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Power Distribution: Instrument Transformers

PDH Credits:

2 PDH

Course No.:

NST101

Publication Source:

USDA – Rural Utilities Service

"RUS Bulletin: Design Guide for Rural Electrical Substations; Chapter 5, Section 10, Instrument Transformers"

Pub. #RUS 1724E-300

Release Date:
June 2001

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5.10 INSTRUMENT TRANSFORMERS

5.10.1 General

This section applies to current and inductively coupled voltage transformers of types generally used in the measurement of electricity and in the control of equipment associated with the transmission and distribution of alternating current.

The primary function of an instrument transformer is stated in the definition provided in ANSI/IEEE Std. C57.13: "An instrument transformer is a transformer that is intended to reproduce in its secondary circuit, in a definite and known proportion, the current or voltage of its primary circuit with the phase relations substantially preserved."

Instrument transformers also provide insulation between the primary and secondary circuits and thus simplify the construction of measuring devices and provide safety for personnel using those devices.

Occasionally, instrument transformers serve another duty as bus supports, especially at the higher voltages where the cost of extra bus supports becomes significant. The manufacturer should always be consulted in such applications to determine what externally applied forces the product can withstand.

If necessary, a voltage transformer may be used for supplying power rather than for measurement. In such situations, it is usually possible to place burdens higher than the volt-ampere rating on the secondary circuit without excessive heating and consequent shortening of life. The limit of such burden is known as the Thermal Burden Rating, i.e., "The volt-ampere output that the transformer will supply continuously at rated secondary voltage without causing the specified temperature limits to be exceeded." The voltage transformer's accuracy of transformation will not be maintained for this type of use.

The primary national standard applicable to current and voltage transformers is ANSI/IEEE Std. C57.13, "IEEE Standard Requirements for Instrument Transformers." This standard covers all-important aspects, including terminology, general requirements, ratings, burdens, accuracy, construction, and test code.

5.10.2 Service Conditions

The standard ratings of instrument transformers are based on operation at the thermal rating of the instrument transformer for defined ambient temperature conditions, provided the altitude does not exceed 1000 meters (3300 feet).

Instrument transformers may be used at higher ambient temperatures, at altitudes higher than 1000 meters, or for other unusual conditions if the effects on performance are considered. Consult the manufacturer for specific applications.

5.10.2.1 Altitude: Table 5-33 in Section 5.5.3.5 shows the altitude correction factors to be used to account for the adverse effect of decreased air density on the insulation withstand capability. These correction factors modify the standard insulation classes shown in Table 5-66. A higher standard BIL may be required at high altitudes in order to obtain the insulation required for the voltage used.

The decreased air density at higher altitudes also affects heat dissipation and the permissible loading on instrument transformers. Current transformers may be operated at altitudes greater than 1000 meters if the current is reduced below rated current by 0.3 percent for each 100 meters the altitude exceeds

Table 5-66: Basic Impulse Insulation Levels and Dielectric Tests

See Table 5-69 for current transformers with the same dielectric test requirements as power circuit breakers.

Maximum System Voltage (kV)	Nominal System Voltage (kV)	BIL and Full Wave Crest (kV) *	Chopped Wave Minimum Time to Crest Flashover (kV) &	(µs)	Power Frequency Applied Voltage Test (kV rms)	Wet 60 Hz 10 s Withstand (kV rms)**	Minimum Creepage Distance (in.) &	(mm)
.66	.6	10	12	—	4	—	—	—
1.2	1.2	30	36	1.5	10	6‡	—	—
2.75	2.4	45	54	1.5	15	13‡	—	—
5.6	5	60	69	1.5	19	20‡	—	—
9.52	8.7	75	88	1.6	26	24‡	—	—
15.5	15	95	110	1.8	34	30‡	—	—
15.5	15	110	130	2	34	34	11	(279)
25.5	25	125	145	2.25	40	36‡	15	(381)
25.5	25	150	175	3	50	50	17	(432)
36.5	34.5	200	230	3	70	70	26	(660)
48.3	46	250	290	3	95	95	35	(890)
72.5	69	350	400	3	140	140	48	(1220)
121	115	450	520	3	185	185	66	(1680)
121	115	550	630	3	230	230	79	(2010)
145	138	650	750	3	275	275	92	(2340)
169	161	750	865	3	325	315	114	(2900)
242	230	900	1035	3	395	350	140	(3500)
242	230	1050	1210	3	460	445	170	(4320)
362	345	1300	1500	3	575	—	205	(5210)
550	500	1675	1925	3	750	—	318	(8080)
550	500	1800	2070	3	800	—	318	(8080)
800	765	2050	2360	3	920	—	442	(11200)

* The selection of the lower BIL for a given nominal system voltage for a marked ratio in Tables 5-73 through 5-77 also reduces other requirements as tabulated above. The acceptability of these reduced requirements should be evaluated for the specific instrument transformer design and application.
** For test procedures, see IEEE Std. 21-1976.
‡ These values are requirements for distribution transformer bushings in IEEE C57.12.00-1993.

1000 meters. Voltage transformers may be operated at higher altitudes only after consultation with the manufacturer.

5.10.2.2 **Temperature:** Table 5-67 provides the limits of temperature rise for instrument transformers, including the average winding temperature and hottest-spot winding temperature rises.

For 30ºC average ambient temperature conditions, the temperature of the cooling air (ambient temperature) does not exceed 40ºC (104ºF), and the average temperature of the cooling air for any 24-hour period does not exceed 30ºC.

Instrument transformers may also be rated for 55ºC ambient temperature for use inside enclosed switchgear, provided the ambient temperature of the cooling air on the inside of enclosed switchgear does not exceed 55ºC. See ANSI Std. C37.20, "Switchgear Assemblies including Metal-Enclosed Bus," and NEMA Std. SG5, "Power Switchgear Assemblies," for further information.

Table 5-67: Limits of Temperature Rise.* Ref. IEEE Std. C57.13-1993, Table 4.

Type of Instrument Transformer	30°C Ambient		55°C Ambient	
	Average Winding Temperature Rise Determined by Resistance Method (°C)	Hottest-Spot Winding Temperature Rise (°C)†	Average Winding Temperature Rise Determined by Resistance Method (°C)	Hottest-Spot Winding Temperature Rise (°C)
55°C Rise	55‡	65	30	40
65°C Rise	65‡	80	40	55
80°C Rise Dry-Type	80	110	55	85

* Temperature rise of current transformers that are a part of high-voltage power circuit breakers or power transformers shall be in accord with ANSI C37.04-1979 or IEEE C57.12.00-1993, respectively.
† Temperature rise of other metallic parts shall not exceed these values.
‡ Temperature rise at the top of the oil in sealed transformers shall not exceed these values.

Current transformers designed for 55ºC temperature rise above 30ºC ambient temperatures are given a continuous-thermal-current rating factor (RF). The RF is multiplied by the rated current to indicate the current that can be carried continuously without exceeding the standard temperature limitations. Figure 5-53 shows the permissible loading for given average cooling air temperatures and RFs. As an example, a current transformer with an RF of 1.5 could be used at 150 percent of rated current at 30ºC average ambient temperature and 100 percent at 60ºC average ambient temperature without exceeding the temperature limitations of the current transformer.

