Instrument Transformers

Technical Information and Application Guide

ABB Power Distribution

Contents

Technology Review

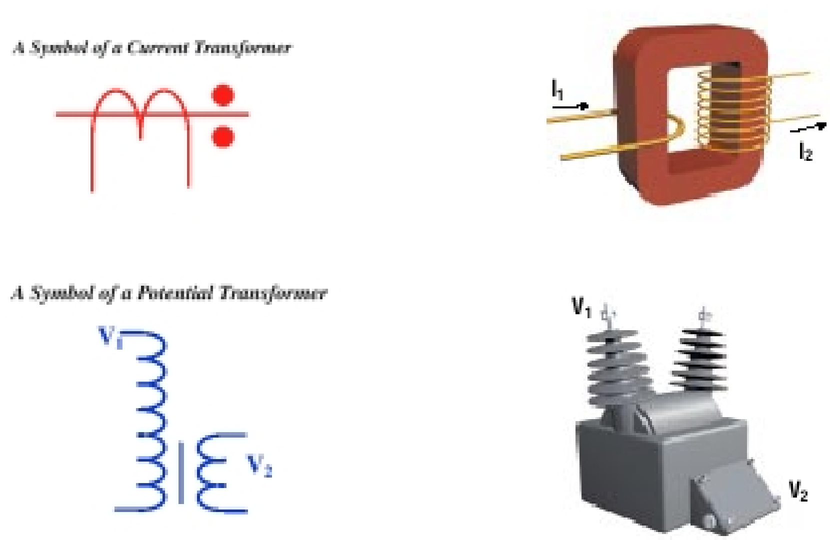
Introduction

Instrument transformers (ITs) are designed to transform: voltage (Voltage (VTs) or Potential Transformers (PTs)) or current (Current transformers (CTs)) from the high values in the transmission and distribution systems to the low values that can be utilized by low voltage current metering devices. There are three primary applications for which ITs are used:

- metering (for energy billing and transaction purposes)
- protection control (for system protection and protective relaying purposes)
- load survey (for economic management of industrial loads)

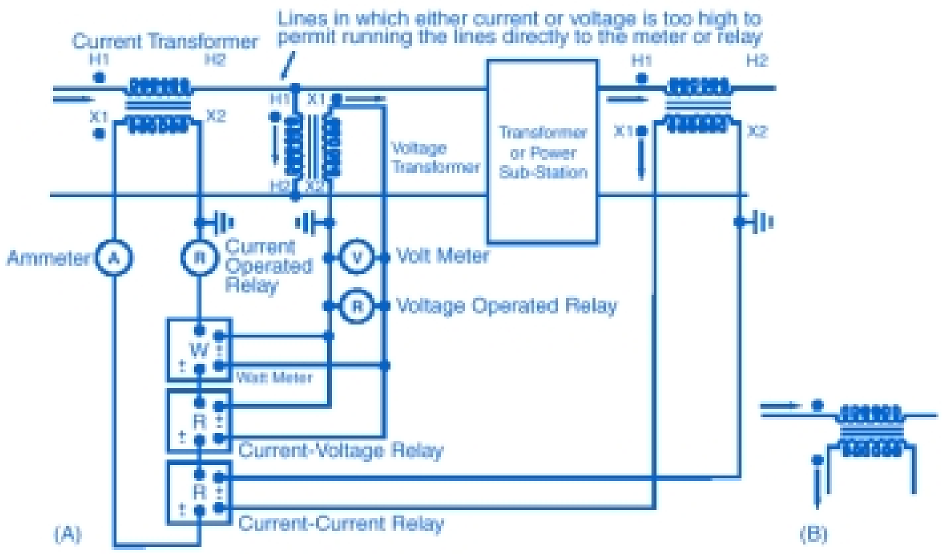
Depending on the requirements for those applications, the IT design and construction can be quite different. Generally, the metering ITs require high accuracy in the range of normal operating voltage and current. Protection ITs require linearity in a wide range of voltages and currents. During the disturbance, such as a system fault or over voltage transients, the output of the IT is used by a protective relay to initiate an appropriate action (open or close a breaker, reconfigure the system, etc.) to mitigate the disturbance and protect the rest of the power system. Instrument transformers are the most common and economic way to detect a disturbance. Typical output levels of instrument transformers are 0-5 A and 115-120 V for CTs and VTs, respectively. There are several classes of accuracy for instrument transformers defined by the IEEE, CSA, IEC and ANSI standards. Figure 1 presents a conceptual design of CTs and VTs.

Figure 1: Current and Potential Transformer Symbols & Simplified Concepts



Electric current or voltage can be measured by bringing it to a suitable instrument. In many electric power circuits, however, the current and voltage are both so high that it is desirable, for cost and safety reasons, to bring the circuit to the primary winding terminals of a voltage transformer, to measure voltage, or through the primary winding of a Current Transformer, to measure current. Standard secondary circuit voltages are 115 or 120 volts. Standard secondary circuit current is 5 amperes. Figure 2 shows how the polarity markers are used to keep the direction of current flow in the meters exactly the same, as if the primary circuit was carried through the meters. Grounding of the secondary circuit is most important, but in complicated three-phase connections, the best point to ground is not always easily determined.

Figure 2: Instrument Transformer Connections



A. The current transformer is designed to connect in series with the line to transform the line current to the standard 5 amperes suitable to the meter or relay. The voltage transformer is designed to connect in parallel with the line to transform the line voltage to 115 or 120 volts suitable for the meter or relay.

To keep the voltage at the meters and relays at a safe value, the secondary circuit must be grounded.

B. The polarity markers indicate the relative instantaneous directions of current in the windings. For current-operated or voltage-operated devices the polarity, or instantaneous direction of current, there is of no significance. Correct operation of current-current, voltage-voltage or current-voltage devices usually depends on the relative instantaneous directions.

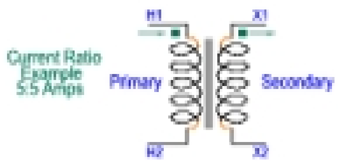
Types of Construction

The principal forms of construction used for instrument transformers, together with standard rating symbols according to IEEE Standard C57.13 are shown in Figure 3.

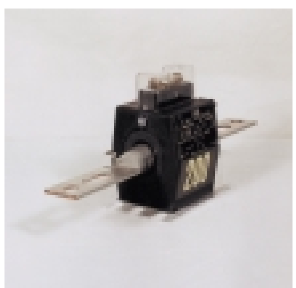
Figure 3: Types of Instrument Transformer Construction

3a. Simple Basic Forms

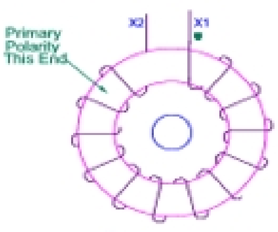
Current Transformer

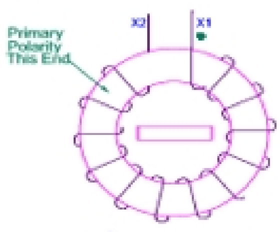


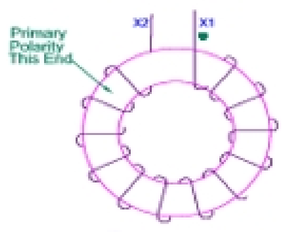
Voltage Transformer



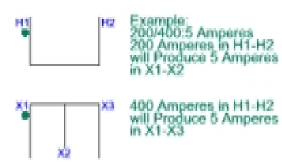
3b. Window, Bar and Bushing

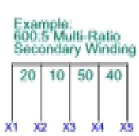






3c. Tapped Secondary





Example:
600:5 Multi-Ratio

Primary Amperes	Secondary Terminals to Get 5 Amps
50	X2-X3
100	X1-X2
150	X1-X3
200	X4-X5
250	X3-X4
300	X2-X4
400	X1-X4
450	X3-X5
500	X2-X5
600	X1-X5

Materials Used in Construction

Butyl Rubber

In the 1970's, the insulating medium for the higher voltage (5-34.5 kV) units was butyl rubber. The material itself is excellent, but the pressures and temperatures necessary to use it as a dielectric were not conducive to the exacting clearances and geometries inside a voltage or current transformer. Without excess bracing, the core/coil assemblies would shift during molding and fail BIL testing. With enough bracing, the material flow inside the unit was restricted, increasing the possibility of voids. For these reasons, another dielectric insulating material was sought. However, Butyl rubber is still used by some manufacturers.

Cycloalophatic Epoxy

A common and excellent insulator in use by other manufacturers in the late '70's was cycloalophatic epoxy. This material was poured under a vacuum and the processing temperatures were not as high as butyl rubber, so this was selected for the dielectric. Because its dielectric characteristics were so similar, almost no changes to the winding designs were necessary electrically, for the change from butyl to epoxy.

During the early 1980's, it was discovered that epoxy's mechanical properties were less than desired. The elongation and expansion coefficient characteristics of epoxy were brittle. Skirts on outdoor units were easily chipped and/or cracked off. The expansion coefficient was not conducive to temperature swings in some areas of the country, so excess cracking occurred. The search for a new dielectric began again, and ended in 1986 with Polyurethane.

Introduction to Urethane Elastomers

Polyurethane (or urethane) elastomers are one type of a large family of elastic polymers called rubber. There are 14 types in general use. All of them have been commercially successful, but they are all different in several ways.

Thirteen of these types are called conventional rubber. That means they are mixed, milled and molded by techniques which have been in use by the rubber industry for the past eighty years.

Polyurethane rubber raw materials are liquid, which permits them to be pumped, metered, mixed and dispensed by machines under very precise control of temperature and ingredient proportions. They enter molds as a liquid at low pressure and are "cured" at the same elevated temperature as that at which they are mixed. This unique characteristic allows molding of large parts which are completely uniform throughout.

Diversity of Urethane Usage

In the electrical industry, polyurethane is used both as a flexible, insulating jacket on control and power supply cables, as well as a dielectric and outdoor jacket for 55° C rise transformers. One of the features of urethane which makes it so popular, is its ability to be permanently attached to metals and composites very readily during the molding or casting process. Bond strength exceeding the tear strength of urethane can be achieved.

