Instruction Manual
AVTM 55-Jd

For the use of the

TTR®
Transformer Turn Ratio Test Sets

Catalog Number 550005 Series

Megger®

Megger, Inc.

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Ninth Edition
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SAFETY PRECAUTIONS

SAFETY IS THE RESPONSIBILITY OF THE USER
LA SEGURIDAD ES EL CARGO DEL OPERADOR

The Test Set and the sample to which it is connected are a possible source of high-voltage electrical energy and all persons making or assisting in the tests must use all practical safety precautions to prevent contact with energized parts of the test equipment and related circuits.

Persons actually engaged in the test must stand clear of all parts of the complete high-voltage circuit, including all connections, unless the set is de-energized and all parts of the test circuit are grounded.

Any persons not directly involved with the work must be kept away from test activities by suitable barriers, barricades or warnings.

If the set is properly operated and all grounds correctly made, no rubber gloves are necessary. As a routine safety procedure, however, some users require the use of rubber gloves, not only in making connections to the high-voltage terminals, but in manipulating the controls. BIDDLE considers this to be an excellent safety practice.

WARNING!

- STAY CLEAR OF ALL EXPOSED CONNECTIONS AND CONDUCTORS WHILE TEST IS IN PROGRESS.
- NEVER CONNECT THE TEST SET TO ENERGIZED EQUIPMENT.
- NEVER USE THE TEST SET IN AN EXPLOSIVE ATMOSPHERE.

Corrective maintenance must be performed only by a person who is familiar with the construction and operation of the test set and the hazards involved.

The equipment provided should not be used for any purpose except as described in the instruction manual.

Accessories and optional equipment, including cables and leads, are only to be used with the specified equipment and not for any other application.

Section A

INTRODUCTION

1. PURPOSE OF MANUAL

This Instruction Manual is published as a guide to the operation and maintenance of a Transformer Turn Ratio Test Set.

This Manual also presents a brief discussion (Section C) of the relation between turn ratio, voltage ratio and leakage flux, and their significance in transformer ratio measurements.

For further information concerning transformer ratio tests see: American National Standard Test Code for Distribution, Power and Regulating Transformers ANSI/IEEE C57.12.90.

RECEIVING INSTRUCTIONS

Your TTR instrument has been thoroughly tested and inspected to rigid specifications before being shipped and is ready for use after it is set up as indicated in the Installation section. Check the equipment received against the packing list. Notify BIDDLE Instruments, Blue Bell, Pa. 19422 of any shortage of materials. The TTR instrument should be examined for damage received in transit. If any damage is found, file a claim with the carrier at once and notify BIDDLE Instruments or its nearest representative, giving a detailed description of the damages observed.

WARRANTY

All products supplied by BIDDLE Instruments are warranted against all defects in material and workmanship for a period of one year following shipment. Our liability is specifically limited to replacing or repairing, at our option, defective equipment. Equipment returned to the factory for repair will be shipped Prepaid and Insured. The Warranty does not include batteries, lamps or tubes, where the original manufacturer's warranty shall apply. WE MAKE NO OTHER WARRANTY.

The Warranty is void in the event of abuse or failure by the customer to perform specified maintenance as indicated in the Instruction Manual.

REPAIR

BIDDLE Instruments maintains a complete instrument repair service. Should this instrument ever require repair, we recommend it be returned to the factory for repair by our instrument specialists. When returning instruments for repairs, either in or out of warranty, they should be shipped Prepaid and Insured, and marked for the attention of the Instrument Service Manager.

CAUTION! Test Sets energized with 220/240 volts input voltage!

These sets are intended to be exported. The sets are energized via an internal transformer which is used for voltage reduction. The black cord lead must be connected to the live pole of the line power source and the white cord lead must be connected to the neutral pole of the line power source. The green ground lead of the input supply cord *must* be connected to the protective ground (earth) contact of the input plug. These sets *must not* be energized from a power source where both poles are live.

2. DEFINITION OF TERMS

In order to describe the operation and theory of the Transformer Turn Ratio Test Set (the TTR Set) concisely, certain terms and abbreviations are used. These are defined in the Appendix, Section E.

3. PURPOSE OF THE TTR SET

The TTR Set is designed to measure accurately the turn ratio of rational transformers* which have a ratio of less than 130, and to give a direct reading of turn ratio when the low voltage winding is the primary during test. The set is so arranged that during ratio tests, polarity is determined and the detection of open or short-circuited turns is facilitated. Where the winding is accessible it offers a means of obtaining the actual turn count. Transformers having ratios as high as 330 may be measured with auxiliary equipment.

The set is used for field and shop testing of single and polyphase power, distribution and other rational transformers designed for 25 to 60 Hz operation, having a low-voltage winding rated at 8 volts or more and having a magnetizing current of less than 1.0 amperes at 8 volts. These ratings permit testing all types and ratings of power and distribution transformers in general use.

Where the low voltage winding cannot be used as the primary during test, because of excessive magnetizing current or low voltage rating, the high-voltage winding may be connected as primary. In this application, the TTR Set reads inverse turn ratio to three decimal places — fourth place interpolated.

The Set is also used for comparison tests on certain irrational and special transformers such as potential transformers, current transformers, and luminous tube transformers. It will give accurate results where the percent impedance and percent magnetizing current are

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*See appendix page 50.

known and for which corrections can be made. It will also give reasonably accurate results without corrections if the transformer primary impedance drop at eight volts excitation is less than 0.1%. In some cases of specialty transformers it has been found that by winding a standard transformer in advance it could be used as a comparison standard for production line testing to cull out defectives as to inability to meet voltage output or ratio specifications. In this case only the no-load ratio test, which includes the effect of primary excitation drop, was required, not the exact turn ratio.

For cases where the magnetizing current of 1.0 ampere at 8 volts is exceeded, as is found in network transformers of 15000/115 volt class, the ammeter can be equipped with a shunt to extend the range to 5 amperes (× 5 range). Because it is inconvenient to crank the hand-powered generator for the higher output, the TTR is available in power-operated models, Cat. Nos. 550022 or 550027, capable of being operated from a 120 volt, 60 Hz supply.

4. ACCURACY

The no-load voltage ratio of the TTR Set reference transformer is approximately .9995 times the ratio indicated on the dials where the ratio indicated is greater than one. For inverse ratios (less than one) the no-load voltage ratio is equal to the dial reading plus or minus .0005.

The accuracy of turn ratio measured by the TTR Set is limited by the difference between no-load voltage ratio and the turn ratio of the transformer being measured.

For well-designed transformers properly tested, it is possible to determine turn ratio to an accuracy of 0.1% or better. Inverse turn ratio can be relied on to the third decimal place under the same conditions. No corrections are needed.

For less rational transformers the true turn ratio will be slightly larger than the indicated ratio. In such cases a correction can be applied if the percent impedance and percent magnetizing current are known approximately.

Discussion of this and other factors affecting accuracy will be found in Section C.

5. PRINCIPLE OF OPERATION

When a transformer is excited by its low voltage winding, the no-load voltage ratio is almost exactly equal to the turn ratio if the transformer is rational. The difference between the two ratios is caused by voltage drop in the primary that results from magnetizing current flowing through the primary. In practical transformers the difference is often less than 0.1%.

All electrical methods of measuring turn ratio are based on the above principle. The basic problem is that of measuring no-load voltage ratio.

The TTR Set is arranged so that the transformer to be tested and the adjustable ratio reference transformer in the TTR Set are excited from the same source of voltage. The secondary windings are connected in series opposing through a null detector. When the ratio of the reference transformer is adjusted so that no current flows in the secondary circuit (null), two conditions are fulfilled simultaneously. The voltage ratios of the two transformers are equal and there is no load on either secondary. The no-load voltage ratio of the reference transformer is known, therefore the voltage ratio of the transformer under test is known, and its turn ratio is also known, subject only to the errors mentioned above.

6. GENERAL DESCRIPTION

The TTR Set is entirely self-contained and self-powered. The following components are built into a case with cover and carrying strap as shown in Figure 1 on page 10. The case is approximately 10 inches high, 10 inches deep and 13 inches long overall. The approximate weight is 19 pounds.

a. Generator: The source of test power is a hand-cranked permanent magnet ac generator which provides 8 volts excitation at approximately 60 Hertz under normal conditions of operation. The generator also supplies a source of 8 volts to be used as a reference for the synchronous detector.

b. Reference Transformer: This is a tapped transformer having precise turn count at each tap and designed so that the primary voltage drop due to magnetizing current is negligible when excited at 8 volts.

c. Decade: Three tap switches are connected to secondary taps of the reference transformer. The shafts of these switches project through the instrument panel and are fitted with indicating plates and control knobs. Reading from left to right while facing the Set, the first switch changes the connected turn count ratio of the reference transformer in steps of 10; the second switch changes ratio in steps of 1, the third in steps of 0.1. The actual connected turn count ratio set up by any combinations of positions of these three switches is indicated by figures which appear in the windows located above the switch knobs.

d. Fourth Dial: A fourth dial in line with the three dials but with a larger window is located on the right. This is connected to a potentiometer across an auxiliary winding in the reference transformer. It provides a continuously variable voltage which is electrically equivalent to variable turn ratio. The dial is marked with 100 divisions each of which corresponds to a change in turn ratio of 0.001.

e. Detector: A phase-sensitive null-detector is used. It consists of a synchronous rectifier and a zero center, dc microammeter used as a detector. The latter is located in the upper right corner of the panel.

f. Meters: An ac voltmeter measures the excitation level. It is marked with a graduation at 8 volts and upper and lower limits which insure operation within the correct voltage range. There is also an ammeter which indicates the magnetizing current of the transformer under test. Both of these meters are mounted at the top of the instrument panel adjacent to the detector.

A divide-by-5 ammeter range, selected by a switch directly below the meter, increases resolution at low magnetizing currents.

g. Leads: Four leads are permanently connected to the set for connecting to the transformer under test. Two of these are 10 ft. long and provided with clamps for connection to the winding which is to be used as primary (generally the low-voltage winding). The other leads are 13 ft. long and are fitted with clips for connecting to the secondary for the test (usually the high-voltage winding). A compartment in the case is used to store the leads.

Figure 1 — The Catalog No. 550005 TTR Test Set complete with leads and carrying strap.

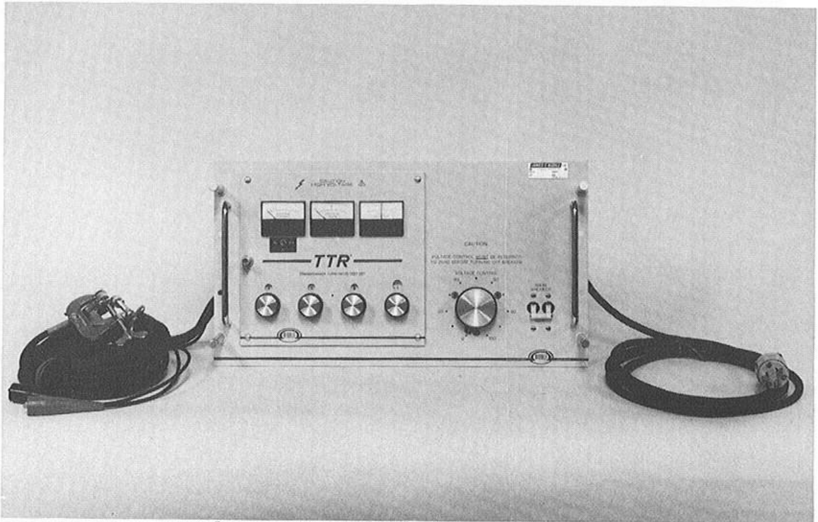


Figure 1a — Catalog 550022; similar to 550005 except variable ratio auto transformer and protective features replace generator. Panel mounted.

Section B
OPERATION

7. SETTING UP EQUIPMENT

The TTR Set is a portable instrument and does not require an installation. Place the set on a bench or other support in such a position that the crank can be operated without discomfort. Open the cover. If it is so desired, the cover can be removed by unsnapping the retaining chain and slipping the cover to the right.

When the instrument is used in a location where there is a possibility of induced voltage on the set or on the transformer being tested, the set should be grounded by a wire connected to the binding post on the instrument panel. This precaution is not often necessary.

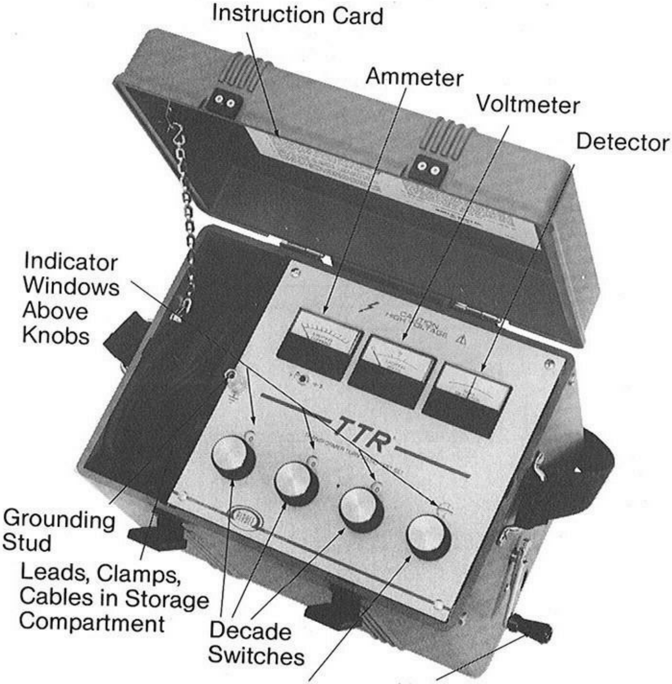


Figure 2: Various visible parts and their locations.

8. CONTROLS & CONNECTORS

Figure 3 is a simplified schematic diagram of the set. Figure 2 shows the location of the controls and connectors. Their designations and functions are as follows:

a. Crank is used to drive the ac generator which supplies all the testing power required by the set.

On line-operated models:

An autotransformer replaces the hand-operated generator.

The autotransformer setting is gradually increased from zero until 8 volts is reached.

b. Exciting Lead (X_1) **Black** is a two-conductor cable. One of these is heavy, the other light. The heavy conductor is used to connect the transformer under test to the primary of the reference transformer in the set. The light conductor brings exciting current to the junction. The light conductor is brought to the frame of a "C" clamp and is electrically connected to the screw of the clamp. The heavy conductor is brought to the anvil of the clamp which is insulated from the frame.

Note that both the screw and the anvil must make contact with the terminal of the transformer being tested.

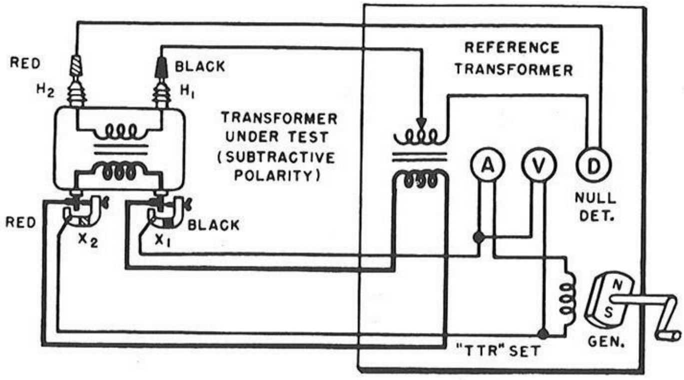


Figure 3 — Simplified schematic diagram for the TTR Set.

c. Exciting Lead (X_2) **Red** is a cable like (X_1) except for the identifying color on the clamp.

d. Secondary Lead, (H_1) **Black** is a single-conductor flexible wire much smaller in diameter than the exciting leads X_1 and X_2. It is terminated in a spring clip. This lead connects the secondary of the reference transformer in the set to the transformer under test.

e. Secondary Lead, (H_2) **Red** is a wire like (H_1) except for the identifying color on the clip insulator.

f. Voltmeter, (V) has one graduation at 8 volts and one graduation each side of 8 volts to define the proper operating voltage range. It is a moving iron-type ac voltmeter connected to read generator output voltage.

g. Ammeter, (A) is also a moving iron ac instrument connected to read generator output current. Since frequency and waveform are likely to vary during tests, the ammeter is not calibrated in amperes. Instead, the scale is arbitrarily divided into 10 equal divisions. The switch below the meter is used to increase resolution at low magnetizing currents. For a 60 Hertz sine wave current, full scale calibration is approximately 1 ampere on the normal X_1 range. The divide-by-5 range ($\div 5$) calibration is approximately 0.2 ampere at full scale.

h. Detector, (D) is a zero-center dc microammeter used to indicate magnitude and polarity of current flowing in the secondary of the reference transformer in the set. The meter is connected so that when the ratio of the transformer under test is greater than the ratio indicated by the set, the galvanometer deflects to the left. DO NOT adjust the zero of this meter except as described in Paragraph (9a).

i. First Ratio Switch (S_1) adds to the turn ratio of the reference transformer in steps of 10 from 0 to 120. The dial is marked with graduations 0, 1, 2 ---- 11, 12. Clockwise rotation of the knob increases ratio.

j. Second Ratio Switch (S_2) adds to the turn ratio of the reference transformer in steps of 1, from 0 to 9. The dial is marked with graduations 0, 1, 2 ---- 9. Clockwise rotation of the knob increases ratio as for S_1.

k. Third Ratio Switch (S_3) adds to the turn ratio of the reference transformer in steps of 0.1 from 0 to 0.9. The dial is the same as that of S_2. Rotation is the same as for S_1.

l. Fourth Dial Potentiometer (R_4) adds to the effective turn ratio of the reference transformer continuously from 0 to 0.1. The dial is divided into 100 parts and marked 0, 05, 10, 15 ---- 95. Rotation is the same as for S_1.

m. Decimal Point is located between the second and third dials to facilitate reading the ratio. To read ratio after balance is obtained, copy down first dial reading, second dial reading, decimal point, third dial reading and finally fourth dial reading. An illustrative reading; (11) (7). (3) (42½) would be written: 117.3425. (See Paragraph 12.)

n. Grounding Stud is a binding post used to connect the case of the instrument to earth if desired.

9. PRELIMINARY CHECK

Three steps are required to check the performance of the set. This procedure quickly spots trouble in the vulnerable portions of the set, the leads and connectors, the detector circuit, the meters, and the fourth dial. Should the set fail in any of these check procedures, refer to Section D, Paragraph 34.

a. Null Check: Adjust the dials to zero, (0.000). Close both X_1 and X_2 clamps so the screws seat firmly on their respective anvils. Separate the X_1 and X_2 clamps electrically and electrically isolate H_1 and H_2 clips.

Observe that all meter pointers are on zero. Crank the generator so that the voltmeter reads 8 volts. The ammeter pointer should deflect approximately 3 divisions on the ÷5 range and ½ division on the X_1 range. If any of these conditions cannot be fulfilled see Section D, paragraph 34.

b. Zero Ratio Checks: Close both X_1 and X_2 clamps so the screws seat firmly on their respective anvils. Separate the X_1 and X_2 clamps electrically. Connect the two secondary leads H_1 and H_2 together. Leave the dials at zero reading. Crank the generator so that 8 volts is indicated on the voltmeter. While cranking observe the galvanometer. If it does not read zero, adjust the fourth dial so that the meter reads zero while cranking at 8 volts. The fourth dial should then read zero within half a division. Error in the zero check affects the fourth-dial reading by the magnitude of the error. Should the error become objectionable, see Section D, Paragraph 34. This check can be made while a transformer under test is connected to the exciting leads.

c. Unity Ratio Check: Close both X_1 and X_2 clamps so the screws seat firmly on their respective anvils. Separate the X_1 and X_2 clamps electrically. Connect the black secondary lead H_1 to the black exciting lead X_1. Connect the red secondary lead H_2 to the red exciting lead X_2. Set the dials to read 1.000. Crank the generator so that 8 volts is indicated on the voltmeter. While cranking observe the galvanometer. If it does not read zero, adjust the fourth dial so that the meter reads zero while cranking at 8 volts. The set should read within ½ division of zero on the fourth dial. Reset the dials to read 0.9+ 100 on the fourth dial (1.000), again adjusting the fourth dial for zero indication (null) of the galvanometer. The set should read unity within half a division on the fourth dial. Error in unity check affects the fourth-dial reading by the magnitude of the error. Should the error become objectionable, see Section D, Paragraph 34.

This check should be made with no connections to the leads except those specified above.