Voltage transformers can be operated at higher ambient temperatures only after consultation with the manufacturer.

5.10.3 Accuracy

To be a useful part of a measurement system, instrument transformers have to change the magnitude of the voltage or current that is being measured without introducing any unknown errors of measurement into the system. The accuracy of transformation should, therefore, be either a known value so that the errors can be included in the computation of the overall measurement, or the errors have to be within the limits of a specified small value so they may be disregarded.

The accuracy obtainable with an instrument transformer depends on its design, circuit conditions, and the burden imposed on the secondary. Accuracy is measured in terms of its true value and phase angle under specified operating conditions.

5.10.3.1 Accuracy Classes for Metering Service: Accuracy classes for metering service have been established that limit the transformer correction factor (TCF) to specified values when the metered load has a power factor of 0.6 lagging to 1.0. The standard accuracy classes for metering service and corresponding TCF limits for current and voltage transformers are shown in Table 5-68. Higher accuracy classes (e.g., 0.15) are available from some manufacturers.

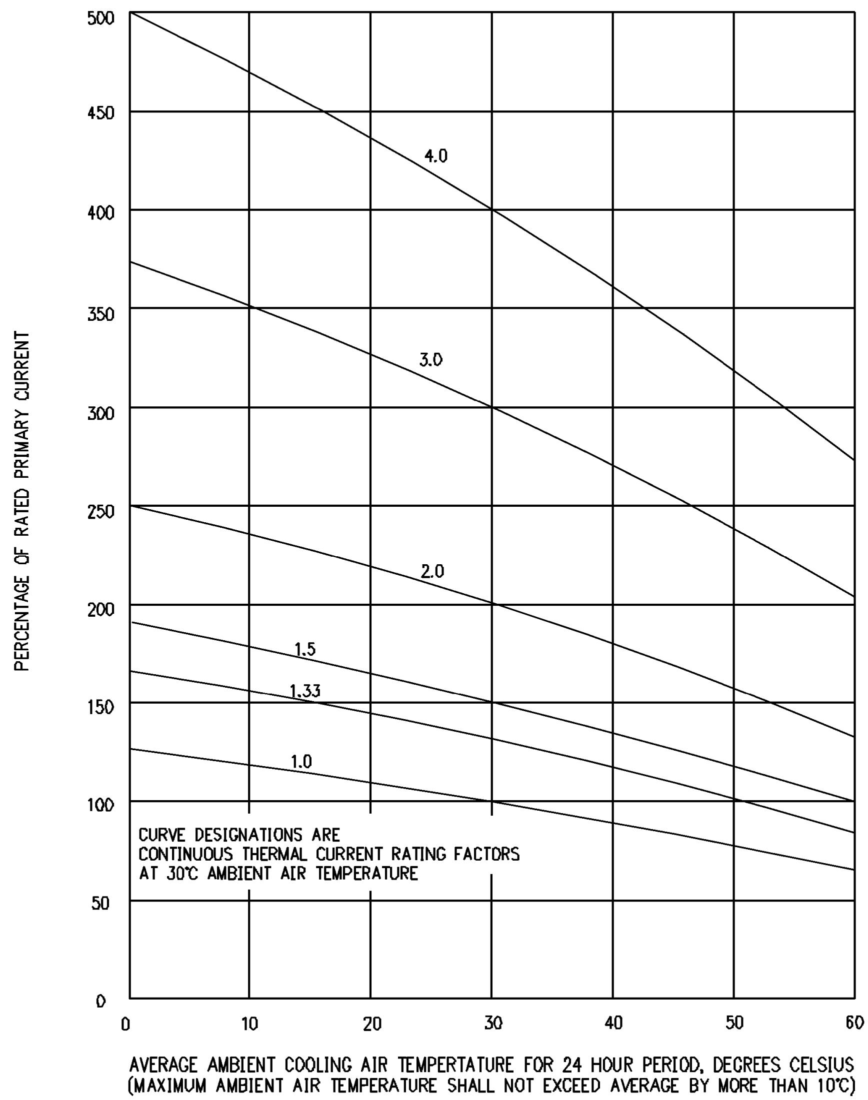

Figure 5-53: 55°C Rise Current Transformer Basic Loading Characteristics (in Air).
Ref. IEEE Std. C57.13-1993, Figure 1.

Table 5-68: Standard Accuracy Class for Metering Service and Corresponding Limits of Transformer Correction Factor (0.6 to 1.0 Power Factor (Lagging) of Metered Load).
Ref. IEEE Std. C57.13-1993, Table 6.

Metering Accuracy Class	Voltage Transformers (At 90 to 100 Percent Rated Voltage)		Current Transformers			
			At 100% Rated Current*		At 10% Rated Current	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
0.3	0.997	1.003	0.997	1.003	0.994	1.006
0.6	0.994	1.006	0.994	1.006	0.988	1.012
1.2	0.988	1.012	0.988	1.012	0.976	1.024

* For current transformers the 100 percent rated current limit also applies at the current corresponding to the continuous thermal current rating factor.

5.10.3.2 Transformer Correction Factor: The transformer correction factor for a current or voltage transformer is the ratio correction factor (RCF) multiplied by the phase angle correction factor for a specified primary circuit power factor.

5.10.3.3 Ratio Correction Factor: The ratio correction factor is the ratio of the true ratio to the marked ratio.

5.10.3.4 Phase Angle Correction Factor: The phase angle correction factor is the ratio of the true power factor to the measured power factor. It is a function of both the phase angles of the instrument transformers and the power factor of the primary circuit being measured.

The phase angle correction factor corrects for the phase displacement of the secondary current or voltage, or both, due to the instrument transformer phase angles.

Phase angle of an instrument transformer is the phase displacement, in minutes, between the primary and secondary values.

5.10.4 Secondary Burdens

As defined in ANSI/IEEE Std. C57.13, burden for an instrument transformer is "that property of the circuit connected to the secondary winding that determines the active and reactive power at the secondary terminals. The burden is expressed either as total ohms impedance with the effective resistance and reactive components, or as the total volt-amperes and power factor at the specified value of current or voltage, and frequency."

The burden on the secondary circuit of an instrument transformer affects the accuracy of the device. Accordingly, the burdens of the various meters and other instruments on the secondary have to be known. This information is usually obtained from data sheets issued by the manufacturers.

For many purposes, such as when the burdens are known to be well within the rated burden capability of the transformer, or when accuracy is not a concern, it is sufficient to add arithmetically the volt-ampere burden of the individual devices. If the burden is expressed as an impedance value, the volt-ampere burden can be calculated from the relationship expressed in Equation 5-10:

Equation 5-10

$$VA = E^2/Z_b$$

Where:

E = Voltage drop across the burden
Z_b = Burden impedance

For more accurate purposes, and when the actual burdens approach the limits of the burden rating, the total burden should be determined by adding the individual burdens vectorially (taking power factors into account).

