

**The Importance of Polarity** An understanding of polarity is essential to correctly construct three-phase transformer banks and to properly parallel single or three-phase transformers with existing electrical systems. A knowledge of polarity is also required to connect potential and current transformers to power metering devices and protective relays. The basic theory of additive and subtractive polarity is the underlying principle used in step voltage regulators where the series winding of an autotransformer is connected to either buck or boost the applied line voltage.

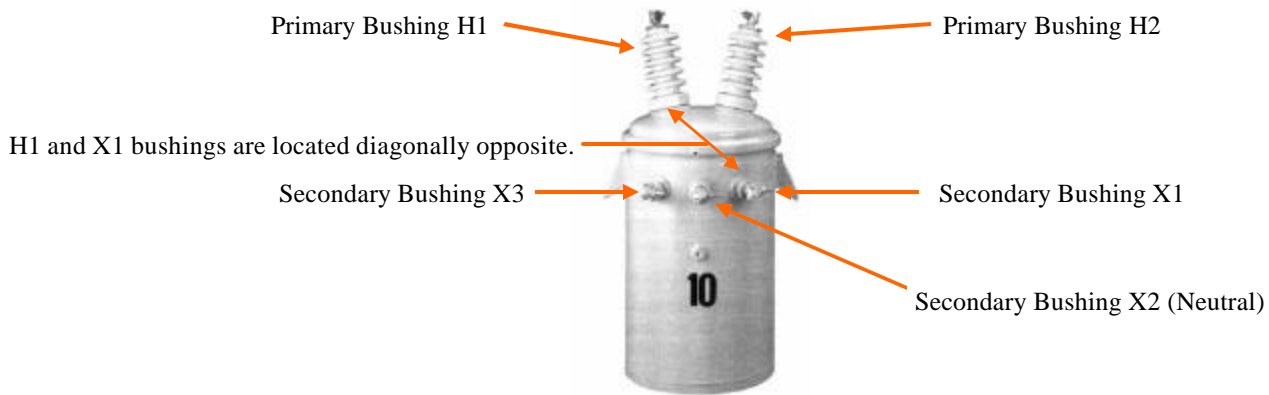
**Transformer Polarity** refers to the relative direction of the induced voltages between the high voltage terminals and the low voltage terminals. During the AC half-cycle when the applied voltage (or current in the case of a current transformer) is from H1 to H2 the secondary induced voltage direction *will be* from X1 to X2. In practice, *Polarity* refers to the way the leads are brought out of the transformer.

**Bushing Arrangement** The position of the High Voltage Bushings is standardized on all power and instrument transformers. The rule is this: *when facing the low voltage bushings*, the Primary Bushing H1 is always on the left-hand side and the Primary Bushing H2 is on the right-hand side (if the transformer is a three-phase unit, H3 will be to the right of H2).

**Distribution Transformers** are Additive Polarity and the H1 and X1 bushings are physically placed diagonally opposite each other. Since H1 is *always* on the left, X1 will be on the right-hand side of a distribution transformer. This standard was developed very early in the development of electrical distribution systems and has been adhered to in order to prevent confusion in the field when transformers need to be replaced or paralleled with existing equipment.

**Instrument Transformers** (PT's and CT's) and large substation transformers are Subtractive Polarity, so the H1 and X1 Bushings will be on the same side of the transformer. This standard was later adopted to make it easier to read electrical schematics and construct phasor diagrams.

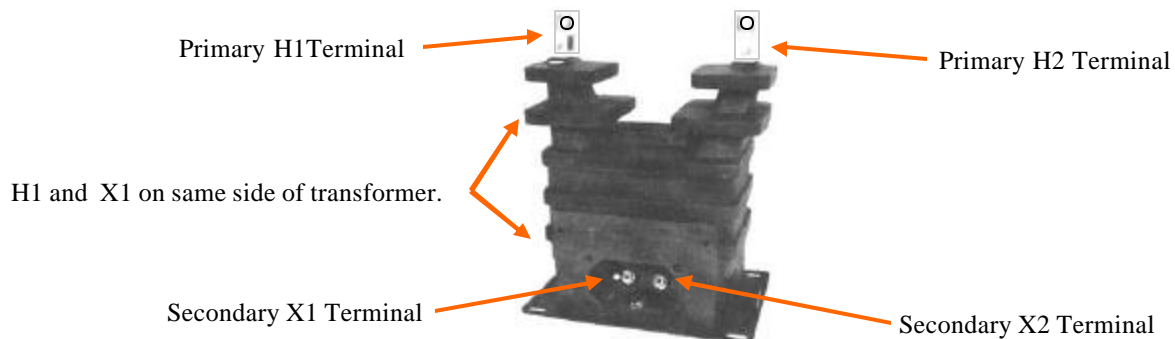
### Additive Polarity



### A Typical Distribution Transformer

Two-bushing primary and center-tapped 120 / 240 volt three-bushing secondary.