10. CONNECTION

The following steps must be followed in the order given. The only real danger involved in using the TTR Set is that of accidently connecting to an energized transformer.

CAUTION!

a. Be certain that the transformer to be tested is completely de-energized. Check every winding.

b. Make certain that all terminals of the transformer are disconnected from line or load at the transformer. Connections to ground may be left in place if desired.

c. If there is energized high-voltage equipment in the immediate vicinity, ground one side of each winding and ground the TTR Set, using the binding post on the instrument panel.

d. Connect the exciting leads X_1 and X_2 to the lower-voltage winding of the two windings to be compared. Connect the H_1 secondary lead to the higher-voltage terminal which corresponds to the X_1 connection as indicated in Figure 3. Connect the H_2 lead to the other high-voltage terminal. Where both windings are grounded on one side, connect X_1 and H_1 (black) leads to the grounded sides. Always excite the entire low-voltage winding. (Read Paragraph 16 before connecting to tertiary-winding transformers or multiple coil windings.)

e. Set the TTR dials to zero and give the generator crank a quarter turn. If the galvanometer deflects to the left, the transformer connection is subtractive. The H_1 and X_1 (black) leads are then connected to terminals of the same polarity as are the H_2 and X_2 (red) leads. Proceed with balancing as in (g) below.

f. If the galvanometer deflects to the right when the transformer is connected as in (d) and tested as in (e), then the transformer connection is additive. It will be necessary to interchange the secondary leads H_1 and H_2 to properly connect the TTR Set to an additive transformer. When this is done, leads of the same color connect to terminals of the same polarity as in (e) above.

g. As soon as the transformer is properly connected, set the ratio dials at 1.000 and slowly turn the crank. Observe the galvanometer. It should deflect to the left. Also observe the ammeter and voltmeter while cranking. If the ammeter moves to full scale while the voltmeter shows no detectable movement, it is an indication that the transformer is drawing too much exciting current. If in addition, the crank is hard to turn, there is reason to suspect a short circuit at the exciting terminals or a short circuit involving a large part of the flux. Check the connections to be sure that the exciting clamps are not shorted. Try the balancing procedure of Paragraph 11. If it is found impossible to obtain a balance see Paragraph 14.

Normally, the ammeter will move up scale and the voltmeter will deflect slightly during preliminary adjustments. Upon completing the balancing operation the generator voltage is increased to 8 volts. The ammeter reading will decrease because the secondary burden reduces to zero at balance.

11. BALANCING

If when the transformer is connected as in Paragraph 10 and deflection to the left is noted as in 10g, balancing may be accomplished. **CAUTION:** Do not crank the TTR Set while anyone is touching the secondary connectors. At high ratio, 1000 volts is developed across the secondary with 8 volts on the primary. Turn the first dial one step clockwise. Crank the generator a quarter turn. Observe the galvanometer. If it still deflects to the left turn the dial further clockwise until finally one of the steps causes the galvanometer to deflect to the right upon cranking the generator. Back up one step (counter clockwise). The meter will then deflect to the left upon cranking.

Follow the same procedure with the second and third dials in turn. Then proceed to the fourth dial, turning it slowly clockwise until the meter deflection becomes small while cranking slowly and continuously. Now increase the cranking speed until the voltmeter reads 8 volts, and while cranking at this rate adjust the fourth dial so that the galvanometer shows no deflection from the null mark in the center.

12. THE RATIO

When the entire low-voltage winding is energized during test, the turn ratio may be read directly from the dials. Copy in sequence the figures showing at balance, on the first two dials. Place a decimal point next. Then copy the figure from the third dial and the reading of the fourth dial. (See Paragraph 8 m.) Note that it is only necessary to write down or call off the digits from the dial settings in the proper order.

NOTE: Fourth dial readings below 10 divisions must be copied with a zero in front to preserve the proper value. For example, a fourth dial reading of eleven divisions, (11) would be written 11 but seven divisions (7) would be written 07. The number of digits which are significant in a TTR measurement depends on the expected accuracy. In most cases the error will not exceed 0.1%. The reading should then be rounded off to four figures except when the first figure is one or two. In this case five figures should be retained. For example, if the reading is 37.3425 it would be rounded off to 37.34.

Another factor influences the practical accuracy of TTR measurements. Power and distribution transformers are wound with exact integral turn count in order to prevent excitation of parasitic iron circuits involving the tank and structural features. In order to get an absolutely accurate turn count in such a transformer it is only necessary to measure ratio to the nearest turn. The minimum turn error will occur when there is a one-turn change in the high-voltage winding. The resulting increment in ratio is equal to the reciprocal of the number of turns in the low-voltage winding. It equals the rated volts per turn of the winding divided by the rated voltage of the winding. This may be defined here as the, "Minimum ratio increment." Accuracy beyond the minimum ratio increment is unnecessary. For example a 3.5 kVA transformer having a low-voltage winding of 230 volts and a high-voltage winding of 460 volts would be expected to have approximately 200 turns on the energized winding. The minimum ratio increment is then 0.005. The ratio is 2.005 for a single turn added to the high-voltage winding.

Minimum Ratio Increment for Typical Power and Distribution Transformers

kVA	Energized Winding Rated Volts	Volts per Turn	Minimum Ratio Increment
3.5	240	1.3	.005
3.5	120	1.3	.011
5.0	240	1.6	.007
5.0	120	1.6	.013
7.5	240	2.0	.008
7.5	120	2.0	.017
25	240	4.5	.019
25	120	4.5	.037
200	2,400	15	.006
200	600	15	.025
500	2,400	27	.011
500	600	27	.045
2,000	13,900	67	.005
2,000	6,900	67	.010

Note that in all cases shown, where the low-voltage windings are energized, the increment lies between 5 and 50 divisions on the TTR fourth dial.

Thus in this case, 5 divisions on the fourth dial of the TTR Set corresponds to the smallest turn error and it is unnecessary to carry the reading to single divisions.

Minimum ratio increment may be calculated if the number of turns on either winding is known. If not, the increment can be estimated from the data tabulated on page 17 for typical transformers.

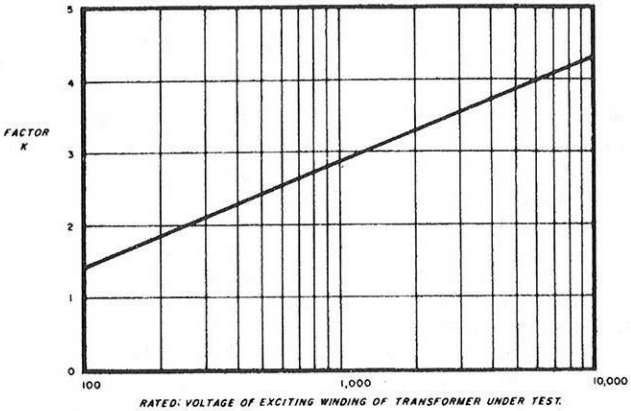


Figure 4 — Approximate values of K for use in correcting TTR readings.

13. CORRECTION

Where extreme accuracy is desired, a correction may be applied to the dial reading to compensate for the difference between turn ratio and voltage ratio for the transformer under test. This correction factor F, when applied to the dial reading N_T, gives the corrected turn ratio N_X.

$$N_X = FN_T \qquad (1)$$

The correction factor consists of two terms. The first term is a constant. The second term involves the percent impedance Z_X, the percent exciting current I_X, and a factor K which may be estimated from the curve of Figure 4 or otherwise determined as described in Paragraph 23.

$$F = .9995 + Z_X I_X K/20{,}000 \qquad (2)$$

The values of the percent quantities need not be accurately known.

For example; given a transformer with 6 percent impedance, 3 percent exciting current, and a K factor of 3, the computed correction factor F is found to be 1.0022.

14. ABNORMAL CONDITIONS

When balance cannot be obtained upon following the procedure given in Sections 10 and 11 two courses of action remain:

a. If the transformer has the same electrical design characteristics as a previously measured transformer, but will not give a balance, the trouble can usually be traced to a short or open circuit in the windings involved. High exciting current and low generator voltage indicates a short circuit in one of the windings. If there are a number of separate coils, they may be tested two at a time as primary and secondary until the faulty coil is determined by a process of elimination. For a more complete discussion of short-circuited turns, see Paragraph 15.

Normal exciting current and normal exciting voltage, but no galvanometer deflection indicates an open circuit. It is possible to determine whether the open circuit is in the energized winding or in the secondary winding. Disconnect both secondary leads H_1 and H_2. Open one of the exciting clamps and insert a piece of sheet fibre between the anvil and the transformer terminal. Tighten the screw again. Crank the generator. If the primary is open, no current will be indicated on the ammeter. If normal exciting current is indicated it can be assumed that the secondary is the open winding.

b. Where the low-voltage winding has a low rating in volts or for other reasons the exciting current is high, it may be impossible to obtain a balance when energizing the low-voltage winding. In such cases the only alternative is to energize the high-voltage winding and use the low-voltage winding as secondary. If this is done, the ratio at balance will be less than one and is properly called inverse turn ratio, since the term turn ratio specifically means the ratio of high-voltage to low-voltage and is always greater than unity. See definitions, Section E.

The TTR Set will indicate inverse turn ratios, correct to the third decimal place. For ratios near unity this is equivalent to 0.1%. For ratios of 1/10, the accuracy reduces to 1%. It will be seen that when inverse turn ratio is measured, the accuracy falls off rapidly as the ratio departs from unity.

Where a transformer is tested in this manner, the turn ratio is found by taking the reciprocal of the TTR dial reading.

15. SHORT CIRCUITED TURNS

Short-circuited turns in a transformer under test produce a load component in the primary current of the transformer and this affects the flux distribution which in turn affects leakage. The number of turns forming a short-circuit path, together with its resistance, reactance, and location all contribute to the deviation from normal primary current and ratio. In extreme cases, the result is to increase primary current beyond the capacity of the TTR generator. Where this occurs, it is impossible to secure a balance and the procedure given in Paragraph 14 should be followed. On the other hand, where a single turn is involved and the resistance of the short is high, it may be difficult to locate or identify unless the exciting current of a normal transformer of the same design is available for comparison.

In such a case, the difference in current readings between a normal transformer and a similar unit having shorted turns is equal to the ratio squared of shorted turns to total turns for the winding involved, multiplied by the applied voltage (8 volts) and divided by the resistance of the shorted path:

$$i_S - i_N = \frac{8N_S^2}{R_S N_T^2} \tag{3}$$

A test of a 50-turn primary having a single-turn short circuit showed 100% increase in primary current over the normal reading obtained with the short removed. The total resistance of the path was calculated to be .007 ohms. When this resistance was increased to 0.1 ohms there was no noticeable difference in magnetizing current with and without the shorted turn.

Shorted turns also cause a difference in turn ratio when they are located in a favorable place. A test was made using a core-type transformer with primary and secondary on different legs and having 50 turns on the primary. This was the same transformer used in the test described above. When the short-circuited turn was located on the primary side, the primary current increased 100% as described above and the turn ratio indicated on the TTR Set decreased 0.3% from normal. The same shorted turn located on the secondary leg caused the same primary current but the turn ratio decreased 2.6%.

A short circuit in an energized winding affects the flux distribution in the core section on which the winding is located. It increases the primary current by increasing the reluctance of the iron path. It does not change the total flux linking the winding and has little effect on the proportion of the total flux which fails to link the secondary. Consequently there is little error in ratio measurement when the short circuit is in an energized winding.

When the short circuit is in the secondary winding and the winding is located on a different section of core than the primary, the increased reluctance increases the primary current as before but it also decreases the total flux linking the secondary winding and this causes noticeable error in ratio measurement.

If the secondary is on the same section of the core as the primary, the core flux is common to both and it is generally impractical to determine which winding is short-circuited.

For locating short-circuited coils it is necessary to be able to energize a coil on one section of core and to use a coil on another section of core as secondary. In these tests it is unnecessary to use more than two coils on a multiple-coil transformer. The difference between shorted turns and turn error may sometimes be detected by increased cranking effort associated with shorted turns.

16. CONNECTING MULTIPLE WINDINGS

Whenever a transformer is tested for ratio in which the low-voltage winding consists of more than one coil, it is necessary to energize the entire winding in order to prevent leakage and consequent error in ratio measurement. Thus, if a core-type distribution transformer has a low-voltage winding on each leg they must both be connected either in series or parallel. Where this is not done, errors of 2% or more can be expected.

In a three-winding transformer the tertiary winding may not be preferable for excitation even though its rated voltage be lower than that of either full-load winding. If the tertiary winding is rated for less than full-load kVA it may have relatively high resistance which would make it less suitable for use as the energized winding than a full-rated winding would be.

Low-side multiple/series connections may be energized according to either connection, but all of the winding should be included. If the exciting current is relatively high the series connection may be preferred since the exciting current will be reduced by a factor of 4 as compared to the multiple connection. On the other hand, if the voltage rating is relatively high and the rated capacity low the multiple connection may be better.

On autotransformers or tapped windings when it is desired to measure the ratios of various taps in terms of the whole winding, the clamps are ordinarily attached to the extreme ends; while the clips are connected to one end and a tap, or to any two taps. The ratio will then be less than unity. For example; the ratio should be exactly 0.500 on a center-tapped winding.

In cases where a tapped section of a winding is designed to operate at full transformer capacity, the clamps may be attached to this section and the clips to the complete winding. The ratio will then be greater than unity.

17. RATIO GREATER THAN 130

Where it is necessary to measure transformer ratio greater than 130, the following method is recommended:

Connect the primary of a rational auxiliary transformer similar to the TTR Reference Transformer in parallel with the primary of the transformer under test. The secondary of the auxiliary transformer is then connected in series with the secondary of the tested transformer. With this connection the percentage error is the same as in a normal TTR measurement but the ratio is increased by the ratio of the auxiliary transformer. When an auxiliary transformer having a ratio of 200 is used, the correct ratio is given by adding this to the setting of the TTR dials at balance. Thus with such a transformer ratios up to 330 may be measured. An auxiliary transformer for this purpose is available as standard equipment with a ratio of 100/200. (See Bulletin 55).

The reference transformer of a second TTR Set may be used as an auxiliary transformer without making any changes in the set. Connect the exciting leads of one TTR Set normally to the unknown transformer. Connect the auxiliary TTR Set exciting leads to the unknown primary terminals, placing the auxiliary red lead on the same terminal occupied by the red lead of the normal TTR Set. Insulate the auxiliary generator by placing heavy fibre or other insulation between the clamp screw points and the transformer terminals. Connect one of the normal secondary leads to the auxiliary secondary lead of the opposite color. The remaining two secondary leads are connected to the unknown secondary as required for proper polarity. Set the auxiliary set ratio at 120 making sure that the fourth dial is set at zero. Proceed with balancing using the galvanometer and dials on the normal TTR Set. At balance add 120 to the reading. The sum is the ratio of the unknown transformer subject to normal TTR error. If desired, the auxiliary TTR transformer can be set at a lower or higher ratio.

Connecting a known transformer of ratio 2:1 between the secondary leads of the TTR Set and the secondary of the transformer under test is not recommended. It introduces first, an error due to loading the TTR secondary, and second, an additional set of errors similar to those in the TTR primary caused by leakage flux and primary resistance. A similar method wherein the auxiliary known transformer is connected between the exciting leads of the TTR Set and the primary of the unknown transformer is also not recommended for similar reasons.

18. POLYPHASE TRANSFORMERS

The measurement of turn ratio in an – "n" phase transformer consists of "n" single-phase measurements to determine the ratio between primary and secondary turns for each phase. Where there are more than two windings per phase, the number of measurements increases accordingly. Turn ratio is the ratio of actual turns of wire on each of two coils. It does not depend on any electrical conditions; therefore, single-phase measurement of turn ratio can be just as accurate as polyphase measurement. The problem becomes one of properly connecting the coils to be measured so that the no-load voltage ratio is very nearly equal to the turn ratio. In order to do this, the two coils to be compared must have a common iron circuit. This is true in polyphase transformers when both coils are on the same phase leg.

Where coils on different phase legs are to be compared (an unusual case), it is necessary to make certain that all the flux links both coils. In core type transformers this can be done effectively by shorting the coils on the unused phase leg.

It is also necessary for good accuracy that every portion of the secondary winding during test be intimately associated with a part of the energized winding. In concentric-type windings this condition is fulfilled when there is an energized winding covering every portion of core which is covered by a secondary winding. This requirement has been discussed before in Paragraph 16. For interleaved windings it is necessary that a primary coil be adjacent to each secondary coil.

When measuring the ratio of two coils on a single core leg of an "n" phase transformer, there are two or more return paths for the flux. For any given winding the leakage flux is proportional to current, so that reduction of magnetizing current in a winding without otherwise changing the winding results in reduction of leakage and improvement in accuracy of a TTR measurement. The lengths of the return paths, the proportion of flux using them, and whether or not the windings are energized are factors which control the magnetizing current without affecting the excited winding or the flux through it. Flux in an iron circuit without air gaps is directly proportional to the product of permeance and magnetizing force.

If the return flux path can be rearranged in such a way that the total permeance is increased, there will be an improvement in accuracy because the magnetizing current will be reduced. This can be done in general by exciting as much of the iron circuit as possible. Where the energized winding is 3-phase delta connected, this condition is fulfilled without changing connections. Where coil terminals are accessible, it will help the accuracy a little if the energized windings on a three-phase transformer are delta connected during the test providing they are not already so connected. The accuracy improvement by this method is not significant in field tests of a well-designed transformer.

In order to illustrate the technique, a few of the more common connections of polyphase transformers are discussed in detail below.

A. THREE PHASE, ALL TERMINALS ACCESSIBLE

Connect the three low-voltage windings in delta and energize one phase as shown in Figure 12 (A) of the appendix Section E. Connect the secondary leads to the high-voltage winding on that phase and measure the ratio. Repeat the measurement for the other phases. Observe the precautions described above.

In practice it will be noted that slight differences appear between turn ratio measurements on different legs, even though it can be established that the actual turn ratios in all cases are identical. This results from the different permeances offered by the return paths. For example, the return paths where an end leg is measured consist of the adjacent center leg and a remote end leg. Where the center leg is measured, the return path consists of two adjacent end legs. The magnitude of the difference is very small in well-designed transformers.

B. THREE PHASE, DELTA-DELTA

The low-voltage winding of a delta-delta transformer need not be disturbed for ratio tests. It may be necessary to open the high-voltage delta to avoid circulating currents. Figure 12 (B) shows the connections for this transformer. Note that the exciting-voltage connection must be changed for each phase tested, as well as the secondary connections. This was also necessary in the transformer of Figure A, as shown on the diagram.

C. THREE PHASE, STAR-STAR

Both neutrals must be accessible if the turn ratio of coils is to be measured. It is also possible to measure turn ratio if the neutrals are common and accessible. The neutral may be considered to be accessible if it is grounded, but care should be taken in making this type of measurement. The ground path from the X lead to the winding offers resistance which will affect the accuracy of ratio measurement. This ground-path resistance should be made as low as possible. For example, if a transformer has a neutral grounded to the station ground, it is not sufficient to connect the X clamp to the nearest available grounded metal. It should be brought as near as possible to the actual coil junction even though this involves some extra trouble. Figure 12 (C) shows representative connections for a Star-Star ratio measurement on A phase. Other phases are measured in a similar manner.

D. THREE PHASE, DELTA-STAR

Where the low-voltage winding is delta connected and the high-voltage winding is star connected, and the neutral is accessible, turn ratio may be measured as shown in Figure 12 (D) which represents a measurement of A phase. Note that the turn ratio is not the voltage ratio in this type of transformer.

E. THREE PHASE, STAR-DELTA

Figure 12 (E) shows connections for testing a transformer having a star-connected low-voltage winding and a delta connected high-voltage winding. Phase A is shown excited, but as in the other cases, measurement of the other legs is done similarly. It may be necessary to open the delta to avoid circulating current.

F. THREE PHASE, DELTA-STAR, NEUTRAL INACCESSIBLE

If the neutral on a high-voltage star-connected winding is inaccessible, satisfactory ratio measurements may be made using the connection of Figure 12 (F). In this connection the return for the H_1 lead is obtained through a coil on another phase leg and flux through this leg is reduced to zero by short circuiting the primary or energized winding on the leg with a low-resistance jumper. With no flux there is no voltage introduced in the secondary circuit, and the only error possible is due to the added resistance of the winding which, in the secondary circuit, is negligible.

