INSTRUMENT TRANSFORMER BASIC TECHNICAL INFORMATION AND APPLICATION

GENERAL ELECTRIC

DEFINITIONS AND FUNCTIONS

The name "Instrument Transformer" is a general classification applied to current and potential devices used to change currents and voltages from one magnitude to another or to perform an isolating function, that is, to isolate (or insulate) the utilization current or voltage from the supply voltage for safety to both the operator and the end device in use. Instrument transformers are designed specifically for use with electrical equipment falling into the broad category of devices commonly called instruments such as voltmeters, ammeters, wattmeters, watthour meters, relays, etc.

It is beyond the scope of this presentation to attempt to show in detail current or potential transformers applied to all the various types of circuits in combination with the many forms of instruments, meters and relays.

CONSTRUCTION FEATURES

Potential transformers consist of two separate windings on a common magnetic steel core. One winding consists of a relatively large number of turns of fine wire on a steel core and is called the primary winding. The other winding consists of fewer turns of heavier wire on the steel core and is called the secondary winding.

Current transformers are constructed in various ways. One method is quite similar to that of the potential transformer in that there are two separate windings on a magnetic steel core. But it differs in that the primary winding consists of a few turns of heavy wire capable of carrying the full load current while the secondary winding consists of many turns of smaller wire with a current carrying capacity of from 5 to 20 amperes, dependent on the design. This is called the wound type due to its wound primary coil.

Another very common type of construction is the so-called "window," "through" or donut type current transformer in which the core has an opening through which the conductor carrying the primary load current is passed.

This primary conductor constitutes the primary winding of the CT (one pass through the "window" represents a one turn primary), and must be large enough in cross section to carry the full load current up to the thermal rating factor of the unit.

The secondary consists of a larger number of turns of smaller wire. The number is dependent on the primary to secondary current transformation desired. If a lower current rating than is available is required due to a low load density, this can be achieved by looping the primary cable through the window of the CT. An example would be the need for a 100 ampere to 5 unit when the lowest current rating made by the manufacturer was 200 to 5 amperes. By looping the cable through the window so that the cable passes through the window twice, we can make an effective 100:5 ampere unit out of a 200:5 ampere unit (thus 100 amps X 2 = 200 amps). Smaller increments of current change can be achieved by adding or backing off secondary turns as well as primary turns, i.e., we can make a 110:5 ampere unit out of a standard 200:5 ampere unit by adding 2 primary turns and adding 4 secondary turns. The primary ampere turns must equal the secondary ampere turns. Thus 110 amperes X 2 turns is 220 ampere turns on the primary. To equalize this on the secondary of a standard 200:5 ampere unit which has 40 turns (40 X 5 amperes = 200 NI), we would have to add 4 secondary turns through the window of the CT thus giving us a total of 44 secondary turns X 5 amperes = 220 ampere turns. Thus we have modified a standard 200:5 ampere CT to be a 110:5 ampere unit by adding 2 external primary turns and 4 external secondary turns to it. Had we chosen to buck off the 4 secondary turns instead of adding them, we would have had a 90:5 ampere CT. Refer to instructions for use as a variable-ratio current transformer.

Another distinguishing feature is the difference between indoor and outdoor construction. The performance characteristics of the two constructions are essentially the same, but the physical appearance and hardware are different. The outdoor unit must be protected for possible contaminated environments while indoor units are protected due to their being mounted in an enclosure of some kind. Thus most outdoor units will have larger spacing between line and ground which is achieved by the addition of skirts on the design. This provides larger surface creepage distances (string distances) from the primary terminals (at line potentials) to the secondary terminals and base plate (at ground potentials). For outdoor types the hardware must be of the noncorrosive type and the insulation must be of the non-arc-tracking type. One other feature that differentiates the indoor from the outdoor is the orientation of the primary terminals. The indoor types must be compatible for connection to buss type electrical construction as opposed to the outdoor types that are normally on pole-top installations.

RATING AND RATIO

The rating of an instrument transformer is expressed by two groups of numbers representing the nominal current or voltage which may be applied to its primary winding and the current or voltage which would then be induced in its secondary winding. For example, the designation 480:120 volt expresses the rating of the potential transformer. This means that it is safe and permissible to apply 480 volts to the primary winding, and that when a voltage of this value is applied to the primary, 120 volts will be induced in the secondary. Likewise a designation of 400:5 amperes expresses the rating of a current transformer and means that when 400 amperes flow in its primary, 5 amperes will flow in the secondary.

Industry standards have established 120 volts as the secondary rating of potential transformers having primary ratings up to 24,000 volts and 115 volts as the secondary rating of PT's having ratings above 24,000 volts. Similarly, industry standards have established 5 amperes as the secondary rating of current transformers.

The ratio of an instrument transformer is the relationship of its primary rating to its secondary rating. For example, the potential transformer mentioned above having a rating of 480:120 volts will have a ratio of 4:1 and the current transformer having a rating of 400:5 amperes will have a ratio of 80:1.