### Subtractive Polarity



### 24 kV Potential Transformer

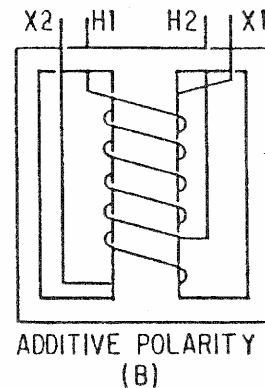
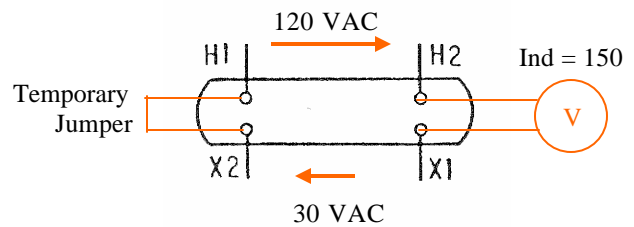
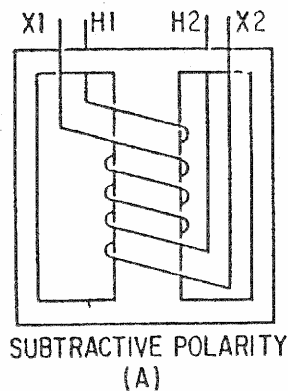
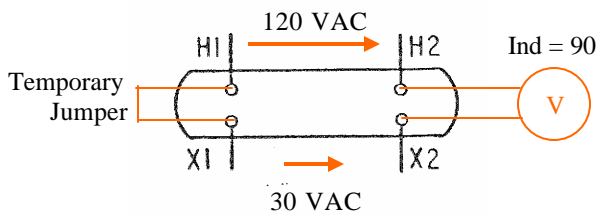
**Polarity Test** In situations where the secondary bushing identification is not available or when a transformer has been rewound, it may be necessary to determine the transformer polarity by test. The following procedure can be used.

The H1 (left-hand) primary bushing and the left-hand secondary bushing are temporarily jumpered together and a test voltage is applied to the transformer primary. The resultant voltage is measured between the right-hand bushings. If the measured voltage is greater than the applied voltage, the transformer is Additive Polarity because the polarity is such that the secondary voltage is being added to the applied primary voltage. If, however, the measured voltage across the right-hand bushings is less than the applied primary voltage, the transformer is Subtractive Polarity.

**Note:** For safety and to avoid the possibility of damaging the secondary insulation, the test voltage applied to the primary should be at a reduced voltage and should not exceed the rated secondary voltage.

In the example below, if the transformer is actually rated 480 - 120 volts, the transformer ratio is 4:1 ( $480 / 120 = 4$ ). Applying a test voltage of 120 volts to the primary will result in a secondary voltage of 30 volts ( $120 / 4 = 30$ ). If transformer is subtractive polarity, the voltmeter will read 90 volts ( $120 - 30 = 90$ ). If the voltmeter reads 150 volts, the transformer is additive polarity ( $120 + 30 = 150$ ).

The red arrows indicate the relative magnitude and direction of the primary and secondary voltages.



**Instrument Transformers** Current Transformers and Potential (voltage) Transformers are used to supply a reduced value of current or voltage to instrument circuits. They provided isolation from the high voltage system, permit grounding of the secondary circuit for safety, and step-down the magnitude of the measured quantity to a value that can be safely handled by the instruments.

**Burden** The load on an instrument transformer is referred to as a “burden”.

**Polarity** All instrument transformers are subtractive polarity.



**Potential Transformers (PT's)** are voltage transformers which are used to supply a proportional voltage to the voltage input of metering and relaying equipment. The standard PT secondary voltage is 120 VAC to match the standard full-scale value of switchboard indicating instruments, power metering equipment, and protective relays. The transformer high-side voltage rating will be the same as the nominal system voltage. PT ratios are expressed as the ratio of the high voltage divided by the secondary voltage. The Potential Transformer pictured at the left has a 24000 volt (24 kV) primary and a standard 120 volt secondary, so the ratio is 200:1 ( $24000 / 120 = 200$ ).

Where three-phase Delta systems are metered, 2 two-bushing PT's would normally be connected open-delta. Three-phase Wye systems would normally be metered with 3 single-bushing PT's connected phase-to-ground, or with 3 two-bushing PT's, rated for the phase-to-ground voltage, having one primary bushing on each transformer connected to ground.

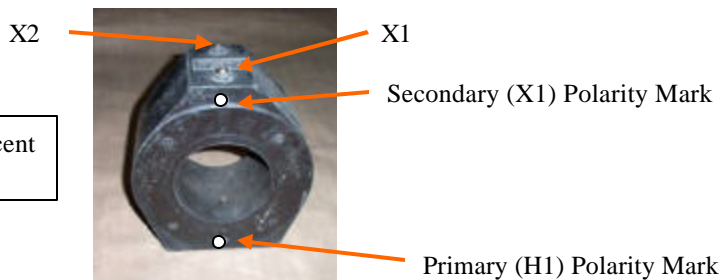
**200:1 Two-Bushing PT**

**Current Transformers (CT's)** are used to supply a proportional current to the current input of metering and relaying equipment. The standard CT secondary current is 5 amps to match the standard full-scale current rating of switchboard indicating devices, power metering equipment, and protective relays. CT ratios are expressed as a ratio of the rated primary current to the 5 amp secondary.