G. SIX AND TWELVE PHASE TRANSFORMERS

Transformation from three-phase to six-phase, and from three-phase to twelve-phase is accomplished by a transformer having a three-phase primary and a number of secondary coils on each leg which are interconnected in various ways. In the simplest of these, there are two secondary coils on each leg. One coil from each leg is connected in a three-phase delta or star and the other coils with polarity reversed are also connected in the same configuration. Ratio measurement of such transformers follow the same methods used on conventional three-phase units. Figure 12 (G) shows a representative case, three-phase to six-phase double-star connection. It is assumed that the neutral is not accessible and that each pair of coils is connected internally together and to neutral. Measurement is shown for Phase A, coil 2 as secondary. Note that as in case F, the return for one H lead is through a coil on a leg having its primary short-circuited.

H. DOUBLE-ZIG-ZAG, OR FORKED-Y

Where three-phase is transformed to six- or twelve-phase current by double-zig-zag or other complicated connection, the measurement of turn ratio is not possible unless both terminals of each secondary coil are accessible either directly, or through a coil on a different phase leg which can have its flux reduced to zero by a short-circuited winding (usually the primary). An example of a double-zig-zag connection which permits measurement is shown in Figure 12 (H). Note that any secondary coil can be reached by connecting through a coil on a short-circuited leg. This leaves all other secondary coils open. The same principle applies to a quadruple zig-zag connection.

Where the zig-zag winding is the lower-voltage winding, it will be impossible to excite the winding properly unless all junctions are accessible. In cases where this is not so, the only alternative is to energize the normal primary and measure inverse turn ratio.

19. COUNTING TURNS

Although the TTR Set normally measures only turn ratio, it is possible to obtain an accurate turn count using the set. In order to do this, it is necessary to wind a number of turns of fine wire on the core adjacent to, or on top of the existing winding. If this cannot be done, a turn count cannot be made. To make such a measurement, wind a known number of turns, "n" as specified above. Connect these in series with the winding used as secondary during TTR tests, and measure turn ratio N_a. Remove the added turns and measure ratio N_b. Subtract the smaller of these readings from the larger to obtain the ratio increment N_d. The number of turns on the energized primary winding n_1 is found from the equation:

$$n_1 = \frac{n}{N_d} \tag{4}$$

This equation involves the difference of two readings in such a way that the accuracy of the computed turn count depends on the number of turns added. For highest accuracy it is recommended that the number of turns added be at least 5% of the secondary turns. For comparative measurements at ratios exceeding unity, the values of N_a and N_b can be relied on to plus or minus 0.01% for purposes of turn counting.

Section C

THEORY OF OPERATION

20. TRANSFORMER TURN RATIO

All electrical measurements of transformer turn ratio depend on an assumption that the no-load voltage ratio of the transformer being tested is equal to the ratio of turns, or that the turn ratio can be calculated from the no-load voltage ratio.

Power and distribution transformers in general are so designed that the no-load voltage ratio as tested on the TTR Set is equal to the turn ratio within 0.1%, or to within 1 part in 1000. Thus the TTR Set measures turn ratio.

In all transformers, the no-load voltage ratio is less than the turn ratio.

An understanding of the reasons for this is essential to successful use of the TTR Set. Any good book on transformer design will describe in great detail the theory set forth below. An excellent text is "Magnetic Circuits and Transformers" by members of the staff of the Department of Electrical Engineering, Massachusetts Institute of Technology; published by John Wiley & Sons, 1957. In this book, Chapters VI, XI, XII, XIII, are of special interest.

Figure 5 shows an equivalent circuit diagram representing a distribution transformer with no load.

In this diagram, the transformer T is an ideal transformer having the same voltage ratio as the turn ratio N of the distribution-transformer winding, and drawing no exciting current. The terms B & G represent susceptance and conductance to account for exciting current I. Note that the turn ratio equals V/E and that the no-load voltage ratio is V/Vo. The discrepancy between turn ratio and no-load voltage ratio is seen to be a voltage drop caused by the exciting current flowing through the primary resistance R and the primary leakage reactance X.

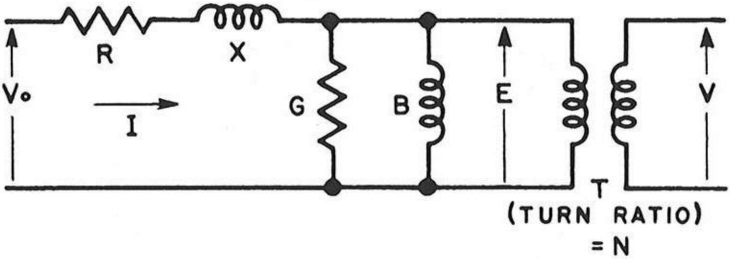


Figure 5: An equivalent circuit diagram for a distribution transformer with no load.

In order to evaluate the voltage difference between Vo and E, it is necessary to know the values of primary resistance R and primary leakage reactance X. The current I can then be determined exactly if the conductance G, susceptance B and voltage Vo are known. At the rated condition of operation, all the above values are known or can be calculated from transformer tests reports. Unfortunately, transformer winding characteristics are not strictly linear. As a result, the values which are represented by G, B, and I vary with the flux density in the transformer core. The values R and X do not depend greatly on the core flux; therefore they remain essentially constant. For purposes of estimating difference between Vo and E, these quantities R and X may be evaluated from test report data. Since such test data are the only convenient sources of values for G, B and I, it will be necessary to know how these values vary as the applied voltage is reduced from the rated value to the value at which the measurement is made. This variation can be shown in a general way by studying the characteristics of the iron used for the core of the transformer. In modern power and distribution transformer practice, manufacturers use steels of several thickness and several compositions. These vary in magnitude of core loss and in maximum permeability but not significantly. Furthermore, the shape of the core-loss curve with flux density is nearly identical for all transformer steels commonly used. Also, the magnetization curve has the same shape. These steels have a silicon content of approximately 4%. A representative steel of this group is U.S.S. – 72, 29 ga.

If the effects of hysteresis and eddy currents can be sufficiently described by conductance G, the current I_B flowing through susceptance B will have a relation to the voltage E that is described by a curve having the same shape as that of the normal magnetization curve of the steel. Since the ratio of the coordinates, Gauss/Oersted for the normal curve is given by the permeability, the ratio E/I_B or $1/B$ is equal to the permeability multiplied by a factor to take into account the scale change resulting from the change of coordinates. Figure 6 shows a magnetizing curve for a hypothetical transformer based on the normal magnetization curve for U.S.S.–72, 29 ga. transformer steel. From permeability data on this steel, the value of B is calculated for various voltages. It has been assumed that there is a flux of 10,000 gauss when the instantaneous value of the voltage E equals the rated rms value. Figure 7 shows values of B plotted against voltage E.

Core loss curves for the same steel can be used to compute relative values of G at various voltages, assuming voltage and flux are proportional. These can be transformed to absolute values if the value of G is known at rated voltage. From the core loss in watts/lb. at various flux densities, a quantity, watts/(kilogauss)^2/lb. can be computed. This gives the relative value of G. An adjustment to absolute values can be made by multiplying all values by a factor which makes the value at rated flux equal to the rated G. Figure 7 shows a computed curve for the values of G plotted against voltage E. It has been assumed from data on an actual transformer that the values of G and B are equal at about 50% rated voltage.

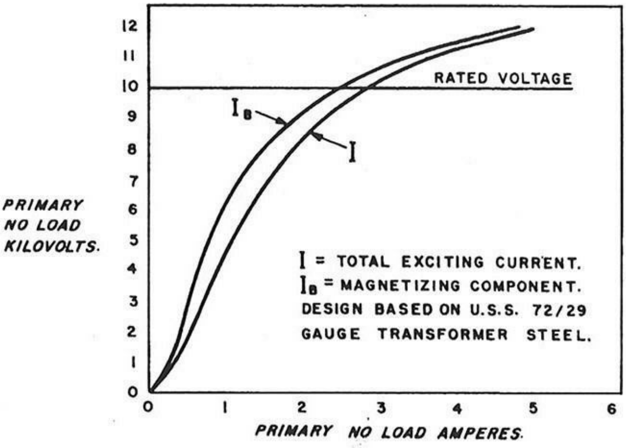


Figure 6: A Transformer magnetizing characteristic.

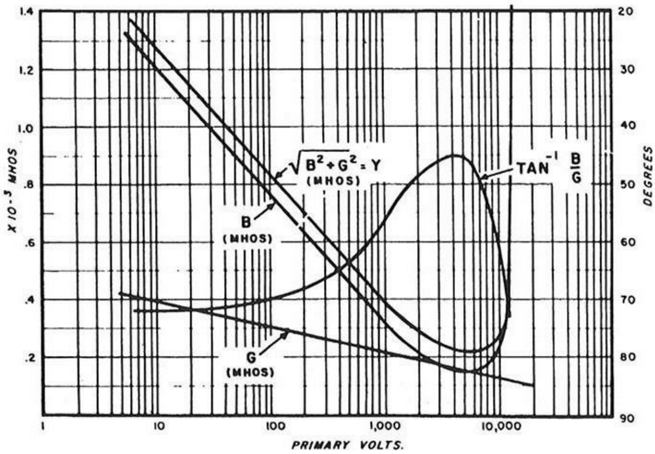


Figure 7: Values of G, B and Y for a representative transformer design.

The exciting admittance Y has a magnitude given by $\sqrt{(G^2 + B^2)}$ and an angle whose tangent is B/G. The ratio of the exciting admittance at any voltage to the exciting admittance at rated voltage is important in the analysis to follow. It is defined here as K. The phase angle a is also important since it has the same value as the phase angle of the current I; that is, if we assume Vo and E are very nearly equal.

Figure 7 also shows magnitudes and angles of the exciting admittance plotted against Vo for the hypothetical transformer discussed above. It should be noted from these curves that the most important factor in the exciting admittance is the magnetizing component B. Most transformer designs are based on a rated voltage such that the exciting admittance at this voltage is part way up the rising part of the characteristic curve. With this in mind it will be seen from the curves that the value of K may vary from .5 to 5 or more as the rated flux density changes and as the test voltage becomes less than the rated voltage. For the hypothetical transformer rated at 10kv and tested at 8 volts with the TTR Set, the ratio K is 4.7. The phase angle of the exciting current is about 72 degrees at 8 volts.

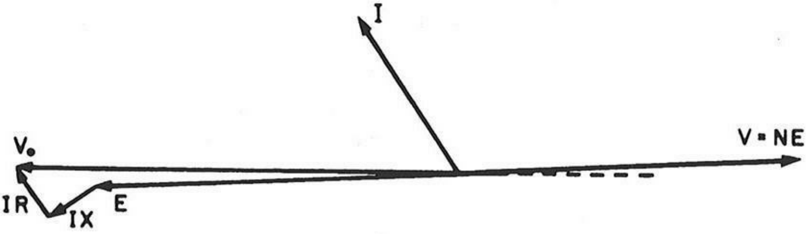


Figure 8: A vector representation of voltages in a distribution transformer with no load (not to scale).

Figure 8 is a vector representation of the voltages and currents shown in the equivalent circuit of Figure 5. This diagram is not to scale. If the transformer were drawing full load current, the magnitude of the IR drop would be about 0.3% of the voltage Vo in a typical distribution or power transformer. The IX drop would be greater, approximately 3%. Since in such a transformer at rated voltage the exciting current is in the order of 3% of the full load current, the voltage drops above should be multiplied by .03 to obtain the correct values for unloaded conditions. The IR drop then is only .009% of Vo and the reactance drop IX is .09%. The impedance drop IZ would have essentially the same value as the IX drop in this case, (.09%).

It can be seen from this that the value of E for a typical distribution or power transformer with no load on the secondary is practically in phase with Vo and equal in magniture to Vo within 0.1%. Therefore, the no-load voltage ratio of a typical distribution or power transformer is equal to its turn ratio within one part in a thousand. The hypothetical transformer used in this discussion can be assumed to have similar characteristics.

The iron used in the reference transformer is a high permeability alloy chosen for its ability to provide low exciting current.

21. COMPARING TURN RATIO

When the TTR Reference Transformer and an unknown transformer are excited from the same source, the input voltage Vo is the same for both transformers and the voltages can be represented by the vector diagram, Figure 9.

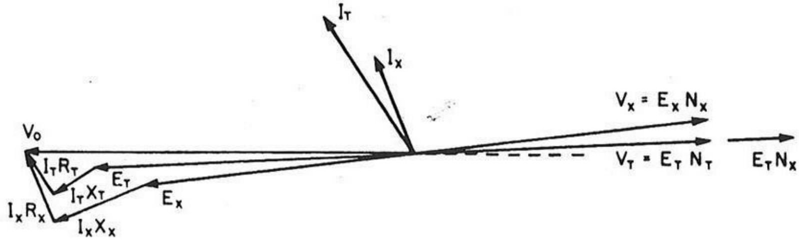


Figure 9: The vector representation of the voltages affecting balance during a TTR measurement (not to scale).

In the diagram, values representing the Reference Transformer are designated by subscript T, and those representing the unknown transformer are designated by X. Although Vo is a common voltage, the reference and unknown transformers have different constants so that in general, E_T and E_X will be different. Note that the difference between E_T and E_X will always be less than the difference between E_T or E_X (whichever is smaller) and Vo. Also note that it is easily possible for the difference to be nearly zero.

The primary induced voltages of the two transformers are slightly different as shown above. If the transformers both have the same turn ratio, the secondary voltages will be different by the same percentage. Compare E_X N_X with E_T N_X.

In the TTR Set, the secondary voltages are made equal by connecting the unknown secondary in series bucking with the Reference Transformer secondary and by adjusting the TTR turn ratio N_T until no current flows in the secondary circuit as evidenced by the detector galvanometer. At this point, the TTR indicated ratio N_T differs from the true turn ratio of the transformer N_X by the same percentage error that separates E_X and E_T. In the case of the typical distribution or power transformer, the error in turn ratio might be as low as .05%.

It can be seen from the above analysis that where an unknown transformer has the same characteristics as the Reference Transformer, the error in turn ratio is zero. It is for this reason that the TTR Reference Transformer was designed to match the average distribution and power transformers.

It also can be seen that where transformers have large leakage reactance, high magnetizing current, high primary resistance, or combinations of these, there will be introduced an error in the measurement of turn ratio. This error is not peculiar to the TTR method, but is present in any electrical measurement of turn ratio.

22. NULL DETECTION

In the previous discussion it has been tacitly assumed that the difference between Vo and E_x involved magnitude only. This is essentially true since in most transformers the vectors representing Vo and E_x are practically parallel. In any complete discussion of ratio measurement, phase angle must be considered. Before discussing how it affects the TTR Set, consider the null detector.

A synchronous rectifier is used for obtaining a dc signal proportional to the secondary alternating current. Since the particular rectifier used in the TTR Set will be described completely in Paragraph 28, only its important characteristics will be given here. The device has two inputs and one output. One input is a reference voltage of the same frequency as the signal to be detected and in phase with the desired component of the unknown signal. The second input is the unknown signal to be detected. The output is a dc current proportional to that component of the unknown signal which is in phase with the reference voltage.

The synchronous detector rejects signals that are 90° out of phase with the reference voltage. It also gives a negative dc current when the signal is 180° out of phase.

If the reference voltage is in phase with the supply voltage Vo, null indication by the synchronous rectifier results when the in-phase components of E_X N_X and E_T N_T are equal.

With this concept, it will be helpful to reread Paragraph 21 bearing in mind that E_X and E_T are effectively the components in phase with Vo.

A study of Figure 9 will show that where E_T and E_X are very nearly in phase with Vo, the only factors seriously affecting the accuracy of the turn ratio are the $I_T Z_T$ and $I_X Z_X$ drops, the difference between these being essentially the error. All the other factors are second order effects.

In that case a good approximation for the error is:

$$\frac{N_X}{N_T} - 1 = \frac{I_X Z_X - I_T Z_T}{V_O} \quad (5)$$

In the above expression:

$$Z_X = \sqrt{(R_X{}^2 + X_X{}^2)} \quad (6)$$

$$Z_T = \sqrt{(R_T{}^2 + X_T{}^2)} \quad (7)$$

23. ERROR IN MEASUREMENT

More rigorously, the error in turn ratio may be defined as the difference between the in-phase components of E_T and E_X divided by Vo.

$$e = \frac{\mathrm{Re}\, E_T - \mathrm{Re}\, E_X}{Vo} \quad (8)$$

In this equation, the abbreviation Re is used to denote the real component; i.e., those components in phase with Vo. Likewise the abbreviation Im can be used to denote the imaginary components; i.e., those components of E_T and E_X which are 90° out of phase with Vo.

The error can be evaluated by properly combining resistance and reactance drops in accordance with the vector diagram Figure 9.

$$e = \frac{\mathrm{Re}\, I_X Z_X - \mathrm{Re}\, I_T Z_T}{Vo} \quad (9)$$

The true turn ratio is then:

$$N_X = (1 + e)\, N_T \quad (10)$$

As was shown in Paragraph 20, the phase angle of the exciting current in a transformer may vary from about 70° to 45°. The real component of impedance drop is proportional to the cosine of the difference between the angle of lag of the exciting current and the angle whose tangent equals X/R. This latter angle is in the order of 80° for most power and distribution transformers. From this, the real component of impedance drop is proportional to the cosine of an angle lying between 10° and 35°, or from 98% to 82% of the magnitude. If the magnitude of the impedance drop is taken as equal to its real part, the resulting calculations of error will be too great by a factor which will never exceed 1.22. This leads to the same expression for turn ratio obtained by preliminary study of the vector diagram:

$$N_X = \left(1 + \frac{I_X Z_X}{Vo} - \frac{I_T Z_T}{Vo}\right) N_T \qquad (11)$$

For the Reference Transformer the value of $I_T\ Z_T/Vo$ is known to be approximately 0.0005. For the transformer to be tested, the value $I_X\ Z_X/Vo$ may be approximated by multiplying the percent exciting current by the percent primary impedance and dividing by 10,000. The value obtained must be further multiplied by the factor K obtained by estimate or by calculation from the known characteristics of the transformer and the methods described in Paragraph 20. It is not expected that the value of K will exceed 5 for a power or distribution transformer of modern design. In the hypothetical transformer discussed in Section 20, the exciting current might be 3% and the impedance 3%. The value for K has been estimated as 4.7%. If we let percent exciting current be represented by i_x and percent impedance be represented by z_x, then the equation for turn ratio becomes:

$$N_X = \left(.9995 + \frac{i_X z_X \quad K}{20{,}000}\right) N_T \qquad (12)$$

Where the percent primary impedance is taken as one half the percent impedance Z_X.

For the typical transformer we have,

$$N_X = N_T\,(.9995 + 3 \times 3 \times 4.7/20{,}000) = (.9995 + .0021)\,N_T$$

$$N_X = 1.002\ N_T \qquad (13)$$

The factor K depends a great deal on the ratio between the rated voltage of the excited winding of the transformer being tested and the TTR voltage. In general the value of K will change uniformly from 5 to unity as the rated voltage of the transformer decreases toward 80 volts. It may go as low as .5 when the voltage approaches 8 volts. Transformers of such low rating do not usually require tests of percent impedance and percent magnetizing current and in that case these values will not be readily available and prediction of error is not possible.

A rough approximation of values of K is made from the data in Figure 7 and the values are plotted against the rated voltage of the excited winding in the transformer under test. See Figure 4 in Section B.

If it is possible to measure the exciting current drawn by the transformer under test at 8 volts by some suitable meter, the value of K may be computed as follows where I_X is the measured current and Io and Eo are the rated values for the transformer under test.

$$K = \frac{E_O I_X}{8 I_O} \qquad (14)$$

24. THE TTR CIRCUIT

Figure 10 appendix, is a schematic diagram of the TTR Set. This shows the circuit which is used to compare the turn ratio of an unknown transformer with the TTR Reference Transformer.

As will be seen from the diagram, the output of a hand-cranked, permanent magnet generator is connected to the low-voltage winding of both transformers through the clamps X_1 and X_2.

A part of the generator output is also connected through an isolating transformer to the reference terminals of the synchronous rectifier.

The input terminals of the synchronous rectifier are connected in series with the secondary of the Reference Transformer and the secondary of the unknown transformer through the clips H_1 and H_2. Since the generator voltage is applied to both transformer primaries at the same point, the input voltages are identical. This is the first condition for comparison as shown in the vector diagram of Figure 9.