CURRENT TRANSFORMER THERMAL RATING FACTOR

Rating factor (RF) is a term which applies to a current transformer. In its application to a current transformer, it is the number representing the amount by which the primary load current may be increased over its nameplate rating without exceeding the allowable temperature rise. In other words, it is a designation of the transformer's overload capability. In order to be completely meaningful, the ambient temperature at which the rating factor applies should be stated. The standard ambient reference levels are at 30°C and 55°C. In the manufacturer's literature, a typical statement would be: RF 2.0 at 30°C ambient with RF 1.5 at 55°C ambient. These statements mean that in a 30°C ambient, the CT will safely carry on a continuous basis 2 times the nameplate rating and at 55°C ambient, it will carry 1.5 times the nameplate rating.

It is very important that the ambient temperature be considered when applying CT's above the nameplate rating. Typical rating factors of CT's are 1.0, 1.25, 1.33, 1.5, 2.0, 3.0 and 4.0.

Many times the manufacturer will only list the CT rating factor at 30°c ambient (room temperature). If you wish to know what the rating factor is at some other ambient temperature, you will have to convert the value by use of a rather simple proportional equation. Following is a typical example:

The manufacturer states his 400:5 ampere CT has a rating factor of 4.0 at a 30°C ambient and you wish to know how much you must derate it when it is put in an enclosure where the highest ambient temperature might be 55°C.

The basic formula is:

$$\frac{(\text{NEW RF AT NEW AMB})^2}{(\text{STATED RF AT } 30^\circ\text{C})^2} = \frac{30^\circ\text{C}}{(\text{NEW AMBIENT } ^\circ\text{C})}$$

And for our particular example:

$$\frac{X^2}{(4.0)^2} = \frac{30}{55}$$

$$X^2 = \frac{480}{55} = 8.73$$

$$X = \sqrt{8.73} = 2.95 \text{ RF AT } 55^\circ\text{C AMBIENT}$$

Thus where the 400 ampere unit could carry (400 X 4.0) 1600 amperes primary at 30°C ambient it can only carry (400 X 2.95) or 1180 amperes continuously at a 55°C ambient without exceeding the manufacturer's recommended transformer thermal rating.

POTENTIAL TRANSFORMER THERMAL RATING

Potential transformers have a thermal rating rather than a rating factor as with the CT and it designates the maximum volt-ampere burden which may be connected to its secondary at specified ambient temperatures of either 30 or 55°C. Note the thermal rating of a PT relates to the secondary loading only as opposed to the rating factor of a CT which applies to both the primary and secondary winding.

POTENTIAL TRANSFORMER OVERVOLTAGE REQUIREMENTS

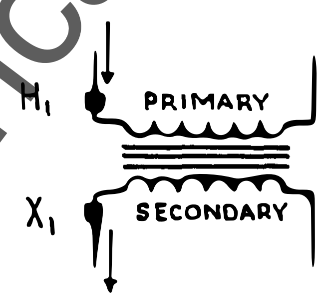
The ANSI standards allow two levels of operation. One is a continuous operation level and one is for emergency conditions. A potential transformer must be capable of operating at 110% above rated voltage continuously provided the secondary burden in volt amperes at this voltage does not exceed the thermal burden rating. The emergency rating of potential transformers is defined at one minute of operation. Thus enough time for protective equipment to operate. Capsulized this would be 125% of nameplate rating for line-to-line units from 600 volts to 15 KV, 173% of nameplate rating for line-to-ground units on 25 KV to 161 KV line-to-line system and 140% of nameplate rating above 161 KV line-to-line systems.

INSULATION CLASS

The insulation class indicates the magnitude of voltage which an instrument transformer can safely withstand between its primary and secondary windings and between its primary OR secondary winding and ground (core, case or tank) without a breakdown in the insulation. Industry standards have established insulation classes ranging from 600 volts up through 545 KV. System voltages presently extend up to 765 KV with 1100 and 1500 KV being investigated for future transmission expansions. Industry recommendations are that the insulation class of an instrument transformer should be at least equal to the maximum line-to-line voltage existing on the system at the point of connection. For example, the insulation class of a potential transformer used on a 7200/12470Y volt system should be 15 KV even though the PT has a primary rating of 7200 volts and is connected phase-to-ground. Similarly, any current transformer used on a 7200/12470Y volt system should be of the 15 KV insulation class. Under fault conditions these units could be subjected to line-to-line voltage.

POLARITY

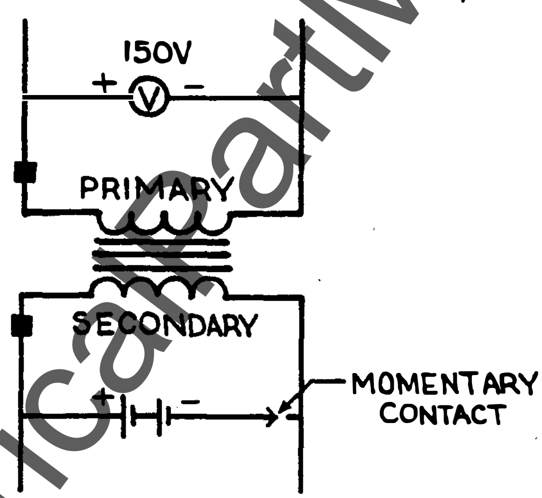
In the application of instrument transformers it is necessary to understand the meaning of polarity and to observe certain rules when connecting watthour meters to them. If you will accept the fact, without proof, that the flow of current in the secondary winding is in a direction opposite to that in the primary winding, that is, 180° out of phase with it, it will be relatively simple to understand the meaning of polarity. At any instant, when the current is flowing into one of the primary terminals it will be flowing out of one of the secondary terminals.