Performance Characteristics

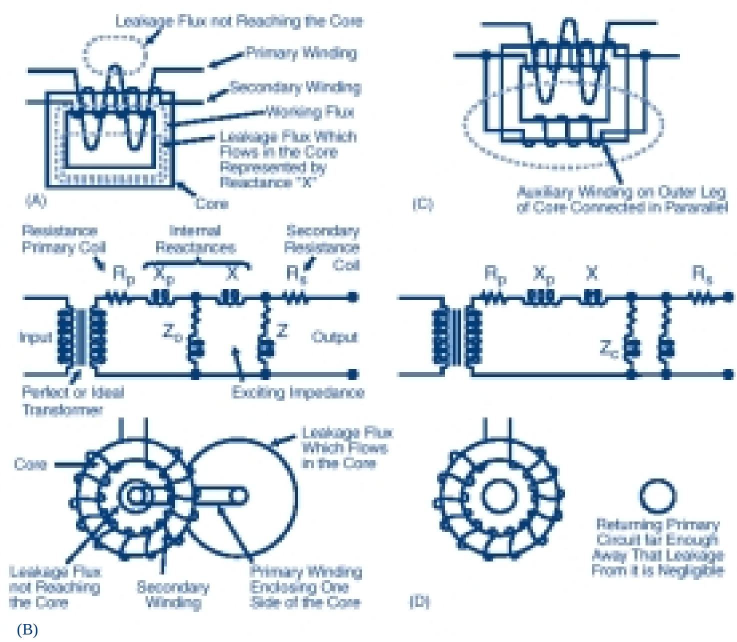
Equivalent Circuits

The specific performance characteristics of instrument transformers are most easily determined from the equivalent circuit. Figure 4 works well for nearly all instrument transformers. For current transformers, the value of the reactance X is determined in a special way so that it will represent the leakage flux. The flux flows in the part of the core which is represented by the left-hand exciting branch of the equivalent circuit shown in Figure 4.

By use of an additional winding (or windings) placed over the outer leg(s) of the core and connected back in parallel with the secondary winding as shown in Figure 4, the leakage flux can be kept out of the core. The leakage reactance is then effectively connected ahead of both exciting branches as shown. This difference is important for current transformers only because leakage flux in the core affects current ratio. It also improves the performance of current transformers and makes their performance subject to simple calculation.

A voltage transformer will be designed so that the through impedance (Rs, R, Xp and X) is as low as possible, while the current transformer will be designed such that the excitation impedance (Z_o and Z_i) is as high as possible. Neither transformer is very good at performing the function of the other.

Figure 4: Equivalent Circuits



A. A typical transformer and its equivalent circuit. The leakage flux is shown entering the outer part of the core and is represented by reactance X. The reactance develops voltage applied to the exciting branch Z_o which represents the outer side of the core. The series impedance $R_p + R_s + j(X_p + X)$ is responsible for the loss of voltage in transformation. The voltage transformers are carefully designed to keep this impedance as low as possible. The loss of current in transformation is due to current by-passed by the exciting branches Z_o and Z_i. Current transformers are specially designed to keep these by-pass exciting impedances as high as possible.

B. A common construction of HV or EHV current transformer. Leakage flux enters the core, even though the winding is uniformly wound over a ring core. The equivalent circuit is the same as for Figure A.

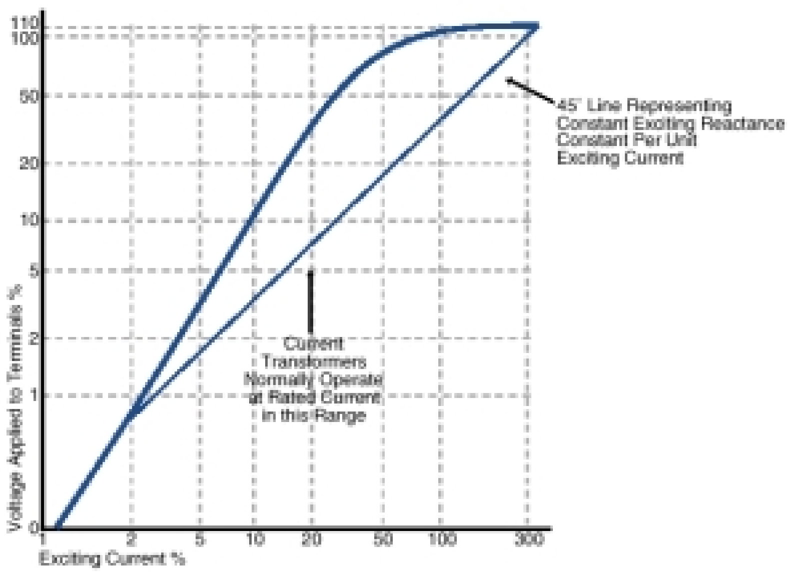
C. A construction used in HV or EHV current transformers. The parallel auxiliary winding effectively keeps the leakage flux out of the core so that the leakage reactance in the equivalent circuit is effectively ahead of the exciting branches. This simplifies the calculation of the current by-passed through Z_o and Z_i. (They can be combined-see Relaying Accuracy.)

D. A typical bushing current transformer. This resembles the transformer in B but has only negligible leakage flux in the core because the return conductor is far away. This transformer still has a good deal of leakage reactance, but the leakage flux does not enter the core in significant amount. The reactance is ahead of the by-pass branches Z_o. and Z_i so that the performance as a current transformer can be easily calculated. (See Relaying Accuracy.)

The value of through impedance is constant, but the value of excitation impedance is variable. The exciting impedances representing the exciting currents for the two parts of the core depend on the voltage applied to them, or the current flowing in them, or flux density in the core. The easiest way to understand Z_o and Z_i, which are of primary importance in current transformers, is to draw "saturation" curves showing how the current flowing into the exciting branch varies with the voltage applied, as in Figure 5. The curve is usually plotted for the combination of Z_o and Z_i in parallel.

Voltage transformers are designed such that the operating point on the saturation curve, as in Figure 5, is typically at a relatively high voltage. This is subject to the limitation that this point must not be so high that the exciting current itself is excessive. Voltage transformers are designed to work without excessive exciting current up to 110% of rated voltage. The IEEE standard for performance requires good performance also at 90% voltage. Figure 5 shows that the exciting current will not reach a higher per unit value, with consequent increase of voltage loss from exciting current, at voltages over the range of 5% to 110%.

Figure 5: Typical Saturation Curve for a Transformer Core



Voltage transformers are designed such that the operating point on the saturation curve is typically at a relatively high voltage.

The voltage must not be so high that the exciting current itself becomes too high. This would cause a voltage drop in the primary impedance that would bring about an excessive error in ratio of phase angle. IEEE C57.13 requires performance standards to be met at 110% of rated voltage. The curve shows that the per unit exciting current, below which the error due to voltage drop caused by the exciting current itself will equal that at 110% rated voltage typically will be less than 5% rated voltage. Down to this value the voltage transformer will meet standard performance limits.

The current transformer, on the other hand, is designed to operate at the low range of the curve (see region marked on the curve) so that the exciting current by-pass will be as low as feasible. The curve shows that as the voltage is reduced, the exciting current is not reduced in proportion. This means, in a current transformer, that as the primary and secondary current decrease, the by-pass current which causes the error actually increases in percentage. The errors in current transformation typically increase at the lower currents.

Ratio Error and Phase Angle

Ideal or "perfect" transformers induce the same voltage per turn in the secondary winding as that applied to the primary voltage transformers. They also produce the same ampere-turns in the secondary as are circulated in the primary current transformers, to deliver any desired ratio of primary to secondary voltage or current. In the actual transformer shown in Figure 6, the secondary current output is deficient by the amount of current bypassed by the exciting branches, Z_o and Z_i, and the secondary output voltage is deficient by the voltage drop in the transformer through impedance.

The transformer nameplates show a "marked ratio," usually an even number such as 20 to 1. The actual ratio of primary to secondary quantity may be slightly higher or lower than the marked value by an amount[1] called Ratio Error, which is defined in IEEE C57.13 as Ratio Correction Factor (RCF). For instance, if the Actual Ratio is 20.2 to 1, the Ratio Correction Factor is 1.01 and the Ratio Error is 1%. In addition, the secondary output may be slightly out of phase with the primary input. This error is called Phase Angle (usually measured in minutes) and is designated as positive if the secondary output leads the primary input.

1. The ratio of turns is usually adjusted to "compensate" for the losses in the transformer, and because of this "compensation" the actual secondary output can be higher than would be expected from the marked ratio.

The Effect of Ratio Error and Phase Angle on Wattmeter Readings

If the Ratio Correction Factor exceeds 1.0, the meters will read low and the readings should be multiplied by the Correction Factor. The effect of Phase Angle, however, is not as obvious. To determine reasonable limits for RCF and Phase Angle, a combination Correction Factor has been invented, called Transformer Correction Factor (TCF). This is dependent on both RCF and Phase Angle and may be used to correct the reading of a wattmeter. Transformer Correction Factor (TCF) is based on the fact that if the power factor of a metered power load is 60% lagging (a figure selected as representing about the usual minimum power factor of actual power loads being metered by watt hour meters), 2.6 minutes of Phase Angle in the current (or voltage) transformer output will cause 0.1% error in the wattmeter reading.

Voltage Transformers

The ratio correction factor and phase angle must be determined at the specific burden involved. However, as with an actual measurement, these values apply to the secondary voltage at the transformer terminals. If the leads from the transformer to the burden are very long, they may have sufficient impedance to introduce additional voltage drop and error. From the current drawn from the transformer and the impedance of the leads, the voltage drop in the leads can be calculated. If it is of appreciable magnitude in percent of secondary voltage, the addition to ratio and phase angle error may be calculated according to the vector diagram in Figure 6 and the formulas:

Percent Ratio will be increased by:

$$\frac{I_s (R_L \cos\theta + X_L \sin\theta)}{E_s} \times 100$$

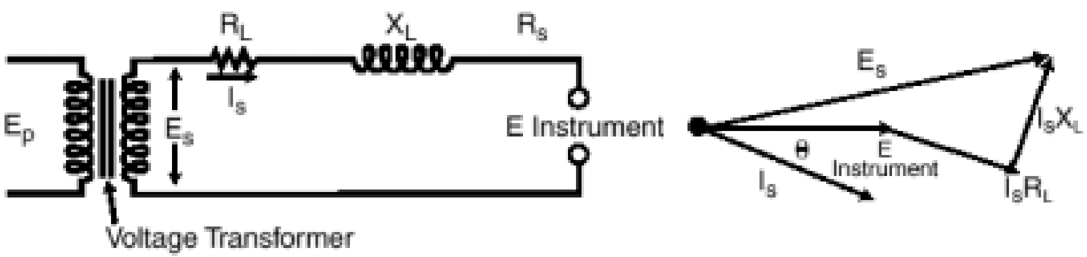
Add this amount to the percent ratio of the transformer to get the actual percent ratio of primary to burden voltage.