The comparison is based on an assumption of no current in the secondary circuit. This is true in the circuit used when the detector current is zero.

A third requirement for comparison is that the in-phase components of the secondary voltages V_T and V_X are equal. This is accomplished in the set by connecting the two windings in series bucking. Then when the secondary current is zero, the two voltages are equal.

In the TTR Set, the various components require specific characteristics to fit them to the needs of the circuit above. The components are described in Paragraph 8 of Section B. Their functions will be described below.

25. THE GENERATOR

The generator winding resistance is approximately one ohm. It will supply 8 volts to a half-ampere load at 60 Hertz when cranked at a speed of approximately 120 rpm.

26. REFERENCE TRANSFORMER

In order to reduce the primary impedance in the Reference Transformer, the primary is wound with the largest wire that can be handled in the space available. There are 90 turns in the primary coil.

The core is made of a high permeability alloy in order to provide the lowest exciting current for a given weight.

The secondary winding consists of 32 sections on the core.

The first 12 sections of the secondary are wound with 900 turns each. They are connected in series with the other connected turns of the secondary by the first decade switch. Each step adds an increment of 10 of the total ratio connected.

Sections 13 to 21 have 90 turns each. These are connected as described to the second decade switch. They provide nine additional steps. Note that each section corresponds to an increment of one in the turn ratio since the turns per section are the same as the primary turns per coil.

The next nine sections consist of nine turns each. They are connected in series with the third decade switch. They provide nine additional steps. Note that each section corresponds to an increment of 0.1 in the turn ratio since the turns per section are 1/10 of the primary turns per coil.

The last section consists of 11 turns. These are connected in series across the fourth dial potentiometer R_{11} and its series trimmer resistance R_9, R_{10} and R_3. The value of R_3 is so adjusted that the voltage output of R_{11} is 0.1 times the primary voltage when R_{11} is set so that its dial reads full scale (100). This provides a continuously-adjustable voltage electrically equivalent to turn ratio within 0.1%. The value of R_{11}, R_9, R_{10} and R_3 in series is large enough so that there is negligible loss of accuracy caused by loading these sections of the winding.

27. CLAMPS

In order to obtain the best accuracy in measurement of turn ratio, it has been found that the resistance in the primary circuit of both test and reference-transformer must be as low as possible. This would occur when the two primaries are connected in parallel with no interconnecting leads. The applied voltage would be connected to the junction. This is impractical in a test set of this type. For convenience, there must be leads at least 10 feet long connecting the TTR Set to the transformer under test. With this requirement two possibilities for excitation appear. The input voltage can be applied at the reference transformer terminals, in which case the resistance of the X leads is added to the resistance of the transformer under test. As an alternative, the input voltage can be brought out to the terminals of the tested transformer on separate S leads and connected there. In this case, the resistance of the X leads is included in the primary of the reference-transformer. Since most transformers to be tested with the TTR Set have larger copper and hence lower resistance in their primary than the reference-transformer, the percentage increase in primary resistance for any given X lead resistance is lowest when the leads are connected in the reference-transformer primary circuit.

In the TTR Set the lead resistance is made very low with respect to the reference-transformer primary and the circuit is arranged so that this resistance is in the reference transformer circuit.

The X leads each consist of a heavy conductor, No. 8 AWG stranded, which connects the tested transformer primary to the reference-transformer primary; and a light conductor, No. 18 AWG, stranded which brings excitation voltage out to the tested transformer-terminals. The light conductor is referred to as S lead.

The clamps are designed with insulated anvils to which the heavy X leads are connected. These anvils are pressed into the tested transformer terminals when the clamp screws are tightened.

The S leads are fastened to the frame of the clamp. With this arrangement, if there is a poor contact between the screw and the tested transformer the contact resistance will be in the generator circuit. If there is poor contact between the tested transformer terminal and the anvil, the contact resistance will appear in the reference-transformer circuit where it has less effect on accuracy! In no case will contact resistance appear in the primary circuit of the transformer under test.

To reduce contact resistance in the reference transformer circuit, the anvils are provided with four hardened steel points which are designed to bite through the film of oxide, dirt and grease usually found on terminals in the field.

28. SYNCHRONOUS RECTIFIER

A synchronous rectifier differs from an ordinary rectifier in that it rectifies only the signals which are in phase with some applied reference signal. A rotating switch or commutator is a synchronous rectifier. The reference signal is in effect the rotation of the commutator shaft. It has a frequency corresponding to the speed of rotation and a phase position corresponding to the position of the switching action on the circle of rotation. Synchronous rectifiers require a reference signal of the same frequency and phase as the signal to be detected. Conversely, a synchronous rectifier is selective to signals of the same frequency and phase as the reference voltage. A completely electric synchronous rectifier can be made from a modulator bridge and a resistor network as shown in the circuit diagram Figure 10 appendix. A modulator bridge consists of four rectifiers connected in a ring or bridge arrangement. It differs from the common bridge rectifier in that the direction of maximum conductivity for each unit is in the same direction around the ring. The addition of the resistor network enables the circuit to be used as a synchronous rectifier. The same network is used in communication circuits as a modulator and de-modulator. It is from this use that the rectifier bridge takes its name.

The effectiveness of the synchronous rectifier depends on the non-linearity of the component rectifier cells. Solid-state rectifiers are used in the TTR Set. When low voltage (10 millivolts) is applied to these cells in either direction the current is nearly the same and is very small, less than a microampere. If the applied voltage is increased to 200 millivolts or more, the current in one direction (forward) will be large, in the order of two milliamperes. If this voltage is applied in the reverse direction, the current will be much lower, in the order of a few microamperes. When a cell is carrying high current in a forward direction, the change in current resulting from a small change in voltage is greater than one would expect. The ratio of the increment of voltage to the increment of current is known as the incremental resistance of the cell. This is a function of the forward current. It is also independent of the direction of the increment (increase or decrease) as long as the amount of the increment is small with respect to the total voltage applied to the cell. In the cells used, the incremental resistance when the cells are carrying two milliamperes is in the order of 15 ohms.

Consider one half-cycle of current from the output of the isolation transformer into the synchronous rectifier. This reference current splits at R1 between R4 and R5. Exactly half of the current travels through R5, rectifier cell CR1D, R8 and back to the isolation transformer. The remainder travels through R4, rectifier CR1B and R7. Practically no current passes through cells CR1A and CR1C because they are so oriented as to block in the direction of the applied voltage. Because of the symmetry of the components which causes the exact split in current, the voltage drops in R7 and R8 are equal and in the opposite direction.

Their resultant voltage applied to the detector is zero. The cells CR1D and CR1B are carrying a relatively high current, however, and this has an effect on signals applied to the outer ends R4 and R5. If this signal is in phase during the same half cycle of reference voltage discussed above, the signal current will pass through rectifier CR1B, through the detector from plus to minus, back through rectifier CR1D, to the terminal at R5. If the signal is small as is the case when the TTR Set approaches balance, it will add a small increment to the current in Cell CR1B and subtract a small increment from CR1D. The incremental resistance of each of these cells will be determined by the reference current, not by the signal current. In this case it will be approximately 15 ohms per cell.

Thus during one half-cycle, the in-phase signal follows a path through the detector in a positive direction, the path having a resistance equal to twice the cell incremental resistance plus the detector resistance (30 + 130 = 160 ohms). There is also a shunt path equivalent to approximately 1400 ohms across the signal-input terminals comprising the series parallel connection of R1, R5, R4, R7 and R8. There is also some current lost through the back resistance of the cells CR1A and CR1C but this is negligible in this equipment.

During the second half-cycle, the reference current is in the opposite direction. Rectifiers CR1D and CR1B now are blocking and the reference current occurs in cells CR1A and CR1C. The conducting rectifier cells may be compared to closed switch contacts while the non-conducting cells act as open contacts. With this in mind it will be seen from the schematic diagram that each time the reference current reverses, the bridge elements R5, R4, R7, and R8 are switched from one configuration to another in which the positions of R5 and R4 are reversed. This changes the bridge with respect to the signal. The signal voltage must also reverse during the second half-cycle. This causes a current from the outer end of the R5 through rectifier CR1C, through the detector from plus to minus, and back through rectifier CR1A to the terminal at R4. Since both bridge and signal are reversed each half-cycle, they compensate so that the detector current is unidirectional. The detector receives a positive current for each half-cycle when the signal is in phase with the reference current and smaller than it in value. The network acts as a full-wave rectifier which offers a series of 30 ohms to small signals.

As the signal approaches the level of the reference current, which occurs at gross unbalance in the TTR Set, all four rectifier cells begin to conduct during each half-cycle. Two distinct actions result. First, the rectifiers form a shunt with lower and lower resistance. Second, as the conductivities of all cells approach equality, there is an approach to bridge balance which eventually results in no detector current. Theoretically this will not occur until the signal current is many times the reference current. Actually, it may not even happen then since the balance of the bridge may not be maintained at such high currents as would be required (20-30 milliamperes). Although the detector current may not reach zero as the signal increases, there will be a definite reduction in current as the signal exceeds the reference level. In the TTR Set the reduction in sensitivity at gross unbalance is negligible.

29. ISOLATION TRANSFORMER

None of the electrical component wiring is connected to the case of the TTR Set. The generator and transformer windings are free to assume any potential.

This is done so that any terminal of a transformer under test may be grounded without imposing any restrictions on the operator as to connection and operation. In some instances more than one winding may be grounded. The case of the TTR Set is frequently connected to ground through a ground terminal on the panel. Often it is practically at ground potential by virtue of actual contact with metal transformer cases or similar grounded metal. In such instances, there may develop a high voltage between parts of the secondary winding and the case. In other instances, when there are no ground connections, high voltages may be developed between the secondary and primary or between the secondary and other parts of the circuit. This voltage is as great as 1000 volts RMS at high ratio. The entire secondary circuit is adequately insulated from the primary and generator circuit for this voltage.

The isolation transformer is used to insulate the detector circuit (secondary) from the generator circuit (primary). This isolation is also necessary in order that the synchronous-rectifier network shall not be unbalanced by a low impedance connected from one signal terminal to one reference terminal.

Section D

MAINTENANCE INSTRUCTIONS

30. GENERAL

The TTR Set is sturdily constructed to withstand the requirements of field use. Aside from "good housekeeping" practices, no special attention is required. Factory inspection including lubrication of the generator is recommended at intervals of approximately 5 years. An adequate schedule of inspections will insure satisfactory performance. The schedule below illustrates a suggested program. Note that there are three degrees of inspection:

Inspection Schedule

Field Inspection – Monthly
Shop Inspection – Every 12 months
Factory Inspection – Every 5 years

31. FIELD INSPECTION

This inspection requires no tools. Examine the case for damage. Check the condition of the carrying strap and the rubber feet. Crank the generator to be sure it turns easily and listen for signs of excess noise in the gear drive. Open the case and check the meters, control knobs and dials. Inspect the test leads and clamps. Be particularly careful in examining the leads. It is often possible to detect a broken lead before all the strands are broken. Perform all the check steps shown on the instruction sheet in the cover of the set. During these tests observe the operation of the meters and controls in order to be sure that they are operating smoothly.

32. SHOP INSPECTION

Shop inspection should include all the above listed steps plus some additional ones which will require a set of screw drivers: a standard screwdriver with quarter-inch blade, and a small screwdriver having a blade less than an eighth-inch wide.

After performing the steps listed in Paragraph 31, remove the main mounting plate assembly from the case as follows: Remove the four screws holding the instrument panel assembly in place and remove the assembly by grasping the grounding stud and the edge of the panel. Next, loosen the screws holding the generator cable terminals. Lift the assembly out.

Examine all solder joints on the instrument panel and main mounting plate. Look for corrosion and for evidence of fractures. Examine all insulation for damage by heat, moisture or fungus. Be sure that all screws and nuts are tight. Inspect the switch wipers and contacts. Lubricate these with a little high grade petrolatum after cleaning off all dirt and corrosion. Clean the case and the sub-assemblies and reassemble the set. Make certain that all cables are properly connected. After reassembly, repeat the check procedure.

33. FACTORY INSPECTION

When necessary to have work done other than that described above, it is recommended that the set be returned to the factory. The delay caused by the need for scheduling can be reduced if notice is given when the set is to be returned. Write to the attention of the Repair Department, Biddle Instruments, at least a week before the set is shipped. Indicate whether the set is being returned for inspection or whether there is some trouble to be corrected. Describe the trouble as completely as possible.

In case emergency repairs are to be made at the factory, send the set first and follow as soon as possible with the complete information.

It is recognized that there will be times when it is desirable to make emergency repairs in the field rather than return the set to the factory. If this must be done, read the following paragraphs.

34. TROUBLESHOOTING

The steps a, b, and c of the preliminary check procedure, Paragraph 9, are the three first steps to take in locating trouble. These are:

a. Null Check: There may be instances where mechanical wear, or more rarely an electrical failure, may cause the TTR Set to be inaccurate or inoperative. Self-checking features of the TTR Set (see paragraph 9, section B) will normally indicate when a defect exists, and such tests can help to isolate the defective component so it can be repaired or replaced.

b. To isolate a faulty component, arrange the TTR Set for a null check in accordance with paragraph a, above. Failure to obtain a voltmeter reading by this check may indicate a faulty generator, a defective voltmeter, a defective ammeter or a wiring defect. Reference to the wiring diagram in Figure 11, and the use of a volt-ohmmeter, is usually sufficient to isolate or identify defects of this type. If in the null check a speed in excess of 120 rpm is required to produce the normal 8 volts, indications are that an abnormal burden on the generator exists or that the generator itself has become demagnetized (see paragraph 39). If in the null check the generator cranks hard, or if the ammeter indicates current, there is obviously a short circuit somewhere in the generator output circuit up to and including the X_1 and X_2 clamps.

c. Finally, if the null detector reading is not within tolerance the synchronous rectifier may be out of balance or defective, (see Paragraph 36). Follow the set-up of Paragraph 34b, except that no sample should be connected. While cranking at 8 volts, observe the ammeter which should read at about 1/5 division deflection. When the $X_1 - X_2$ clamps are short-circuited, the ammeter should read full scale and the voltmeter should be essentially at zero. Generator cranking should become hard for this test, and no attempt should be made to crank at a speed greater than about 20 rpm. These tests check the integrity of the ammeter circuit, and should, with the guidance of the schematic diagram in Figure 10, permit the isolation of defects between the generator and the sample primary connections. If, during the performance of the test under Paragraph 34b the fourth dial error is objectionable, the synchronous rectifier may be out of balance or defective. In this case, see Paragraph 36.

The test under the above paragraph also serves as a spot-check on the reference transformer in the TTR Set, provided the synchronous rectifier is known to be well-balanced and of normal sensitivity.

In order to perform a complete calibration check, the TTR Set must be returned to the factory or checked against a field reference standard. Biddle offers Catalog No. 550050, a special standard for this purpose. Each reference standard is furnished with a Calibration Certificate of turns ratio accuracy which is traceable to the National Bureau of Standards.

35. DETECTOR

The galvanometer used for the detector has a resistance of 130 ohms and a sensitivity of 200-0-200 microamperes. For checking, connect a battery in series with a resistor across the meter. The value of the resistor is obtained by dividing the battery voltage by the meter current, 200 microamperes. For a 1½-volt flashlight cell, a resistance of 7000 to 8000 ohms should give approximately full scale deflection.

36. SYNCHRONOUS RECTIFIER

The synchronous rectifier can be accurately balanced and its sensitivity checked by following the tests and adjustments given below. If at any point it is not possible to achieve the stated results it is to be assumed that a component has failed and must be isolated and replaced. Normally a defective rectifier should be eliminated by replacement. Recommended steps for checking out the synchronous rectifier are as follows (Ref. wiring diagram, Figure 11):

1. Set all dials to zero.
2. Locate the three potentiometers, R1 (upper) 1000 ohms; R2 (middle) 50 ohms; and R3 (lower) 50 ohms. These are accessible through an opening located in the partition that forms the lead compartment.
3. Close the screws of the X_1 and X_2 clamps on their respective anvils. Separate the X_1 and X_2 clamps electrically and electrically isolate the H_1 and H_2 clips.
4. Slowly crank the generator, noting the deflection of the null detector. If the deflection is small, increase the speed until 8 volts are indicated, simultaneously adjusting R1 for zero reading of the null detector. This must be done as accurately as possible.
5. Close the screws of the X_1 and X_2 clamps on their respective anvils and short H_1 to H_2. Do not allow X_1 and X_2 to short or contact H_1 or H_2.
6. Set the fourth dial to precisely zero (within the thickness of the index line). Locate R2 (50 ohms). Be careful not to upset the fourth dial range adjustment R3.
7. Crank the generator to 8 volts, simultaneously adjusting R2 for precise balance of the null detector. Crank slowly at first, gradually increasing the speed as the final adjustment is approached.
8. Close both X_1 and X_2 so the screws seat firmly on their respective anvils. Separate the X_1 and X_2 clamps electrically. Connect the black secondary lead H_1 to the black exciting lead X_1. Connect the red secondary lead H_2 to the red exciting lead X_2. Set the dials to read 1.000. Crank the generator so that 8 volts is indicated on the voltmeter. While cranking, observe the galvanometer. If it does not read zero, adjust the fourth dial so that the meter reads zero while cranking at 8 volts. The set should read within ½ division of zero on the fourth dial. Reset the dials to read 0.9 + 100 on the fourth dial (1.000) as accurately as possible.
9. Crank the generator to 8 volts, simultaneously adjusting R3 for precise balance of the null detector. Crank slowly at first, gradually increasing the speed as the final adjustment is approached.
10. Check the null-detector sensitivity by cranking the generator to 8 volts, and setting the fourth dial to 10. If sensitivity is normal, the null detector will deflect to the right to a position corresponding to the letter "R" in the word detector.

If the synchronous rectifier is found to be defective in the foregoing tests, and the null detector was found to be operable as described in Paragraph 35, it would be best to check the unity ratio isolation transformer before assuming the synchronous rectifier to be defective. To do this the panel assembly must be removed from its case and the terminals of the isolation transformer exposed. Open the screws of the X_1 – X_2 clamps. Connect a voltmeter having a sensitivity of at least 100 ohms per volt across the red and green output terminals connected to the synchronous rectifier circuit, and then in turn to the input terminals from the generator. Crank the generator to 8 volts as indicated by the TTR Set voltmeter. The input and output voltage of the isolation transformer as read by the test voltmeter should be the same (8 volts).

37. REFERENCE TRANSFORMER

The primary resistance of the transformer from the X_1 anvil to the X_2 anvil, including the X leads, is close to 0.11 ohms at 25°C. In making this measurement the clamp screws should be insulated from the anvils either by leaving them unscrewed or by inserting a heavy piece of insulation between the screw point and the measuring lead contact. If the X leads are flexed while this measurement is made, any bad contact or broken wire should be discovered.

Magnetizing current should be measured as an indication of the condition of the core. At 8 volts it is normally about 50 milliamperes (2½ divisions deflection on divide-by-5 meter range). Mechanical abuse of the core will reduce its quality in such a way that magnetizing current will increase. If the magnetizing current is found to be in excess of 100 milliamperes (5 divisions on divide-by-5 range), it is advisable to send the set back to the factory for inspection.

The secondary winding can be checked by connecting a test lead to the common arm of dial 3 switch. Refer to the wiring diagram, Figure 11 lead "b". Measure the resistance between this connection and the H_1 (black) secondary clip for different dial settings on the ratio switches.

The values of resistance for each combination of dial settings is shown in the table below.

Secondary Resistance Values
Reference Transformer

SWITCH STEP	1ST* DIAL	2ND* DIAL	3RD DIAL
0	0.12	0.2	0.2
1	100	10	0.4
2	195	20	0.6
3	290	30	0.8
4	385	40	1.0
5	475	50	1.2
6	565	60	1.4
7	655	70	1.6
8	745	80	1.8
9	835	90	2.0
10	925	—	—
11	1,015	—	—
12	1,105	—	—

*All other dials set at zero

38. POTENTIOMETER R_{11}

This potentiometer should be replaced if the following symptoms are noticed:

a. The potentiometer element becomes open because of wear or accident.

b. Either mechanical stop points are broken.

c. Erratic operation is noted. Normally, this will be observed as a jitter in the null detector during balancing.

d. Any question of calibration error in the potentiometer.