5.10.5 Construction

All instrument transformers have external terminals or leads to which the high-voltage or primary circuit and the secondary circuits are connected. These terminals are marked to indicate the polarity of the windings.

When letters are used to indicate polarity, the letter H shall be used to distinguish the terminals of the primary winding. The letters X, Y, Z, W, V, U are used to identify the terminals of up to six secondary windings, respectively.

In addition to the letters, each terminal is numbered (e.g., H1, H2, X1, X2). Letters followed by the same number are of the same polarity.

If multiple primary windings are provided, the H terminals are numbered with consecutive pairs of numbers (H1-H2, H3-H4, etc.). The odd-numbered terminals are of the same polarity.

When taps are provided in the secondary windings, the terminals of each winding are numbered consecutively (X1, X2, X3, etc.). The lowest and highest numbered terminals indicate the full winding with intermediate numbers indicating the taps. When the X1 terminals are not in use, the lower number of the two terminals used is the polarity terminal.

5.10.6 Current Transformers

A current transformer is an instrument transformer intended to have its primary winding connected in series with the conductor carrying the current to be measured or controlled. The ratio of primary to secondary current is roughly inversely proportional to the ratio of primary to secondary turns and is usually arranged to produce either five amperes or one ampere (IEC Standard) in the full tap of the secondary winding when rated current is flowing in the primary.

Current transformers can be included in two general categories: metering service and relay service. As a rule, current transformers designed for metering service should not be used for relay applications or system protection. Likewise, current transformers designed for relay service should not be used for high-accuracy metering applications.

Current transformers designed for relay service are fabricated with large cores, which allows the current transformer to replicate the primary current during fault (high primary current) conditions. The large core requires a high exciting current, which limits the accuracy of the current transformer, especially for low primary currents.

Current transformers designed for metering service have smaller cores with small or negligible exciting currents, which enables the current transformer to be highly accurate at normal load currents. However, the smaller core saturates (secondary current is not a replica of the primary current) at currents slightly above rated current. A current transformer designed for metering service may not reliably operate protective devices during fault conditions.

Current transformers can be supplied with single-ratio, dual-ratio, or multi-ratio secondary windings. A multi-ratio current transformer is one from which more than one ratio can be obtained by the use of taps on the secondary winding.

5.10.6.1 Types: Various types of current transformers are available. Figures 5-54 and 5-55 display several types of current transformers.

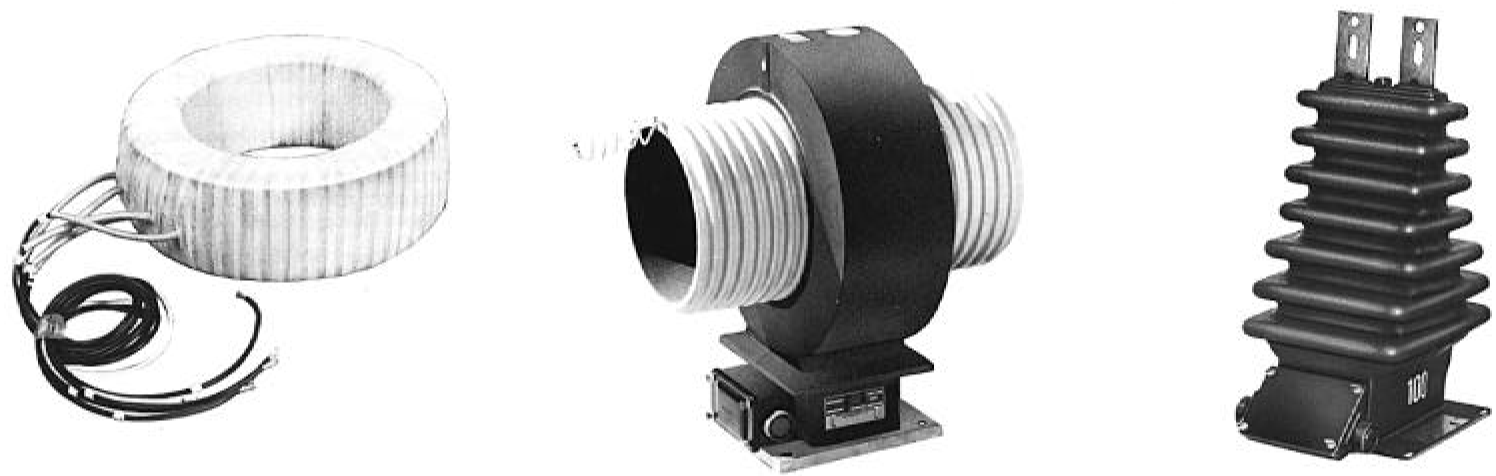

Figure 5-54: Bushing, Window, and Wound-Type Current Transformers.
Courtesy of Kuhlman Electric – Instrument Transformer Division, Versailles, Kentucky.