The Phase Angle will be increased by:

$$\frac{I_s (R_L \sin\theta - X_L \cos\theta)}{E_s} \times 3438 \text{ Minutes}$$

Add this amount to the phase angle of the transformer (algebraically) to get the actual phase difference between primary and burden voltages.

Figure 6: Effect of Leads in Voltage Transformers



R_L and X_L represent the resistance and reactance in the leads

Method for calculating impedance drops in the leads and resulting ratio and phase angle errors

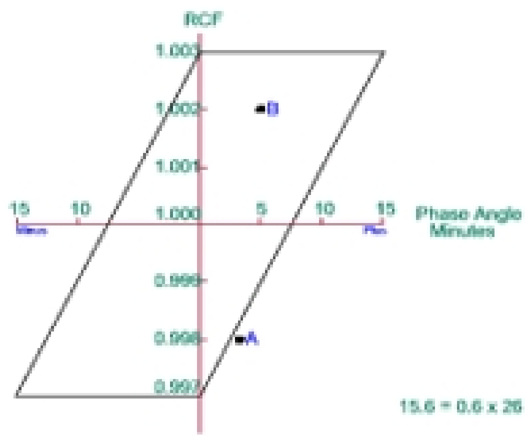
Current Transformers

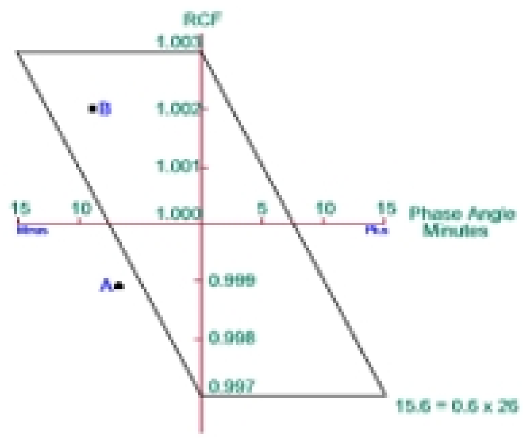
The ratio correction factor and phase angle must be determined at the specific burden and current involved. Current transformer characteristics at special burdens can only be determined by an actual measurement. The test burden must duplicate the actual burden, including the secondary leads. The secondary terminal voltage and power factor must be identical to that of the installation. In addition, these measurements need to be made and applied at the actual service currents.

Accuracy Classifications for Metering

An explanation of accuracy classes can be obtained from careful inspection of Figure 7 for current transformers and Figure 8 for voltage transformers. These figures show the Accuracy Classes as adopted by IEEE, as well as the special limitations which apply to current and voltage transformers. IEEE C57.13 has recognized 0.3% as a reasonable error limit and has designated this as "Accuracy Class 0.3."

Figure 7: The Basic 0.3 Class Parallelogram for Current Transformers
Figure 8: The Basic 0.3 Class Parallelogram for Voltage Transformers





This parallelogram outlines an area in which the measurements of RCF and Phase Angle at 100% current must plot if the transformer accuracy is to be designated as 0.3 Class, with TCF within the limits of 0.997 and 1.003. For example, if the RCF at a given burden at 100% current is 0.998 (99.8% Ratio) and the Phase Angle is 3.5 minutes, the point A is seen to fall outside the parallelogram.

Another example: RCF = 1.002, Phase Angle 5 minutes, representing greater absolute error, the point "B" is now inside the parallelogram, and meets the required limits for 0.3 Accuracy Class. In the second case, TCF is less than 1.003 because the effect of phase angle on the wattmeter compensates for the error in ratio.

IEEE C57.13 recognizes that current transformers naturally have greater errors at lower currents, and that error at low current does not usually represent significant error in total registration of kilowatt hours. This permits twice the error at 10% that is permitted at 100% current. The error at the maximum current permitted by the Thermal Rating Factor of the transformer (a multiplier of 1.5 or 4.0 applied to many transformers) is limited to the same value as at 100% current.

Other Accuracy Classes: In addition to the 0.3 Class, C57.13 recognizes the 0.6 and 1.2 Classes in which the permissible errors are twice as great (0.6%) and twice again (1.2%) as compared to the 0.3 Class. Any one of these classes may be selected for specification by the user depending on whether 0.3%, 0.6% or 1.2% seem reasonable for a given application.

This parallelogram outlines an area in which the measurements of RCF and Phase Angle at 100% (also at 110%) voltage must plot if the transformer accuracy is to be designated as 0.3 Class, with TCF within the limits of 0.997 and 1.003. For example, if the measured RCF at a given burden is 0.999 and the phase angle is — 8 minutes, the point A is seen to fall outside the parallelogram. Another example: RCF = 1.002, Phase angle in 10 minutes, both representing greater absolute errors, but the point "B" is now inside the parallelogram, and meets the required limits for the 0.3 Class. In the second case the TCF is less than 1.003 because the effect of phase angle on the wattmeter compensates for the phase angle.

The reason for the reversed appearance of Figure 8 compared to Figure 7 is that phase angle in the current transformer brings the secondary current more nearly in phase with the load voltage, increasing the wattmeter reading. In the voltage transformer the effect is just the opposite.

C57.13 requires that the limits be met also at 90% voltage; in reality the performance at voltages down to 5% are not significantly different, at the same burden connected to the transformer secondary. The error limits required by C57.13 apply not only at a given burden but at zero burden.

Other Accuracy Classes, in addition to the 0.3 Class, C57.13 recognizes the 0.6 and 1.2 Classes in which the permissible errors are twice as great (0.6%) and twice again (1.2%) as compared to the 0.3 Class. Any one of these classes may be selected for specification by the user depending on whether 0.3% , 0.6%, or 1.2% seem reasonable for a given application.

Burdens

The errors in ratio and phase angle will depend on the impedance connected to the secondary of the transformer. This impedance is commonly referred to as "burden". The calculations required for determining the performance of a transformer when different burdens are applied, are beyond the scope of this discussion. Therefore, the standard burdens as outlined in IEEE C57.13 will be used to represent typical service conditions. Each transformer is rated according to its performance at these standard burdens.

Standard Burdens for Current Transformers

Many current transformers supply only a limited number of watthour meter elements with a limited number of runs. For metering and relaying applications IEEE C57.13 has established the standard burdens as given in Figure 9.

Figure 9: Standard Burdens for Current Transformers

Standard Burdens for Current Transformers with 5 A Secondaries *

Burden Designation†	Resistance Ω	Inductance (mH)	Impedance Ω	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	1.040	0.9	22.5	0.9
B-1.8	1.62	2.080	1.8	45.0	0.9
Relaying Burdens					
B-1	0.50	2.300	1.0	25.0	0.5
B-2	1.00	4.600	2.0	50.0	0.5
B-4	2.00	9.200	4.0	100.0	0.5
B-8	4.00	18.400	8.0	200.0	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.

Actual Burdens for Current Transformers

Actual devices connected to instrument transformers often include an inductor with an iron core, which usually means that the inductance is not constant but varies during the cycle, and varies differently with different currents. Exact analysis of current transformer performance with such devices is difficult. Fortunately, the impedances of most instruments and meters are sufficiently constant that no appreciable error is introduced by considering them to be constant. Many electro-mechanical relays, however, have variable impedance. Analysis of the transformer performance is usually based on an equivalent value at normal current. This can be justified on the basis that the burden at higher current is usually less and thus the current transformer will perform better than expected from the equivalent burden. Some relays operate from two or more sources of current: differential (current-current), or power or impedance-measuring (current-voltage) relays. If the two circuits are magnetically coupled by the relay, the burden on one source is affected by the current in the other source, and vice versa. Most of the two-source relays act by balance-beam or other mechanical coupling, so that the burdens are fixed.

Standard Burdens for Voltage Transformers

The standard burdens to be used for testing and comparing voltage transformers are rated at 120 volts and at 69.3 volts. IEEE C57.13 specifies that the 120 volt-rated burden will be used for any transformer with the secondary voltage in the range of 115 to 120 volts, while the 69.3 volt burden will be used for any transformer with the secondary voltage in the range of 65 to 72 volts. This means that the actual volt amperes in the burden in a given test may be different than the nominal value of the burden in volt amperes. For instance, if the standard burden is 25 volt amperes, the actual burden when it is used for testing a transformer with 115 volt secondary is $(115/120)^2$ or .918 times the nominal value of 25.

The burdens rated 69.3 volts have an impedance only 1/3 of that of burdens rated 120 volts and they should not be used in testing or rating transformers rated at 115 to 120 volts. Transformers rated at 115 or 120 volts should be treated as 115 or 120 volt transformers, and if they are actually used at reduced voltage, the performance will not be different if the 120 volt burden is used as a basis for performance. This is because the performance of a transformer down to voltages of about 5% of its rating is not significantly different from the performance at 100% voltage.

Reference Figure 10 for standard burdens for voltage transformers as outlined in IEEE C57.13.

Figure 10: Standard Burdens for Voltage Transformers

Standard Burdens for Voltage Transformers

				Burden Impedance Ω	
	Burden Designation	**Volt Amperes**	**Power Factor**	**120 V Burden**	**69.3 V Burden**
Metering Burdens	W	12.5	0.10	1152	384
	X	25.0	0.70	576	192
	M	35.0	0.20	411	137
	Y	75.0	0.85	192	64

Current Transformers Accuracy Classes for Relaying

Relaying accuracy classes for CTs are defined either with a “C” or a “T” classification.

C– indicates that the transformer ratio can be calculated. These are transformers which are constructed so that the effect of leakage fluxes on its performance are negligible.