It is possible that the dial plate on the potentiometer may become loose during the life of the set. This will show up as an error in the unity ratio check and the zero ratio check. To correct it, loosen the set screw holding the dial plate to the shaft. Shift the dial to give an equal mechanical travel below 0 and above 100 at the mechanical stop points (normally 3 divisions). While tightening the set-screw, make sure the dial plate is pressed firmly against the felt spacer washer. The washer is used to add torque to this dial.

39. GENERATOR

Do not disassemble the generator in the field. The permanent magnet used in these generators is charged while in position and should it be removed from its associated iron circuit, its energy level will drop and the available output will also drop. A loss of 50% of the output voltage can be expected if these instructions are not followed.

As mentioned previously, the generator will provide an output of 8 volts and 1.0 ampere at approximately 60 Hertz when properly magnetized. A good check on the condition of the magnet can be made by cranking the unloaded generator so that 8 volts is indicated on the voltmeter. The cranking speed should be approximately 120 rpm. Next, close the screws of the X_1 and X_2 clamps on their respective anvils and short H_1 to H_2. Do not allow X_1 and X_2 to short or contact H_1 and H_2. Set the dials to read 10.000. Crank the generator so that the ammeter reads full scale on the X_1 range. The voltmeter indication should be approximately midway between 0 and 8 volts.

40. CLAMPS

Any time it becomes necessary to re-assemble the X clamps during maintenance on the TTR Set, it should be kept in mind that the multiplicity of parts used to assemble the anvils is necessary. Their purpose is the insulation of the anvil from the frame. It is easily possible to defeat this purpose by assembling the parts in the wrong order. When replacement lead assemblies are ordered from the factory, a blueprint is sent showing the proper assembly method.

41. LIST OF REPLACEABLE PARTS

The table of parts on pages 48-49 lists all the parts that may need replacement during the life of the instrument. They are normally stocked in small quantities and may be obtained direct from the factory. Those parts which are identified with a manufacturer's name and stock number are standard production items and may be obtained direct from their source.

LIST OF REPLACEABLE PARTS

Part No.	Description
550005	COMPLETE ASSEMBLY, Transformer Turn Ratio Set
22207	CASE, ASSEMBLY without carrying strap, rubber feet, TTR Emblem, or Generator
22206	PARTITION
6580-1	CARRYING STRAP, ASSEMBLY
5599-1	RUBBER FEET (4 reqd.)
18976	CASE LATCH (2 reqd.) (SOUTH Co. Inc. #07-10-201-12 black)
7451	TTR Emblem
7839	INSTRUCTION CARD
10350-5	GENERATOR ASSEMBLY
22183	SWITCH (S1, S2, S3)
12119-3	SWITCH (S4) (Alco #MTA106D)
11166-4	BINDING POSTS (Superior GP3ONC)
22151	Panel Overlay
10363	AMMETER (M1), includes TRANSFORMER T3
10364	VOLTMETER (M2)
10365	DETECTOR (Galvanometer) (M3)
4690-18	KNOB (4 reqd.) (Buckeye PS-125-2)
19650	STANDARD REFERENCE TRANSFORMER (T1)
7844	ISOLATION TRANSFORMER (T2)
22144-1	SYNCHRONOUS RECTIFIER ASSEMBLY
19494	LEAD-CLAMP, ASSEMBLY X_1-X_2 & H_1-H_2
22188	CABLE-ASSEMBLY H_1-H_2 only
2756	CLAMP-ASSEMBLY (1 Pr. reqd.)
2796	H CLIP, (Mueller Cat. 27 C; 2 reqd.)
2797-1	RUBBER INSULATOR, (Mueller Cat. 29 Red)
2797-2	RUBBER INSULATOR, (Mueller Cat. 29 Black)
13183-7	POTENTIOMETER, 1000 Ohms (R1) (Bourns 3006P-1-102)

13183-3	POTENTIOMETER, 50 Ohms (R2,R3) (Bourns 3006P-1-500)
22182	POTENTIOMETER, 500 Ohms (R11)
12074-50	ZENER DIODE (CR2,CR3) (Unitrode UZ5714)

ADDITIONAL REPLACEABLE PARTS FOR LINE-OPERATED UNITS

6807-14	CIRCUIT BREAKER (K1)
9256	VOLTAGE CONTROL (T2) (General Radio Type W2)
15573-8	TRANSFORMER (T1) (Signal #DP-241-7-10)
10363-1	TRANSFORMER, AMMETER (T3)
12119-7	SWITCH (S4) (C & K #7411)
22144-1	SYNCHRONOUS RECTIFIER ASSEMBLY
12074-51	ZENER DIODE (CR1,CR2) (Motorola IN2812A)
11025-19	RESISTOR (R1) (3 reqd.), 0.75Ω, 5%, 1W (I.R.C. Type BW-20)

Section E

APPENDIX

DEFINITIONS OF TERMS

The Ratio of a Transformer is the turn ratio of the transformer unless otherwise specified.

The Voltage Ratio of a Transformer is the ratio of the rms primary terminal voltage to the rms secondary terminal voltage under specified conditions of load.

The Turn Ratio of a Transformer is the ratio of the number of turns in the high-voltage winding to that in the low-voltage winding. Note that this will always be greater than unity.

Inverse Turn Ratio is defined here as the ratio of the number of turns in low-voltage winding to that in the high-voltage winding. It is equal to the reciprocal of the Turn Ratio, and, therefore, is always less than unity.

Primary Winding is the winding on the input side.

Secondary Winding is the winding on the output side.

In the use of the terms primary and secondary winding, it is necessary to make clear in the context which winding on a transformer is to be considered as primary. For example, the normal secondary of a distribution transformer may be the low-voltage winding and would be used as primary during measurement of turn ratio with the TTR Set.

A Rational Transformer for the purposes of this Manual may be defined as one having:

1. The winding chosen for excitation suitable for full rated load output at a usable impedance or regulation.
2. The excited winding as in (1) include approximately half the copper in the (single phase) transformer, and the excited turns should be distributed throughout the window.
3. The magnetic core should be properly stacked and complete without magnetic shunts or air-gaps.

Section F

APPENDIX

INSTRUCTIONS FOR LINE-POWERED TTR SET

Catalog 550022:	Similar to the hand-operated Catalog No. 550005 except variable ratio autotransformer and protective features replace generator; panel-mounted design.
Catalog 550027:	Same as Catalog 550022 except in portable wooden case.

GENERAL

The function of the power-operated Turn Ratio Test Set, (Fig. 1a), is identical to that of the hand-operated generator type. The only difference is that a variable ratio autotransformer, connected to a 120 or 240 volt 50/60 Hertz power supply, is substituted for the hand-operated generator. Because of this substitution and the possibility of making tests with full power applied, certain protective features have been added to protect the operator and the equipment.

PRECAUTIONS

The set must only be energized from the correct 120 or 240 volts, 50/60 Hertz line. Before proceeding with any tests, be sure the circuit-breaker is in "OFF" position, and the variable ratio autotransformer is at zero-setting before energizing. Refer to Safety Precautions in the front of this manual.

PROCEDURE

Make a preliminary null-zero ratio and unity check of the TTR Set per instructions page 14. Make connections and follow the procedure outlined. To energize the set, close the circuit-breaker, rotate the voltage control gradually, at the same time observing the deflection of the null galvanometer. Keep the null galvanometer deflection to a minimum by using the lowest voltage control setting which will just give the required sensitivity so the null galvanometer pointer will not go violently off-scale when switching dials for the required balance or null. This method should always be followed when the desired ratio is far off null. If the null, zero and ratio checks are satisfactory, follow the procedure outlined on page 15, Section 10, steps (a) through (g) to test a transformer; note that in place of using a slight pulse (step e) of energy supplied by the hand-operated generator the voltage control should be advanced from zero to a fraction of a volt and then returned again immediately to zero. Repeat this step by step exploring for null as described in Section 11. As null is approached, increase the voltage control setting to 8 volts and finish the null balance by using the fourth dial as described.

A schematic diagram, Figure 13, illustrates the function of each piece of control equipment. A wiring diagram, Figure 14, is also included.

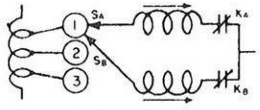
TTR Measurements on Tap-Changing-Under-Load Transformers and Step-Type Feeder Voltage Regulators

Many users of the Biddle TTR Test Set who make a practice of testing ordinary distribution and power transformers as they are received, also find the test very advantageous in the case of Tap-Changing-Under-Load Transformers and Step-Type Regulators. They find from experience that the complicated tap-changing mechanism introduces the possibilty of defects and assembly errors which can be revealed by accurate ratio measurements.

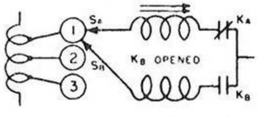
An example of this occurred recently in one Public Utility where a Tap-Changing-Under-Load Transformer was being given an acceptance test. The TTR Set indicated correct ratios at the 16 normal tap positions, but indicated a ratio equivalent to the neutral position during the transition between each tap position. This was obviously wrong since the transition ratios should have been, due to the presence of preventive autos in the circuit, about midway between the ratios of two adjacent taps.

A basic requirement of all transformers, that change ratios under load, is that the change be without discontinuities. That is, when changing from one step to another, there should be no opening of a current carrying link unless it is shunted by an auxiliary path.

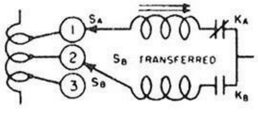
In practical applications this is accomplished by a bridging mechanism. This can be represented as shown in the figure, which shows all the steps in a tap changing operation.



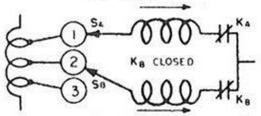
STEP NO 1 RATIO CORRESPONDS TO TAP NO 1



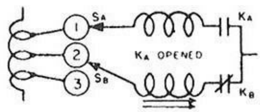
STEP NO 2 RATIO CORRESPONDS TO TAP NO 1



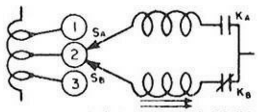
STEP NO 3 RATIO CORRESPONDS TO TAP NO 1



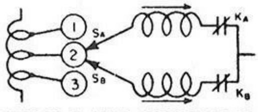
STEP NO 4 RATIO CORRESPONDS TO INTERMEDIATE VALUE BETWEEN TAP NO 1 AND TAP NO 2



STEP NO 5 RATIO CORRESPONDS TO TAP NO 2



STEP NO 6 RATIO CORRESPONDS TO TAP NO 2



STEP NO 7 RATIO CORRESPONDS TO TAP NO 2

Note that if at any point in the cycle, K_A and K_B are both open, there is an open circuit between the tapped winding and its output terminal. This is also true if S_A and S_B are both open at one time. The combinations, S_A and K_B open or S_B and K_A will also result in the output circuit being open. Such an open circuit would damage the transformer if it occurred in service. The condition can be detected during ratio measurements by observing the TTR detector during the tap changing cycle.

Connect the transformer or step regulator to the TTR Set in order to get a satisfactory ratio measurement. Set the regulator at its lowest step and balance the Set. Record the ratio reading. Crank the TTR Set at its rated voltage while an assistant cranks the tap changing gear through one cycle.

At some point in the operation corresponding to Step 4 in the figure, the pointer of the detector will move toward the left end of the scale indicating a small increase in ratio if the mechanism is operating properly. Almost immediately it will move farther to the left indicating a further increase as shown in Step 5. The test should be continued until the cycle is completed as shown in Step 7. At this point the Set should be balanced and the ratio recorded.

This procedure should be followed for each tap.

If at any point during the cycle, the output circuit becomes open due to faulty contacting as discussed above, the ratio at that point will be abnormal.

Where the regulator involves a series transformer, an open circuit in the tap changer will result in the ratio changing to the neutral ratio.

Where there is no series transformer, the detector indication, at open circuit, will be zero since either the TTR exciting circuit will be opened or the secondary circuit will be opened.

If the TTR Set is balanced at the time of this "open" there will be no indication other than a transient kick due to opening an inductive circuit. This kick will only be apparent when the exciting circuit is opened.

For a better indication of this type of trouble in a transformer not having a series transformer, a somewhat different procedure should be followed. Before cranking the tap changer through a cycle, adjust the galvanometer pointer by means of the ratio dial so that at the start of the cycle it reads half scale to the left. Then at mid cycle it will read further to the left, and in case of open circuit it will return to zero.

In order to maintain the proper relationships in all these tests it is necessary to operate the tap changer in such a direction as to increase the ratio indication on the TTR Set.

TTR Test Set Measurement on Star-Delta Transformers

In the measurement of delta-star or star-delta transformers where the star side must be excited in making a "TTR" test, one should keep in mind the following facts:

1. The Nameplate Ratio is not the Turn Ratio. It is the ratio of the phase-to-phase voltages at no load.
2. The Turn Ratio, assuming the delta side is the higher voltage, can be found by multiplying the Nameplate Ratio by $\sqrt{3}$.
3. If the TTR Set's X leads are connected phase-to-phase on the star winding and the H leads to the corresponding delta phase, the measured ratio will be approximately half the true Turn Ratio. This ratio, by unfortunate coincidence, is also approximately 87% of the Nameplate Ratio.
4. The method described above is of course not technically correct.

Some users of TTR Sets have made measurements on three-phase transformers as described, and noting the similarity between the measured ratio and the Nameplate Ratio, have assumed that they should be equal.

The correct method of measuring ratio on delta-star and star-delta transformers is given in Paragraph 18 of this manual. Where the star winding is the low-voltage side and is to be excited, connect the X leads between one phase and neutral. Connect the H leads to the corresponding coil on the delta. The manual states that the delta be opened for this test, but if the transformer is well constructed and rationally designed, a satisfactory measurement is likely without opening the delta. The measurement is the Turn Ratio of the windings and should be divided by $\sqrt{3}$ to get the Nameplate Ratio.

If the experience with a given type of transformer indicates that the ratio measurements made by the above method are unsatisfactory, another method is available which can be made when the delta cannot be opened and can be made even when the neutral is inaccessible. This method is a modification of the test described in Item 3 of the first paragraph.

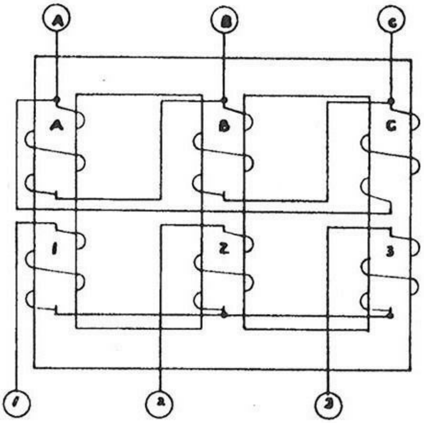


FIGURE 1: Representative Delta-Star Transformer Coil Connections.

Figure 1 shows a transformer of the type under consideration with the windings identified in accordance with the terminal connections. The three coil ratios required are designated N_A, N_B, and N_C.

In order to determine these ratios, it is necessary with this method to make six measurements as indicated in Figure 2. Note that in each measurement a short is placed across the delta winding which is on the same core leg as the unexcited star winding. These measurements are identified as N_{1A}, N_{1B}, N_{2A}, N_{2B}, N_{3A}, N_{3B}.

When these measurements are made, the Turn Ratios can be calculated from the equations below.

$$N_A = \frac{N_{1A} + N_{1B} \dfrac{N_{2B}\,N_{3B}}{N_{2A}\,N_{3A}}}{1 - \dfrac{N_{2B}}{N_{2A}} + \dfrac{N_{2B}\,N_{3B}}{N_{2A}\,N_{3A}}}$$

$$N_B = \frac{N_{2A} + N_{2B} \dfrac{N_{3B}\,N_{1B}}{N_{3A}\,N_{1A}}}{1 - \dfrac{N_{3B}}{N_{3A}} + \dfrac{N_{3B}\,N_{1B}}{N_{3A}\,N_{1A}}}$$

$$N_C = \frac{N_{3A} + N_{3B} \dfrac{N_{1B}\,N_{2B}}{N_{1A}\,N_{2A}}}{1 - \dfrac{N_{1B}}{N_{1A}} + \dfrac{N_{1B}\,N_{2B}}{N_{1A}\,N_{2A}}}$$

The fast growing list of TTR Transformer Turn Ratio Test Set owners has been a source of some very interesting problems in application. We welcome correspondence from users and are particularly interested in new problems and their solutions.

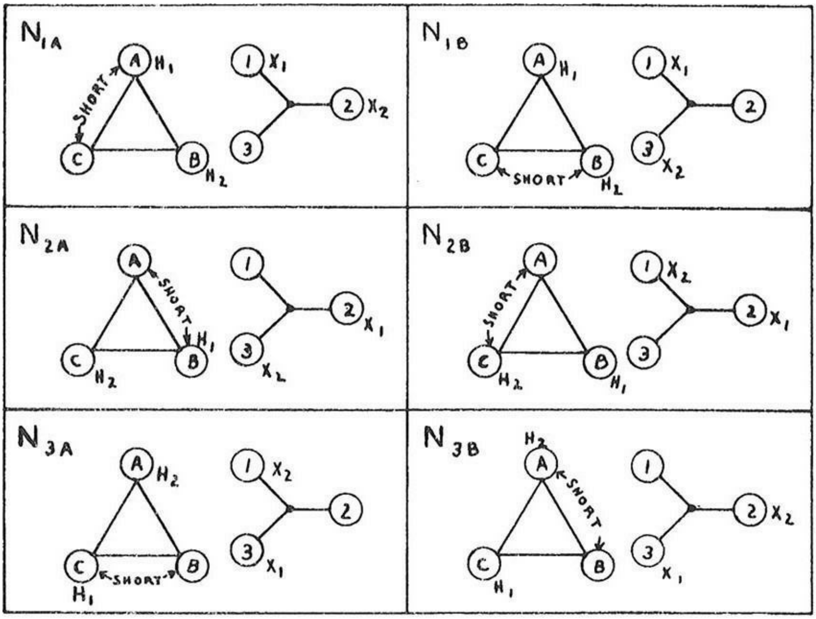


FIGURE 2: Identification of Ratio Measurements, where A, B, C, 1, 2, 3 indicate transformer terminals and X_1, X_2, H_1, H_2 indicate TTR Connections.

NOTE: Short circuit on delta winding may be replaced by a short on the corresponding star winding if the neutral is available.