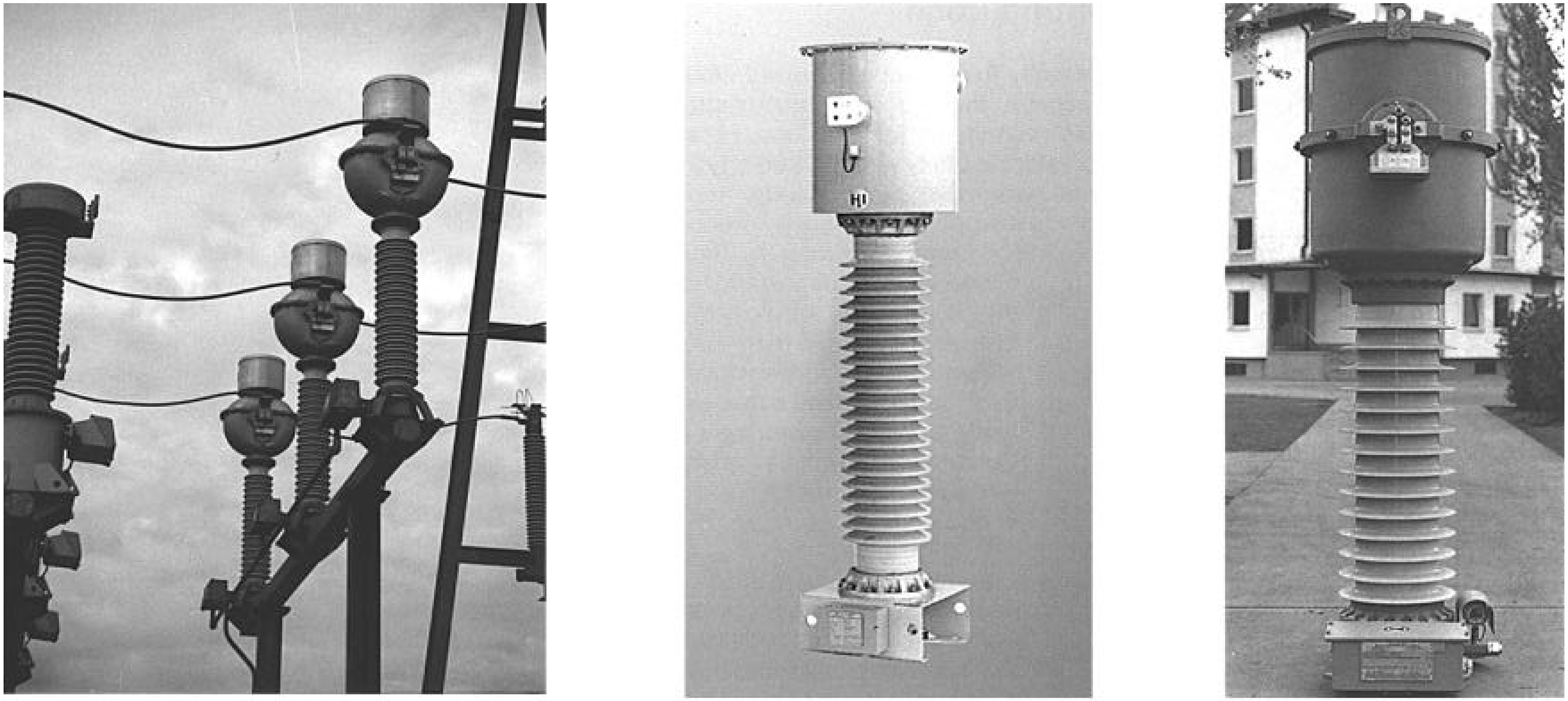

Figure 5-55: High-Voltage Current Transformers.
Courtesy of Haefely Trench, Scarborough, Ontario, Canada

5.10.6.1.1 Bar: A bar-type current transformer is one that has a fixed, insulated straight conductor in the form of a bar, rod, or tube that is a single primary turn passing through the magnetic circuit and that is assembled to the secondary, core, and winding.

5.10.6.1.2 Bushing: A bushing-type current transformer is one that has a round core and a secondary winding insulated from and permanently assembled on the core but has no primary winding or insulation for a primary winding. This type of current transformer is for use with a fully insulated conductor as the primary winding.

5.10.6.1.3 Double-Secondary: A double-secondary current transformer is one that has secondary coils each on a separate magnetic circuit with both magnetic circuits excited by the same primary winding. Multiple-secondary (three or more) current transformers are also manufactured.

5.10.6.1.4 Window/Donut: A window- or donut-type current transformer is one that has a secondary winding insulated from and permanently assembled on the core, but has no primary winding as an integral part of the structure. Complete or partial insulation is provided for a primary winding in the window through which one or more turns of the line conductor can be threaded to provide the primary winding.

5.10.6.1.5 Wound: A wound-type current transformer is one that has a fixed primary winding mechanically encircling the core; it may have one or more primary turns. The primary and secondary windings are completely insulated and permanently assembled on the core as an integral structure.

5.10.6.1.6 Others: Other types are available in addition to those listed. Descriptions can be found in manufacturers' literature.

5.10.6.2 **Ratings:** Ratings are used to specify the operating characteristics and construction of the current transformer. The following paragraphs provide the terms used to express the ratings for current transformers. ANSI/IEEE Std. C57.13 is a source of additional information for some ratings.

5.10.6.2.1 BILs: Basic impulse insulation levels (BILs) in terms of full wave test voltages, nominal system voltages, and maximum line-to-ground system voltages are shown in Tables 5-66 and 5-69. Table 5-69 also provides the BILs, maximum system voltage, and maximum line-to-ground voltages for applications requiring current transformers to have the same dielectric test requirements as power circuit breakers.

Table 5-69: Basic Impulse Insulation Levels and Dielectric Tests for Current Transformers with the Same Dielectric Test Requirements as Outdoor Power Circuit Breakers.*

Low Frequency (kV, rms)			Impulse Test 1.2 x 50 µs Wave (kV, Crest)[†]					Minimum Creep Distance	
Rated max.	1 min. dry	10 s wet	Full wave withstand	Interrupter full wave	2 µs withstand	3 µs withstand	Switching impulse insulation level	(mm)	(in.)
121	260	230	550B[‡]	412	710	632	Not req'd	1780	70
145	310	275	650B	488	838	748	Not req'd	2130	84
169	365	315	750B	552	968	862	Not req'd	2490	93
242	425	350	900B	675	1160	1040	Not req'd	3560	140
362	555	Not req'd	1300B	975	1680	1500	825	5310	209
550	860	Not req'd	1800B	1350	2320	2070	1175	8080	318
800	960	Not req'd	2050B	1540	2640	2360	1425	11200	442

*See IEEE Std. C37.09-1979 for impulse and applied potential test procedures.
[†]No flashovers are permitted on current transformers.
[‡]The letter "B" values are established by ANSI C37.06-1987 for current transformers that have the same requirements as power circuit breakers.

5.10.6.2.2 Current Ratings: Current ratings are shown in Table 5-70 (for other than bushing type) and Table 5-71 (multi-ratio bushing type).

Table 5-70: Ratings for Current Transformers with One or Two Ratios.

Current Ratings (A)			
Single Ratio		Double Ratio With Series-Parallel Primary Windings	Double Ratio with Taps in Secondary Winding
10:5	800:5	25 x 50:5	25 / 50:5
15:5	1200:5	50 x 100:5	50 / 100:5
25:5	1500:5	100 x 200:5	100 / 200:5
40:5	2000:5	200 x 400:5	200 / 400:5
50:5	3000:5	400 x 800:5	300 / 600:5
75:5	4000:5	600 x 1200:5	400 / 800:5
100:5	5000:5	1000 x 2000:5	600 / 1200:5
200:5	6000:5	2000 x 4000:5	1000 / 2000:5
300:5	8000:5		1500 / 3000:5
400:5	12 000:5		2000 / 4000:5
600:5			

Table 5-71: Current Transformer Ratings, Multi-Ratio Type.
Ref. IEEE Std. C57.13-1993, Table 8.

Current Ratings (A)	Secondary Taps	Current Ratings (A)	Secondary Taps
600:5		3000:5	
50:5	X2 - X3	300:5	X3 - X4
100:5	X1 - X2	500:5	X4 – X5
150:5	X1 - X3	800:5	X3 – X5
200:5	X4 – X5	1000:5	X1 – X2
250:5	X3 – X4	1200:5	X2 – X3
300:5	X2 - X4	1500:5	X2 – X4
400:5	X1 – X4	2000:5	X2 – X5
450:5	X3 – X5	2200:5	X1 – X3
500:5	X2 – X5	2500:5	X1 – X4
600:5	X1 – X5	3000:5	X1 – X5
1200:5		4000:5	
100:5	X2 – X3	500:5	X1 – X2
200:5	X1 – X2	1000:5	X3 – X4
300:5	X1 – X3	1500:5	X2 – X3
400:5	X4 – X5	2000:5	X1 – X3
500:5	X3 – X4	2500:5	X2 – X4
600:5	X2 – X4	3000:5	X1 – X4
800:5	X1 – X4	3500:5	X2 – X5
900:5	X3 – X5	4000:5	X1 – X5
1000:5	X2 – X5		
1200:5	X1 – X5		
2000:5		5000:5	
300:5	X3 – X4	500:5	X2 – X3
400:5	X1 – X2	1000:5	X4 – X5
500:5	X4 – X5	1500:5	X1 – X2
800:5	X2 – X3	2000:5	X3 – X4
1100:5	X2 – X4	2500:5	X2 – X4
1200:5	X1 – X3	3000:5	X3 – X5
1500:5	X1 – X4	3500:5	X2 – X5
1600:5	X2 – X5	4000:5	X1 – X4
2000:5	X1 – X5	5000:5	X1 – X5

5.10.6.2.3 Standard Burdens: Standard burdens for current transformers are shown in Table 5-72. The first five burdens listed are burdens for which metering accuracy classes have been assigned, and the last four are for relay accuracy.