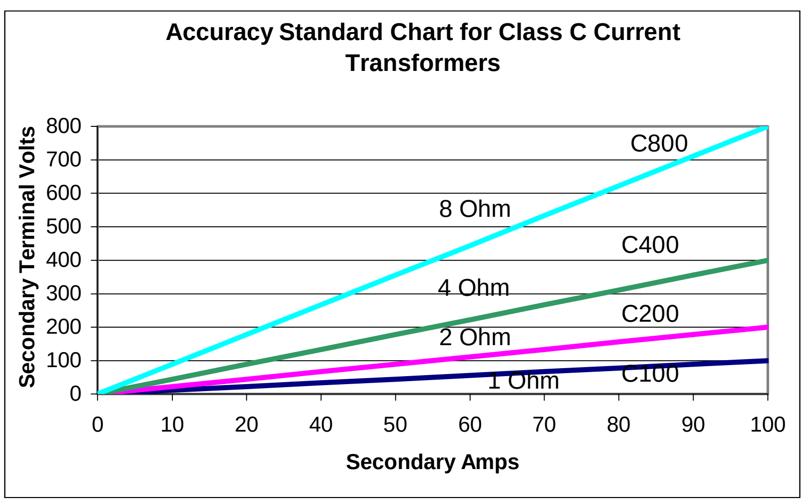
T– indicates the transformer where the leakage flux has an appreciable effect on the ratio. Since the calculation of the excitation current by-passed is a tedious process, the performance of the transformer can only be determined by test.

The basis for classification of performance for relaying is an error limit of 10% at any current from 1.0 to 20 times normal. The accuracy class is the description of how much voltage the transformer can supply to the output circuit (burden), without the CT’s core going into saturation.

For example, a transformer that can supply a 2 ohm output circuit (burden) at 100A [20 times normal current (5A)] or 200V, without saturating the core and within a 10% error limit, is classified as 200 accuracy class. See Figure 11.

Standard accuracy classes, which may be assigned for a relaying current transformer, are 50, 100, 200 and 800. If a C200 transformer can supply 100A secondary output at exactly 10% error into a 2 ohm burden, then we know that the exciting branch is not over 10 amps. If the current is lower, then the burden can be higher without exceeding the output voltage limit if a transformer can carry 2 ohms at 50 amps and deliver 200 volts. However, if the burden is 1 ohm at 200 amps, it will not work since the internal impedance will be significant in relation to the 1 ohm burden.

Figure 11: Accuracy Standard Chart



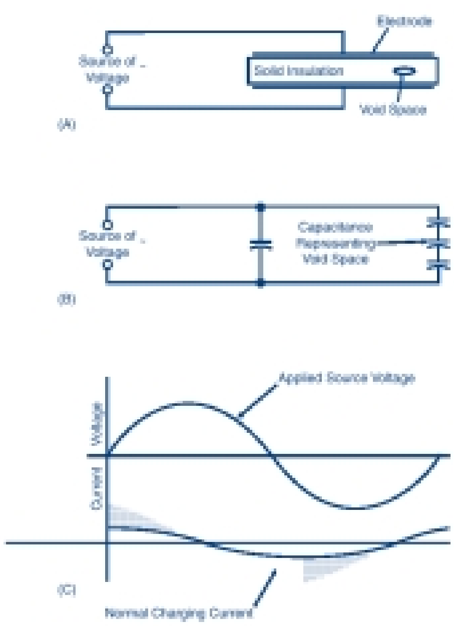
Insulation Systems

Partial Discharges in Transformer Insulation

Partial discharges (PD) are minute electrical discharges that result from the electric field stresses imposed on any insulation system. As the name suggests, they do not cause a complete electrical breakdown of the insulation, so their short term effect is not catastrophic. However, over the long term, PD can slowly deteriorate the quality of the insulation. In solid insulation systems (such as in instrument transformers), PD can occur where a void or discontinuity in solid insulation is introduced Figure 12. Because of the difference between dielectric properties of a void (filled with air or gas) and solid material, the localized electrical stress in the void can be higher than in a solid. This will cause a void to break down although the voltage across the solid will remain (Figure 12). These localized void breakdowns, resulting in small, high frequency current impulses, can be detected by using sensitive instrumentation. Sophisticated, specialized analysis of PD patterns can then be used to gain insight to the nature of PD, its possible location, and mitigation. PD is measured in pico Coulombs (pC) unit of electrical charge. After many years of deliberation, different standards for different electrical equipment (ANSI, IEC, IEEE) do not consistently agree on the allowable or maximum limits of PD. Manufacturers of ITs use different ways of minimizing or controlling the level of PD:

- Control of manufacturing processes (casting, curing, temperatures, vacuum, viscosities, etc.) to minimize the introduction of voids
- Develop designs of ITs that result in minimizing stress fields
- Fill voids with dielectric gas to lower the risk of void breakdown
- Increase design margin to lower overall electric field stresses within the unit
- Use different materials as solid insulation system

Figure 12: Partial Discharges



A. A sample of solid insulation between electrodes, which forms a capacitor, can have a void as shown.

B. The electrically equivalent capacitance network.

C. Applied voltage and the corresponding PD current caused by breaking down the void .

Overloading, Overheating and Aging

All insulation materials are deteriorated by the combination of overheating and exposure to moisture and oxygen. ABB insulation systems are well protected against moisture and oxygen. ABB ITs meet and/or exceed the IEEE Guides for Loading Applications per Appendix C57.92.

IEEE Standard C57.13 recognizes two classes of insulation insofar as resistance to temperature is concerned: (a) 55^{o}C temperature rise and (b) 80^{o}C rise, both over a 30^{o}C daily average ambient temperature. These values are the average temperature rise of the winding (as measured by rise of resistance) during the temperature test at rated maximum continuous current. The Guides for Loading recognize that these temperatures can be considerably exceeded for short periods of time without causing excessive deterioration of the insulation (reference Section 10 of IEEE C57.13).

Maintenance and Inspection Testing of Insulation

Instrument transformer users like to be able to make tests on new transformers, as well as on transformers in service, to assure their adequacy for service. It is rarely possible for the end user to make a complete series of tests, but there are some things the user can do for reassurance.

Measurement of the resistance of each winding to ground (when one winding is measured, ground all other winding terminals) with a megger will indicate if something has happened to reduce the resistance values. Such an incident is most improbable on encapsulated transformers. All ABB insulated current and voltage transformers should have typical readings from the high voltage winding to the low voltage winding, and ground above 1 Megohm per volt at 25^{o}C.

Insulation resistance should be measured at ambient temperature (not over 30^{o}C) because it decreases rapidly at higher temperatures.

Voltage Ratings

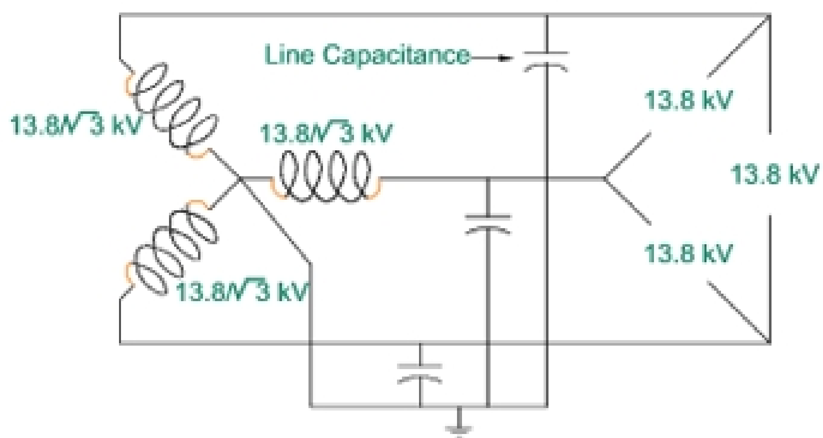
Voltage Ratings for Current Transformer

Current transformers are always rated at the line-to-line voltage of the three-phase system on which they will operate. A 13.8 kV current transformer, for example, is designed for use on a 13.8 kV three-phase system. The actual voltage from the current transformer primary winding to ground is only 13.8/√3 or 7.9 kV as shown in Figure 13.

In the Transformer Standards IEEE C57.13, an insulation class, which has the appearance of a system voltage rating, is associated with each of the standard arrays of dielectric tests (60 Hertz and impulse voltage). It has become standard practice to apply transformers on systems with actual voltage higher than the insulation class value. This is done on the basis that if the power system is designed such (grounded, usually) that the line-to-ground voltage can never be more than 70% or 80% of the line-to-line value, lower-voltage-rated lightning arresters can be used and the insulation is protected from all the higher voltages to which it might otherwise be subjected.

The transformer test voltages consist of a full wave impulse, chopped waves, 60 Hertz applied, and induced voltage test according to the schedule outlines in IEEE C57.13

Figure 13: Equivalent System Diagram



Whether or not this neutral is actually connected to ground, the natural symmetry of the circuit and the equal line capacitors to ground will cause the neutral to assume ground potential.

Voltage Ratings for Voltage Transformers

The voltage which may be applied to a voltage transformer is limited not only by the permissible voltage to ground (as it is in a current transformer) but by the insulation between turns, between layers, and coil sections. It is also limited by the ability of the core to carry enough magnetic flux to induce the voltage. The voltage transformer is somewhat different from the distribution transformer, and certainly from the power transformer, in having a very limited capacity to store energy.

Over Voltage Limits

IEEE C57.13 recognizes three groups of voltage transformers for different capabilities and connections. These groups are explained by Figures 14, 15 and 16. There is also a fourth group which is widely manufactured for use in certain switchgear.

All transformers, according to IEEE C57.13, are capable of operating continuously, and of maintaining their accuracy at 110% of rated voltage. As indicated in the figures, Group 2 transformers need do no more than this, and Group 1 transformers must be able to operate (but not necessarily maintain accuracy) at 125% voltage during emergencies, while Group 3 and 4 transformers must be able to operate for one minute at line-to-line voltage, which is $\sqrt{3}$ times their rating.

