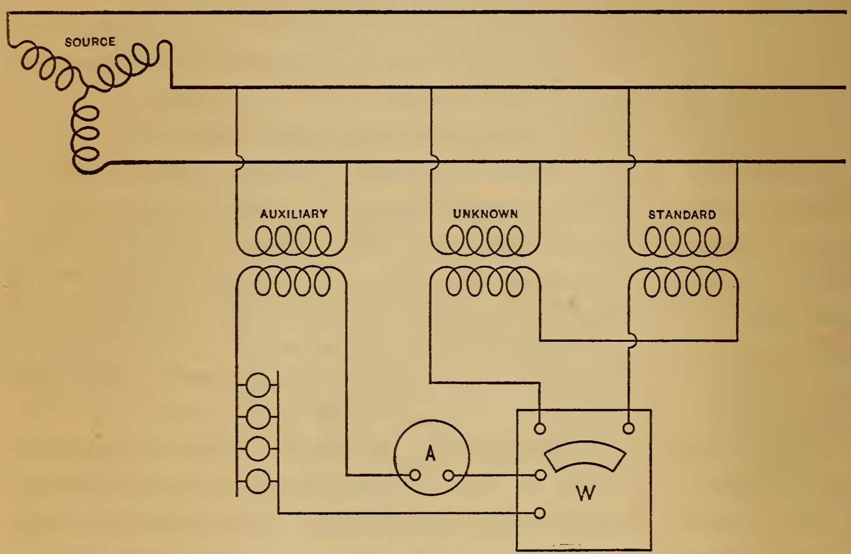

Fig. 1.—*Diagrammatic plan of connections for potential transformer testing*

voltage can not be measured satisfactorily with even a low-range voltmeter. However, a 5-ampere indicating wattmeter may be used as a voltmeter by separately exciting its current coil.[3] This may be done by passing 5 amperes through the coil to a lamp load. This exciting current must not be drawn from either of the two transformers whose ratios are to be compared, but must come from the secondary of any other available transformer connected to the same phase as the transformers under comparison. The current through the series coil of the wattmeter should be kept at approximately 5 amperes, but this current

[3] A similar use of the wattmeter is described by Drysdale, Electrician, 57, p. 783; 1906.

needs to be measured with only moderate accuracy. The potential circuit of the wattmeter may now be used as a voltmeter to measure the small difference in the secondary voltages of the two transformers under comparison. For example, if the wattmeter is made for 5 amperes, 150 volts, 750 watts, and has a 150-division scale, then one division is 5 watts, and will be given by 5 amperes in the current coil and 1 volt on the potential circuit; hence the difference between the two secondary voltages, in volts, will be shown by the number of divisions deflection of the wattmeter. Since the ratio of good voltage transformers changes very little with ordinary fluctuations of line voltage, the difference of the secondary voltages will be practically constant; as the wattmeter reading is steady and can be taken to one-tenth of a division, the ratio of one transformer in terms of the other can be read to 1 in 1000. If the wattmeter has a 75-volt range, this may be used, and the reading will be doubled; that is, one volt difference between voltages will give two divisions deflection. It is obvious that with a wattmeter having a still lower voltage range, say 30 volts,[4] the difference between the secondary voltages could be still more accurately read.

The question as to which transformer has the greater ratio may be easily answered from the fact that increasing the noninductive load on the secondary always lowers the secondary voltage, and thus increases the ratio of transformation. If the reading of the wattmeter is up scale when there is no load on the secondary of the transformer under test, and if this reading increases as successive lamps are connected to the secondary of the transformer under test, this shows that at no load the voltage of this transformer is lower than that of the standard transformer. Similarly, if the deflection is below zero with no load, and the addition of load brings the deflection up through zero to a reading on the scale, this shows that at no load the voltage of the transformer under test is higher than that of the standard transformer. In this case the voltage leads to the wattmeter should be reversed at the start to bring the readings on the scale; they will decrease as load is

[4] With this range, at 60 cycles, no error due to mutual inductance enters, for two usual types of portable wattmeter. It is not advisable, in general, to reduce the range below 30 volts.

gradually applied, and pass through zero, when the leads may be replaced in the original position.