5.10.6.2.4 Accuracy Ratings: Accuracy ratings are given for each standard burden for which the current transformer is designed. Table 5-68 lists the accuracy classes and corresponding limits for transformer correction factors for current transformers for metering service.

For example, the accuracy rating of a current transformer for metering service might be 0.3B-0.1 and B-0.2, and 0.6B-0.5. Based on these ratings, the transformer will maintain 0.3 accuracy class limits for standard burdens of B-0.1 and B-0.2 and maintain 0.6 accuracy class limits for a standard burden of B-0.5. The standard metering burdens, with the characteristics shown by Table 5-72, are 0.1, 0.2, 0.5, 0.9, and 1.8.

Table 5-72: Standard Burdens for Current Transformers with 5 A Secondaries.*
Ref. IEEE Std. C57.13-1993, Table 9.

Burden Designation†	Resistance (Σ)	Inductance (mH)	Impedance (Σ)	Volt-Amperes (at 5 A)	Power Factor
		Metering Burdens			
B-0.1	0.09	0.116	0.1	2.5	0.9
B-0.2	0.18	0.232	0.2	5.0	0.9
B-0.5	0.45	0.580	0.5	12.5	0.9
B-0.9	0.81	1.04	0.9	22.5	0.9
B-1.8	1.62	2.08	1.8	45.0	0.9
		Relaying Burdens			
B-1	0.5	2.3	1.0	25	0.5
B-2	1.0	4.6	2.0	50	0.5
B-4	2.0	9.2	4.0	100	0.5
B-8	4.0	18.4	8.0	200	0.5

* If a current transformer is rated at other than 5 A, ohmic burdens for specification and rating may be derived by multiplying the resistance and inductance of the table by $[5/(\text{ampere rating})]^2$, the VA at rated current and the power factor remaining the same.
† These standard burden designations have no significance at frequencies other than 60 Hz.

5.10.6.2.5 Relay Accuracy: Relay accuracy ratings (or classes) are designated by a classification and a secondary voltage terminal rating as follows:

a. C or K classification means the transformer ratio can be calculated according to ANSI/IEEE Std. C57.13, Paragraph 8.1.10. In other words, the true ratio of the transformer (primary current to secondary current) can be readily determined for each application using the marked ratio and typical excitation curves.
b. T classification means the transformer ratio have to be determined by test. The manufacturer has to supply test data to determine performance.
c. The secondary terminal voltage rating is the voltage that the transformer will deliver to a standard burden listed in Table 5-72 at 20 times normal secondary current (and also at any current from 1 to 20 times rated current at any lesser burden) without exceeding 10 percent ratio error.

For example, relay accuracy class C400 means that the ratio can be calculated and that the ratio error will not exceed 10 percent at any current from 1 to 20 times normal secondary current if the burden does not exceed 4.0 ohms (4.0 ohms x 5 amperes x 20 times normal current = 400 volts).

Standard secondary terminal voltage ratings are 10, 20, 50, 100, 200, 400, and 800 volts.

5.10.6.2.6 Tapped Secondary or Multi-Ratio Current Transformer: For current transformers with tapped secondaries or multi-ratio secondaries, the accuracy class applies only to the full secondary winding unless specifically stated otherwise. Performance on lower taps may be significantly reduced and limited. Use of the lower taps should be avoided if possible.

5.10.6.2.7 Continuous Thermal Current Rating Factors: Continuous thermal current rating factors shall be 1.0, 1.33, 1.5, 2.0, 3.0, or 4.0, based on 30ºC ambient temperature.

5.10.6.2.8 Short-Time Current Ratings: Short-time current ratings (mechanical and thermal) are described in ANSI/IEEE Std. C57.13, Paragraph 6.6. The ratings represent the short-time (typically

1 second) primary current the current transformer can withstand with the secondary windings short circuited without damage or exceeding temperature limitations.

5.10.6.3 Open-Circuit Secondary Voltage: Dangerously high voltages (more than 3500 volts for Class 1) can exist at the open circuit of current transformer secondary circuits, and appropriate measures have to be taken for safety and insulation withstand capability. Always short the secondary windings of current transformers when not in use.

5.10.6.4 Application Data Required for Metering Service: The following information has to be available for calculating the performance of current transformers for metering service:

- Typical ratio correction factor and phase angle curves for the standard burdens for which accuracy ratings are assigned
- Mechanical and thermal short-time ratings

5.10.6.5 Application Data Required for Relaying Service: The following information has to be available for calculating the performance of current transformers for relaying service:

- Relaying accuracy classification
- Mechanical and thermal short-time ratings
- Resistance of secondary winding to determine value for each published ratio
- For Class C and K transformers, typical excitation curves
- For Class T transformers, typical overcurrent ratio curves

5.10.7 Voltage Transformers

A voltage transformer or potential transformer is an instrument transformer intended to have its primary winding connected in shunt with a power supply circuit, the voltage of which is to be measured or controlled.

5.10.7.1 Types: There are several types of voltage transformers available. Figure 5-56 displays several voltage transformers.

5.10.7.1.1 A cascade-type voltage transformer is a single high-voltage line terminal voltage transformer with the primary winding distributed on several cores with the cores electromagnetically coupled by coupling windings and the secondary winding on the core at the neutral end of the high-voltage winding. Each core of this type of transformer is insulated from the other cores and is maintained at a fixed potential with respect to ground and the line-to-ground voltage.

5.10.7.1.2 A double-secondary voltage transformer is one that has two secondary windings on the same magnetic circuit insulated from each other and the primary. Either or both of the secondary windings may be used for measurements or control.

5.10.7.1.3 A grounded-neutral, terminal-type voltage transformer is one that has the neutral end of the high-voltage winding connected to the case or mounting base.

5.10.7.1.4 An insulated-neutral, terminal voltage transformer is one that has the neutral end of the high-voltage winding insulated from the case or base and connected to a terminal that provides insulation for a lower voltage insulation class than required for the rated insulation class of the transformer.

Figure 5-56: Voltage Transformers.
Courtesy of Kuhlman Electric, Instrument Transformer Division, Versailles, Kentucky.