Figure 14: Application Limitation—Group 1 Voltage Transformers

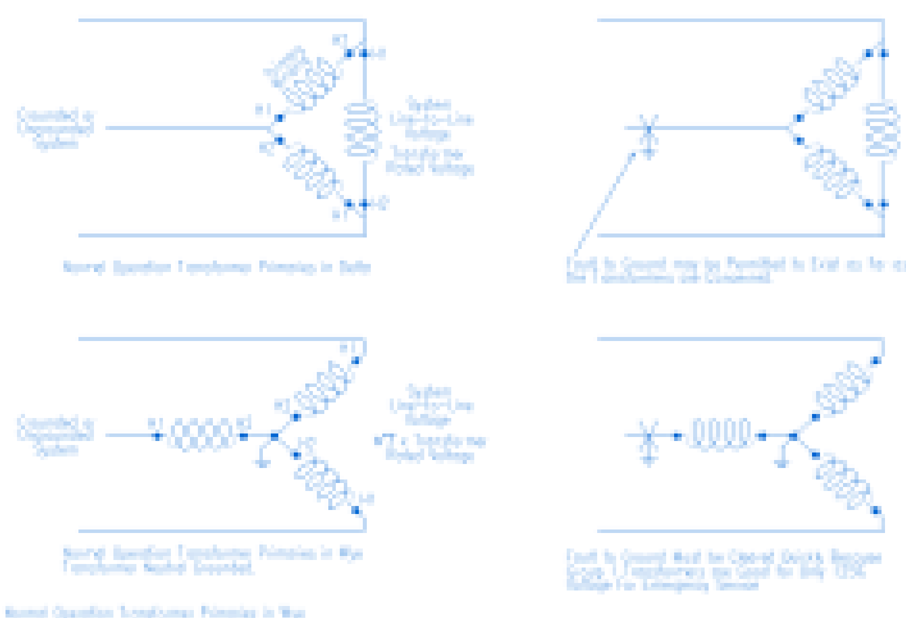


Figure 15: Application Limitation—Group 2 Voltage Transformer

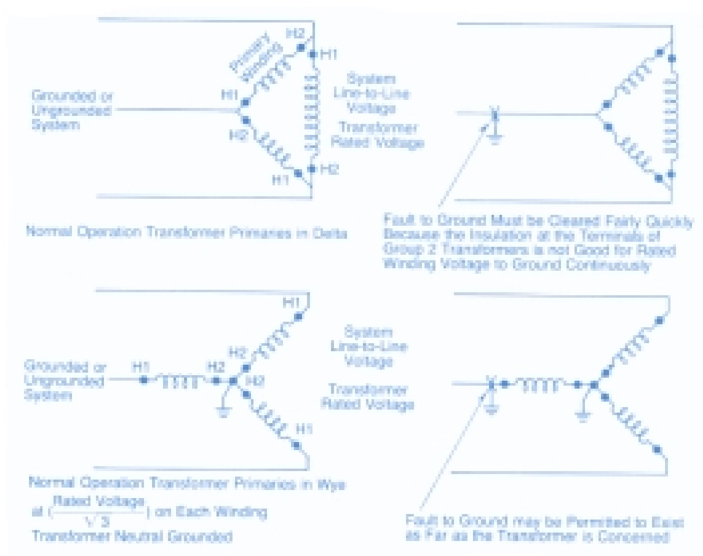
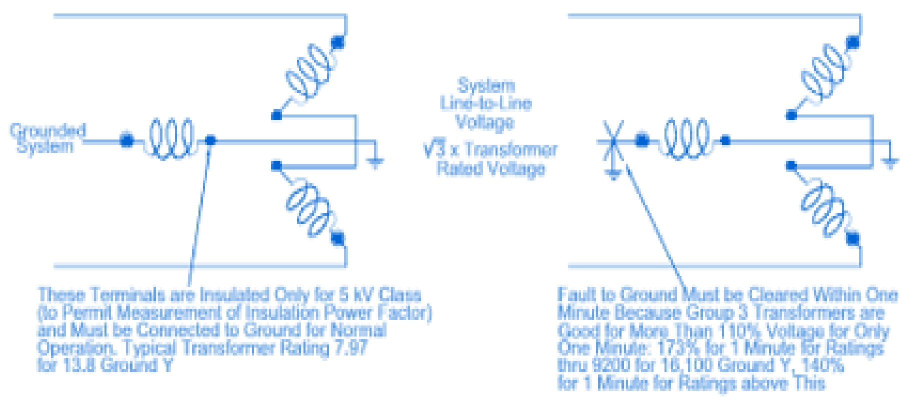


Figure 16: Application Limitation—Group 3 Voltage Transformers



These transformers have two secondary windings, one with a rating of 115 volts (except for the lowest rated 14400 for 25000 ground wye which is rated at 120 volts) and another secondary winding rated at approximately 115/√3 volts. The value is not always exactly 115V/√3 because, for simplicity, the primary/secondary voltage ratio is adjusted to a round number.

Power Quality

Power quality is an important consideration in designing any power system. Distribution systems are especially vulnerable to power quality problems. These problems should be taken into account when selecting and purchasing equipment. Power quality issues may be more pronounced in the US ANSI market than in Europe IEC market because of the different nature of the two systems. Distances for power delivery, density of loads, and customer concentrations are among the aspects that differ. Power quality problems include:

- voltage sags and dips
- momentary interruptions (flicker)
- harmonics (harmonic current and/or harmonic voltages)

Voltage Sags and Dips

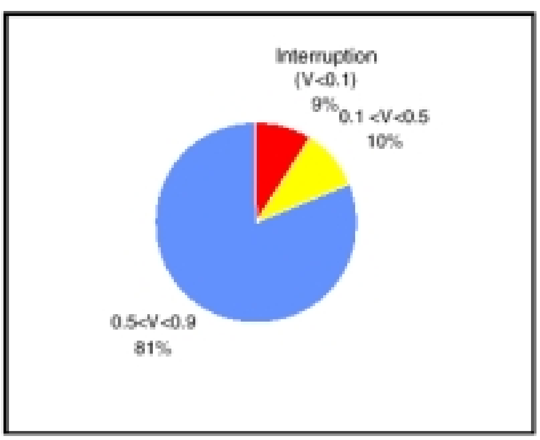
Voltage sags and dips are associated with switching or fault events in the power system that cause voltages on adjacent or neighboring circuits to partially collapse. These events can last from a few milliseconds to more than a second.

Momentary Interruptions

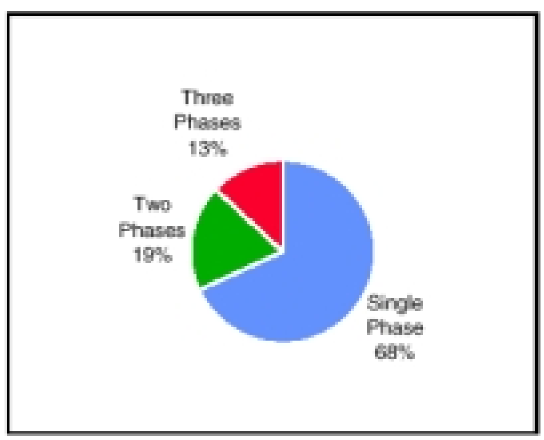
Momentary interruptions are the same type of power system events as voltage sags and dips, but are caused by lightning and other transients. The primary difference is that momentary interruptions occur primarily in the circuits directly involved in the event rather than in an adjacent circuit. Momentary interruptions are more severe power quality problems than voltage sags and dips.

Figures 17A & 17B below show statistics of voltage sags and momentary interruptions in a typical ANSI power system.

Figures 17A & 17B: Distribution of RMS Events



A. Pie-chart showing the statistics of voltage sags and interruptions-note most events (81%) are sags (between 0.5 pu and 0.9 pu)

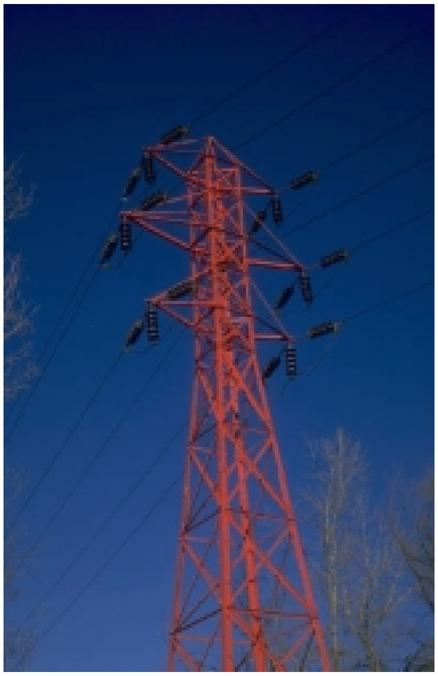


B Pie-chart showing the statistics of all PQ event types-note most events (68%) are single phase

Harmonics

Harmonics are caused primarily by non-linear loads. The nature of non-linear power equipment causes a perfectly sinusoidal voltage waveform to result in currents containing other frequencies. A sinusoidal current can cause the generation of non-sinusoidal voltages. Non-linear power equipment includes saturated transformers (including instrument transformers), motors, and generators, but is primarily associated with power electronics. The act of triggering or switching a Silicon Controlled Rectifier (SCR), a diode, an Insulated Gate Bipolar Transistor (IGBT), or a Gate Turn-Off device (GTO), is in principle a non-linear operation. Power electronics devices such as Adjustable Speed Drives (ASDs), or Variable Speed Drives (VSDs) can sometimes exhibit a high level of harmonics, often more than 100% Total Harmonic Distortion (THD). In the case of ASDs, this level of harmonics varies with the selected rpm of the motor, and mechanical load on the shaft.

Harmonics are unwanted events in distribution systems. They can cause excessive heating and damage to neutral connections and cables, and can saturate instrument transformers. Harmonics may also precipitate from the original location of the non-linear equipment to other locations like feeders and loads. They also may cause false tripping or malfunctioning of equipment, false readings from the CTs and VTs especially sensitive relays, computer loads, other ASDs, and Programmable Logic Controllers (PLCs).



There are a variety of techniques to mitigate and control the level of harmonics, and industry standards regulating harmonics (see IEEE 519, *Standard Practices and Requirements for Harmonic Control in Electrical Power Systems*, or IEC 555/1000-3). Possible mitigation procedures include reconfiguring the system, re-sizing the cables or transformers to include additional loading due to harmonic currents, or installing filters and harmonic blockers. It is important to remember that these measures work for some, but not for all harmonics. Often a comprehensive study has to be performed to determine the level of harmonic currents, their impact on the power system, and possible suppression measures.

In real systems, one disturbance in the system can cause a cascade of other disturbances. For example, a lightning surge (fast overvoltage transient) traveling along an overhead feeder line can cause a flashover and subsequent short circuit in a substation supplying an industrial plant, which in turn can cause abnormal acceleration of a local generator and so on.

Service Conditions

Overload and Short-Circuit Capability

A voltage transformer is connected across the line or line-ground, and is loaded to a greater or lesser degree depending on the number of devices connected in parallel at the secondary terminals (Figure 18). As the load is increased, the curves for ratio error and phase angle will show how the accuracy is affected.