The 300:5 CT pictured below will produce 5 amps of secondary current when 300 amps flows through the primary. As the primary current changes the secondary current will vary accordingly. For example, with 150 amps through the 300 amp rated primary, the secondary current will be 2.5 amps ( $150 : 300 = 2.5 : 5$ ).

On the Window or Donut-type CT's, such as pictured below, the conductor, bus bar, or bushing which passes through the center of the transformer constitutes one primary turn. On Window-type units with low primary current ratings, where the primary conductor size is small, the ratio of the transformer can be changed by taking multiple wraps of the primary conductor through the window. If, for example, a window CT has a ratio of 100:5, placing two primary conductor wraps (two primary turns) through the window will change the ratio to 50:5. Some types of equipment employ this method to calibrate the equipment or to permit a single ratio CT to be utilized for several different sizes (ampacities) of equipment.

**Caution:** the secondary of a Current Transformer must always have a burden (load) connected; an open-circuited secondary can result in the development of a dangerously-high secondary voltage. Draw-out type meter and relay cases incorporate shorting contacts which short-circuit the CT secondary when the instrument is removed from the circuit for calibration.



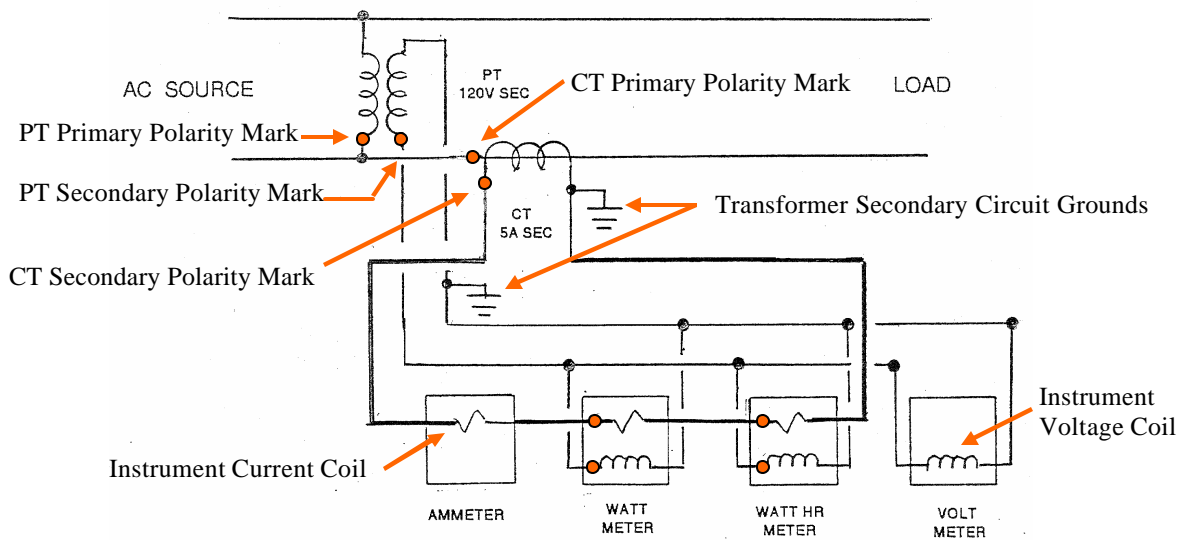
Polarity marks identify (are adjacent to) the H1 and X1 terminals.

**300:5 Window-Type CT**

**Polarity Marks** To insure correct wiring, polarity marks are shown on Instrument Connection Diagrams, Control Schematics, and Three-Line Power Diagrams. The polarity mark is usually shown as a round dot, on or adjacent to, the H1 and X1 terminals of PT's and CT's. Sometimes alternate marking, in the form of a square dot, slash mark (/), or plus/minus sign ( $\pm$ ) will be used to identify the polarity terminals on electrical drawings.

Instrument transformers may also have the terminals identified with polarity marks as shown in the illustration of the 300:5 CT on Sheet 3. If instrument transformers do not have polarity marks on them, it is understood that the H1 (primary) and the X1 (secondary) terminals are polarity.

Meters, relays, and other equipment which require proper polarity connections may also have polarity marks, but usually this information must be obtained from the Instrument Connection Diagram.



**Typical Current and Potential Transformer Connection Diagram**

The PT, CT, and instrument polarity marks are shown by the red dots on the above drawing. (Red dots were used in this example only for clarity.)

Current elements of the instruments are connected in series, voltage inputs are connected in parallel.

Polarity is not a consideration on single-element devices such as an ammeter or voltmeter, but is essential for proper operation of power measuring devices, and for directional or differential protective relays.