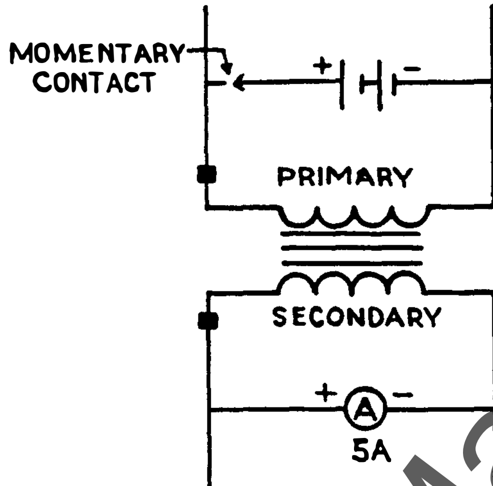
The polarity of a transformer therefore is simply an identification of the primary terminal and the secondary terminal which satisfies the previously stated conditions. All instrument transformers, whether current or potential will have polarity marks associated with at least one primary terminal and one secondary terminal. These markings usually appear as white dots or letter and number combinations. The standards refer to H_1 as the primary terminal marking and X_1 for the secondary polarity mark.

In applications which depend on the interaction of two currents, such as a watthour meter, it is essential that the polarity of both current and potential transformers be known and that definite relationships be maintained when connecting them to watthour meters.

While all instrument transformers should be clearly marked as to their polarity, it is sometimes necessary to verify existing markings or to determine the polarity of an old or unmarked transformer. One simple and rapid method of determining polarity on a potential transformer is to connect a suitable d-c permanent magnet voltmeter, preferably one with a 150 volt range, across the high voltage terminals, with the marked primary terminal of the transformer connected to the plus (+) terminal of the voltmeter. Then connect two dry cells in series and connect the plus (+) terminal of the battery to the marked secondary terminal. Make an instantaneous contact between the negative (-) terminal of the battery and the unmarked or (X_2) secondary terminal of the transformer. A deflection or "kick" will be indicated on the voltmeter. If the initial "kick" (the one resulting from making, not breaking the circuit) is in an upscale direction, the potential terminals are marked correctly.



Similarly, a polarity check may be made on a current transformer. Connect a d-c permanent magnet ammeter of 5 ampere capacity or less (depending on the transformer ratio) across the current transformer secondary. Connect the plus (+) terminal of the ammeter to the marked terminal of the secondary. Then connect two dry cells in series and connect the negative (-) terminal of the battery to the unmarked of (H_2) marked terminal of the transformer, make an instantaneous contact between the marked or (H_1) primary terminal of the transformer and the plus (+) terminal of the battery. If the initial kick (the one resulting from making not breaking the circuit) is upscale, the current transformer terminals are marked correctly.



Precautions should be taken when making this test on current transformers to prevent core magnetization from occurring due to the direct current. Window or bar type units with low current ratings (400 ampere and down) are particularly susceptible to this residual magnetism. The longer the d-c is maintained, the larger the effect this will have on the accuracy of the unit. It is the best practice to demagnetize the CT after using d-c. This can be accomplished by connecting at least 50 ohms variable across the secondary terminals and bring the primary current up to full load. Then gradually reduce the series resistance until it reaches zero without opening the secondary circuit. For best results, gradually reduce the primary circuit to zero before disconnecting the resistance circuit.

ACCURACY CLASSIFICATIONS AND BURDENS

The American National Standards Institute (called ANSI) has established standardized methods of classifying instrument transformers as to accuracy and burden. An accuracy classification for an instrument transformer includes the standard burden as well as the maximum percent error limits for line power factors between 100% and 60% lagging. A typical CT classification might be 0.3 B0.5 where the 0.3 is the percent allowable error and the B0.5 is the secondary burden in ohms impedance. The accuracy is dependent on the burden.

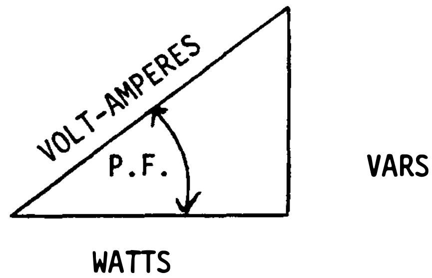
It is extremely important at this point to have a very clear understanding of the term "burden" as it is used in connection with instrument transformer accuracy classifications. The term "burden" has been adopted to distinguish it from "load" which is generally associated with the primary, especially with current transformers. For example, the load rating of a current transformer indicates the load (in current) which may be applied to its primary, while the burden rating indicates the amount of resistance (in ohms) and inductance (in milli-henries) which may be connected to its secondary without causing a metering error greater than specified by its accuracy classification.