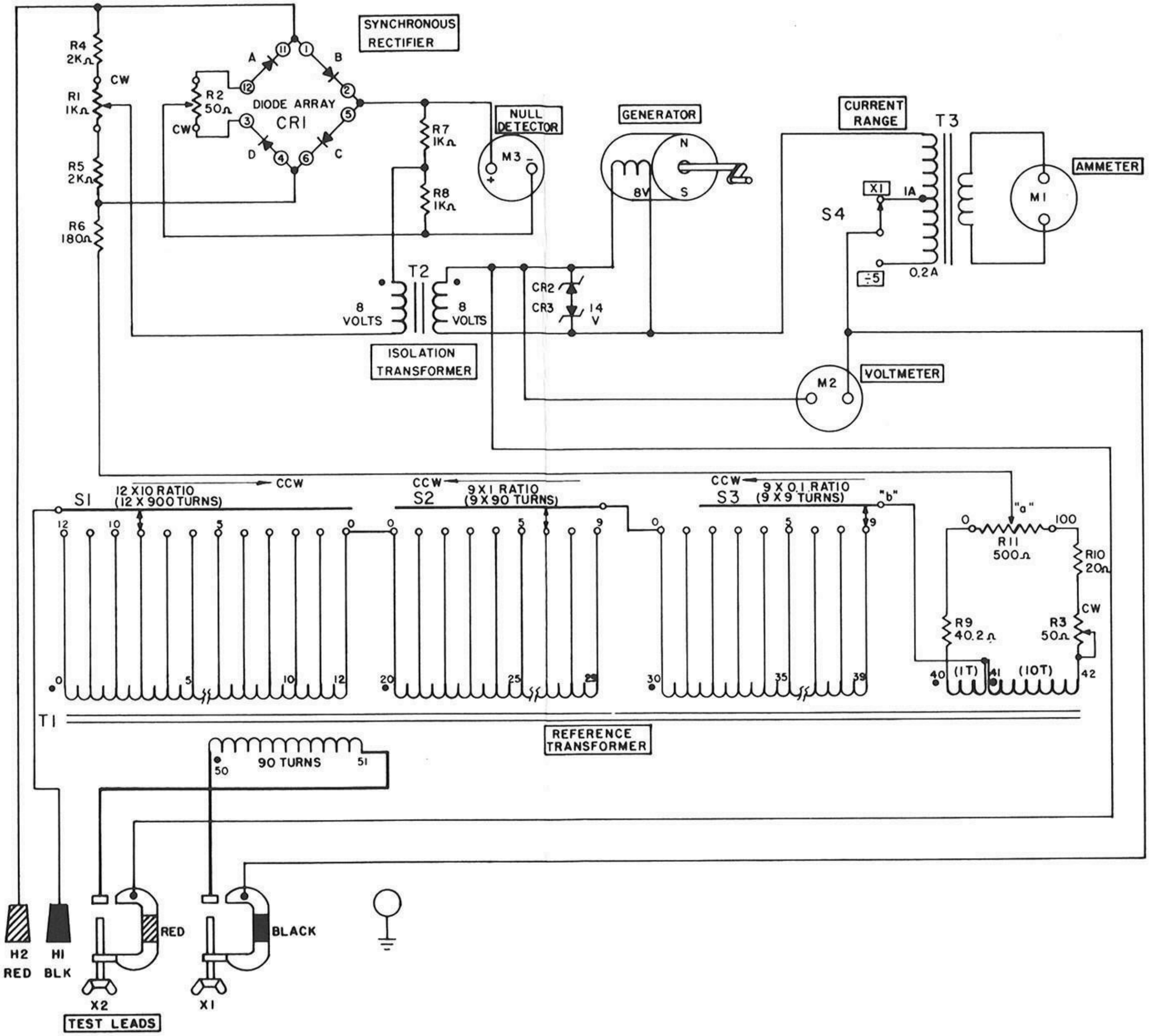
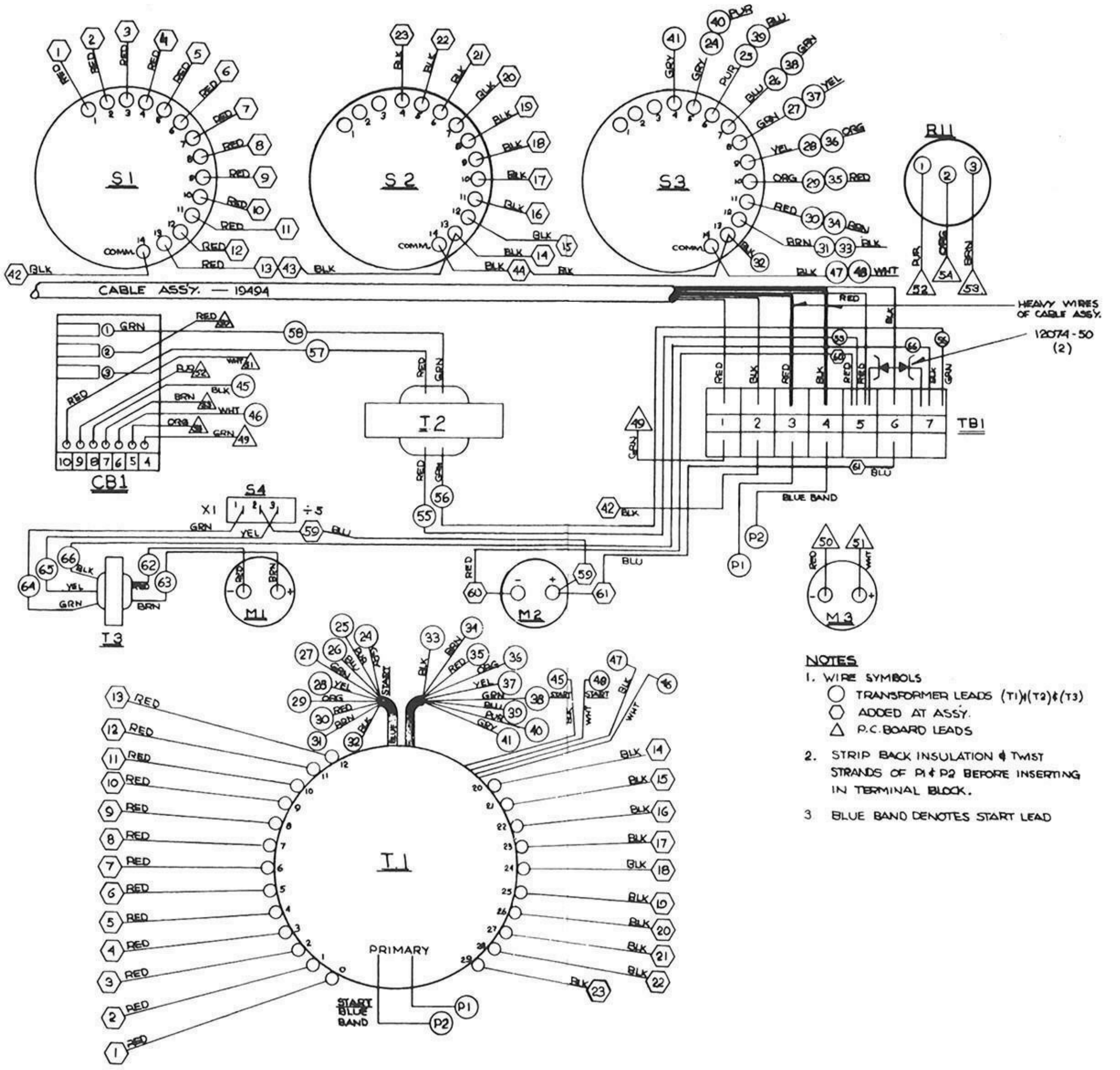


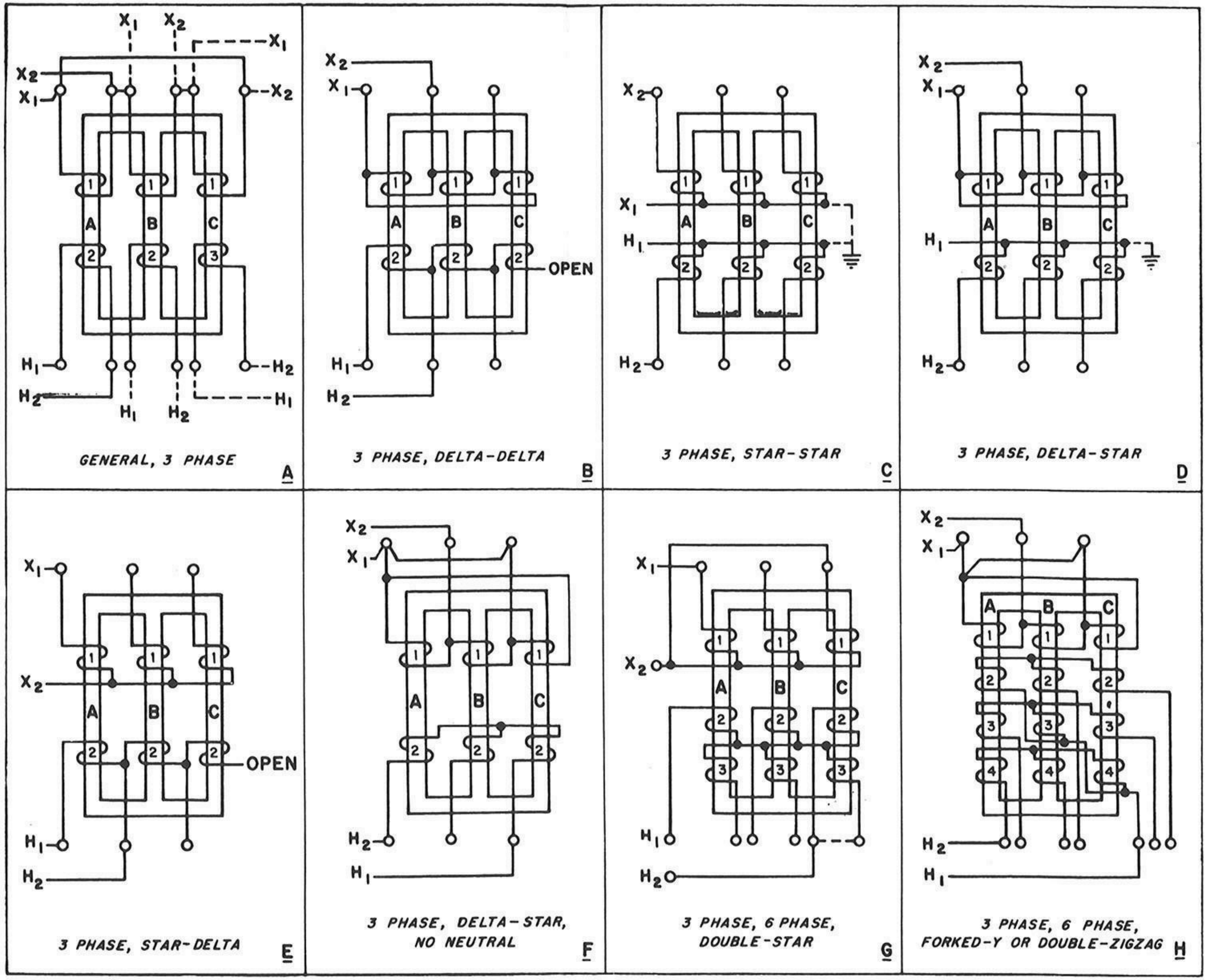
Figure 10: Schematic Diagram of Catalog No. 550005 TTR Set.



NOTES

1. WIRE SYMBOLS
   - ○ TRANSFORMER LEADS (T1)(T2)&(T3)
   - ⬡ ADDED AT ASSY.
   - △ P.C. BOARD LEADS
2. STRIP BACK INSULATION & TWIST STRANDS OF P1 & P2 BEFORE INSERTING IN TERMINAL BLOCK.
3. BLUE BAND DENOTES START LEAD

Figure 11: Wiring Diagram of Catalog No. 550005 TTR Set.



GENERAL, 3 PHASE

3 PHASE, DELTA-DELTA

3 PHASE, STAR-STAR

3 PHASE, DELTA-STAR

3 PHASE, STAR-DELTA

3 PHASE, DELTA-STAR, NO NEUTRAL

3 PHASE, 6 PHASE, DOUBLE-STAR

3 PHASE, 6 PHASE, FORKED-Y OR DOUBLE-ZIGZAG

Figure 12: Connections for testing polyphase transformers.

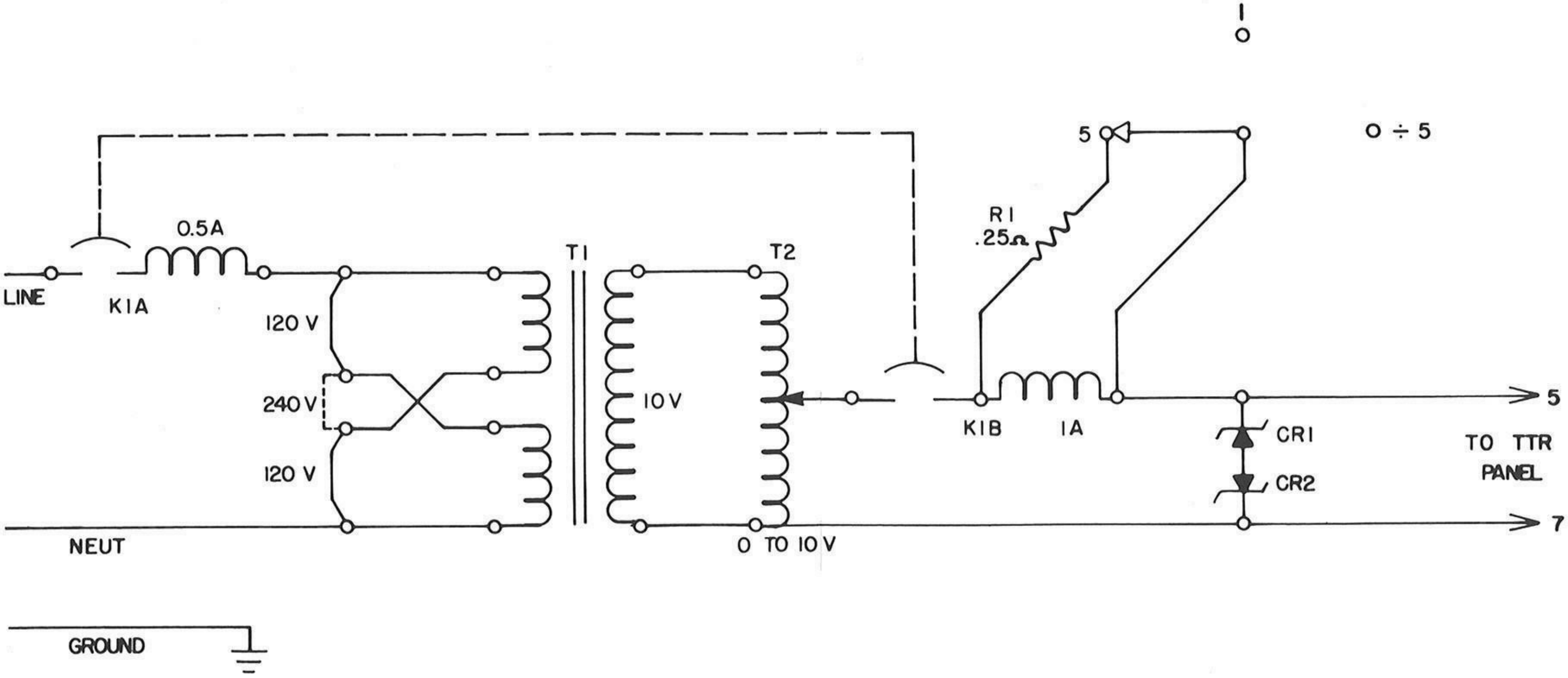
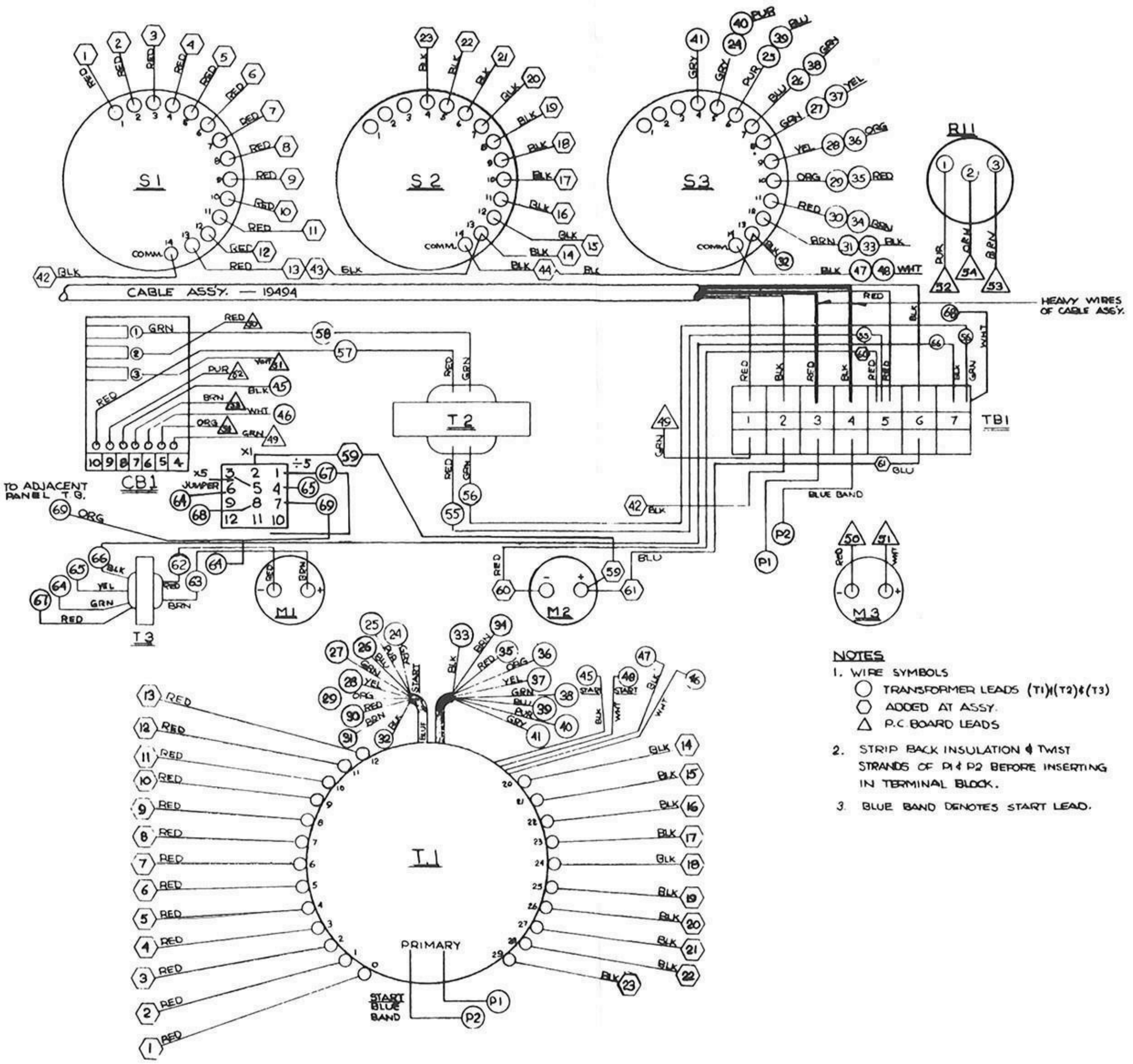


Figure 13: Schematic diagram of Catalog Nos. 550022 and 550022-47.

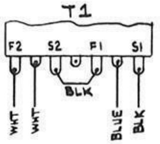


NOTES
1. WIRE SYMBOLS
- ○ TRANSFORMER LEADS (T1)&(T2)&(T3)
- ⬡ ADDED AT ASSY.
- △ P.C BOARD LEADS

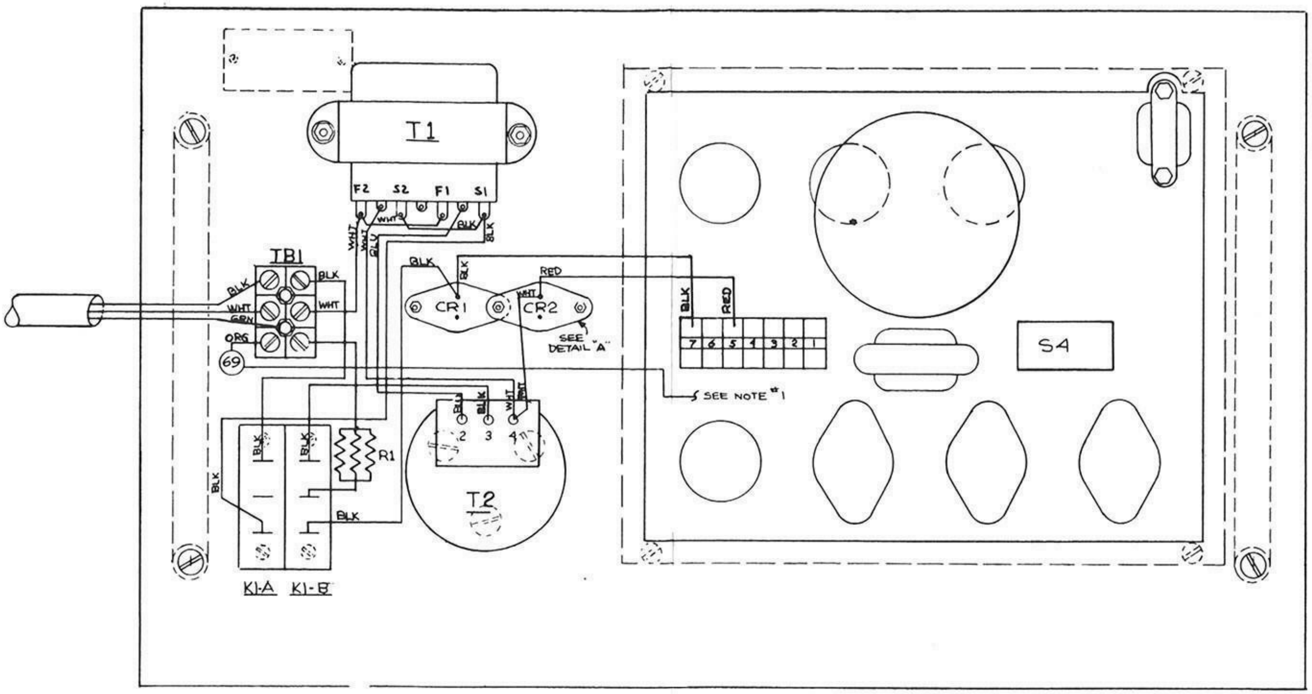
2. STRIP BACK INSULATION & TWIST STRANDS OF P1 & P2 BEFORE INSERTING IN TERMINAL BLOCK.