If accuracy is not important, the load can be increased to the thermal volt-ampere rating, the maximum which can be carried without overheating.

Voltage transformers must be able to withstand an accidental short-circuit for one second.

A current transformer's primary is connected in series with the line and must carry whatever current flows in the line. The burden impedance connected to the secondary terminals affects the accuracy, as shown by the curves for ratio error and phase angle, but generally has no significant effect on temperature.

Because watthour meters are usually capable of carrying at least 400% of rated current continuously, many of those current transformers used almost exclusively with watthour meters have been designed especially to carry two to four times normal current. Also because many of those current transformers, used almost exclusively in enclosed switchgear, must be designed to operate in a high ambient temperature (55^{o}C), they will carry 1.33 times normal current in a normal (30^{o}C daily average) ambient temperature. The factor designating the continuous current capacity in terms of rated current at 30^{o}C ambient is called thermal current rating factor. Standard values are 1.33, 1.5, 2.0, 3.0 and 4.0. The continuous thermal rating factor is based on 30^{o}C average ambient temperature unless otherwise noted.

The IEEE Guides for Loading recognize that transformer insulation can withstand a considerable degree of overheating for a short time without severe deterioration. For example, in the event of a line short circuit, the fault current may easily be 50 times the rated current of the current transformer, but will probably flow for not over one second. IEEE C57.13 permits a 250^{o}C temperature for this very short time (compared to 95^{o}C average continuous winding temperature). All current transformers are assigned a one-second thermal current limit which denotes how much current they will carry (usually denoted in terms of times normal rated current) for one second. For durations up to five seconds, current transformers will carry currents lower than this.

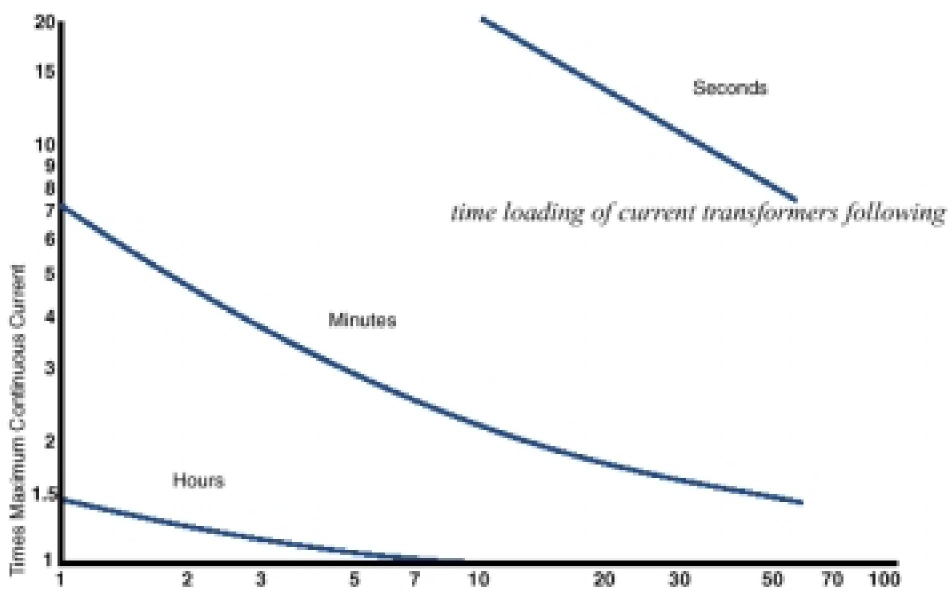
The transformer will carry more current for a time less than one second according to the same rule, up to the mechanical current limit (which is also given for standard current transformers.) At this limit of current, the electromechanical forces tending to separate the primary and secondary coils, become high enough to damage the transformer.

The mechanical current limit is specified in terms of times normal rated current, as is the thermal one-second limit, but it is always assumed that the current may be fully offset initially. If it is known that the current cannot be initially fully offset, the current transformer will be able to withstand mechanically a larger RMS value of current, larger than its rated mechanical limit.

The temperature at these high currents and short times (less than five seconds) cannot be measured, but is always calculated on the basis that all heat generated by the current is stored in the copper for the duration (not over five seconds) of the high current.

Currents higher than the rated value, but less than the five second limit, can be determined by the rules set forth in the IEEE Guides for Loading. The calculation for any given transformer is lengthy, and as a general guide for standard transformers, the curves of Figure 18 can be used.

Figure 18: Overload Capability of Current Transformers



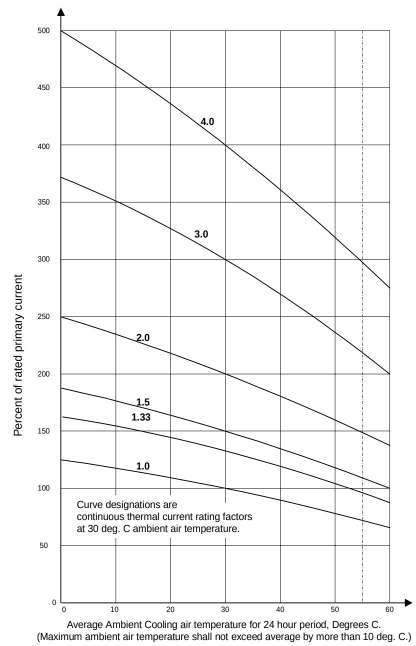
Time in Hours, Minutes, and seconds Following Full Load

Recommended guide for short time loading of current transformers following rated load for 0.1% loss of life.
Transformers so loaded will reach temperatures in excess of 55^{o}C rise over ambient.
Loading according to this curve is not safe if the ambient exceeds 30^{o}C on the average, or if the overload occurs more often than once a day.

Higher and Lower Ambient Temperatures

At temperatures over the standard 30°C, daily average ambient temperature current transformers should be derated 1% for each degree over (up to 55°C ambient). At temperatures under 30°C, they may be uprated 3/4% for each degree (down to 0°C).

Figure 19: Thermal Loading Guide



Open-Circuit Voltage in Current Transformers

Figure 2 shows that the line current must flow through the current transformer, and Figure 4 shows that if the secondary circuit is accidentally opened, all the current will have to pass through the exciting current branches of the equivalent circuit. This will develop a rather high voltage across the exciting branch, which will appear as a high voltage at the secondary terminals. Because this voltage is limited by saturation of the core, the RMS value measured by a voltmeter may not appear to be dangerous. As the current cyclically passes through zero, the rate of change of flux at current zero is not limited by saturation, and is very high indeed. This induces extremely high peaks or pulses of voltage.

These high peaks of voltage may not register on the conventional voltmeter, but they can break down insulation and are dangerous to personnel. Current transformers are insulated to withstand, for emergency operation, secondary peak voltages up to 3500 volts. This takes care of the smaller transformers with relay accuracy class under T200, but if open-circuit of larger transformers is probable, some protective circuit should be permanently connected to the secondary terminals. In general, open-circuit of the secondary terminals should be considered as a serious accident.

The actual open-circuit voltage peak is difficult to measure accurately because it exists only as very short peaks. The method outlined in the Test Methods Section of IEEE C57.13 represents an excellent compromise between precision and feasibility.

Permanent Magnetization of Current Transformer Cores

If a system short-circuit occurs, with a current of several times normal, the voltage at the burden may be rather high. The flux density in the equivalent exciting reactance (the core of the current transformer) may be high enough that if the fault current is abruptly interrupted, the core may be permanently magnetized at a fairly high flux density.

If the secondary circuit of the current transformer is accidentally opened, the flux density will become very high and even if the circuit is immediately closed again, the core may be left with permanent magnetization.

When normal current and flux variation is restored, the flux variation starts from the residual value and varies somewhat as shown in Figure 20. If the flux starts to increase from point a, the flux variation cannot be maintained in loop a-A in Figure 20, because such a loop would require direct current to maintain it in its offset position. The flux loop must shift down to the symmetrical (around the vertical axis) loop c-C. As it shifts down it actually generates a small direct current in the secondary circuit. The secondary burden will establish the rate of change. The flux variation will stay in this loop indefinitely.

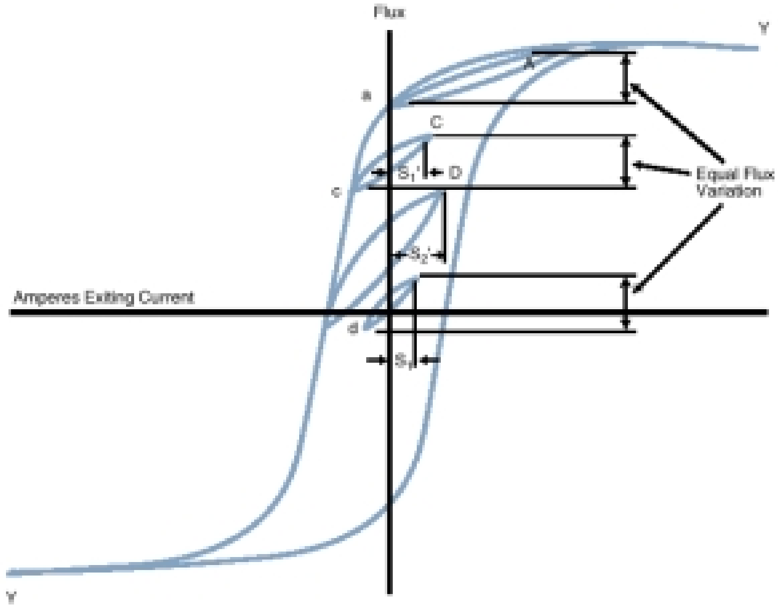
The slope of the loop c-C will be less than the slope of the normal, completely symmetrical loop at the origin The peak exciting current S_1' will be higher than the normal exciting current S_1. If the alternating flux density increases, the hysteresis loop moves to d-D and the slope of this loop becomes nearly equal to the symmetrical loop. The exciting current S_2' is still greater than the symmetrical value, but not as much greater in percent, as the difference between S_1' and S_1.

The final result is that the effective exciting current, which causes ratio error and phase angle, is increased if the core becomes permanently magnetized. This will usually cause no more than 0.1% and 3 minutes of additional error in practical metering transformers at metering burdens[10]. The difference is less dependent on burden and current than might be expected. This is because the increase in exciting current from permanent magnetism is less at low flux variation, and moves to a constant ampere-turn value as the flux variation increases.