The types of meters and relays and the size and length of wire connected to the secondary side of the instrument transformer make up its burden.

These values can be calculated by converting each device into terms of voltamperes and power factor and doing a vector analysis to determine what the total effective burden on the transformer is. A more practical way is to obtain from the manufacturer the burden of each device in terms of watts and vars and calculate the total effective burden on the instrument transformer. A typical example might be as follows:

The utility is trying to determine what accuracy and burden classification CT to purchase for a particular metering application. The various meters and instruments to be used are known and the distance and size of wire to be used between the CT and the meters are known.

	Burden at 5 Amperes 60 Hz	
Devices	Watts	Vars
IB-10 (Rotating Std 5A)	0.80	0.80
I-50 Watthour Meter (TR-3W)	0.31	0.42
P-3 Ammeter (5A)	1.50	0.90
50 Ft. Distance CT to Meter Location 100 Circuit Ft. of #12 AWG Cu Wire	4.00	0.00
Total	6.61 Watts	2.12 Vars



$$VA = \sqrt{(WATTS)^2 + (VARS)^2}$$

$$VA = \sqrt{(6.61)^2 + (2.12)^2} = 6.94 \text{ VOLT-AMPERES}$$

$$P.F. \text{ (POWER FACTOR)} = \text{COSIGN OF THE } \angle \text{ WHOSE TAN IS } \frac{VARS}{WATTS}$$

$$P.F. = COS\ TAN^{-1}\ \frac{2.12}{6.61} = 0.321\ COS\ OF\ 72.2^\circ = .95$$

CONCLUSION: Since 6.94 VA a .95 P.F. exceed B0.2 burden (which is 5.0 VA at .9 P.F.) the utility must use a transformer that has a 0.3 B0.5 classification (or 12.5 VA at .9 P.F. capability).

If the circuit is much less complicated than the above and meets some simple guide lines, there is a practical rule-of-thumb tabulation provided that eliminates the need to make the calculation.

The following tabulation gives the maximum distance in feet between the CT and the meter that is allowable for the CT to meet a 0.3% accuracy classification.

The tabulation assumes the installation will have one or two watthour meters and that the line power factor is 0.80 or higher.

ANSI Accuracy Classification	AWG Secondary Copper Wire Size				
	#14	#12	#10	#8	#6
	Maximum Lead Length in Feet Between the Meters and the Current Transformers				
0.3 B0.2	19	31	49	79	126
0.3 B0.5	75	120	190	305	485

Standard ANSI values of accuracy burdens for CT's and PT's are listed in both the manufacturer's literature as well as the standards manual, the latest issue would be USAS C57.13-1968.

METERING ACCURACY

There are two sources of error in instrument transformers, namely ratio error and phase angle error. In a given transformer, the metering error is the combination of the two separate errors. This combination is called TCF (Transformer Correction Factor). ANSI has established accuracy classes for both current and potential transformers. The limit of permissible error in a potential transformer for a given accuracy class remains constant over a range of voltage from 10% below to 10% above rated voltage.

On the other hand, the limit of permissible error in a current transformer for a given accuracy class has one value at 100% rated current and allows twice that amount of error at 10% rated current. Typically 0.3% error is acceptable for watthour metering. 0.6% to 1.2% error for indicating instruments and 10% error for relaying.

To convert the manufacturer's accuracy test tag to the expected error (TCF) in an actual installation with a meter, you would need to know the average line power factor of the load as well as the burden on the instrument transformer. To illustrate this we would set up a hypothetical test tag for a current transformer.

The tag might read --

Secondary Burden	Secondary Current	Ratio Correction Factor	Phase Angle In Minutes
B0.5	5.0 amps	1.0025	+4
	0.5 amps	1.0040	+15

To convert these values into accuracy effect on the meter we must get the transformer connection factor (TCF) or the combined error effect.

The manufacturer's test results are given at 1.0 power factor, thus to know the effect at the actual installation we must know the line power factor of the metered load lagging. By knowing this we then have the multiplying factor to apply to the phase angle to adjust the ratio correction factor. The multiplying factors to be used are shown in the following table:

	IF THE LINE P.F. IS	THE PHASE ANGLE CORRECTION FACTOR IS
Limit of Standards ↑	1.0	.000000
	.9	.000137
	.8	.000218
	.7	.000297
↓	.6	.000386
	.5	.000502

Thus assuming a line power factor of .7 in our particular example would yield the following:

At 5.0 amps sec the phase angle at 1.0 P.F. on the manufacturer's test card was +4 minutes in phase angle

```
 .000297  RCFΔ /PA
     X 4  PA
 .001188
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With CT's the PA adjustment is subtracted from the RCF when the phase angle is (+) or the opposite from what the PA sign indicates. With a PT the addition or subtraction follow the same sign as the PA sign indicates.

In our example the phase angle is positive (+) and since it is a CT we will subtract the value arrived at thus

```
   1.0025  RCF
 -  .0012  PA adjustment
   1.0013 = TCF at 100% Current
```

Thus due to the transformer error (.13%) the meter will run slow by this amount at full rated current.

At 10% current the adjustment would be:

```
 .000295
    X 15
  001475
 000295
 .004425
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Since the PA is + on the CT we subtract

1.0040	RCF
.0044	PA Adjustment
.9996	= TCF at 10% Current

Thus due to a transformer error of (.04%) negative the meter will run fast by this amount at 10% rated current.