5.10.7.1.5 A single high-voltage line, terminal voltage transformer is one that has the line end of the primary winding connected to a terminal insulated from ground for the rated insulation class. The neutral end of the primary winding may be connected as described in Sections 5.10.7.1.3 or 5.10.7.1.4.

5.10.7.1.6 A two-high-voltage line, terminal voltage transformer is one that has both ends of the high-voltage winding connected to separate terminals that are insulated from each other, and from other parts of the transformer, for the rated insulation class of the transformer.

5.10.7.2 **Ratings:** The following paragraphs describe the terms and figures used to express the ratings of voltage transformers.

5.10.7.2.1 BILs in terms of full wave test voltages, primary voltage ratings, and marked ratios are shown in Tables 5-73 through 5-77.

The standard voltage transformers listed in the tables are divided into Groups 1, 2, 3, 4, and 5.

Group 1: Designed for 100 percent of rated primary voltage across the primary winding when connected line-to-line, line-to-ground, or line-to-neutral.

Group 2: Designed for line-to-line service, but may be used line-to-ground or line-to-neutral at a voltage across the primary winding equal to the rated line-to-line voltage divided by $\sqrt{3}$. This restriction is due to insulation limitations from line to ground.

Group 3: Designed for line-to-ground service only and having two secondaries. The neutral terminal may be an insulated or grounded type.

Group 4: Designed for line-to-ground service in indoor applications only. The neutral terminal may be an insulated or grounded type.

Group 5: Designed for line-to-ground service only in outdoor applications. The neutral terminal may be an insulated or grounded type. Similar to Group 3 except single ratio and includes lower voltage classes.

Table 5-73: Ratings and Characteristics of Group 1 Voltage Transformers.
Ref. IEEE Std. C57.13-1993, Table 10.

Group 1 voltage transformers are for application with 100 percent of rated primary voltage across the primary winding when connected line-to-line or line-to-ground. (For typical connections, see Figs 6A and 6B in IEEE C57.13-1993.)

Group 1 transformers shall be capable of operation at 125 percent of rated voltage on an emergency basis (this capability does not preclude the possibility of ferroresonance), provided the burden, in volt-amperes at rated voltage, does not exceed 64 percent of the thermal burden rating, without exceeding the following average winding temperatures: 105°C for 55°C rise types, 115°C for 65°C rise types, and 130°C for 80°C rise types. This will result in a reduction of life expectancy.

Rated Primary Voltage for Rated Voltage Line-to-Line (V)	Marked Ratio	Basic Impulse Insulation Level (kV Crest)
120 for 208Y	1:1	10
240 for 416Y	2:1	10
300 for 520Y	2.5:1	10
120 for 208Y	1:1	30
240 for 416Y	2:1	30
300 for 520 T	2.5:1	30
480 for 832Y	4:1	30
600 for 1040Y	5:1	30
2400 for 4160Y	20:1	60
4200 for 7280Y	35:1	75
4800 for 8320Y	40:1	75
7200 for 12 470Y	60:1	110 or 95
8400 for 14 560"Y	70:1	110 or 95

NOTE: Voltage transformers connected line-to-ground on an ungrounded system cannot be considered to be grounding transformers and should not be operated with the secondaries in closed delta because excessive currents may flow in the delta.

Table 5-74: Ratings and Characteristics of Group 2 Voltage Transformers.
Ref. IEEE Std. C57.13-1993, Table 11.

Group 2 voltage transformers are primarily for line-to-line service, and may be applied line-to-ground or line-to-neutral at a winding voltage equal to the primary voltage rating divided by $\sqrt{3}$. (For typical connections, see Figs. 6C and 6D in IEEE C57.13-1993.)

Rated Primary Voltage for Rated Voltage Line-to-Line (V)	Marked Ratio	Basic Impulse Insulation Level (kV Crest)
120 for 120Y	1:1	10
240 for 240Y	2:1	10
300 for 300Y	2.5:1	10
480 for 480Y	4:1	10
600 for 600Y	5:1	10
2400 for 2400Y	20:1	45
4800 for 4800Y	40:1	60
7200 for 7200Y	60:1	75
12 000 for 12 000Y	100:1	110 or 95
14 400 for 14 400Y	120:1	110 or 95
24 000 for 24 000Y	200:1	150 or 125
34 500 for 34 500Y	300:1	200 or 150
46 000 or 46 000Y	400:1	250
69 000 for 69 000Y	600:1	350

NOTE: Voltage transformers connected line-to-ground on an ungrounded system cannot be considered to be grounding transformers and should not be operated with the secondaries in closed delta because excessive currents may flow in the delta.

Table 5-75: Ratings and Characteristics of Group 3 Outdoor Voltage Transformers.
Ref. IEEE Std. C57.13-1993, Table 12.

Group 3 voltage transformers are for line-to-ground connection only and have two secondaries. They may be insulated-neutral- or grounded-neutral-terminal type.

Ratings through 161 000 Grd Y/92 000 shall be capable of the $\sqrt{3}$ times rated voltage (this does not preclude the possibility of ferroresonance) for 1 min. without exceeding 175°C temperature rise for copper conductor or 125°C rise for EC aluminum. Ratings 230 000 Grd Y /138 000 and above shall be capable of operation at 140 percent of rated voltage with the same limitation of time and temperature. (For typical connections, see Fig. 6E of IEEE C57.13-1993.) Group 3 transformers shall be capable of continuous operation at 110 percent of rated voltage, provided the burden in volt-amperes at this voltage does not exceed the thermal burden rating.

Rated Voltage (V)	Marked Ratio	Basic Impulse Insulation Level (kV Crest)
24 940 Grd Y/14 400	120/200 and 120/200:1	150 or 125
34 500 Grd Y/20 125	175/300 and 175/300:1	200
46 000 Grd Y/27 600	240/400 and 240/400:1	250
69 000 Grd Y/40 250	350/600 and 350/600:1	350
115 000 Grd Y/69 000	600/1000 and 600/1000:1	550 or 450
138 000 Grd Y/80 500	700/1200 and 700/1200:1	650 or 550
161 000 Grd Y/92 000	800/1400 and 800/1400:1	750 or 650
230 000 Grd Y/138 000	1200/2000 and 1200/2000:1	1050 or 900
345 000 Grd Y/207 000*	1800/3000 and 1800/3000:1	1300 or 1175
500 000 Grd Y/287 500*	2500/4500 and 2500/4500:1	1800 or 1675
750 000 Grd Y/431 250*	3750/6250 and 3750/6250:1	2050

* The higher figures 362 000, 550 000, and 800 000 are the maximum rated primary voltage values as designated for use with extra-high-voltage systems by the ANSI C92 Committee.

NOTES:

(1) The double voltage ratio is usually achieved by a tap in the secondary; in such cases the nonpolarity terminal of the winding shall be the common terminal.

(2) Voltage transformers connected line-to-ground on an ungrounded system cannot be considered to be grounding transformers and should not be operated with the secondaries in closed delta because excessive currents may flow in the delta.

Table 5-76: Ratings and Characteristics of Group 4 Indoor Voltage Transformers.
Ref. IEEE Std. C57.13-1993, Table 13.