3. BLUE BAND DENOTES START LEAD.

Figure 14: Sub-Panel Wiring Diagram of Catalog Nos. 550022, 550022-47, 550027 and 550027-47.



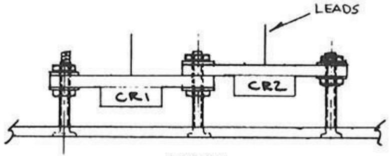
ALTERNATE WIRING
FOR 220/240V.



REAR VIEW

NOTE

1. WIRE #69 FROM COMPONENT S4-7 OF TTR ASSY. 22153-1



DETAIL
"A"

Figure 15: Main Panel Wiring Diagram of Catalog Nos. 550022 and -47, 550027 and -47.

Turn ratio testing of three-phase power and distribution transformers with AVO Biddle Instruments Catalog No. 550005 Transformer Turn Ratio Test Set (TTR®)

When turn ratio testing three-phase transformers, it is necessary to understand the phase relationships, vector diagrams,, and winding connection diagrams for these transformers. A detailed explanation of these parameters is contained in specifications ANSI C57.12.70-1978, American National Standard Terminal Markings and Connections for Distribution and Power Transformers.

Table I shows the winding phase relationship and connection diagrams for the common standard transformers and Table 2 for most nonstandard transformers. To measure the transformer turn ratio, match the vector diagram from the transformer nameplate with the corresponding vector diagram in the table, then follow the table setup instructions. The tables show the connections and winding phase relationships for each phase. Tables 1 and 2 also show the relationship between the measured turn ratio and the actual line-to-line voltage ratio. The rated voltage on the high-voltage winding is represented by V_H; V_X represents rated voltage on the low-voltage winding.

The TTR set is also capable of measuring the turn ratio on three-phase transformers with an inaccessible neutral point. In this case, additional jumper leads may be required to short circuit a winding, and a nonstandard test procedure must be used. Table 2 shows diagrams and setup instructions for testing this type of transformer.

For an understanding of winding phase relationships, refer to Diagram 5 in Table 1 which will be used as an example to illustrate the relationship between windings in a typical delta-wye connected transformer with accessible neutral connection point. The delta winding is the high-voltage winding and the terminals are marked H_1, H_2, and H_3. The wye winding is the low-voltage winding and the terminals are marked X_0, X_1, X_2, and X_3. Now determine which windings (lines) are parallel to each other. In the diagram, winding H_1 - H_3 is parallel to X_1 - X_0; H_2 - H_1 is parallel to X_2 - X_0; and H_3 - H_2 is parallel to X_3 - X_0. All ratio measurements must be made between parallel windings. For example, only H_1 - H_3 will correctly ratio against X_1 - X_0. The phase polarity must also be observed and is designated by the order of terminal mention, i.e., H_1 - H_3 is of the same phase polarity as X_1 - X_0. In this example, bold lettered terminals are used to designate the same polarity.

Notes to Tables 1 and 2

* Indicates preferred test method when alternate method is listed for same three-phase winding connection.

Transformer terminal markings comply with requirements of C57.12.70 - 1978.

Definitions of Symbol Designations

H_1, H_2, H_3: Winding terminals on high-voltage side of transformer

X_1, X_2, X_3: Winding terminals on low-voltage side of transformer

H_0: Neutral terminal on high-voltage side of transformer

X_0: Neutral terminal on low-voltage side of transformer

V_H: Nameplate voltage rating (line-to-line) on low-voltage side of transformer

V_X: Nameplate voltage rating (line-to-line) on low-voltage side of transformer

A, B, C: Winding tested on high-voltage side of transformer

a, b, c: Winding tested on low-voltage side of transformer

IEC Vector Group Coding: The letters indicate the three-phase winding connections; D, Y, and Z designate the high-voltage side winding; d, y, and z designate the low-voltage side winding. With D and d representing a delta connection, Y and y a wye connection, and Z and z a zigzag connection. The letter N designates an accessible neutral point on the high-voltage side winding; and n an accessible neutral point on the low-voltage side winding. The number indicates the phase displacement (lag) of the low-voltage winding with respect to the high-voltage winding in units of 30 degrees. For example 0 = 0° lag (voltages in phase with each other), 1 = 30° lag, 2 = 60° lag ---, 6 = 180° lag ---, 11 = 330° lag. The high-voltage winding is the reference vector or vector of origin (dash line used on delta and zigzag winding). Vector rotation of the low-voltage winding is counterclockwise.

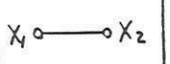
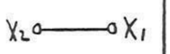
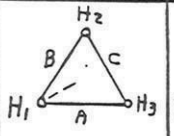
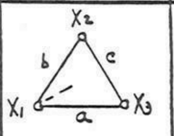
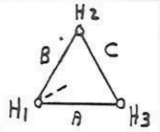
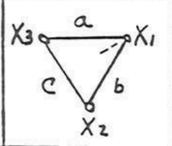
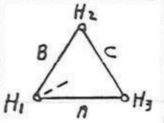
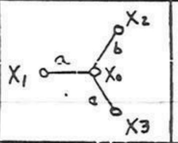
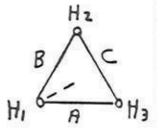
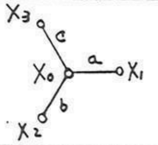
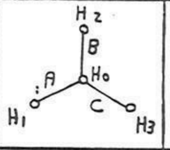
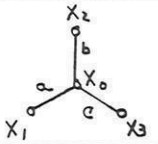
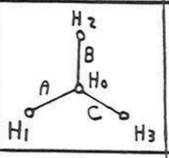
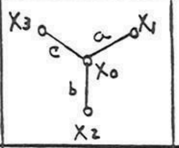
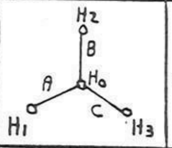
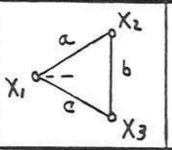
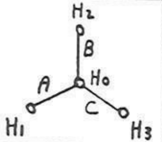
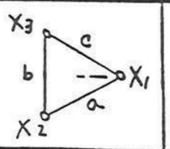
Transformer Terminal Markings

Comparison between ANSI/IEEE standard terminal markings and IEC/VDE standard terminal markings.

Terminal on high-voltage side of transformer	
ANSI/IEEE Standard	IEC/VDE Standard
H_1	U
H_2	V
H_3	W
H_0	N

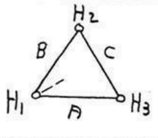
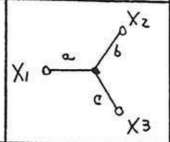
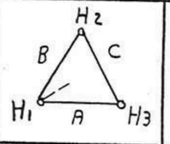
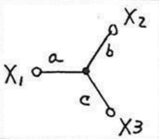
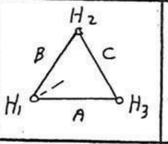
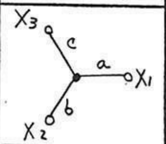
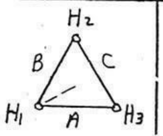
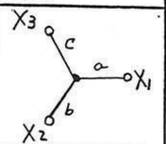
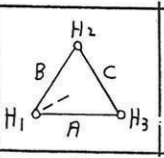
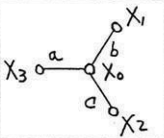
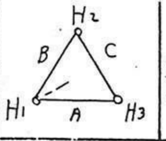
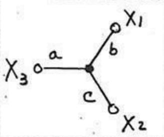
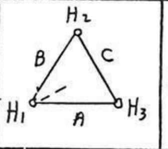
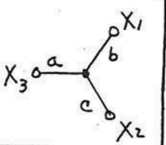
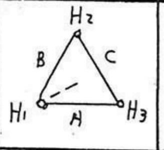
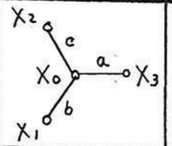
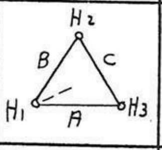
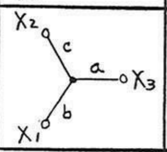
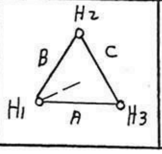
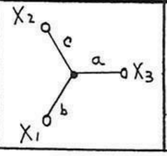
Terminal on low-voltage side of transformer	
ANSI/IEEE Standard	IEC/VDE Standard
X_1	u
X_2	v
X_3	w
X_0	n

TABLE 1 STANDARD TRANSFORMER WINDING PHASE RELATIONSHIP CONNECTIONS USING CAT NO. 550005 TTR

DIAG NO.	TRANSFORMER TYPE		JUMPER	H WINDING		X WINDING		MEASURED TURN RATIO	IEC VECTOR GROUP	REMARKS
	HIGH-VOLTAGE WINDING (H)	LOW-VOLTAGE WINDING (X)		TERMINAL CONNECTION	PHASE TESTED	TERMINAL CONNECTION	PHASE TESTED			
1			—	—		—		$\frac{V_H}{V_X}$	Ii0	SINGLE-PHASE TRANSFORMER
				H_1-H_2		X_1-X_2				
				—		—				
2			—	—		—		$\frac{V_H}{V_X}$	Ii6	SINGLE-PHASE TRANSFORMER
				H_1-H_2		X_2-X_1				
				—		—				
3			—	H_1-H_3	A	X_1-X_3	a	$\frac{V_H}{V_X}$	D,d0	
				H_2-H_1	B	X_2-X_1	b			
				H_3-H_2	C	X_3-X_2	c			
4			—	H_1-H_3	A	X_3-X_1	a	$\frac{V_H}{V_X}$	D,d6	
				H_2-H_1	B	X_1-X_2	b			
				H_3-H_2	C	X_2-X_3	c			
5			--	H_1-H_3	A	X_1-X_0	a	$\frac{V_H \cdot \sqrt{3}}{V_X}$	D,yn1	
				H_2-H_1	B	X_2-X_0	b			
				H_3-H_2	C	X_3-X_0	c			
6			—	H_1-H_3	A	X_0-X_1	a	$\frac{V_H \cdot \sqrt{3}}{V_X}$	D,yn7	
				H_2-H_1	B	X_0-X_2	b			
				H_3-H_2	C	X_0-X_3	c			
7			—	H_1-H_0	A	X_1-X_0	a	$\frac{V_H}{V_X}$	YN,yn0	
				H_2-H_0	B	X_2-X_0	b			
				H_3-H_0	C	X_3-X_0	c			
8			--	H_1-H_0	A	X_0-X_1	a	$\frac{V_H}{V_X}$	YN,yn6	
				H_2-H_0	B	X_0-X_2	b			
				H_3-H_0	C	X_0-X_3	c			
9			—	H_1-H_0	A	X_1-X_2	a	$\frac{V_H}{V_X \cdot \sqrt{3}}$	YN,d1	
				H_2-H_0	B	X_2-X_3	b			
				H_3-H_0	C	X_3-X_1	c			
10			—	H_1-H_0	A	X_2-X_1	a	$\frac{V_H}{V_X \cdot \sqrt{3}}$	YN,d7	
				H_2-H_0	B	X_3-X_2	b			
				H_3-H_0	C	X_1-X_3	c			

NOTE: TRANSFORMER TERMINAL MARKINGS COMPLY WITH REQUIREMENTS OF C57.12.70-1978

TABLE 2 NON STANDARD TRANSFORMER WINDING PHASE RELATIONSHIP CONNECTIONS USING CAT. NO. 550005 TTR

DIAG NO.	TRANSFORMER TYPE		JUMPER	H WINDING		X WINDING		MEASURED TURN RATIO	IEC VECTOR GROUP	REMARKS
	HIGH-VOLTAGE WINDING (H)	LOW-VOLTAGE WINDING (X)		TERMINAL CONNECTION	PHASE TESTED	TERMINAL CONNECTION	PHASE TESTED			
* 1			H_1-H_2 H_2-H_3 H_3-H_1	H_1-H_3 H_2-H_1 H_3-H_2	A+C B+A C+B	X_1-X_3 X_2-X_1 X_3-X_2	a+c b+a c+b	$\frac{V_H}{V_X}\cdot\frac{\sqrt{3}}{2}$	D,y1	NO ACCESSIBLE NEUTRAL ON WYE WINDING
1a			X_3-X_2 X_1-X_3 X_2-X_1	H_1-H_3 H_2-H_1 H_3-H_2	A+B+C B+C+A C+A+B	X_1-X_3 X_2-X_1 X_3-X_2	a+b+c b+c+a c+a+b	$\frac{V_H}{V_X}\cdot\frac{2}{\sqrt{3}}$	D,y1	NO ACCESSIBLE NEUTRAL ON WYE WINDING
* 2			H_1-H_2 H_2-H_3 H_3-H_1	H_1-H_3 H_2-H_1 H_3-H_2	A+C B+A C+B	X_3-X_1 X_1-X_2 X_2-X_3	a+c b+a c+b	$\frac{V_H}{V_X}\cdot\frac{\sqrt{3}}{2}$	D,y7	NO ACCESSIBLE NEUTRAL ON WYE WINDING
2a			X_3-X_2 X_1-X_3 X_2-X_1	H_1-H_3 H_2-H_1 H_3-H_2	A+B+C B+C+A C+A+B	X_3-X_1 X_1-X_2 X_2-X_3	a+b+c b+c+a c+a+b	$\frac{V_H}{V_X}\cdot\frac{2}{\sqrt{3}}$	D,y7	NO ACCESSIBLE NEUTRAL ON WYE WINDING
3			—	H_1-H_3 H_2-H_1 H_3-H_2	A B C	X_3-X_0 X_1-X_0 X_2-X_0	a b c	$\frac{V_H\cdot\sqrt{3}}{V_X}$	D,yn5	
* 4			H_1-H_2 H_2-H_3 H_3-H_1	H_1-H_3 H_2-H_1 H_3-H_2	A+C B+A C+B	X_3-X_2 X_1-X_3 X_2-X_1	a+c b+a c+b	$\frac{V_H}{V_X}\cdot\frac{\sqrt{3}}{2}$	D,y5	NO ACCESSIBLE NEUTRAL ON WYE WINDING
4a			X_2-X_1 X_3-X_2 X_1-X_3	H_1-H_3 H_2-H_1 H_3-H_2	A+B+C B+C+A C+A+B	X_3-X_2 X_1-X_3 X_2-X_1	a+b+c b+c+a c+a+b	$\frac{V_H}{V_X}\cdot\frac{2}{\sqrt{3}}$	D,y5	NO ACCESSIBLE NEUTRAL ON WYE WINDING
5			—	H_1-H_3 H_2-H_1 H_3-H_2	A B C	X_0-X_3 X_0-X_1 X_0-X_2	a b c	$\frac{V_H\cdot\sqrt{3}}{V_X}$	D,yn11	
* 6			H_1-H_2 H_2-H_3 H_3-H_1	H_1-H_3 H_2-H_1 H_3-H_2	A+C B+A C+B	X_2-X_3 X_3-X_1 X_1-X_2	a+c b+a c+b	$\frac{V_H}{V_X}\cdot\frac{\sqrt{3}}{2}$	D,y11	NO ACCESSIBLE NEUTRAL ON WYE WINDING
6a			X_2-X_1 X_3-X_2 X_1-X_3	H_1-H_3 H_2-H_1 H_3-H_2	A+B+C B+C+A C+A+B	X_2-X_3 X_3-X_1 X_1-X_2	a+b+c b+c+a c+a+b	$\frac{V_H}{V_X}\cdot\frac{2}{\sqrt{3}}$	D,y11	NO ACCESSIBLE NEUTRAL ON WYE WINDING

NOTE: TRANSFORMER TERMINAL MARKINGS COMPLY WITH REQUIREMENTS OF C57.12.70-1978

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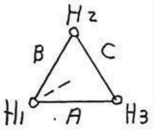
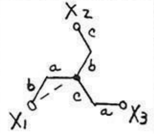
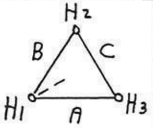
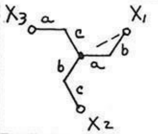
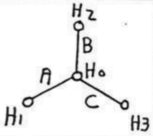
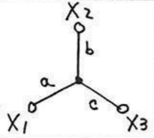
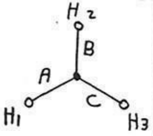
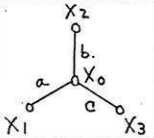
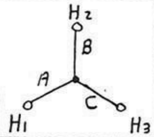
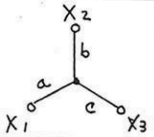
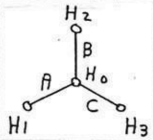
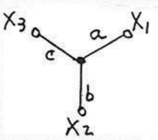
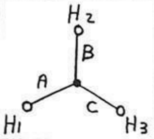
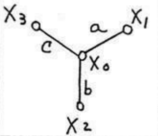
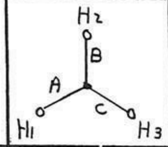
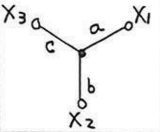
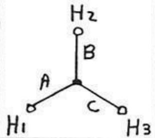
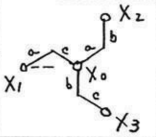
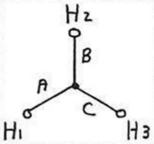
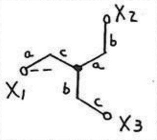
TABLE 2 NON STANDARD TRANSFORMER WINDING PHASE RELATIONSHIP

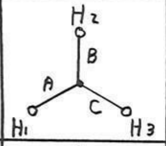
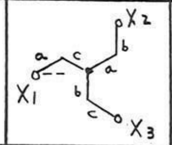
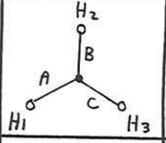
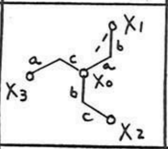
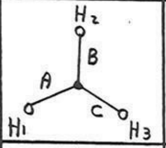
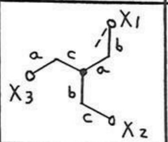
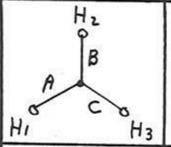
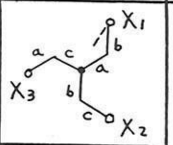
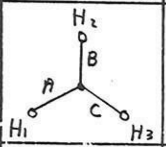
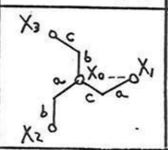
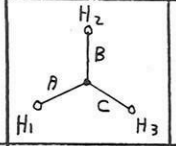
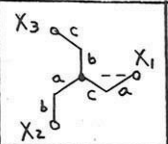
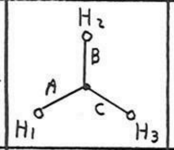
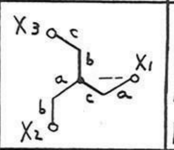
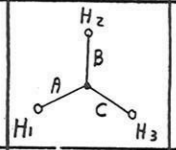
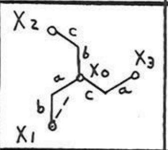
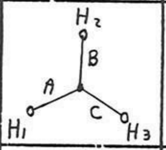
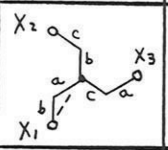
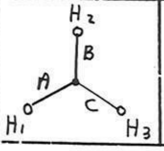
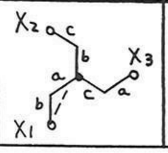
CONNECTIONS USING CAT. NO. 550005 TTR