A similar analysis can be made for the TCF on a potential transformer except the phase angle correction factor must be (+) added or (-) subtracted dictated by the preceding sign on the phase angle.

RELAY ACCURACY OF A CURRENT TRANSFORMER

Current transformers that are used to operate relays for control and system protection must have certain accuracy under over-current conditions. The transformer must be able to not only withstand the high currents involved, but must also transform current to a lower value suitable for application to the relay terminals, and do this with a reasonable accuracy. A typical relay accuracy classification might be.

C200 or T200

Previous standards used the designations

10L200 or 10H200

The "L" stood for "low impedance" such as a window or thru bar design and the "H" stood for "high impedance" such as a wound primary design. The 10 stood for the accuracy such as 10% and the 200 stood for the secondary voltage output capability.

In the new relay designations, the 10% accuracy is inferred by standard definition. The "C" stands for calculated and means that window and bar type units which have a fully distributed secondary winding on the core will have very low leakage reactance thus lend itself to calculated values. The "T" stands for tested because wound type units do not have fully distributed windings, they must be tested because the leakage reactance is not predictable. The last number is the secondary voltage that can be developed at the secondary terminals without saturation.

Thus the meaning of the relay classification!

C200 would be

(10% Acc)
(Inferred) at 20 X normal current X secondary impedance

OR

E = IR

200 volt = (20 X 5 amps) X B2.0 ohms

Thus, this CT would have an error of no larger than 10% at 20 times normal secondary current with a secondary burden of 2.0 ohms.

Another example would be

T - 100

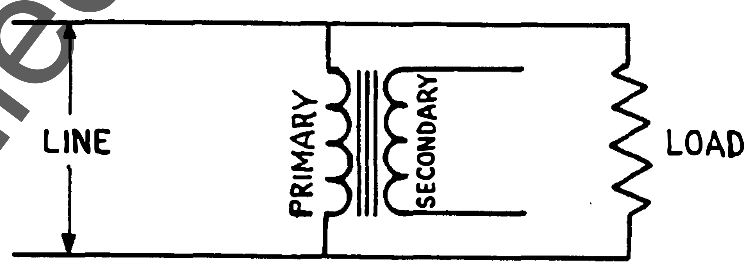
E = IR

100V = (20 X 5 AMPS) X B1.0 ohms

In this one the secondary output voltage is 100 volts and the maximum burden limitation is B1.0.

CONNECTIONS - POTENTIAL TRANSFORMERS

Potential transformers are always connected across two lines of the circuit in which the voltage is to be measured. The usual connection is as follows:

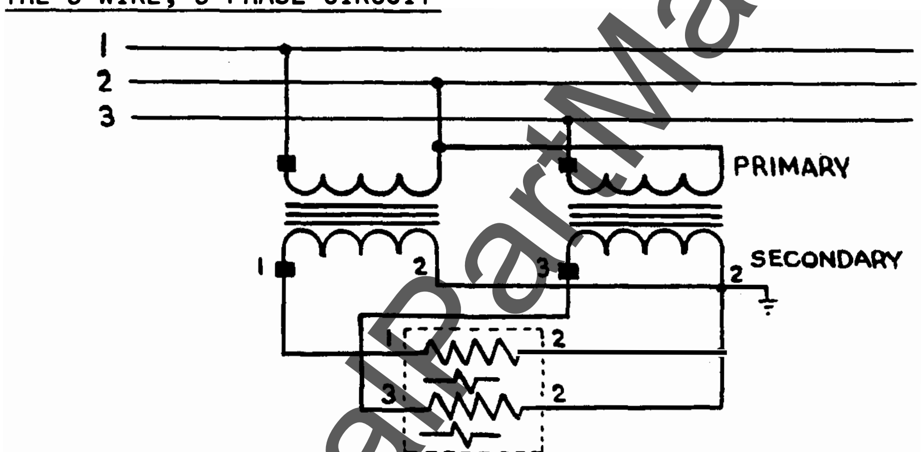


When a phase relationship of "direction of flow" is of no consequence, such as in a voltmeter which operates only according to the magnitude of the voltage, there is no need to observe the polarity of the transformer. However, in watthour meter applications, polarity must always be observed.