If precision measurement of ratio and phase angle is important, especially if ratio and phase angle measurements made at different times or in different laboratories are to be compared, demagnetization of the core by the conventional method of applying an alternating voltage high enough to circulate rated current in the secondary winding, reducing it gradually to zero, is desirable. (See IEEE C57.13).

[10.] *At 100% current*

Figure 20: Permanent Magnetism in Current Transformers



To allow loop a-A to exist, a direct current must flow, requiring a DC voltage. This in turn requires a downward change in flux to induce it, with the result that the loop shifts down to c-C which is symmetrical about the vertical axis and requires no direct current. Operation is stable over this loop. The iron is permanently magnetized by having been at point a, and the loop c-C will not of itself shift down further. Imposition of a still higher AC flux variation will cause the larger loop d-D, shifted down from c-C. A very high flux density will restore the original symmetrical loop y-Y.

Voltage Transformer Connected Line-to-Ground on an Otherwise Ungrounded System

An ungrounded system is always actually grounded, although perhaps very poorly, by the capacitance and resistance of its insulation to-ground, as shown in Figure 22. If a voltage transformer is connected from one line to-ground, it is in effect connected in parallel with a capacitor. The equivalent circuit is shown in Figure 22. Figure 22 also shows how parallel resonance can occur between transformer and capacitor, and how it can cause a very high voltage with destruction of the voltage transformer. If examination of a voltage transformer which has failed, shows only the primary winding uniformly roasted from end-to-end, gross over excitation is undoubtedly the cause and "ferro-resonance" can be suspected. It is called ferro-resonance because this resonance depends on partial saturation of an iron core.

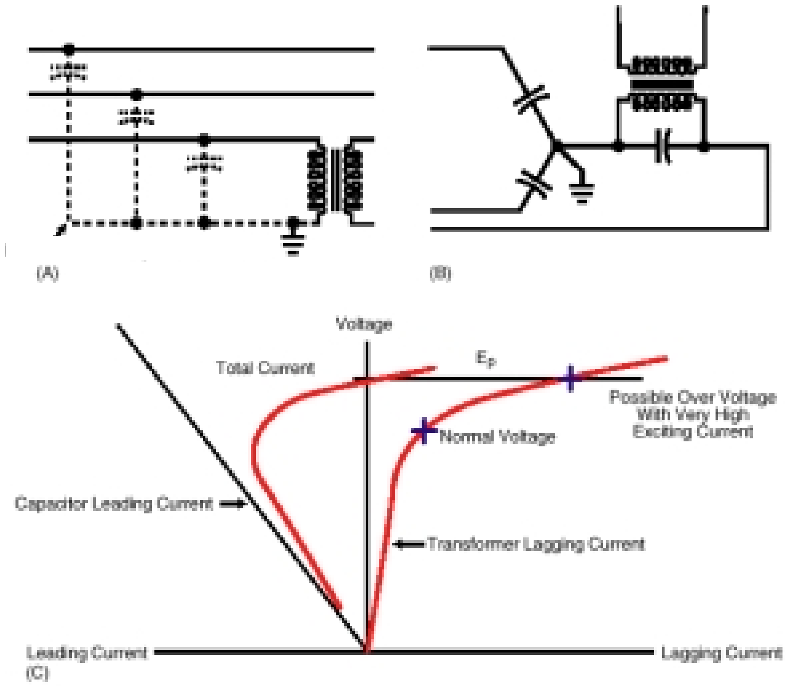
The number of combinations of constants which can cause ferro-resonance is large, and the analysis of the circuit and prediction of possible destructive voltage is not simple. For ABB transformers of present and foreseeable future manufacture, this works out as shown in Figure 21.

These high loadings may cause errors greater than 0.3%, but a transformer connected line-to-ground on an ungrounded system would never be used for accurate metering anyway (units connected line-to-line should be used instead). If three transformers are connected in Y, the secondaries should never be connected in Delta.

Figure 21: Watt Loading - Ferro-resonance Prevention

Voltage Class (Primary)	Watt Loading on Secondary to Prevent Ferro-resonance	Approx. Ohms Equivalent Resistance per Phase (120 V)	Connected Across Corner of Broken Delta
To 500	200	72	216
7200-15000	500	29	87
25000 & up	750	20	60

Figure 22: Ferro-resonance Voltage Transformers



A. Line-to-ground capacitance circuit

B. Equivalent Y circuit

C. Approximate possible curve of current (neglecting resistance components) showing that at some particular value of voltage (Ep) the capacitor and transformer's reactive current total zero, representing infinite impedance, with the result that the voltage-to-ground on this line may reach Ep. This is a high enough value that excessive exciting current will burn out the primary winding.

Auxiliary Current Transformers

Many circuit problems can be solved by connecting one current transformer to supply another current transformer, usually called an Auxiliary current transformer, shown in Figure 23.

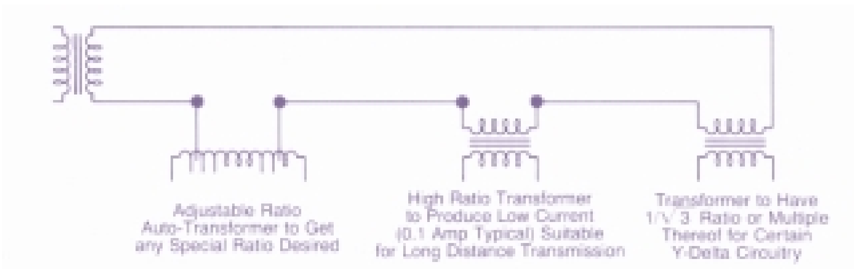
Auxiliary current transformers perform like other current transformers, but there are certain problems associated with their use which merit discussion.

First, the auxiliary current transformer constitutes an additional burden on the main current transformer, which usually increases the errors of the main current transformer.

Secondly, the performance of auxiliary current transformers is not usually as good as the performance of main current transformers. This is because the auxiliary current transformer is designed to impose as small a burden as possible on the main current transformer. This means its own burden capacity must be relatively low.

These two considerations mean that the errors of transformation when an auxiliary current transformer is used, will typically be three times the value which might be expected with single transformer. However, the special functions which can be performed by the auxiliary current transformer as indicated in Figure 23 often dictate their use.

Figure 23: Auxiliary Current Transformers



Fusing Voltage Transformers

Primary fuses are used with voltage transformers mainly to take the transformer off the line in the event of an internal failure. This prevents a failed VT from becoming an L-G fault which requires the breaker to interrupt the customer's electric service.

Since modern transformers are much more reliable than older ones, the fuses may never operate due to internal transformer failure. Transformer failure may still be caused by overload or short circuit on the secondary. If such failure occurs, it may involve other apparatuses, perhaps causing an outage.

Modern fuses are more substantial and reliable than older fuses, so the chance of fuse failure is smaller. Only the exceptional installation will be so dependent on continuity of voltage, that the transformer must be connected solidly to the primary circuit. With modern fuses, the principal disadvantages are the cost of fuses and mounting, and the space required.

Most primary fuses will also protect the transformer against partial short circuit in the primary winding and against secondary short circuit. Some operators choose fuses which will not operate on secondary short circuit.

All voltage transformer fuses will interrupt only a certain maximum fault current. The so-called current limiting fuses have higher interrupting ratings and can, in most cases, be used without external resistors to limit the current.

Primary fuses may be mounted on indoor transformers at the factory, or in separate mountings. Generally, this would increase the cost and the space required for installation.

Whether to use fuses or not is determined by the operator's established practice, but, apparently, operation without fuses has proven satisfactory in the majority of installations. The same considerations apply for outdoor transformers, but separately mounted fuses in their own mountings must be used. They are not mounted on the transformer.

The use of secondary fuses is relatively rare and is a matter of personal choice with the operator. Such fuses should be rated so that they will carry the secondary current indicated by the thermal VA rating of the transformer, but should blow in a short time at any higher current to protect the transformer. Obviously, if blowing or mechanical failure of a fuse occurs and is not quickly detected, a considerable loss of revenue or protection may occur.

New Technologies

The technology of measuring the voltage and current is continuously improving.

New Materials

Materials used for encapsulating CTs and VTs are continuously improving. Advancements in material science lead to the continuing improvements:

- increased dielectric properties so the same voltage rating can be achieved with less material and smaller designs
- increased resistance to arcing and surface tracking
- reduced corona and partial discharge (pD)
- increased mechanical strength of the unit
- increased resistance to environmental conditions (particularly important for outdoor applications)
- increased longevity and stability of the material so the same electrical and mechanical properties can be maintained during a long service life
- increased thermal handling properties so the same current ratings can be achieved with less material and lower stresses on joints, inter-turn insulation, and corners, etc.

New Sensing Technologies

Parallel to the instrument transformers, the new techniques of measuring voltage and current are becoming commercially available.

Voltage Sensing

Resistive voltage dividers are becoming a commercially viable alternative to measuring voltage. Although they draw slightly larger (resistive) current, they can be embedded in a cast of solid dielectric material (such as epoxy or polyurethane) and provide a stable output in a wide frequency range, including high harmonics. The voltage from the resistive divider is equal to:

$$V_{SEC} = V_{PRI} * \frac{R_{SEC}}{R_{PRI} + R_{SEC}}$$

Capacitive voltage dividers have been in high voltage testing for a long time. They provide a stable output proportional to the ratio of capacitances.

$$V_{SEC} = V_{PRI} * \frac{C_{PRI}}{C_{PRI} + C_{SEC}}$$

Capacitive voltage dividers have very high inherent impedance so they have to be connected to a high-impedance (light) burden. With the advancement of electronic relays and meters, this is becoming a commercially viable option for some applications.

Optical voltage sensors are becoming available for high voltage applications where the insulation line-to-ground is a major concern. Optical voltage sensors are based on the electro-optical phenomenon called Kerr effect by which a light-wave is polarized depending on the electric field generated by the voltage in the system. The technology is available to be used in distribution systems as well, but some improvements in cost and complexity of the optical systems are still needed.