Group 4 voltage transformers are for line-to-ground connection only. They may be insulated-neutral- or grounded-neutral-terminal type. (For typical connections of Group 4A, see Fig. 6f. For typical connections of Group 4B, see Fig. 6g in IEEE C57.13-1993.)

Group 4 voltage transformers shall be capable of continuous operation at 110 percent of rated voltage, provided the burden, in volt-amperes at this voltage, does not exceed the thermal burden rating. Group 4A voltage transformers shall be capable of operation at 125 percent of rated voltage on an emergency basis (this capability does not preclude the possibility of ferroresonance), provided the burden, in volt-amperes at rated voltage, does not exceed 64 percent of the thermal burden rating, without exceeding the following winding temperatures: 105°C for 55°C rise types, 115°C for 65°C rise types, and 130°C for 80°C rise types. (This will result in a reduction of normal life expectancy.) The manufacturer may be consulted for information about a possible higher rating.

Rated Primary Voltage for Rated Voltage Line-to-Line (V)	Marked Ratio	Basic Impulse Insulation Level (kV Crest)
	Group 4A: For Operation at Approximately 100 Percent of Rated Voltage	
4160 Grd Y/2400	20:1	60
7200 Grd Y/4200	35:1	75
8320 Grd Y/4800	40:1	75
12 470 Grd Y/7200	60:1	110 or 95
14 560 Grd Y/8400	70:1	110 or 95
	Group 4B: For Operation at Approximately 58 Percent of Rated Voltage	
4160 Grd Y/4200	35:1	60
4800 Grd Y/4800	40:1	60
7200 Grd Y/7200	60:1	75
12 000 Grd Y/12 000	100:1	110 or 95
14 400 Grd Y/14 400	120:1	110 or 95

NOTE: Voltage transformers connected line-to-ground on an ungrounded system cannot be considered to be grounding transformers and should not be operated with the secondaries in closed delta because excessive currents may flow in the delta.

Table 5-77: Ratings and Characteristics of Group 5 Outdoor Voltage Transformers.
Ref. IEEE Std. C57.13-1993, Table 14.

Group 5 voltage transformers are for line-to-ground connection only, and are for use outdoors on grounded systems. They may be insulated-neutral- or grounded-neutral-terminal type. They shall be capable of operation at 140 percent of rated voltage for 1 min. without exceeding 175°C temperature rise for copper conductor or 125°C rise for EC aluminum conductor (this will result in a reduction of normal life expectancy). (For typical connections see Fig. 6h in IEEE C57.13-1993.)

Group 5 voltage transformers shall be capable of continuous operation at 110 percent of rated voltage, provided the burden, in volt-amperes at this voltage, does not exceed the thermal burden rating. This capability does not preclude the possibility of ferroresonance.

Rated Primary Voltage for Rated Voltage Line-to-Line (V)	Marked Ratio	Basic Impulse Insulation Level (kV Crest)
7200 for 12 470 Gnd Y	60:1	110
8400 for 14 560 Gnd Y	70:1	110
12 000 for 20 800 Gnd Y	100:1	150 or 125
14 400 for 25 000 Gnd Y	120:1	150 or 125
20 125 for 34 500 Gnd Y	175:1	200 or 150

Typical primary connections for the voltage transformers of Groups 1, 2, and 3 are shown in Figure 5-57.

5.10.7.2.2 A voltage transformer shall be assigned an accuracy class rating (see ANSI/IEEE Std. C57.13) for each of the standard burdens for which it is designed. For example, an accuracy rating may be 0.3W and X, 0.6Y, and 1.2Z. The values 0.3, 0.6, and 1.2 indicate the accuracy class and represent the percent deviation (maximum and minimum) from the rated voltage. The designations W, X, Y, and Z are standard burdens.

Standard burdens for voltage transformers for accuracy rating purposes are given in Table 5-78. The burdens are expressed in volt-amperes at a specified power factor at either 120 or 69.3 volts.

Table 5-78: Standard Burdens for Voltage Transformers.
Ref. IEEE Std. C57.13-1993, Table 15.

Characteristics on Standard Burdens*			Characteristics on 120 V Basis			Characteristics on 69.3 V Basis		
Designa-tion	Volt-Amperes	Power Factor	Resistance (Ω)	Inductance (H)	Impedance (Ω)	Resistance (Ω)	Induc-tance (H)	Impe-dance (Ω)
W	12.5	0.10	115.2	3.04	1152	38.4	1.01	384
X	25	0.70	403.2	1.09	576	134.4	0.364	192
M	35	0.20	82.3	1.07	411	27.4	0.356	137
Y	75	0.85	163.2	0.268	192	54.4	0.0894	64
Z	200	0.85	61.2	0.101	72	20.4	0.0335	24
ZZ	400	0.85	30.6	0.0503	36	10.2	0.0168	12

* These burden designations have no significance except at 60 Hz.

NOTE: For rated secondary voltages from 108 V through 132 V or from 62.4 V through 76.2 V, the standard burdens for accuracy tests within ±10% of rated voltage are defined by the characteristic burden impedances at 120 V or 69.3 V respectively. For other rated secondary voltages, the standard burdens for accuracy tests within ±10% of rated voltage are defined by the characteristic burden volt-amperes and power factor. The characteristic volt-amperes apply at rated secondary voltage and appropriate impedances are required. When transformers with rated secondary volts from 108 V through 132 V are tested at secondary voltages within ±10% of ½ times rated voltage, the standard burdens for accuracy tests are defined by the characteristic burdens impedances at 69.3 V. When transformers with other rated secondary volts are to be tested at secondary voltages within ±10% of 1/13 times rated voltage, the standard burdens for accuracy tests are defined by the characteristic burden volt-amperes and power factor. The characteristic volt-amperes apply at 1/13 times rated voltage, for a given standard burden; the burden impedances are lower and the changes in accuracy resulting from burden current are greater than at rated voltage.