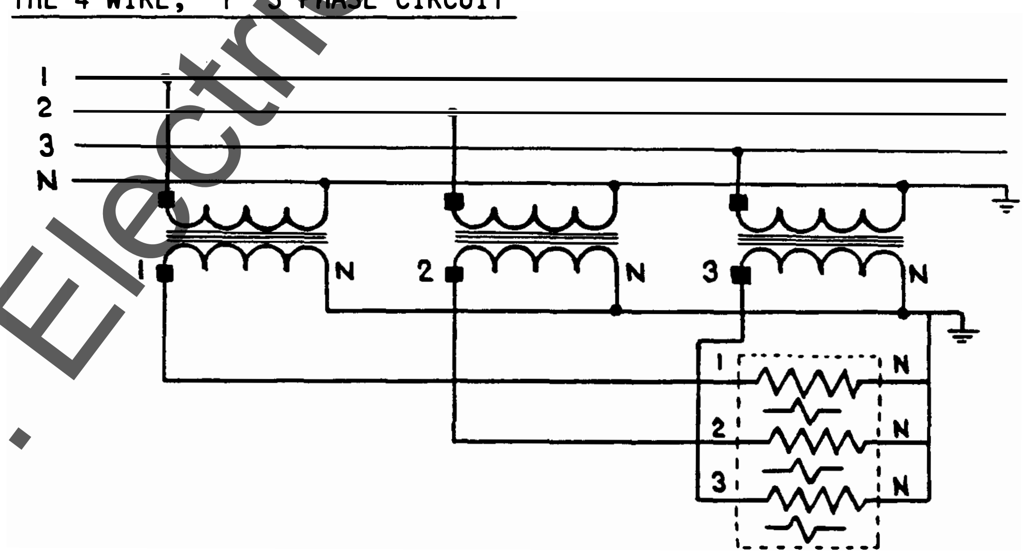
Most potential transformers have a single winding secondary as previously shown, however, they may have tapped secondary windings.

Two typical connections of potential transformers will illustrate the principles which apply in making instrument transformer installations.

THE 3 WIRE, 3 PHASE CIRCUIT



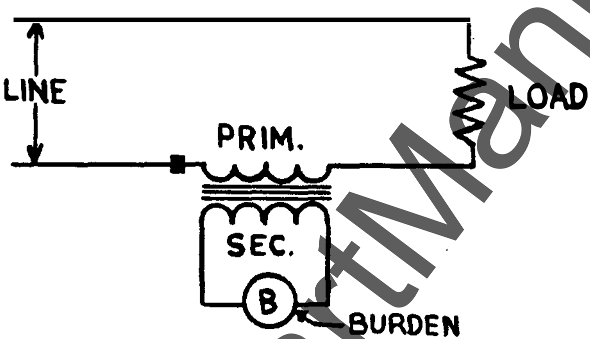
THE 4 WIRE, "Y" 3 PHASE CIRCUIT



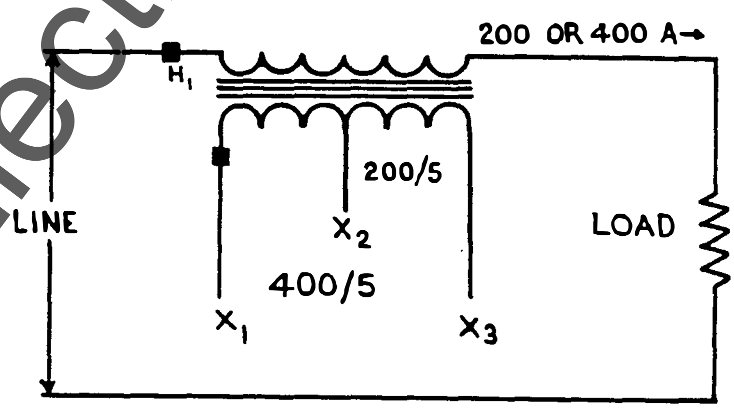
Note the polarity markings and their relationship to one another as well as the watthour meter potential coils. It also should be noted that the secondary windings are grounded at a common junction.

CURRENT TRANSFORMERS

CT's with wound primaries always have their primary windings connected in series with the line and the load and their secondary windings connected to the burden (the watthour meter current coil) as shown below:



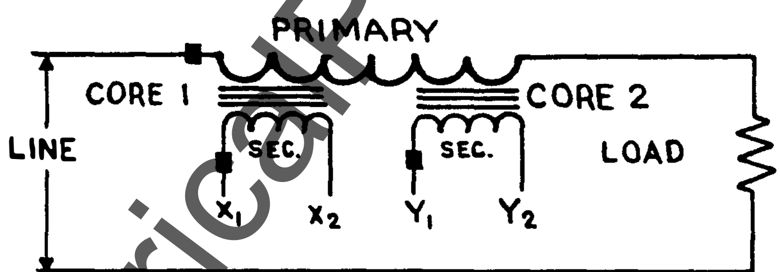
Current transformers having tapped secondaries are referred to as double-rated, tapped secondary CT's. They are used in applications where it is necessary to have available two ratios of primary to secondary current from the same secondary winding of the CT. This may be accomplished by adding a tap in the secondary winding to get a second ratio. The ratio obtained by the tap is usually one-half the ratio obtained by the full secondary winding. A schematic example is shown below.