It is obvious that the above method is a suitable one for determining the regulation of power transformers, by using one transformer of a bank on no load as the standard transformer, and determining the drop of voltage of another transformer as the load on it is increased. This method is similar in principle to the one described by Drysdale,[5] but differs in important details. In his method the voltage circuit of the wattmeter is connected to the secondary of the standard transformer, and the current coil of the wattmeter, with some added resistance, is used as a low-range voltmeter to measure the difference of the secondary voltages. The method described in the present article inverts these uses of the two coils, the current coil being the one which is separately excited, and the voltage circuit being used as the low-range voltmeter. This has the advantage of drawing a very much smaller current from the transformers under comparison, and thus avoiding what might be an appreciable error in the case of small transformers.

If the preceding test for ratio is made with the primaries connected to one phase of a two-phase circuit, a determination of the difference of the phase angles of the two transformers may then be made by connecting the wattmeter series coil and 5-ampere lamp load to the other phase. Before doing this, the ratios of the transformers should be made equal by loading the secondary of one or the other with lamps or other noninductive load.[6] The current taken by this load should be determined; if it must be applied to the standard transformer in order to make the ratios equal, the value of phase angle of the standard transformer corresponding to the given load may be taken from a curve plotted from the certified values.[7] The small voltage shown by the wattmeter with its current coil on the second phase is a measure of the difference of the phase angles of the two transformers, with the given secondary loads. For example, suppose that the watt-

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[5] Electrician, 65, p. 644; 1910.

[6] The writer is indebted to Dr. P. G. Agnew and Mr. F. B. Silsbee for this and other helpful suggestions.

[7] Such an interpolation is easily made, since the ratio and phase-angle curves of potential transformers are sensibly straight lines.

meter constants are those previously referred to, and the 150-volt potential circuit is in use, so that one division deflection is given by 1 volt applied to the potential circuit. Suppose the deflection is 0.3 division when the 5-ampere current in the series coil is drawn from the second phase of the two-phase circuit while the primaries of the two voltage transformers are on the first phase. The 0.3 volt divided by the secondary voltage (say, 110) of the transformer under test equals 0.0027. This number is the sine of the small angle by which the phase angles of the two transformers differ. By reference to a table of natural sines,[8] the angle is found to be 9 minutes. Hence 0.1 division of the wattmeter corresponds to 3 minutes; by using the 75-volt range of the wattmeter, 0.1 division will correspond to 1.5 minutes.

It remains to determine which of the two secondary voltages is leading the other. To test this point, use may be made of the fact that increasing a noninductive load connected to the secondary of a potential transformer tends to make the reversed secondary voltage lag behind the primary voltage. With the connections made for phase-angle test as just described, and the wattmeter reading 0.3 division up the scale, connect one or more incandescent lamps to the secondary terminals of the transformer under test, without disturbing any of the former connections. If the deflection of the wattmeter is increased, this shows that a reading up scale denotes that the secondary voltage of the transformer under test lags behind that of the standard transformer. If the application of the lamp load to the transformer under test sends the wattmeter reading down below 0.3 division, this shows that a reading up scale denotes that the secondary voltage of the transformer under test leads that of the standard transformer.

If a 2-phase circuit is not available, a 3-phase to 2-phase arrangement of transformers may be used. If this is not convenient, the test for phase angle may be made by exciting the wattmeter series coil from another phase of a 3-phase circuit. In this latter case, however, the wattmeter reading must be multi-

[8] If a table of natural sines is not available, the angle (in minutes) may be obtained by multiplying the quotient of the two voltages by 3438; thus, 0.0027 times 3438 equals 9.+ This assumes that the sine of a small angle is equal to the angle expressed in radians. For the small phase angles of instrument transformers this assumption introduces no appreciable error.

plied by 1.16 (the reciprocal of 0.866) in order to get the deflection which would be given if test were made on a 2-phase line. The calculation is then made as before. The phase-angle test may also be made with the series coil connected to the third phase as a check. If the deflections are slightly different from those obtained when phase 2 is used, the mean of the two values may be taken.

Figure 1 shows no connected load on the secondary of the transformer whose ratio and phase angle are to be determined. However, any desired load may be connected to it and the comparison made in the same way. The load is simply connected to the secondary terminals without disturbing any of the other connections.

To test the accuracy of the foregoing method, two 5500 to 110 volt potential transformers were compared at three secondary loads. The test was then repeated, using an accurate laboratory method. The values for ratio by the two methods agreed to within 0.02, 0.05, and 0.08 per cent for the three loads, which were, respectively, light load, rated load, and twice rated load. The values of phase angle by the two methods agreed to within less than half a minute. The wattmeter used was provided with a 30-volt potential range especially for the test.

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