Current Sensing

Rogowski coils or linear couplers are essentially air-core transformers that use a power conductor as a primary winding, and an air-core coil wrapped around it as secondary. The difference is that the primary current induces a secondary voltage signal in the Rogowski coil (not a current), which is a proportional derivative of the primary current dI/dt. This requires some careful processing of the dI/dt signal to convert to the true measurement of the primary current. Again, with the advancement of the electronic signal processing, these devices are now commercially available. Rogowski coils are very linear and do not saturate, even under extreme current conditions and high frequencies.

Magneto-optical phenomenon, called Faraday's effect, can be used to measure the current as well. When polarized light passes around the conductor with the current, the magnetic field associated with the current changes the polarization angle of the light. The change can be measured optically and converted to the electrical signal, proportional to the primary current. Optical transducers are inherently good for very high voltages since they do not require any electrical connection to the primary phase conductors. The devices are linear over their entire current range.

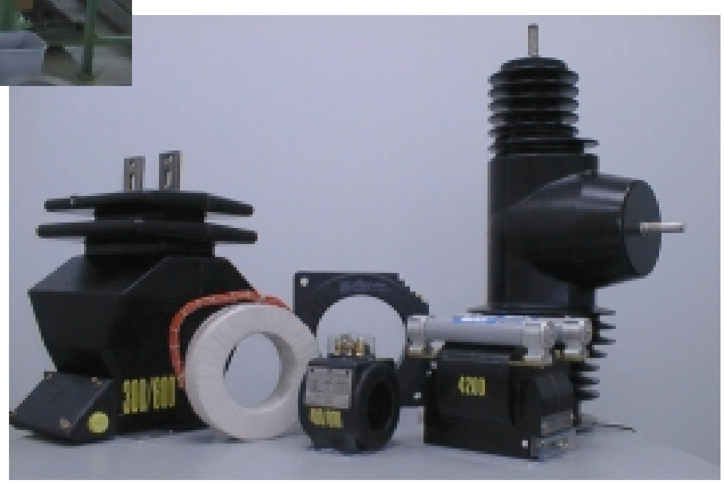
Product Description

General Description

ABB offers a complete line of instrument transformers from 600 V to 34.5 kV. In the 600 V class, ABB manufactures current transformers (CTs) and voltage transformers (VTs), using both thermoplastic rubber and plastic casings. In the 5-34 kV category, ABB provides a wide range of indoor and outdoor CTs and VTs cast in polyurethane, using a new state-of-the-art casting process. Also offered are specialty items such as linear couplers, bushing type, and ring type CTs. ABB builds transformers to ANSI, IEEE, CSA, IEC, Australian and other specifications. ISO-9001 certification was received from UL on November 29, 1995. ISO-14001 certification was received on August 31, 2000.

ABB instrument transformers are manufactured in Pinetops, North Carolina. The Pinetops operation began in 1978 and is considered a worldwide center of excellence for instrument transformers. The operation is widely recognized for its success in on-time deliveries, short lead-times, focus on quality and customer responsiveness. On going operations initiatives include:

- Customer Responsiveness
- Focused Factory
- Investments in New Equipment
- Productivity Improvement
- Inventory Reduction
- Manufacturing Cycle Time Reduction



Contemporary Design

The ABB instrument transformer family of products consists of :

- Urethane - Cast
- Plastic - Encased
- Thermoplatic Rubber - Molded
- Rings - Wound

Voltage ranges are defined as low voltage under 700 V and medium voltage 1.2 kV thru 36 kV.

Urethane

- Current and Voltage Transformers
- Voltage Class (1.2 kV to 36 kV)
- Basic Impulse Level - 60 kV to 200 kV BIL
- Application:
  - ⇒ Indoor and Outdoor
  - ⇒ Utilities - Substations
  - ⇒ Switchgear
    - ∗ Primary Revenue Metering
    - ∗ Protection

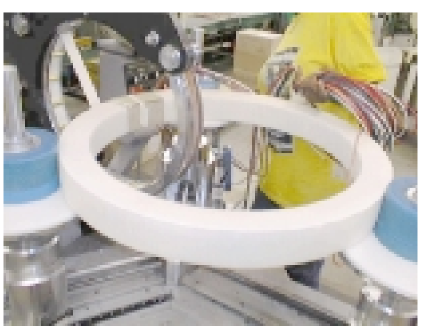
Plastic

- Current Transformers, Window Type
- Voltage Class (600 V)
- Application
  - ⇒ Distribution Circuit Breakers (Switchgear and Outdoor Vacuum Breakers)

Thermoplastic Rubber

- Current and Voltage Transformers
- Voltage Class (600 V)
- Basic Impulse Level - 10 kV
- Application
  - ⇒ Indoor and Outdoor
  - ⇒ Utilities - Substations
    - * Secondary Revenue Metering

Rings



- Current Transformers
- Voltage Class (600 V)
- Varnished Dipped
  - ⇒ Vacuum Impregnated
- Application
  - ⇒ Power Transformers
  - ⇒ Power Circuit Breakers

The industry commonly classifies instrument transformers in families of current transformers (CTs) and voltage transformers (VTs) and these categories are further broken down by indoor or outdoor application.

Current Transformers

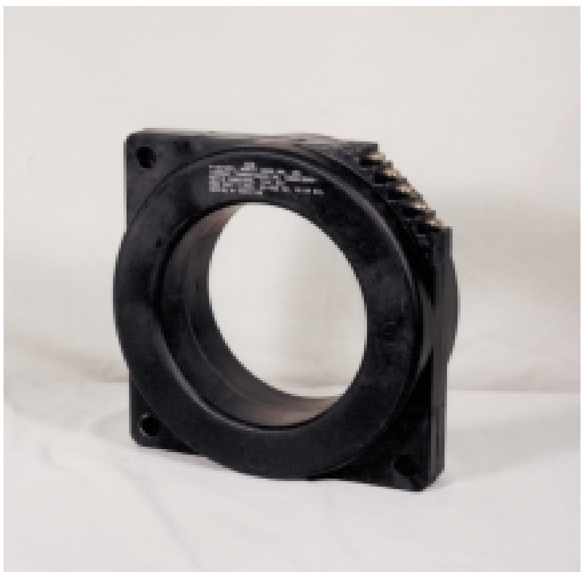
Outdoor (600 V—34.5 kV)

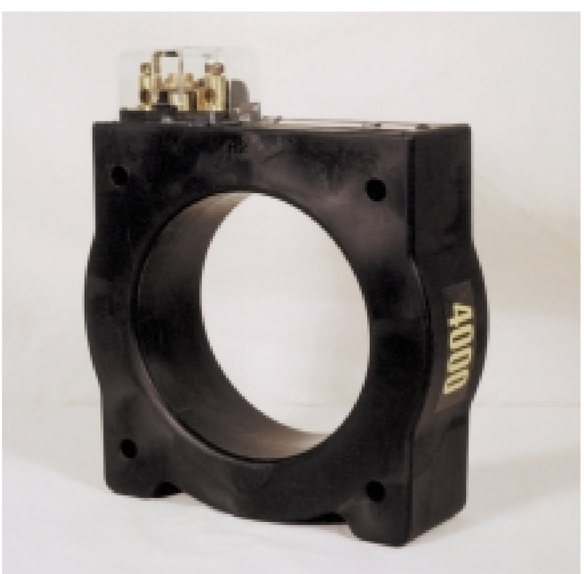
- Used for Medium Voltage Switchgear
  - ⇒ Free Standing
- Dielectric Types
  - ⇒ Polyurethane
- Current Ratio
  - ⇒ Prim: 5-1200A (Single/dual ratio)
  - ⇒ Sec: 1 or 5A
- Accuracy Class
  - ⇒ Metering 0.3 B-1.8 or 30VA class 0.2
  - ⇒ Relay C 200 or 30VA 5P20

Product Description

Indoor (600 V-25 kV)

- Used for Medium Voltage Switchgear
  - ⇒ Circuit Breaker (DCB)
  - ⇒ Metering Enclosures
- Dielectric Types
  - ⇒ Thermoplastic Rubber (TPR)
  - ⇒ Plastic Case
- Current Ratio
  - ⇒ Prim: 50-6000A (Single/dual/multi-ratio)
  - ⇒ Sec: 1 or 5A
- Accuracy Class
  - ⇒ Metering 0.3 B-1.8 or 30VA class 0.2
  - ⇒ Relay C400 or 30VA 5P20





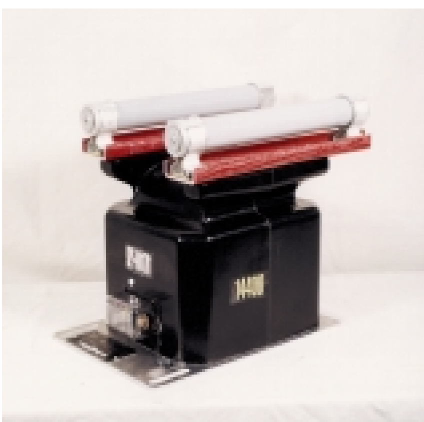
Voltage Transformers

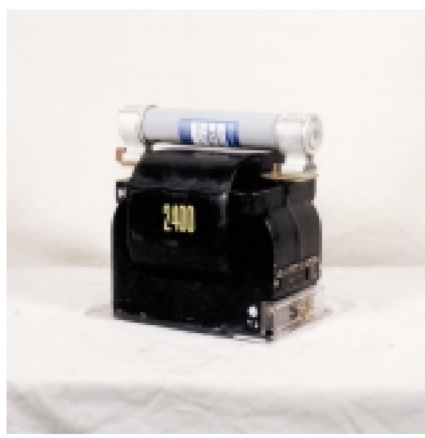
Outdoor (5-34.5 kV)

- Used for Medium Voltage Switchgear
  - ⇒ Y is for line-line or line-ground application
  - ⇒ GY is only for line-ground application
- Dielectric Types
  - ⇒ Polyurethane
- Voltage Ratio
  - ⇒ 2400-24000:120 V
- Accuracy Class
  - ⇒ Metering 0.3 Y or 30VA class 0.2

Indoor (600 V)

- Used for Medium Voltage Switchgear
  - ⇒ Metering Enclosures
- Dielectric Types
  - ⇒ Thermoplastic Rubber (TPR)
- Voltage Ratio
  - ⇒ 600:120 V
- Accuracy Class
  - ⇒ Metering 0.3 Y or 30VA class 0.2





Summary

A number of considerations are involved in selecting proper instrument transformers. Many of the transformer types have similar characteristics, but each type has its own unique combination of features that best meet the application for which it is designed.

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