With 200 amperes flowing in the primary, a connection X_2 - X_3 will produce 5 amperes out of the secondary. Then as the load grows to 400 amperes, the secondary circuit will be reconnected to X_1 - X_3 to produce 5 amperes in the secondary. If the reconnection is done while the unit is energized, the secondary terminals must be short circuited so as not to induce high voltage in the secondary circuit when the circuit is opened to make the connection. Voltage from a few hundred volts to several thousand volts, dependent on the design, can be developed in the secondary circuit when it is open circuited with current flowing in the primary winding. On a dual ratio tapped secondary CT, both the full winding and the tapped winding cannot be operated simultaneously. Another word of caution is in order when operating these tapped secondary CT's, namely that the unused terminals must be left open to avoid short circuiting a portion of the secondary winding.

Another design of CT quite commonly used is the double secondary CT. In this configuration the CT has two cores, two secondary windings and one common primary winding. Its application would be for using one CT to both meter and relay a common circuit where the metering circuit must be isolated from the relaying circuit.

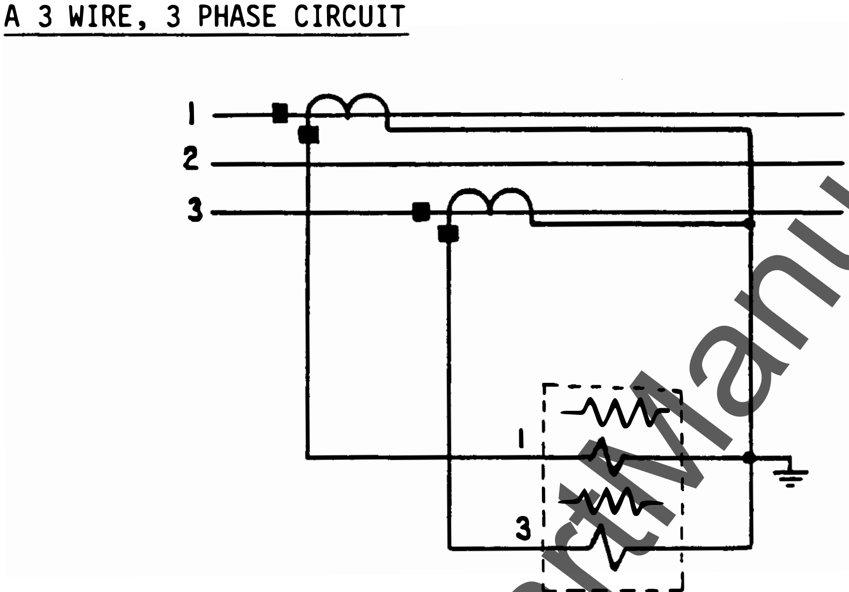
A schematic of this would look like this:



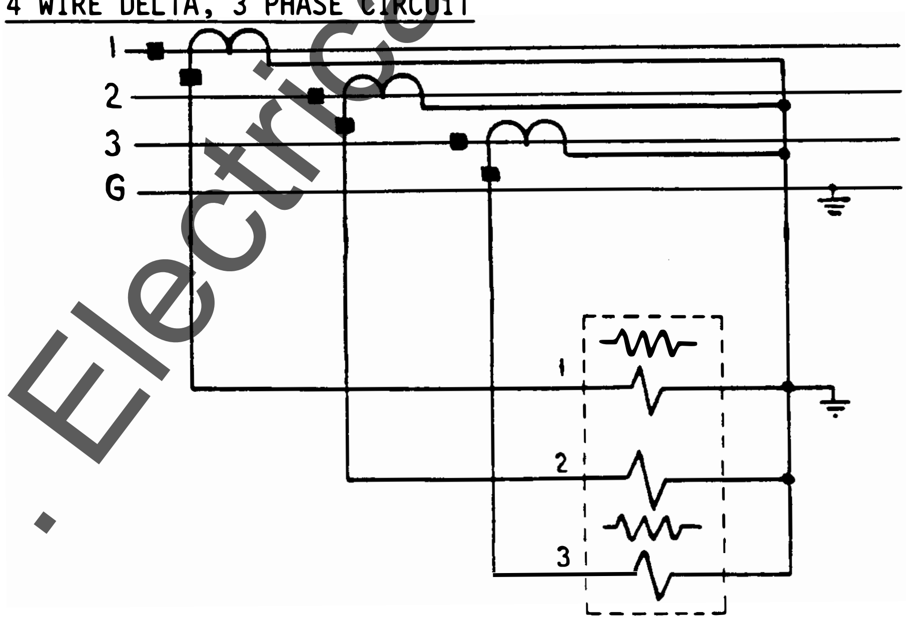
In this design, if both the circuits are not going to be used simultaneously, then the unused circuit must be short circuited while the other is energized or again you will develop an induced high voltage on the open circuited unused portion as pointed out previously.

Typical current transformer connections on three common circuits will illustrate the principles involved in making CT installations.