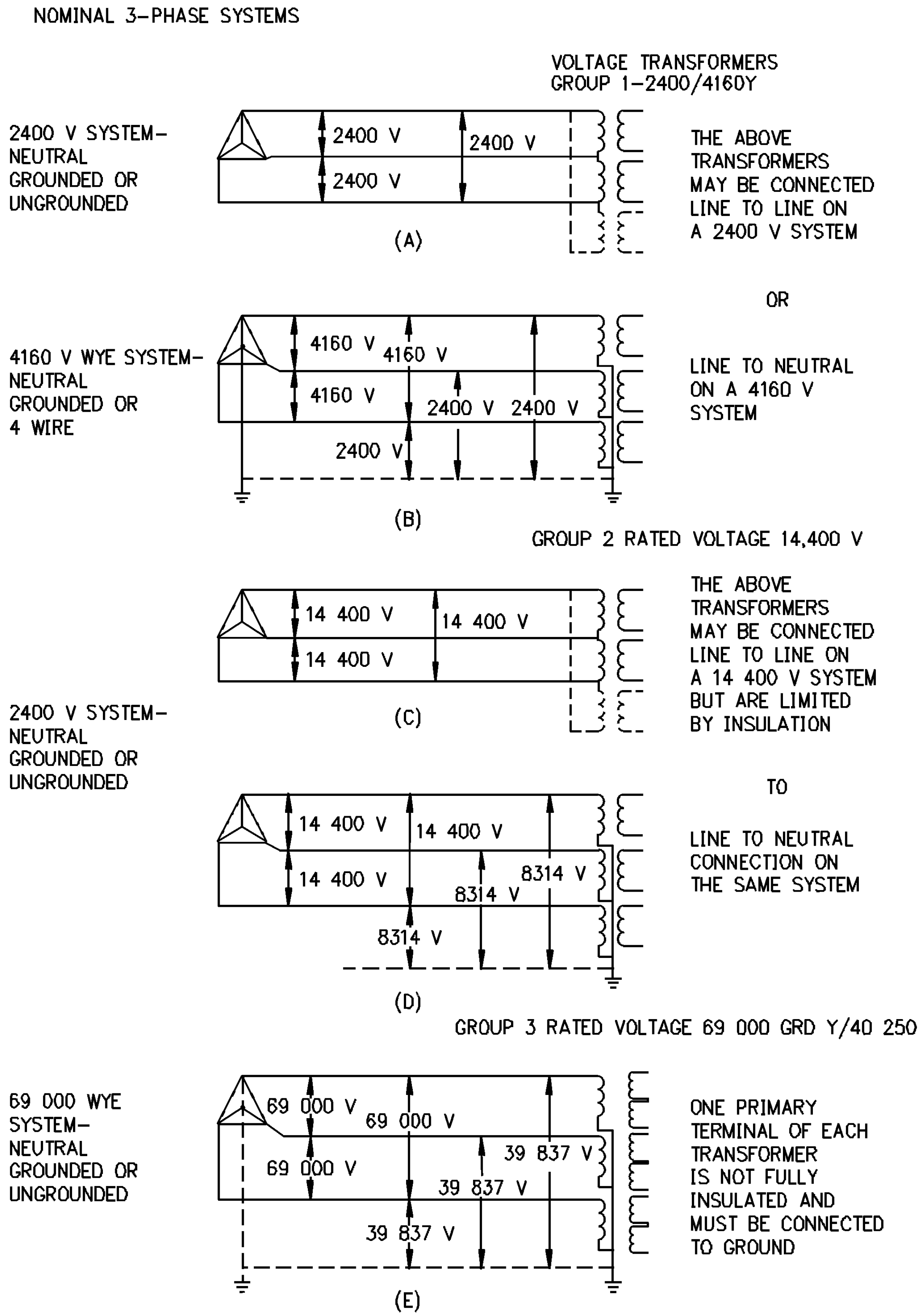

Figure 5-57: Typical Primary Connections for Voltage Transformers.
Ref. IEEE Std. C57.13-1993, Figures 6 A, B, C, D & E.

Accuracy classes are based on the requirement that the transformer correction factor shall be within specified limits when the power factor of the metered load has any value from 0.6 lag to 1.0, from zero burden to the specified standard burden and at any voltage from 90 to 110 percent of the rated transformer voltage. Accuracy classes and corresponding limits of TCF are shown in Table 5-68.

5.10.7.2.3 The thermal burden rating of a voltage transformer shall be specified in terms of the maximum burden that the transformer can carry at rated secondary voltage without exceeding the temperature rise above 30°C (86°F) ambient permitted by Table 5-67.

5.10.7.3 **Application Data:** The following information has to be obtained from the manufacturer to accurately determine operating characteristics and limits:

- Typical ratio and phase angle curves for rated primary voltage, plotted for the standard burdens and for the same numerical burdens with unity power factor, from zero burden to the maximum standard burden volt-amperes of the transformer
- Accuracy ratings for all standard burdens up to and including the maximum standard burden rating of the transformer
- Thermal burden rating

5.10.8 Combination Units

5.10.8.1 **Combined Instrument Transformers:** Combined instrument transformers, sometimes called metering units, include a voltage transformer and current transformer in a single free-standing unit. These units are used primarily in metering applications where a dedicated voltage transformer and current transformer are used for revenue metering.

Each instrument transformer in the combined instrument transformer has to meet the requirements and ratings of ANSI/IEEE Std. C57.13 for the application. Ratings are provided for each instrument transformer in the combined unit.

These units have the advantage of cost savings by eliminating a set of support structures and foundations and reducing substation space requirements. A disadvantage of the combined instrument transformers is a failure of one component requires the entire unit to be removed from service and repaired or replaced.

5.10.8.2 **Power Voltage Transformers:** Another type of combination unit called a power voltage transformer combines an auxiliary power transformer with instrument voltage transformers.

A common primary winding is included with multiple secondary windings in a single free-standing unit. One or more of the secondary windings are rated for power application, typically 10 kVA to 100 kVA. Additional secondary windings are also included and can be rated either metering or relay accuracy classes with standard burdens as given in Table 5-78.

The advantage of these devices is cost saving by eliminating a set of support structures and reducing space requirements. The devices are also useful at remote switching stations or high-voltage substations where no local distribution service is available for station service. One disadvantage of the power voltage transformer is the loss of accuracy in the metering or relaying secondary windings when the power secondary winding is loaded. Consult the manufacturer to determine the effects of power winding load on the performance of the voltage transformer.

5.10.9 Tests

5.10.9.1 Routing Tests: Paragraph 4.7.2 of ANSI/IEEE Std. C57.13 lists the minimum routine tests an instrument transformer receives at the factory to ensure the instrument transformer meets the specified requirements. The routine tests include applied potential dielectric tests, induced potential tests, accuracy tests, and polarity checks. Additional tests are performed by the manufacturer for each transformer design (type tests) and are not performed on every transformer. These tests are listed in ANSI/IEEE Std. C57.13, Paragraph 4.7.3.

5.10.9.2 Test Procedures: Section 8 of ANSI/IEEE Std. C57.13 describes the methods recommended for testing an instrument transformer. Although most of these tests are usually performed only in the factory, there may be occasions when the user will perform some of them in the user's own testing facility or in the field. It is recommended that Section 8 be consulted for guidance and precautions whenever such tests are planned.

5.10.10 References

ANSI Std. C37.04, "Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis."

ANSI Std. C37.06, "Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Required Capabilities."

ANSI Std. C37.20, "Switchgear Assemblies Including Metal-Enclosed Bus."

ANSI/IEEE Std. C57.13, "Standard Requirements for Instrument Transformers."

ANSI/IEEE Std. C57.13.1, "Guide for Field Testing of Relaying Current Transformers."

ANSI/IEEE Std. C57.13.2, "Conformance Test Procedures for Instrument Transformers."

ANSI/IEEE Std. C57.13.3, "Guide for the Grounding of Instrument Transformer Secondary Circuits and Cases."

IEEE Std. 37.09, "Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis."

IEEE Std. C57.12.00, "IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers."

NEMA Std. SG 5, "Power Switchgear Assemblies."