DIAG NO.	TRANSFORMER TYPE		JUMPER	H WINDING		X WINDING		MEASURED TURN RATIO	IEC VECTOR GROUP	REMARKS
	HIGH-VOLTAGE WINDING (H)	LOW-VOLTAGE WINDING (X)		TERMINAL CONNECTION	PHASE TESTED	TERMINAL CONNECTION	PHASE TESTED			
7			—	H_1-H_3	A+B+C	X_1-X_3	a+b+c	$\frac{V_H}{V_X}$	D,z0	NO ACCESSIBLE NEUTRAL
				H_2-H_1	B+A+C	X_2-X_1	b+a+c			
				H_3-H_2	C+A+B	X_3-X_2	c+a+b			
8			—	H_1-H_3	A+B+C	X_3-X_1	a+b+c	$\frac{V_H}{V_X}$	D,z6	NO ACCESSIBLE NEUTRAL
				H_2-H_1	B+A+C	X_1-X_2	b+a+c			
				H_3-H_2	C+A+B	X_2-X_3	c+a+b			
9			H_3-H_0	H_1-H_0	A	X_1-X_3	a	$\frac{V_H}{V_X}$	YN,y0	NO ACCESSIBLE NEUTRAL ON LOW VOLTAGE WINDING
			H_1-H_0	H_2-H_0	B	X_2-X_1	b			
			H_2-H_0	H_3-H_0	C	X_3-X_2	c			
10			X_3-X_0	H_1-H_3	A	X_1-X_0	a	$\frac{V_H}{V_X}$	Y,yn0	NO ACCESSIBLE NEUTRAL ON HIGH VOLTAGE WINDING
			X_1-X_0	H_2-H_1	B	X_2-X_0	b			
			X_2-X_0	H_3-H_2	C	X_3-X_0	c			
11			—	H_1-H_3	A+C	X_1-X_3	a+c	$\frac{V_H}{V_X}$	Y,y0	NO ACCESSIBLE NEUTRAL
				H_2-H_1	B+A	X_2-X_1	b+a			
				H_3-H_2	C+B	X_3-X_2	c+b			
12			H_3-H_0	H_1-H_0	A	X_3-X_1	a	$\frac{V_H}{V_X}$	YN,y6	NO ACCESSIBLE NEUTRAL ON LOW VOLTAGE WINDING
			H_1-H_0	H_2-H_0	B	X_1-X_2	b			
			H_2-H_0	H_3-H_0	C	X_2-X_3	c			
13			X_3-X_0	H_1-H_3	A	X_0-X_1	a	$\frac{V_H}{V_X}$	Y,yn6	NO ACCESSIBLE NEUTRAL ON HIGH VOLTAGE WINDING
			X_1-X_0	H_2-H_1	B	X_0-X_2	b			
			X_2-X_0	H_3-H_2	C	X_0-X_3	c			
14			—	H_1-H_3	A+C	X_3-X_1	a+c	$\frac{V_H}{V_X}$	Y,y6	NO ACCESSIBLE NEUTRAL
				H_2-H_1	B+A	X_1-X_2	b+a			
				H_3-H_2	C+B	X_2-X_3	c+b			
15			—	H_1-H_3	A+C	X_1-X_0	a+c	$\frac{V_H \cdot \sqrt{3}}{V_X}$	Y,zn1	NO ACCESSIBLE NEUTRAL ON WYE WINDING
				H_2-H_1	B+A	X_2-X_0	b+a			
				H_3-H_2	C+B	X_3-X_0	c+b			
* 16			X_3-X_2	H_1-H_3	A+C	X_1-X_3	a+c	$\frac{V_H}{V_X} \cdot \frac{2}{\sqrt{3}}$	Y,z1	NO ACCESSIBLE NEUTRAL
			X_1-X_3	H_2-H_1	B+A	X_2-X_1	b+a			
			X_2-X_1	H_3-H_2	C+B	X_3-X_2	c+b			

NOTE: TRANSFORMER TERMINAL MARKINGS COMPLY WITH REQUIREMENTS OF C57.12.70-1978

9/21/92

TABLE 2 NON STANDARD TRANSFORMER WINDING PHASE RELATIONSHIP
CONNECTIONS USING CAT NO. 550005 TTR

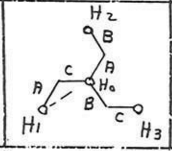
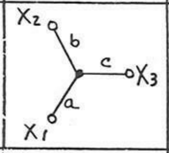
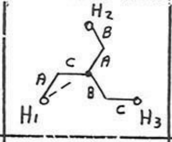
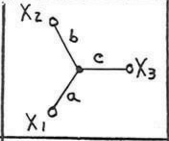
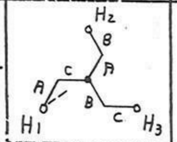
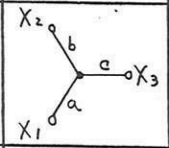
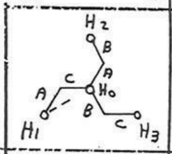
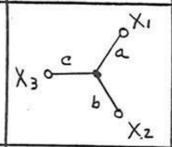
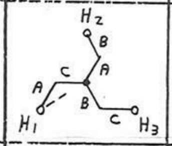
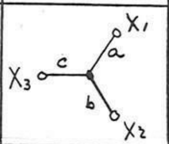
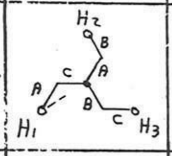
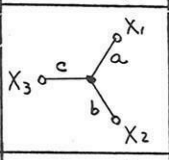
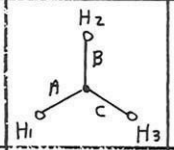
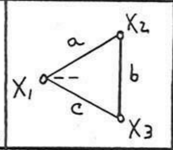
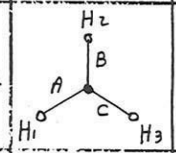
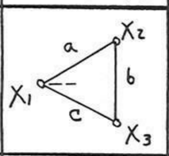
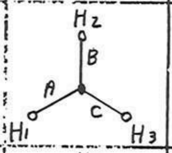
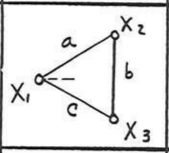
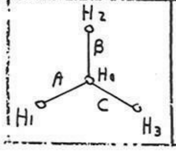
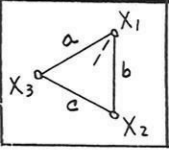
DIAG NO.	TRANSFORMER TYPE		JUMPER	H WINDING		X WINDING		MEASURED TURN RATIO	IEC VECTOR GROUP	REMARKS
	HIGH-VOLTAGE WINDING (H)	LOW-VOLTAGE WINDING (X)		TERMINAL CONNECTION	PHASE TESTED	TERMINAL CONNECTION	PHASE TESTED			
16a			H_2-H_1 H_3-H_2 H_1-H_3	H_1-H_3 H_2-H_1 H_3-H_2	C+A+B A+B+C B+A+C	X_1-X_3 X_2-X_1 X_3-X_2	c+a+b a+b+c b+a+c	$\frac{V_H}{V_X}\cdot\frac{\sqrt{3}}{2}$	Y, z1	NO ACCESSIBLE NEUTRAL
17			—	H_1-H_3 H_2-H_1 H_3-H_2	A+C B+A C+B	X_3-X_0 X_1-X_0 X_2-X_0	a+c b+a c+b	$\frac{V_H\cdot\sqrt{3}}{V_X}$	Y, zn5	NO ACCESSIBLE NEUTRAL ON WYE WINDING
* 18			X_2-X_1 X_3-X_2 X_1-X_3	H_1-H_3 H_2-H_1 H_3-H_2	A+C B+A C+B	X_3-X_2 X_1-X_3 X_2-X_1	a+c b+a c+b	$\frac{V_H}{V_X}\cdot\frac{2}{\sqrt{3}}$	Y, z5	NO ACCESSIBLE NEUTRAL
a			H_2-H_1 H_3-H_2 H_1-H_3	H_1-H_3 H_2-H_1 H_3-H_2	C+A+B A+B+C B+A+C	X_3-X_2 X_1-X_3 X_2-X_1	c+a+b a+b+c b+a+c	$\frac{V_H}{V_X}\cdot\frac{\sqrt{3}}{2}$	Y, z5	NO ACCESSIBLE NEUTRAL
7			—	H_1-H_3 H_2-H_1 H_3-H_2	A+C B+A C+B	X_0-X_1 X_0-X_2 X_0-X_3	a+c b+a c+b	$\frac{V_H\cdot\sqrt{3}}{V_X}$	Y, zn7	NO ACCESSIBLE NEUTRAL ON WYE WINDING
0			X_3-X_2 X_1-X_3 X_2-X_1	H_1-H_3 H_2-H_1 H_3-H_2	A+C B+A C+b	X_3-X_1 X_1-X_2 X_2-X_3	a+c b+a c+b	$\frac{V_H}{V_X}\cdot\frac{2}{\sqrt{3}}$	Y, z7	NO ACCESSIBLE NEUTRAL
a			H_2-H_1 H_3-H_2 H_1-H_3	H_1-H_3 H_2-H_1 H_3-H_2	C+A+B A+B+C B+A+C	X_3-X_1 X_1-X_2 X_2-X_3	c+a+b a+b+c b+a+c	$\frac{V_H}{V_X}\cdot\frac{\sqrt{3}}{2}$	Y, z7	NO ACCESSIBLE NEUTRAL
21			—	H_1-H_3 H_2-H_1 H_3-H_2	A+C B+A C+B	X_0-X_3 X_0-X_1 X_0-X_2	a+c b+a c+b	$\frac{V_H\cdot\sqrt{3}}{V_X}$	Y, zn11	NO ACCESSIBLE NEUTRAL ON WYE WINDING
			X_2-X_1 X_3-X_2 X_1-X_3	H_1-H_3 H_2-H_1 H_3-H_2	A+C B+A C+B	X_2-X_3 X_3-X_1 X_1-X_2	a+c b+a c+b	$\frac{V_H}{V_X}\cdot\frac{2}{\sqrt{3}}$	Y, z11	NO ACCESSIBLE NEUTRAL
22a			H_2-H_1 H_3-H_2 H_1-H_3	H_1-H_3 H_2-H_1 H_3-H_2	C+A+B A+B+C B+A+C	X_2-X_3 X_3-X_1 X_1-X_2	c+a+b a+b+c b+a+c	$\frac{V_H}{V_X}\cdot\frac{\sqrt{3}}{2}$	Y, z11	NO ACCESSIBLE NEUTRAL

NOTE: TRANSFORMER TERMINAL MARKINGS COMPLY WITH REQUIREMENTS OF C57.12.70-1978

CRS 9/21/92

TABLE 2 NON STANDARD TRANSFORMER WINDING PHASE RELATIONSHIP

CONNECTIONS USING CAT. NO. 550005 TTR

DIAG NO.	TRANSFORMER TYPE		JUMPER	H WINDING		X WINDING		MEASURED TURN RATIO	IEC VECTOR GROUP	REMARKS
	HIGH-VOLTAGE WINDING (H)	LOW-VOLTAGE WINDING (X)		TERMINAL CONNECTION	PHASE TESTED	TERMINAL CONNECTION	PHASE TESTED			
23			—	H_1-H_0	A+C	X_1-X_3	a+c	$\frac{V_H}{V_X \cdot \sqrt{3}}$	ZN,yll	NO ACCESSIBLE NEUTRAL ON WYE WINDING
				H_2-H_0	B+A	X_2-X_1	b+a			
				H_3-H_0	C+B	X_3-X_2	c+b			
24			X_2-X_1	H_1-H_3	C+A+B	X_1-X_3	c+a+b	$\frac{V_H}{V_X}\cdot\frac{2}{\sqrt{3}}$	Z,yll	NO ACCESSIBLE NEUTRAL
			X_3-X_2	H_2-H_1	A+B+C	X_2-X_1	a+b+c			
			X_1-X_3	H_3-H_2	B+A+C	X_3-X_2	b+a+c			
24a			H_3-H_2	H_1-H_3	A+C	X_1-X_3	a+c	$\frac{V_H}{V_X}\cdot\frac{\sqrt{3}}{2}$	Z,yll	NO ACCESSIBLE NEUTRAL
			H_1-H_3	H_2-H_1	B+A	X_2-X_1	b+a			
			H_2-H_1	H_3-H_2	C+B	X_3-X_2	c+b			
25			—	H_1-H_0	A+C	X_3-X_1	a+c	$\frac{V_H}{V_X \cdot \sqrt{3}}$	ZN,y5	NO ACCESSIBLE NEUTRAL ON WYE WINDING
				H_2-H_0	B+A	X_1-X_2	b+a			
				H_3-H_0	C+B	X_2-X_3	c+b			
26			X_2-X_1	H_1-H_3	C+A+B	X_3-X_1	c+a+b	$\frac{V_H}{V_X}\cdot\frac{2}{\sqrt{3}}$	Z,y5	NO ACCESSIBLE NEUTRAL
			X_3-X_2	H_2-H_1	A+B+C	X_1-X_2	a+b+c			
			X_1-X_3	H_3-H_2	B+A+C	X_2-X_3	b+a+c			
6a			H_3-H_2	H_1-H_3	A+C	X_3-X_1	a+c	$\frac{V_H}{V_X}\cdot\frac{\sqrt{3}}{2}$	Z,y5	NO ACCESSIBLE NEUTRAL
			H_1-H_3	H_2-H_1	B+A	X_1-X_2	b+a			
			H_2-H_1	H_3-H_2	C+B	X_2-X_3	c+b			
* 27			X_1-X_3	H_1-H_3	A	X_1-X_2	a	$\frac{V_H}{V_X \cdot \sqrt{3}}$	Y,d1	NO ACCESSIBLE NEUTRAL ON WYE WINDING
			X_2-X_1	H_2-H_1	B	X_2-X_3	b			
			X_3-X_2	H_3-H_2	C	X_3-X_1	c			
27a			X_3-X_2	H_1-H_3	A+C	X_1-X_3	a+c	$\frac{V_H}{V_X}\cdot\frac{2}{\sqrt{3}}$	Y,d1	NO ACCESSIBLE NEUTRAL ON WYE WINDING
			X_1-X_3	H_2-H_1	B+A	X_2-X_1	b+a			
			X_2-X_1	H_3-H_2	C+B	X_3-X_2	c+b			
27b			H_2-H_1	H_1-H_3	C+A+B	X_1-X_3	c+a+b	$\frac{V_H}{V_X}\cdot\frac{\sqrt{3}}{2}$	Y,d1	NO ACCESSIBLE NEUTRAL ON WYE WINDING
			H_3-H_2	H_2-H_1	A+B+C	X_2-X_1	a+b+c			
			H_1-H_3	H_3-H_2	B+A+C	X_3-X_2	b+a+c			
28			—	H_1-H_0	A	X_3-X_1	a	$\frac{V_H}{V_X \cdot \sqrt{3}}$	YN,d5	
				H_2-H_0	B	X_1-X_2	b			
				H_3-H_0	C	X_2-X_3	c			

NOTE: TRANSFORMER TERMINAL MARKINGS COMPLY WITH REQUIREMENTS OF C57.12.70-1978

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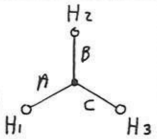
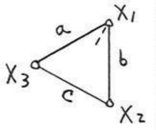
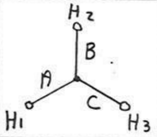
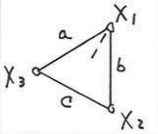
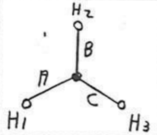
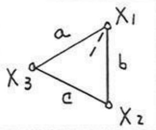
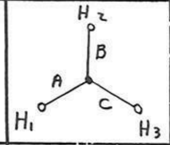
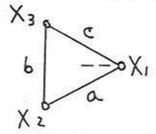
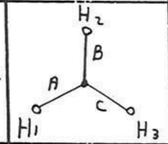
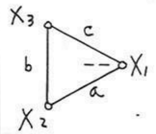
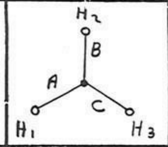
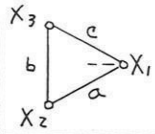
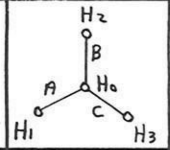
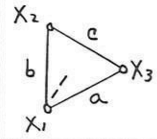
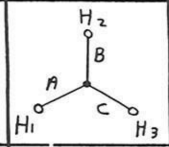
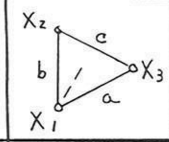
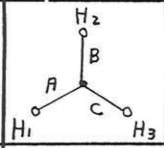
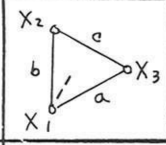
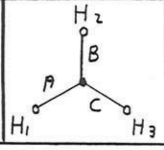
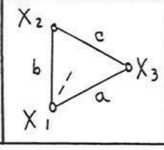
TABLE 2 NON STANDARD TRANSFORMER WINDING PHASE RELATIONSHIP CONNECTIONS USING CAT. NO. 550005 TTR

DIAG NO.	TRANSFORMER TYPE		JUMPER	H WINDING		X WINDING		MEASURED TURN RATIO	IEC VECTOR GROUP	REMARKS
	HIGH-VOLTAGE WINDING (H)	LOW-VOLTAGE WINDING (X)		TERMINAL CONNECTION	PHASE TESTED	TERMINAL CONNECTION	PHASE TESTED			
* 29			X3-X2	H1-H3	A	X3-X1	a	$\frac{V_H}{V_X \cdot \sqrt{3}}$	Y,d 5	NO ACCESSIBLE NEUTRAL ON WYE WINDING
			X1-X3	H2-H1	B	X1-X2	b			
			X2-X1	H3-H2	C	X2-X3	c			
29a			X2-X1	H1-H3	A+C	X3-X2	a+c	$\frac{V_H}{V_X} \cdot \frac{2}{\sqrt{3}}$	Y,d 5	NO ACCESSIBLE NEUTRAL ON WYE WINDING
			X3-X2	H2-H1	B+A	X1-X3	b+a			
			X1-X3	H3-H2	C+B	X2-X1	c+b			
29b			H2-H1	H1-H3	C+A+B	X3-X2	c+a+b	$\frac{V_H}{V_X} \cdot \frac{\sqrt{3}}{2}$	Y,d 5	NO ACCESSIBLE NEUTRAL ON WYE WINDING
			H3-H2	H2-H1	A+B+C	X1-X3	a+b+c			
			H1-H3	H3-H2	B+A+C	X2-X1	b +c			
* 30			X1-X3	H1-H3	A	X2-X1	a	$\frac{V_H}{V_X \cdot \sqrt{3}}$	Y,d 7	NO ACCESSIBLE NEUTRAL ON WYE WINDING
			X2-X1	H2-H1	B	X3-X2	b			
			X3-X2	H3-H2	C	X1-X3	c			
30a			X3-X2	H1-H3	A+C	X3-X1	a+c	$\frac{V_H}{V_X} \cdot \frac{2}{\sqrt{3}}$	Y,d 7	NO ACCESSIBLE NEUTRAL ON WYE WINDING
			X1-X3	H2-H1	B+A	X1-X2	b+a			
			X2-X1	H3-H2	C+B	X2-X3	c+b			
30b			H2-H1	H1-H3	C+A+B	X3-X1	c+a+b	$\frac{V_H}{V_X} \cdot \frac{\sqrt{3}}{2}$	Y,d 7	NO ACCESSIBLE NEUTRAL ON WYE WINDING
			H3-H2	H2-H1	A+B+C	X1-X2	a+b+c			
			H1-H3	H3-H2	B+A+C	X2-X3	b+a+c			
31			—	H1-Ho	A	X1-X3	a	$\frac{V_H}{V_X \cdot \sqrt{3}}$	YN,d 11	
				H2-Ho	B	X2-X1	b			
				H3-Ho	C	X3-X2	c			
* 32			X3-X2	H1-H3	A	X1-X3	a	$\frac{V_H}{V_X \cdot \sqrt{3}}$	Y,d 11	NO ACCESSIBLE NEUTRAL ON WYE WINDING
			X1-X3	H2-H1	B	X2-X1	b			
			X2-X1	H3-H2	C	X3-X2	c			
32a			X2-X1	H1-H3	A+C	X2-X3	a+c	$\frac{V_H}{V_X} \cdot \frac{2}{\sqrt{3}}$	Y,d 11	NO ACCESSIBLE NEUTRAL ON WYE WINDING
			X3-X2	H2-H1	B+A	X3-X1	b+a			
			X1-X3	H3-H2	C+B	X1-X2	c+b			
32b			H2-H1	H1-H3	C+A+B	X2-X3	c+a+b	$\frac{V_H}{V_X} \cdot \frac{\sqrt{3}}{2}$	Y,d 11	NO ACCESSIBLE NEUTRAL ON WYE WINDING
			H3-H2	H2-H1	A+B+C	X3-X1	a+b+c			
			H1-H3	H3-H2	B+A+C	X1-X2	b+a+c			

NOTE: TRANSFORMER TERMINAL MARKINGS COMPLY WITH REQUIREMENTS OF C57.12.70-1978

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CRS 9/21/92

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