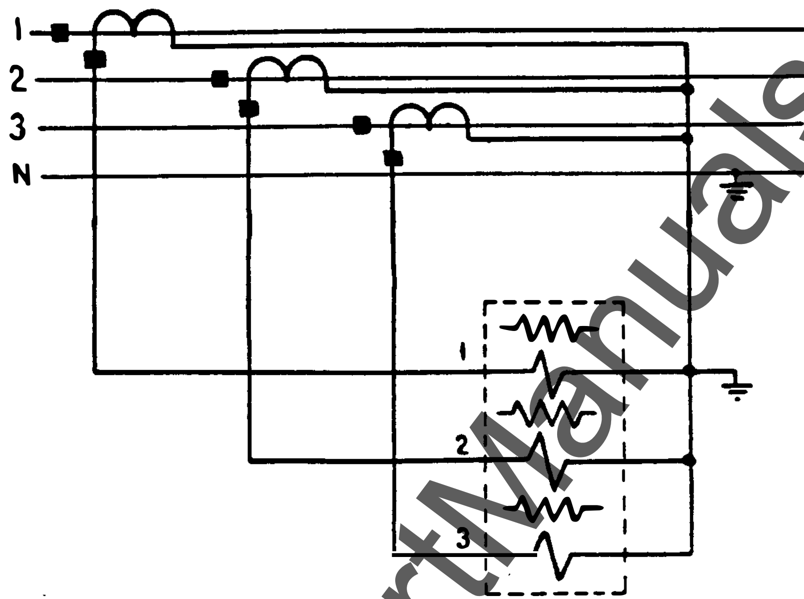
A 3 WIRE, 3 PHASE CIRCUIT



4 WIRE DELTA, 3 PHASE CIRCUIT



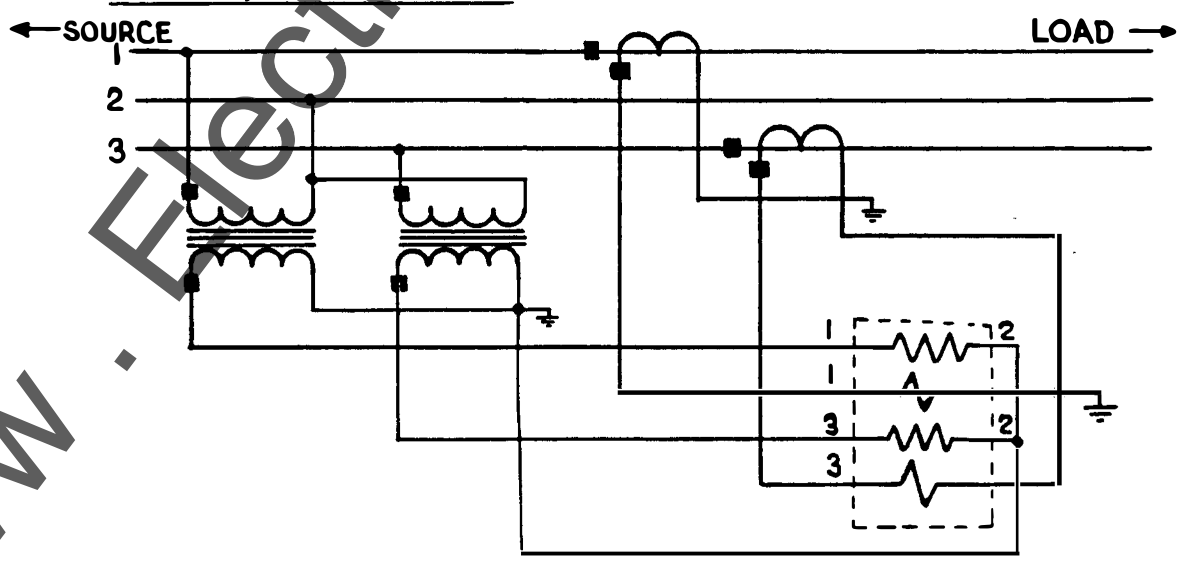
4 WIRE Y, 3 PHASE CIRCUIT



Note particularly the relationship of the polarity markings to one another and to the instrument terminals. As was previously shown for potential transformers, the current transformers should also have their secondary windings grounded.

The final principle to be illustrated is that the potential transformers should be connected ahead of (that is, on the line source side) of the current transformers as shown in the following schematic:

A 3 WIRE, 3 PHASE CIRCUIT



In summary, there are several important factors that must be considered in the application and connection of instrument transformers. They are:

1. Select the proper primary rating for the circuit voltage and the load.

2. Select the proper insulation class.

3. Select instrument transformers which have the highest ANSI accuracy classification at a burden rating equal to, or greater than, the maximum burden to be connected to their secondaries.

4. When connecting instrument transformers, carefully observe polarity marks.

5. Observe caution by proper grounding of secondaries.

6. NEVER OPEN CIRCUIT A CT SECONDARY while the primary is energized. Always short circuit the secondary terminals before changing connections to prevent inducing high voltage into the secondary circuit.

7. NEVER SHORT CIRCUIT THE SECONDARY TERMINALS OF A POTENTIAL TRANSFORMER. A secondary short circuit will cause the unit to overheat and fail in a very short period of time.

8. After exposing current transformer windings to d-c current, it is always best practice to demagnetize the unit to eliminate the errors caused by retained residual magnetism.

9. After the correct and most accurate instrument transformers have been chosen and all safety precautions have been observed, make the installation in a neat and workmanlike manner.

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